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**Brigham Young University  
Science Bulletin**

**THE PEREGRINE FALCON IN UTAH,  
EMPHASIZING ECOLOGY AND  
COMPETITION WITH THE  
PRAIRIE FALCON**

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**Richard D. Porter and Clayton M. White**

**in collaboration with  
Robert J. Erwin**



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Frontispiece. Male (tiercel) Peregrine Falcon on rock in front of eyrie (Table 1, site 7); it is clutching a young American Avocet (*Recurvirostra americana*), that was fed to the young falcons. c. New York Times Co., 1971. Photo by R. D. Porter, 1952.

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# THE PEREGRINE FALCON IN UTAH, EMPHASIZING ECOLOGY AND COMPETITION WITH THE PRAIRIE FALCON

by

Richard D. Porter<sup>1</sup> and Clayton M. White<sup>2</sup>

in collaboration with Robert J. Erwin<sup>3</sup>

## ABSTRACT

This study was undertaken to record the known history of the Peregrine Falcon (*Falco peregrinus*) in Utah as we have been able to construct it from both the literature and from our original research that extends over about a 30-year period in the state. The present total population of the peregrine in Utah is possibly only 10 percent of what it has been in historic times. In an effort to find explanations for the decline, we have explored hypotheses of climatic changes, impact of pesticides, disease, and human disturbances. We conclude that pesticide contamination and climatic changes may have been the major reasons for their decline in Utah.

A general background of the geographical and ecological distribution of the species in Utah is provided as are also details of its nest-

ing behavior from some Wasatch Mountain eyries. Our data suggest that its nesting density along the Wasatch Mountains was about the same order of magnitude as nesting densities in other regions of North America that are generally considered more favorable to the peregrine.

We have considered some of the environmental factors that may limit the species in Utah and especially its relationship with a congener, the Prairie Falcon (*Falco mexicanus*). We conclude that the peregrine may live jointly with the Prairie Falcon with a minimum of intra-specific competition. We present evidence which suggests that the peregrine has been in Utah since the late Pleistocene and that it has had a long history of sympatric existence with the Prairie Falcon.

## INTRODUCTION

Breeding populations of the Peregrine Falcon (*Falco peregrinus*) have declined sharply over much of its historic range in North America and Europe during the last two decades. Although this decline has been well documented for many areas (Hickey, 1969), little has been published on the status, past or present, of the species in the Great Basin, especially as a breeding bird in Utah, an area encompassing 84,916 sq miles (219,932 km<sup>2</sup>).

We wish, therefore, to place on record our observations of the peregrine in Utah from data collected over the past 30 years. In presenting these data, it is our purpose to: (1) describe the ecological distribution of the species in the state, (2) delineate the ecological factors which

may have limited its distribution and breeding success there, (3) describe its food and habitat niches, (4) discuss its competition with related species, especially the Prairie Falcon (*Falco mexicanus*), and (5) compare its present levels of population with those formerly known, since peregrines in Utah have not been immune to the decline that afflicted its populations elsewhere. Because the known active eyries of this species in the state are now only about 10 percent of those known to have been present earlier in the century, another of our objectives is to (6) discuss and evaluate the factors which may have led to the near extirpation of this species in the state.

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## GEOGRAPHIC DISTRIBUTION

## Historic Records

The peregrine was not mentioned in the ornithological literature for Utah until 1871, when it was reported by Allen (1872) to prey on waterfowl about the marshes of the Great Salt Lake near Ogden. He found it to be common there in September. The next to mention the presence of the species was Henshaw (1874), who with Yarrow, collected 600 specimens of birds representing 165 species on a trip from Salt Lake City to St. George between July and December 1872. The peregrine was considered by Henshaw to be a rather common resident in Utah and to nest in the state. Henshaw's later account (1875) mentions only an observation of this species by Allen (1872) in the vicinity of Ogden, thus opening to question the source of his data supporting the status of the species in Utah.

The lack of observations by Allen (1872) of the Prairie Falcon in the Great Salt Lake Valley and the complete absence of this species in his account of the birds encountered in Kansas, Colorado, Wyoming, and Utah is difficult to understand, since the peregrine apparently was noted at all but two of Allen's collecting localities and a specimen (young bird) was obtained by him (*ibid.*) at Fairplay (South Park), Colorado Territory. Did Allen (*ibid.*) overlook the Prairie Falcon or did he consider all large falcons to be peregrines? Nevertheless, his observations of the peregrine along the Great Salt Lake marshes probably were accurate, as the species has been seen there many times since then. Although Ridgway (1874, 1877) found the Prairie Falcon to be common in the rocky canyons of the Wasatch Mountains and a rare breeder along cliffs of canyons and valleys in Salt Lake City and neighborhood in 1869, he apparently made no observations of the peregrine in Utah. Several earlier naturalists and explorers (Fremont, 1845; Stansbury, 1852; Baird, 1852; and Remy and Brenchley, 1861) also failed to mention the presence of the peregrine in Utah.

## Specimen Records

Specimens from both the arctic tundra population (*F. p. tundrius*) and the more southern population (*F. p. anatum*) have been taken in Utah during the winter months. A specimen of the *tundrius* race, identified by C. M. White (CMW), was found shot and wounded by R. Vern Bullough on 15 December 1956, near Farmington Bay, Davis County. (For a dis-

cussion of peregrine systematics, see White, 1968b.)

A male specimen of unknown racial affinity was collected by Wolfe (1928) near St. George, Washington County, on 5 February 1926. John Hutchings (Bee and Hutchings, 1942) collected a specimen of *anatum* (*sensu lato*; western subgroup) (CMW) near Pelican Point, Lake Mountains, Utah County (date not given, Woodbury, Cottam and Sugden, unpubl. ms, indicate specimen was taken alive, 2 August 1935). Five specimens (Twomey, 1942)—a male, molting into adult plumage; an adult female, collection date not given; and three males, collected on 23 April and 5 and 23 August in 1935 at the Ashley Creek marshes, Uintah County—were assigned to the race *anatum* (*sensu lato*; western subgroup) (CMW).

Woodbury et al. (unpubl. ms) record the following additional specimens by county: **Box Elder**, at Bear River marshes, specimens taken 1 July and 6 September 1914; 14 September 1915; 28 July and 28 September 1916 (U.S. Biol. Surv.); 18 August and 7 September 1927 (Phil. Acad. Sci.); all *anatum* (*sensu lato*; western subgroup) (CMW). **Davis**, Jordan Fur Farm, W of Bountiful, 5 January 1939 (Univ. Utah Coll.; UU) *anatum* (*sensu lato*). **Salt Lake**, near Salt Lake City, 4 September 1947 (UU). **Iron**, near Cedar City, 12 May 1936 (Chicago Field Mus.; LBB), *anatum* (*sensu lato*; western subgroup) (CMW). **Uintah**, Ashley Creek marshes, a young male in 1937 (Carnegie Mus.). **Washington**, Zion Canyon (Zion National Park), 16 July 1939 (Zion Park Museum) *anatum* (*sensu lato*; western subgroup) (CMW).

Additional specimens of *F. p. anatum* (*sensu lato*; western subgroup) have been examined by C. M. White for Emery County, two specimens, July; and Salt Lake County, two specimens, January and November.

## Nesting Records

Historically, the peregrine is known to have nested in 13 counties of Utah and is suspected of nesting in at least three others. Figure 1 shows the pattern of known and suspected breeding distribution in Utah, and Table I gives their known histories in the state.

The first recorded eyrie for the state was an observation by Johnson (1899), who in May 1898, found three young peregrines in a shallow cave under an overhanging rock of an 80-foot (24 m) cliff [Land Rock] in Lake Mountains, west of Utah Lake, Utah County, and five eggs

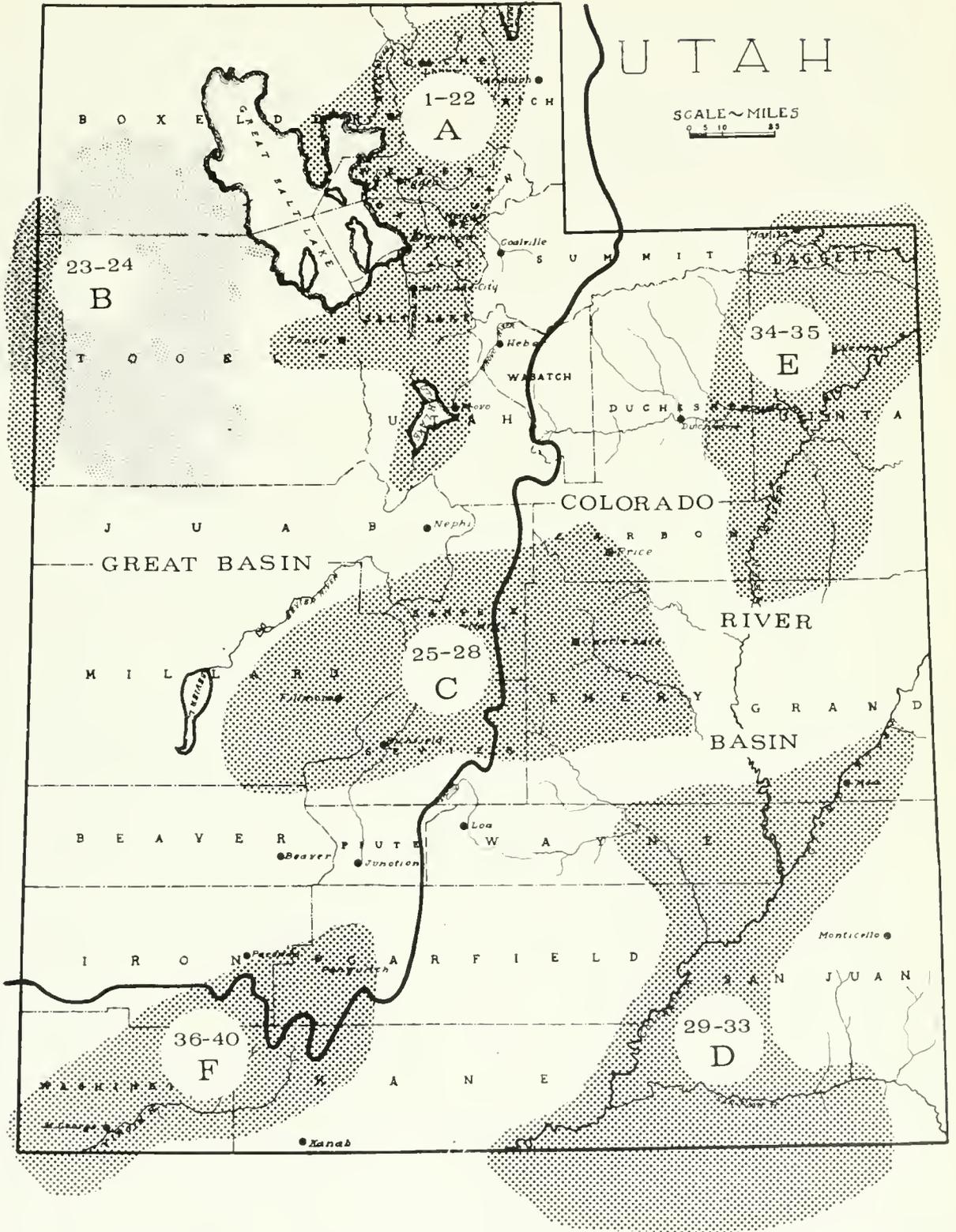


Fig. 1. Pattern of known and suspected breeding distribution of the Peregrine Falcon in Utah. Letters for the regions and numbers correspond to those on Table 1. The line running nearly vertically through the center of the state separates the Great Basin from the Colorado River Basin. The west face of the Wasatch Mountains bisects area A and is encompassed within the northern and southern boundary of the area. Lightly stippled area between regions A and B delimits the Great Salt Lake Desert, although there are also other areas of salt flats at the southwest edge of the Great Salt Lake that are not classified within the confines of the desert.

Table 1. Peregrine eyries in Utah. Eyrie site numbers and letters for regional areas correspond with those given in Figure 1.

Site No.	First Located and Subsequent History		Last Known to be Active	
	Date	Observer	Date	Observer
<b>A—Great Basin Region—Surrounding Utah and Great Salt lakes, and North Central Utah</b>				
1	1898	H. C. Johnson (1899)	Early 1900s	H. C. Johnson (field notes of R. G. Bee)
2 <sup>1</sup>	1940 1939-42	R. G. Bee (field notes) Nelson (1969) <sup>o</sup>	1940	R. G. Bee (field notes) Nelson (1969)
3	1935	Bee and Hutchings (1942)		
4	ca. 1926-27 1939-42	L. R. Wolfe (in letter) Nelson (1969) <sup>o</sup>	1957-58	C. M. White (unpubl. data)
	1954 1956	Porter et al. (unpubl. ms) C. M. White		
5	1940s	Morlan Nelson (pers. comm., 1971) Boyd Shaeffer (pers. comm.)		
6	1939-42	Nelson (1969) <sup>o</sup>		
7	1939-42 1943	Nelson (1969) <sup>o</sup> R. D. & R. L. Porter R. J. Erwin, J. F. Poorman (unpubl. data)	1953	R. J. Erwin (unpubl. data)
8	ca. 1900-20? 1939-42 1943	Treganza (in Woodbury et al., unpubl. ms) Nelson (1969) <sup>o</sup> R. D. Porter & R. J. Erwin (unpubl. data)	1969	C. M. White (unpubl. data), single bird
9	1939	Morlan Nelson (pers. comm., 1971)		
10	1939-42 1950 1955	Nelson (1969) <sup>o</sup> C. Wilson (pers. comm.) Lorin Carsey (pers. comm.), one young female taken for falconry	1956	C. M. White (unpubl. data)
11	1939-42	Nelson (1969) <sup>o</sup>		
12	1939-42	Nelson (1969) <sup>o</sup>		
13	1940s 1951	Boyd Shaeffer (pers. comm.) reported eyrie to have been found and photographed in the 1930's by a different party R. D. Porter and Jack Hagan (unpubl. data), birds seen, eyrie not located	1952	R. J. Erwin (unpubl. data)
14	ca. 1900-20 1926-27 1939-42 1940s	Treganza (in Woodbury et al., unpubl. ms) L. R. Wolfe (in field notes of R. G. Bee), seen carrying food toward cliffs, and Wolfe (1928) Morlan Nelson (pers. comm., 1971) Boyd Shaeffer (pers. comm.), took young from eyrie		
15	1930	Dr. Harold Austin (pers. comm.)		
16	1943 1940s	R. D. & R. L. Porter, and R. J. Erwin (unpubl. data) Boyd Shaeffer (pers. comm.)		
17	1930s 1940s 1950s 1967	Clyde Ward (pers. comm.) Boyd Shaeffer (pers. comm.) C. M. White (unpubl. data) Del Diamond (pers. comm.)	1968?	Clyde Ward
18	1930s 1939-46?	Clyde Ward (pers. comm.) Morlan Nelson (pers. comm.)	1954 1969	Clyde Ward H. Austin and L. Wakefield one adult seen.
19	1930-32	Clyde Ward (pers. comm.)	1930-32	Clyde Ward (pers. comm.)
20	1946-?	Boyd Shaeffer (pers. comm.) Marcus Nelson?		

Table 1 (Continued)

21 (SNV) <sup>2</sup>	ca. 1926-27	L. R. Wolfe (in field notes of R. G. Bee)		
22 (SNV)	1939-42	Morlan Nelson (pers. comm., 1971)	1970	C. M. White (unpubl. data)
<b>B—Great Basin Region—Great Salt Lake Desert</b>				
23 <sup>3</sup>	1942	H. Webster (letter, 1961)	1959-60	C. M. White and Gary D. Lloyd (unpubl. data)
24	1942	H. Webster (letter, 1961)		
<b>C—Central Utah, eastern edge Great Basin, western edge Colorado River Basin (Plateau)</b>				
25	ca. 1939	Gunther and Nelson (in Woodbury et al., unpubl. ms.)		
26	1969	C. M. White (unpubl. data)	1969	C. M. White (unpubl. data)
27 (SNV)	1960	G. G. Musser, A. D. Stock, and C. M. White (unpubl. data)		
28	1961	White and Lloyd (1962)	1964	C. M. White and G. D. Lloyd (unpubl. data)
<b>D—Colorado Plateau and Navajo Country</b>				
29 (SNV)	1916 & 1936	Woodbury and Russell (1945)	1961	C. M. White and G. D. Lloyd (unpubl. data), pair seen in area
30 (SNV)	1958	R. J. Erwin (unpubl. data)	1962	G. D. Lloyd (unpubl. data), adult in general area
	1959	R. D. Porter (unpubl. data)		
31 (SNV)	1953	Behle (1960)		
32	1958	G. L. Richards (pers. comm.), saw fledged young		
33 (SNV)	1958-59	C. M. White (pers. comm. from M. Hopkins, unpubl. data)		
<b>E—Uinta Basin and Upper Colorado River Basin</b>				
34	1937	Twomey (1942)	1961	G. L. Richards (pers. comm.), at nearby locality
35 (SNV)	1935-? 1965-66	Twomey (1942) E. Peck, W. Pingree, and J. Gaskill (pers. comm.)		
<b>F—Southwestern Utah, edge Great Basin; and Virgin River Valley</b>				
36 (SNV)	1961	C. M. White and G. Worthen (unpubl. data)	1961	C. M. White (unpubl. data)
37	1936	W. S. Long (breeding female collected)	1962	C. M. White and G. D. Lloyd (unpubl. data), an adult in area
38	1939	Grater (1947)	1964 1966	Wauer and Carter (1965) C. M. White (unpubl. data), lone adult seen
39 (SNV)	1963	Wauer and Carter (1965)		
40 (SNV)	ca. 1926	Wolfe (1928)		

<sup>1</sup>May be an alternate site for number 1; located only 2 or 3 miles (3.2 or 4.8 km) from site number 1, but nearly 40 years later.  
<sup>2</sup>SNV, (suspected, but not verified) adults were observed at these localities, but eyrie sites not actually located; although adult birds have been seen one or more times, in the authors' opinions, the sites need further verification. The validity of these sites is probable.

<sup>3</sup>The eyrie proper is about 0.5 mile (0.8 km) into Nevada

\*These sites are the ones referred to by Nelson (1969); their locations were communicated to us in a letter from Nelson dated 25 April 1969

on the same ledge on 30 March 1899 (Figs. 1-5; Table I, site 1). While circling Utah Lake, Johnson (ibid) noted Long-billed Curlew (*Numenius americanus*), snipes (*Capella gallinago*), bitterns (*Botaurus lentiginosus*), and a goodly number of ducks of various species which probably served as a food supply for the peregrines.

Bee and Hutchings (1942) report finding a nest containing four fresh eggs on a ledge over-

looking Utah Lake, (5 miles south of the Land Rock site) near Pelican Point in the Lake Mountains, 20 May 1935 (Fig. 1, Table 1, site 3). They collected the adults to verify identification. Local residents report that peregrines had been observed nesting there for many years (ibid.). A visit to the sites on 22 April 1950 by R. D. Porter and R. J. Erwin revealed no indications of recent occupancy. In recent years lime mining



Fig. 2. Land Rock, west side of Utah Lake; location of first known peregrine eyrie site in Utah. It is a marginal site, which in some recent years has been occupied by Prairie Falcons. Note scrubby nature of vegetation in foreground. Photo by Kim Despain, 1971.

operations have destroyed the Pelican Point site (Fig. 6) and Prairie Falcons have occasionally occupied the Land Rock site.

Nelson (1969) located 9 or 10 eyries (*in letter*, 25 April 1969, Nelson gave 9 eyrie locations) in the area surrounding the Utah and Great Salt lakes during the period 1939-1942. This area included parts of Box Elder, Weber, Davis, Salt Lake, Utah, and Tooele counties. Treganza (*in letter*, 5 January 1930; Woodbury et al., unpubl. ms) found the species breeding on the cliffs fronting the lake from Brigham to Ogden [at least four eyries overlooked the Bear River Marshes in the 18 miles from Ogden to Brigham City (Woodbury, pers. comm., *in* White, 1969b)]. Although he located nests, he was unable to negotiate the cliffs; one was over 1,000 feet (305 m) high (Fig. 7). Females were collected off the nests, but precise nesting data were not obtained.

Gunther and Nelson (Woodbury et al., unpubl. ms) noted the species nesting at a site in the Great Basin Desert of west central Utah during the nesting season (year not given). Gunther (Woodbury et al., unpubl. ms) saw the species at a large reservoir in Wasatch County in the summer of 1938.



Fig. 3. Utah Lake and adjacent habitat as presently seen from atop the Land Rock eyrie site; marshes formerly were more extensive than today and came closer to the eyrie. Photo by Kim Despain, 1971.



Fig. 4. A view of Land Rock eyrie showing nature of terrain and vegetation. Photo by Kim Despain, 1971.

Grater (1947) reorded peregrines at Angel's Landing in Zion Canyon, Washington County, from March to August 1939, where adults frequently were seen carrying food to a high ledge on the face of the peak. On 16 July 1939 (the more precise dates from Woodbury et al., unpubl. ms) a young female, only a few weeks old, was accidentally killed in the canyon (Figs. 1

and 8, Table 1, site 38). Wauer and Carter (1965) reported this site to be active as late as 1964.

In the Uinta Basin, Twomey (1942) reported an inaccessible eyrie about 40 feet (12.2 m) up on a deep shelf of a cliff, east of the Green River, near Vernal (Fig. 1; Table 1, site 34), Uintah County. Actions of the adults indicated that young were in the nest and immature birds were seen at the Ashley Creek marshes in early August and in the vicinity of Jensen from August through September. G. L. Richards (pers. comm.) saw a pair in the marshes in 1961, the most recent evidence of activity at this eyrie.

In southern Utah, single falcons were seen at Kanab, Kane County, on 28 April 1935, and 6 April 1947, and two were recorded along Kanab Creek on 29 May 1947 (Behle, Bushman, and Greenhalgh, 1958). Behle (1960) also noted the species near the Colorado River at Dewey on 21 May 1953 (Fig. 1; Table 1, site 31), and in Glen Canyon on 6 August 1958. Peregrines were seen several times in July and August at Navajo Mountain, San Juan County, by Woodbury and Russell (1945) in 1936, and by C. M. White and G. D. Lloyd (unpubl. data) in 1960 and 1961 (Fig. 1; Table 1, site 29). White and Lloyd (1962) reported on the predation of young peregrines which had not yet fledged from an eyrie in the Colorado River Basin (Figs. 1, 9, and 10; Table 1, site 28).

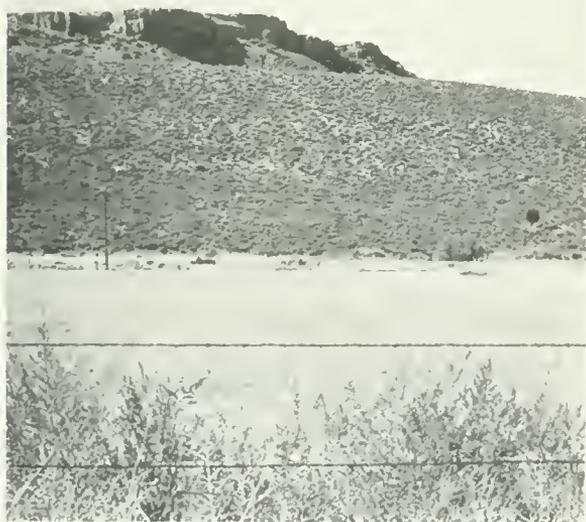


Fig. 5. A different view of the Land Rock eyrie showing terrain. Flat area formerly contained some marsh habitat. Photo by Kim Despain, 1971.

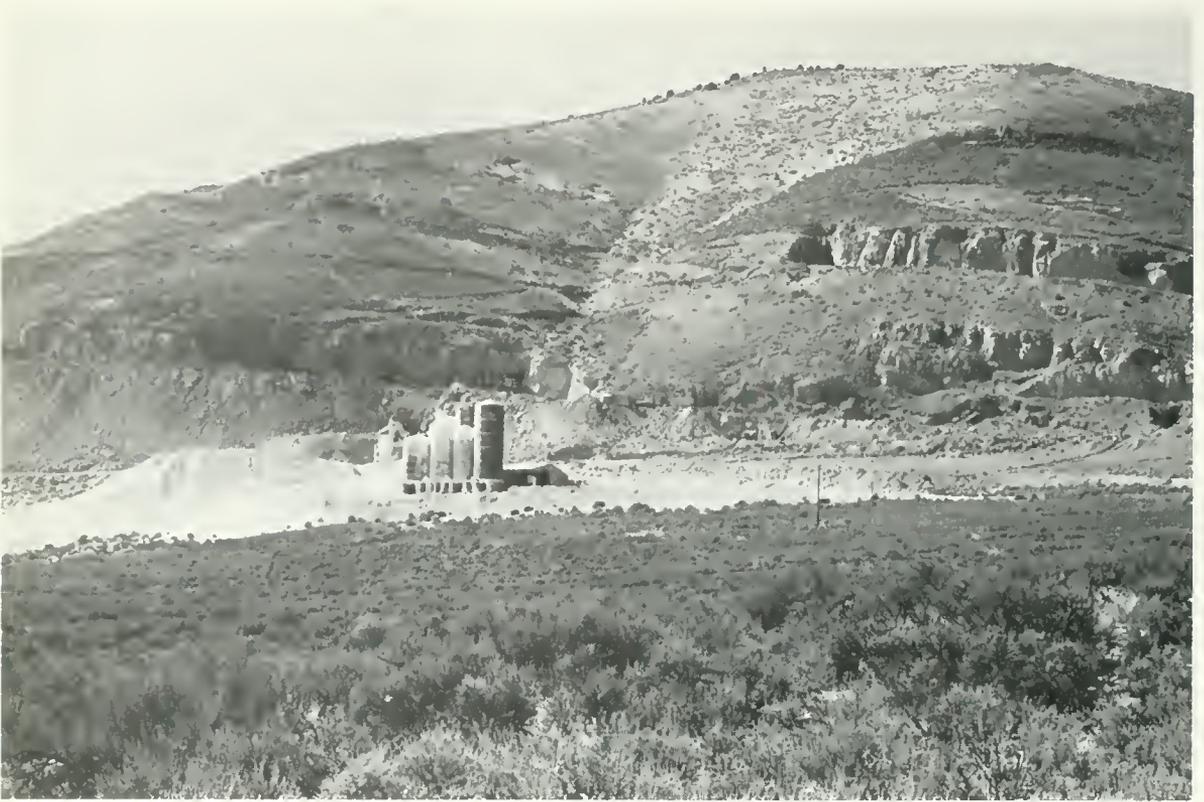


Fig. 6. Pelican Point eyrie site (Table 1, site 3, Fig. 1) showing lime mining operation, which in recent years destroyed the nesting cliff. Photo by Kim Despain, 1971.



Fig. 7. Treganza noted a pair of peregrines nesting on the distant 1,000 ft. (305 m) cliff in the early 1900s, but he was unable to reach the eyrie site (Woodbury et al. unpubl. ms). Photo by R. J. Erwin, 1971.



Fig. 8. Angel's Landing, Zion Canyon. Cliff in center where Grater (1947) saw peregrines nesting high on face of peak (Fig. 1, Table 1, site 38). Photo by Grant, 1 September 1929, Courtesy U. S. National Park Service.

#### Postnesting Season and Winter Records

The species is present in the state throughout the year (Woodbury, Cottam, and Sugden, 1949). Postbreeding adults, immatures, migrants, and wintering falcons congregate near marshes where a plentiful supply of food is available, especially near the marshes of the Great Salt Lake (Woodbury, Cottam, and Sugden, unpubl. ms). At the Bear River marshes, for example, records extend back to 1915, when Alexander Wetmore found the peregrine to be a regular and frequent visitor after mid-July (ibid.). The Christmas bird censuses taken by Vanez T. Wilson et al. (in *Bird Lore* 42, 1940; *Audubon Magazine* 43-48, 1941-1946; and *Audubon Field Notes* 1-24, 1947-1970) at the Bear River Migratory Waterfowl Refuge, indicate that the species wintered there in small numbers until the early 1960s (Fig. 11). The greatest number of peregrines seen during the seven- to eight-hour censuses was seven, in 1940. The Christmas bird counts at the Bear River marshes were exceptionally consistent from one year to the next beginning in 1939 through 1960 as regards the number of participants, the area covered, and the party hours afield. Additionally, V. T. Wilson directed

and participated each year until 1960, after which other observers were involved and a greater area was covered, although the number of party hours afield remained essentially the same.

The racial affinity of specimens taken at the Bear River marshes between 1 July and 28 September (*anatum*, *sensu lato*; western subgroup), suggest that most of the postbreeding and fall peregrines in these marshes were from local cyries. The steady decline in the numbers of peregrines recorded at the Bear River marshes during the Christmas bird counts (ibid.) from 1939 to the early 1960s (Fig. 11) closely corresponded with the decline in the number of active cyries in the area surrounding the marshes. This correspondence suggests that most peregrines wintering in the marshes of Great Salt Lake probably were from local breeding populations, although they also may have been from some other sharply declining population of the *anatum* race. It is probable that only a small percentage of these wintering birds were from the arctic populations (*F. p. tundrius*), because arctic birds normally winter farther south, and because the arctic populations were not known

to have declined between 1939 and the late 1960s.

Peregrines also have been reported on Christmas bird counts both at Ogden and Salt Lake City over the past 30 years. In addition, they have been recorded at Parowan, Iron County, on 27 December 1963 (*Audubon Field Notes* 18; 1964) and at St. George, Washington County, on 1 January 1969 (*Audubon Field Notes* 23; 1969). Christmas bird count data for the areas other than the Bear River marshes are either too spotty or are too heterogeneous in their method of collection to be evaluated statistically.

The peregrine was recorded at Clear Lake State Waterfowl Management Area by R. Williams on 16 September 1939, and by Gunther

and Nelson on 24 October, 10 November, and 4 December 1941 (Woodbury et al., unpubl. ms), indicating that the species winters at other marshes as well as at those near the Great Salt Lake. Members of arctic populations (*F. p. tundrius*) apparently utilize Utah's marshes both as stopping places during migration and, sparingly, as wintering grounds. This is suggested by Lincoln's (1933) report of a peregrine banded as a juvenile at King's Point, Yukon Territory, within the geographic range of *tundrius* on 30 July 1924; by its recovery at Duchesne, Duchesne County, Utah, on 20 February 1925; and by the collection in December of the previously mentioned specimen of *tundrius* from Farmington Bay.

Late summer sightings, which could represent either resident birds or early migrants, have been recorded from several other areas. Twomey (1942) reported peregrines at Hill Creek, 40 miles (64.4 km) south of Ouray, Uintah County, on 5 August [1935?], at Strawberry Reservoir, Wasatch County, on 17 August [1935?], and Behle (1960) recorded the species at Glen Canyon near Wahweep Creek, Mile 17, on 6 August 1958 and at 10,500 feet (3,200 m) on the north slope of Mt. Ellen, Henry Mountains, on 8 September 1957. Finally, a subadult was seen near Park City, Wasatch County, in late August 1959 (M. Nelson and F. Welch, pers. comm.).



Fig. 9. Peregrine cliff in desert of Colorado Plateau, reported by White and Lloyd (1962) (Fig. 1, Table 1, site 28). Distance from the rock at point A to the eyrie ledge at point B is 70 ft (21.3 m). Poplar trees (*Populus fremontii*), along a water course in foreground (C) are 40–50 ft (12.2–15.2 m) in height. Photo by J. B. Platt, May 1971.



Fig. 10. Two-day-old young and an addled egg on nesting ledge at desert eyrie in Colorado Plateau (site 28) shown in Figure 9. Photo by G. D. Lloyd and C. M. White, 10 June 1961.

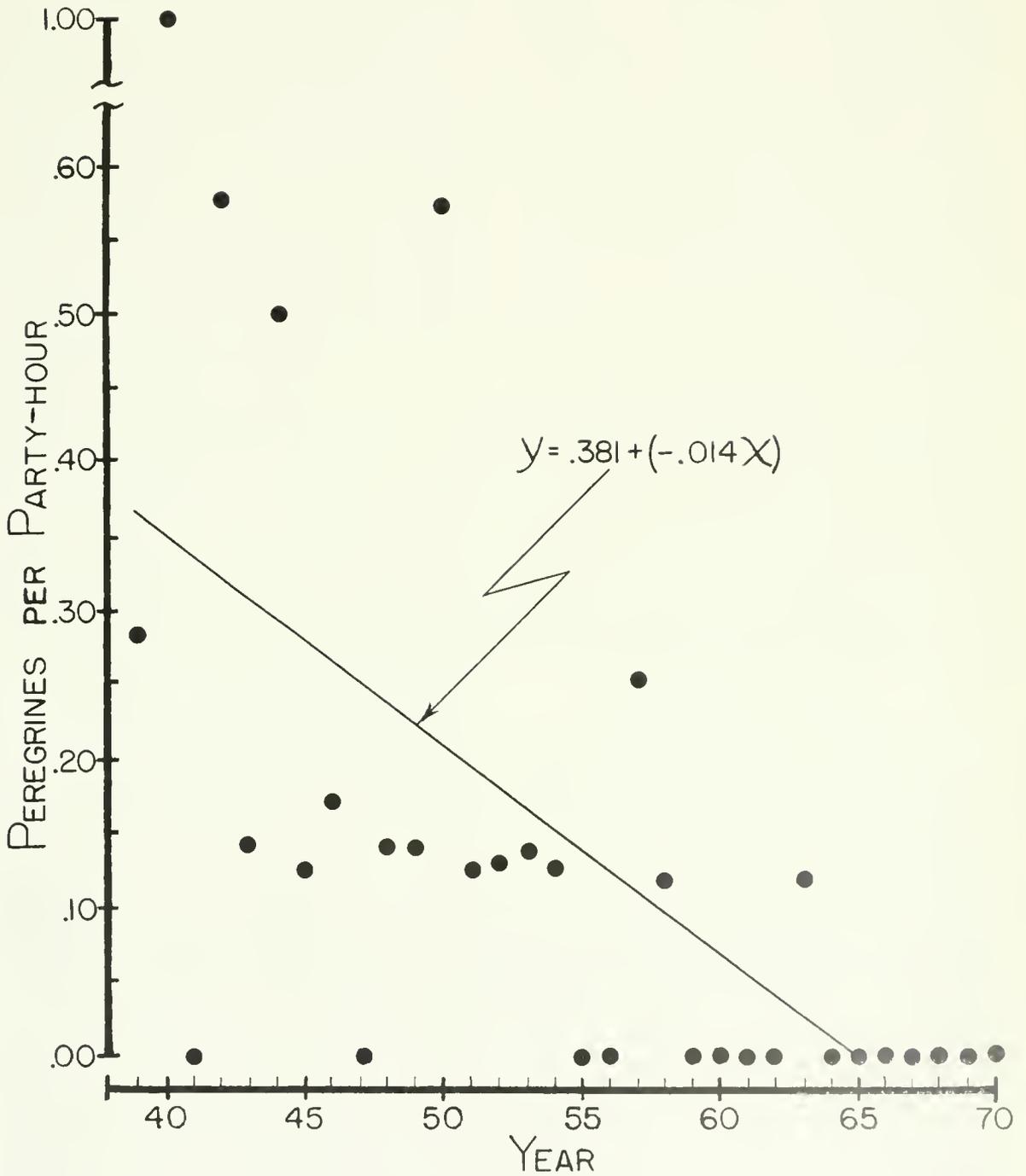


Fig. 11. Linear regression analysis of the number of Peregrine Falcons recorded per party hour, during Christmas bird counts at the Bear River Migratory Waterfowl Refuge between 1939 and 1970. Each circle represents the observations for one Christmas bird count. Downward trend is statistically significant ( $p < 0.01$ ). This analysis suggests that the peregrine had essentially disappeared as a wintering bird in the Bear River marshes by 1965.

## DENSITY DISTRIBUTION OF PEREGRINE EYRIES IN UTAH

Utah's desert climate should seem to be a significant barrier to the nesting of the peregrine, yet we have compiled a list of about 40 eyries in the state (Table 1), which appear to have been active at one time or another. On the basis of density, if all 40 eyries were active simultaneously, there would be about 2,123 sq miles (5,499 km<sup>2</sup>) per eyrie site. If the 11 suspected but unverified eyries (SNV, Table 1) are excluded, the density would be reduced to one eyrie site for every 2,928 sq miles (7,584 km<sup>2</sup>).

Density of peregrine nesting sites in Utah appears to be directly related to the availability of food and suitable cliffs for nesting. The importance of these two factors to the distribution and density of the peregrine in the state will be discussed separately in a later section. Eyrie sites usually were situated near marshes, lakes, or rivers, where there was a plentiful supply of prey species. Where the nesting habitat was extensive, such as in the area of the Great Salt Lake (Fig. 1, Table 1), eyrie sites were clustered around the marshes in a pattern conforming to the availability of nesting sites (Fig. 12). Elsewhere in the state, where suitable habitat is greatly restricted, each eyrie site usually was located many miles from its closest known neighbor (Fig. 1).

The density of peregrine eyries in Utah, exclusive of the area surrounding the Great Salt Lake (4,500 mi<sup>2</sup>; 11,655 km<sup>2</sup>), is one site per 4,232 sq miles (10,962 km<sup>2</sup>), if the 19 additionally known and suspected eyries were all active simultaneously. If the 10 suspected eyries in the remainder of the state are excluded, the average area per nest site would be 8,935 sq miles (23,142 km<sup>2</sup>). There were 20 known eyries in the area surrounding the Utah and Great Salt lakes (Fig. 1, Table 1, eyrie sites, 1-20). This is exclusive of eyrie site 22 (Table 1) which is outside of the region. One other probable eyrie is suggested by the presence of adults on each of several visits by L. R. Wolfe (field notes of R. G. Bee) to one other site (site 21, Table 1). If all 20 known eyries were active concurrently, there would have been one eyrie site for about every 225 sq miles (583 km<sup>2</sup>) in an area covering about 4,500 sq miles (11,655 km<sup>2</sup>), surrounding and including the Utah and Great Salt lakes (Fig. 1, Table 1).

The average distance between 13 eyries (sites 5, 7-10, 12-19, Table 1) located along 130 linear miles (209 km) of the west face of the Wasatch Mountains from the south end of Utah Lake to the north end of the Great Salt Lake was 10.0 linear miles (16.1 km). The closest eyries to each other were about 2 miles (3.2 km) apart and the



Fig. 12. Looking east from the peregrine's hunting habitat at a large Utah marsh toward its nesting habitat along the escarpment of the Wasatch Mountains. Two pairs of peregrines and three pairs of Prairie Falcons nested on the portion of the cliffs seen in the distance and both species utilized the marshes. Photo by R. J. Erwin, August 1971.

farthest were 20 miles (32.2 km) apart. However, since cliffs make up only about 25 miles (40 km) of the 130 linear miles, including side canyons (estimated from U. S. Geological Survey topographic maps), peregrine eyries, on the average, were only about two miles (3 km) apart on the cliff sections of the mountain. Several additional eyries near the western edge of Utah Lake and the eastern and southern edges of the Great Salt Lake were not included because they did not fall in a direct line with the 13 eyries mentioned above.

It is possible that populations of the peregrine were substantially greater prior to arrival of the first white settlers than historically, considering the apparent abundance of food that was available in nearby marshes, the number of cliffs which appear to be suitable (but which have not been known to harbor peregrines), and the probable lack of human disturbance.

Population densities of the magnitude of those occurring around the Great Salt Lake seemingly did not differ greatly from some of those present in other regions of North America where the environment is considered more congenial to the peregrine. For instance, Herbert and Herbert (1965) recorded nine eyries along 55 miles (88.5 km) of the Hudson River (eight on the west side) for an average of 6.1 miles (9.8 km) per eyrie. Berger and Mueller (1969) found 14 eyries along a 198.4-mile (319 km) stretch of upper Mississippi River for an average of 14.2 miles (22.8 km) between eyries.

White and Cade (1971) recorded a peregrine density along the Colville River in 1967-1969 to be one pair per 8.3 miles (13.4 km) above Umiat Mountain and one pair per 3.7 miles (6.0 km) below Umiat Mountain, giving an overall average of 6.03 river miles (9.7 km) between eyries. The distance between active eyries ranged from 0.4 miles (0.64 km) to 27 miles (43.4 km). There were 32 nesting pairs of peregrines along 183 miles (294 km) of the Colville River in Alaska in 1952, 40 pairs in 1959, and 27 pairs in 1967, for an average distance in miles between eyries of 5.7, 4.6, and 6.8 (9.2, 7.4, and 10.9 km), respectively (Cade, 1960; White and Cade, 1971).

The average distance between 19 eyries along 172 miles (277 km) of the Yukon River in Alaska was 9.3 miles (15 km) (range, 2.75-31 mi; 4.4-49.9 km) in 1951 and 10.1 miles (16.3 km) (range, 2-31; 3.2-49.9 km) in 1966 (Cade, White, and Haugh, 1968). Cade, White, and Haugh (1968) believed that the peregrine probably was never more common along the Yukon than in 1966.

For the Aleutian Islands, White, Emison, and Williamson (1971) found the average distance between peregrines defending territories to be about 5.8 miles (9.3 km) (range, 0.81-21 mi; 1.3-34 km) for Amehitka Island, similar densities on Rat and Semisopochnoi islands, and equal or perhaps greater densities on Kiska Island (M. Nelson, pers. comm., 1971).

On the other hand, no locality in Utah had populations approaching the densities found in several other regions. Hickey (1942), for example, in a local area of the eastern United States, reported five pairs of peregrines on 7 miles (11.3 km) of escarpment. In Great Britain, Ratcliffe (1962) found three pairs residing along a linear distance of 1,000 yards (914 m) of sea cliff, and 15 pairs along a 17-mile (27.4 km) distance. The highest densities known are for the Queen Charlotte Islands, where five to eight pairs of falcons utilized a linear distance of a mile (1.61 km) of sea cliff (Beebe, 1960).

Hickey (1942) listed 19 pairs of peregrines in an area of about 10,000 sq miles (25,900 km<sup>2</sup>) around New York City, for an average of one pair for every 526 sq miles (1,362 km<sup>2</sup>). Cade (1960) estimated a probable density of 200 and 300 sq miles (518 and 777 km<sup>2</sup>) per pair in the Colville and Yukon river systems, respectively, and one known pair per 2,000 sq miles (5,180 km<sup>2</sup>) in the Yukon country. Bond (1946) considered the peregrine to be common along the western coast of the United States and Baja, Mexico, where there was an average of less than 2,000 sq miles (5,180 km<sup>2</sup>) per known pair. Judging from the data presented above, the peregrine was relatively common in the area of the Great Salt Lake and uncommon elsewhere in Utah.

## TOPOGRAPHY, CLIMATE, AND PLANT COVER IN UTAH

Utah is in a region of generally high inland plateaus and mountains which have been dissected by numerous canyons and dotted with many lakes and inland valleys. A chain of mountains and high plateaus beginning at the corner

of Wyoming and extending southwestward approximately two-thirds of the length of Utah separate the major part of the state into the Colorado and Great Basin drainage areas (see Fig. 1). The elevation of this central mountain

chain ranges from 9,000 to 12,000 feet (2,743-3,658 m). The Wasatch Mountains make up the northern third of the central chain (to the southern end of Utah Lake) and high plateaus the remainder.

Nearly all of Utah west of the central mountain chain lies in the Great Basin and contains the entire drainage of ancient Lake Bonneville, of which Utah, Sevier, and Great Salt lakes are remnants. The Great Salt Lake, which is about 83 miles (134 km) long by 51 miles (82 km) wide, has fluctuated in area from 2,400 sq miles (6,216 km<sup>2</sup>) in 1870 to 950 sq miles (2,461 km<sup>2</sup>) in 1961 (Nelson, 1969). It contains high concentrations of salts (about 25 percent) comprising principally sodium chloride and sodium sulfate. Utah Lake, which is about 23 miles (37 km) long and 15 miles (24 km) wide, is fresh water. Water comprises nearly three percent of Utah's area due mainly to these lakes. The lowlands on the floor of the basin range from 4,200 to 5,550 feet (1,280-1,692 m) in elevation. Just west of the Great Salt Lake lies the Great Salt Lake Desert, one of the most formidable deserts in North America. In its greatest length and width it exceeds 150 by 60 miles (240 by 97 km) (see Fig. 1).

The eastern half of the state is in part of the Colorado Plateau or Colorado River Basin. The Colorado River Basin is bordered on the north by the high Uinta Mountains, some peaks of which exceed 13,000 feet (3,962 m), and contains the Uinta Basin immediately south of the mountains and the canyonlands farther south. It is dissected from north to south by the Green and Colorado rivers. The basin floor ranges in elevation from about 4,300 feet to 6,000 feet (1,311-1,829 m). The Virgin River Basin, in southwestern Utah, is about 2,250 feet (686 m) in elevation.

Because Utah lies in the rain shadow of the high coastal ranges, it is one of the drier regions in North America, with an average of only 4 to 10 inches (10.2-25.4 cm) of annual precipitation in the desert lowlands. The precipitation

generally increases with an increase in altitude and may reach 30 to 50 inches (76.2-127.0 cm) annually in the higher mountains. Daily and seasonal temperatures in Utah vary widely. The summer maximum may exceed 100°F. The relative humidity is extremely low and the evaporation rate is high.

The desert lowlands are dotted with salt desert shrubs consisting chiefly of greasewood (*Sarcobatus vermiculatus*) and shadscale (*Atriplex confertifolia*) in areas below 5,500 feet (1,676 m) in elevation, and sagebrush (*Artemisia tridentata*) in areas higher than 5,500 feet (1,676 m) throughout much of the Colorado Plateau and the Great Basin. This low scrubby vegetation ranges from several inches to several feet in height. Desert scrub, consisting predominantly of mesquite (*Prosopis glanduliflora*), creosote bush (*Larrea divaricata*), and black brush (*Colcogyne ramosissima*), occurs in the southern desert of southwestern Utah.

The more arid foothills in the Great Basin and Colorado Plateau, which receive 10 to 15 inches (25.4-38.1 cm) of rainfall annually, are covered with pinon-juniper forests (*Pinus* and *Juniperus*), 10 to 30 feet (3.0-9.1 m) in height. Foothills receiving 16 to 20 inches (40.6-50.8 cm) of rainfall are covered with a variety of scrubby trees and bushes called chaparral, consisting of oak (*Quercus*), maple (*Acer*), serviceberry (*Amelanchier*), mountain mahogany (*Cercocarpus*), mountain laurel (*Ceanothus*), and manzanita (*Arctostaphylos*). Above the foothills lie montane forests of spruce (*Picea*), fir (*Abies*), and aspen (*Populus tremuloides*). The aforementioned data on relationships between precipitation and vegetation are modified from Woodbury and Cottam (1962).

Utah's numerous mountain ranges, its extensive plateaus, and its high cliffs and mesas supply a plentitude of suitable nesting sites for birds of prey. The low scrubby vegetation of its foothills and desert lowlands provides the extensive hunting areas preferred by the larger falcons.

## ECOLOGICAL DISTRIBUTION OF UTAH PEREGRINES

### Climate

The peregrine, as represented by a cosmopolitan assortment of geographically variable races, has adapted to a wide variety of environmental conditions. This is true also for the *anatum* race, which ranges from the tree line of the North American Arctic south sparingly into northern Mexico and the southern tip of Baja

California. In Utah, the peregrine has been known to nest in the Great Salt Lake Desert, one of the more arid regions known to be inhabited by this cosmopolitan species. At Wendover, for example, the monthly rainfall for the critical breeding period of March through July averaged only 0.44 inches (1.12 cm) over a 49-year period; the mean monthly temperature

ranged from 42° F (6°C) in March to 79°F (26°C) in July (U. S. Dept. of Commerce, 1965). Bond (1946) tells of peregrines nesting in the hot, arid climates along the lower Colorado River in California, in northeastern California, and eastern Oregon.

Climate along the Wasatch Mountains of Utah, where the peregrine historically attained its maximum density in the state, is more moderate. Here (Salt Lake City) the monthly rainfall for March through July averaged 1.03 inches (2.62 cm) over a 32-year period; the monthly temperature ranged from 40°F (4.4°C) in March to 77°F (25°C) in July (U. S. Dept. of Commerce, 1965).

Figures 13–15 delineate some of the climatic extremes associated with nesting peregrines in Utah. The hythergraphs given in Figure 13 are composites of the mean monthly extremes of daily temperature (for record period) and the mean monthly precipitation for weather stations near 18 known peregrine eyries distributed throughout Utah. The breeding period, March through August, is indicated also. The composite hythergraphs are constructed the same as those given by Twomey (1936) and Linsdale (1937), except that these authors used mean monthly averages of daily temperature rather than extremes (data from U. S. Dept. of Commerce, 1965).

In Figure 14 we have plotted the monthly average of the daily minimum temperature against the monthly average of the daily maximum relative humidity (from readings taken at three-hour intervals, 1965 through 1969) and the monthly average of the daily maximum temperatures against the monthly average of the daily minimum relative humidity for Salt Lake City (U. S. Dept. of Commerce, Local Climatol. Data 1965-1969).

Figure 15 gives a composite of the mean number of days per month that the precipitation was equal to or exceeded 0.1 inch (0.25 cm) and the mean number of days per month in which the temperature was equal to or exceeded 90°F (32.2°C), averaged for the 18 stations utilized in Figure 13 (data from U. S. Dept. of Commerce, 1965, [for record period]).

We used the extremes of climate since they, more than means, are likely to influence the general distribution of a species. According to Odum (1959:116-117):

... temperature exerts a more severe limiting effect on organisms when moisture conditions are extreme, that is, either very high or very low, than when such conditions are moderate. Likewise, moisture plays a more critical role in the extremes of temperature.

It is at the environmental extremes that the evolutionary processes for a species are most pronounced in regards to the development of new limits of tolerance. By comparing the climatic extremes at the periphery of the ecological range of a species, such as the peregrine in Utah, one may gain an insight into the climatic factors which may limit its range.

### Altitude

For western North America, Bond's data (1946) indicate that the peregrine rarely nests above 5,000 feet (1,524 m) in elevation, with a few nesting up to 10,000 feet (3,048 m) in California. However, many of the 18 eyries cited by Enderson (1965) for Colorado were above 5,280 feet (1,610 m), while the majority of them were above 6,000 feet (1,829 m) (Enderson, pers. comm.), with one eyrie in a high mountain region of Colorado, situated at an elevation of 12,000 feet (3,658 m) (Thomas D. Ray, pers. comm.). It may be that the habitat requirements of the peregrine are best satisfied in Colorado at these higher elevations. The paucity of eyries known to Bond (1946) to be at the higher elevations may be due, in part, to the difficulties encountered in reaching and searching the cliffs.

Nelson (1969) reported that peregrines in Utah nest at elevations up to tree line, between 6,000 and 7,000 feet (1,829 and 2,134 m). The only eyrie in Utah exceeding 6,000 feet (1,829 m), that is known to us, is at an elevation of 6,700 feet (2,042 m) (Table 1, site 36), but two are at 6,000 feet (Fig. 1, Table 1, sites 22 and 37), and the elevations of four others approach 6,000 feet (Fig. 1, Table 1, sites 26, 28, 35, 38). One suspected eyrie site, however, is at an elevation of 8,500 feet (2,591 m) (Fig. 1, Table 1, site 29) and another is at 9,750 feet (2,972 m) (Fig. 1, Table 1, site 27), suggesting the possibility that if higher areas were searched, others would be found. The mean elevation of peregrine eyries in Utah is about 5,000 feet (1,524 m) (Table 2). They ranged from 3,360 to 6,750 feet (1,024–2,057 m), with a preponderance of eyries (89 percent) between 4,000 and 6,000 feet (1,219 and 1,829 m) in elevation, and with nearly 50 percent of them at elevations between 4,500 and 4,999 feet (1,372 and 1,524 m). A frequency distribution of the elevations of Utah eyries is given in Table 2.

### Habitat Niche

The habitat niche of the peregrine may be divided into two parts: (1) the cliff or substrate upon which it lays its eggs and rears its young

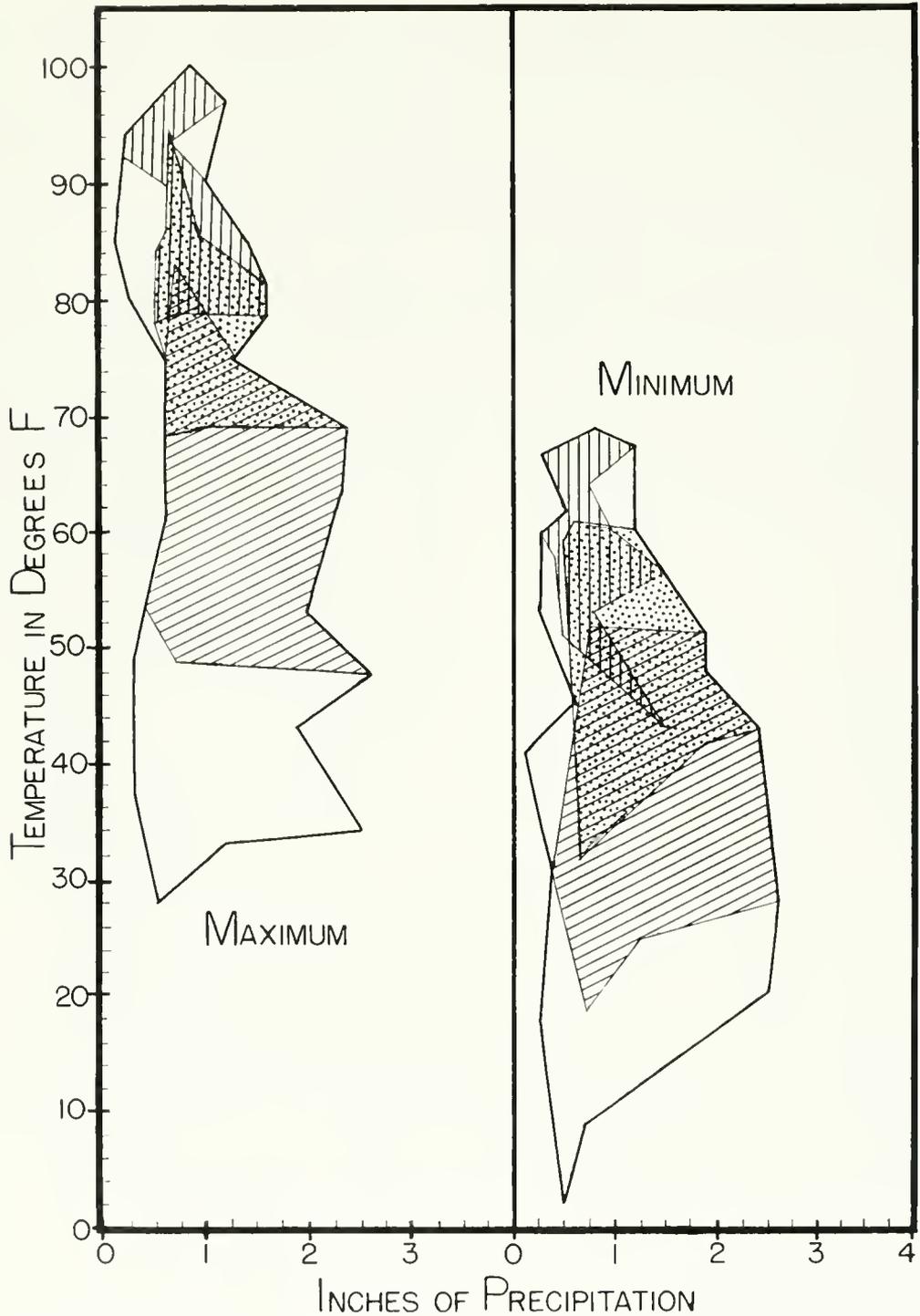


Fig. 13. Composite hythergraph for 18 stations situated near known peregrine eyries in Utah. Mean total monthly precipitation is represented in inches and mean monthly extremes of temperature (daily maximum and minimum, for record period) are represented in degrees F; they were constructed the same as those given by Twomey (1936) and Linsdale (1937), except that these authors used mean monthly temperatures (U.S. Dept. Commerce, 1965). The diagonally lined area depicts the climatic conditions for the egg-laying and incubation period (March-May); the stippled area represents the hatching and nesting period (May and June); the vertically lined area shows the fledging period (June-August).

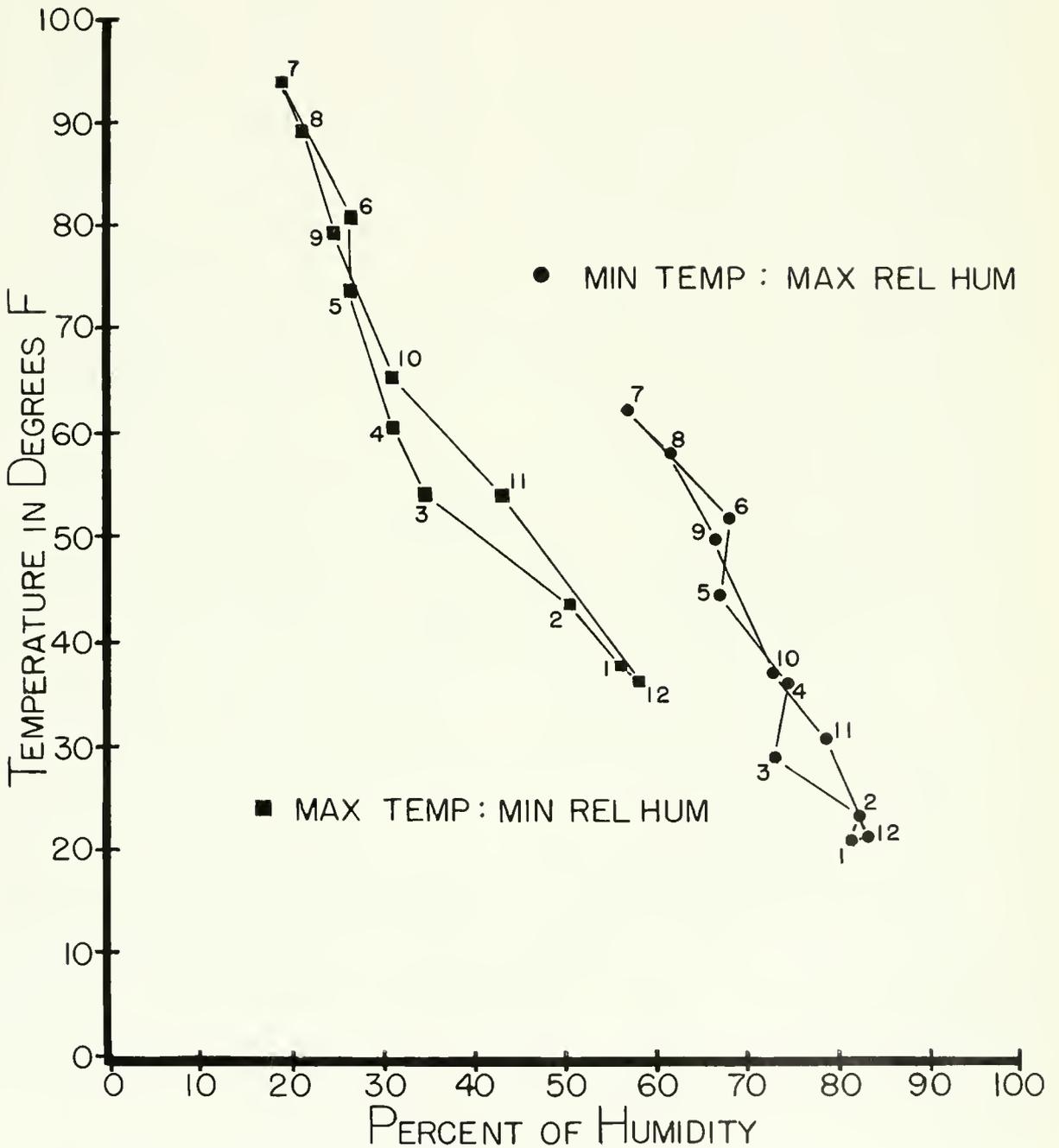


Fig. 14. Climographs for Salt Lake City, Utah. Daily maximum temperatures (averaged monthly for years 1965-1969), represented in degrees F are plotted against the mean daily minimum relative humidity for the same period; and the mean daily minimum temperatures for the same period are plotted against the mean daily maximum relative humidity. Humidity values were average from the maximum and minimum readings, taken at 3-hour intervals for 1965 through 1969 (U.S. Dept. Commerce, Local Climatological Data). Numbers beside points designate months of the year.

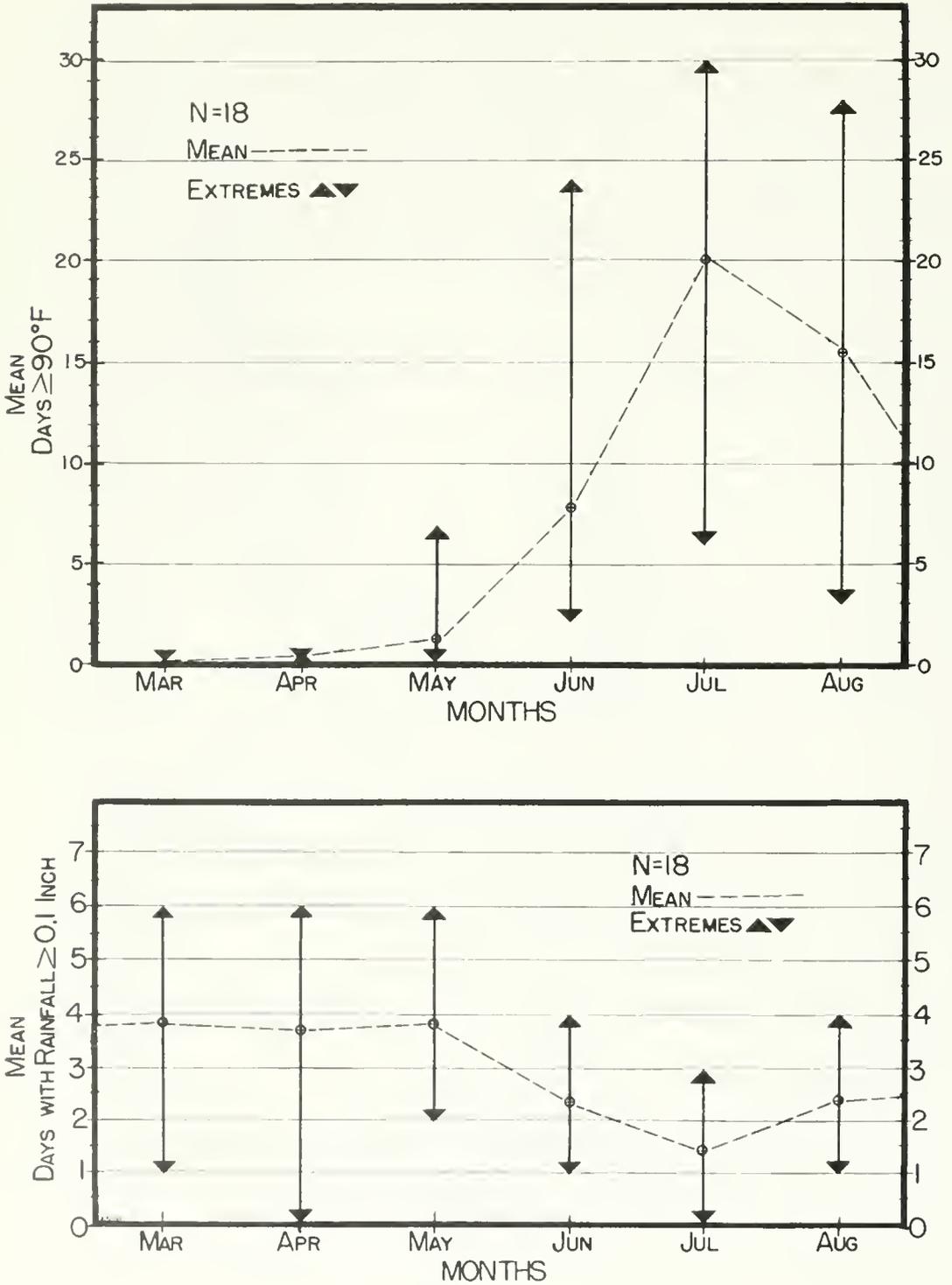


Fig. 15. Composite graph for 18 stations near peregrine eyries in Utah depicting the mean number of days per month in which precipitation was 0.1 inch (0.25 cm) or more and the average number of days per month in which the temperature was  $90^\circ\text{F}$  ( $32.2^\circ\text{C}$ ) or higher. (For record period, U.S. Dept. of Commerce, 1965.) Values were averaged (dashed lines) for the same 18 eyrie sites used in Fig. 13; extreme values are represented by solid triangles.

Table 2. Frequency distribution of peregrine eyrie site elevations in Utah.

Elevation (500-ft. intervals)	n	Percent	Elevation (intervals in meters)
3000-3499	1	3.2	914.4-1066.7
3500-3999	0	0.0	1066.8-1219.1
4000-4499	3	9.7	1219.2-1371.5
4500-4999	15	48.4	1371.6-1523.9
5000-5499	6	19.4	1524.0-1676.3
5500-5999	4	12.9	1676.4-1828.7
6000-6499	1	3.2	1828.8-1981.1
6500-6999	1	3.2	1981.2-2133.3
Totals:	31	100.0	
$\bar{x}$ elev. 4987 ft (1520 m)			
Range 3360-6750 ft (1024-2057 m)			

and around which its reproductive activities take place (nesting sites), and (2) the surrounding environs or territory where it obtains its food (hunting sites).

#### Nesting Sites

Most peregrine eyries in Utah were situated on a high ledge on the face of a cliff, but one female peregrine was reported to have laid her eggs in 1946 (Boyd Shaeffer, pers. comm.) on one of the dikes (elevated roadways) that separated two impoundment lakes at Ogden Bay State Waterfowl Management Area (Table 1, site 20). Additionally, an ornithologist (verbal report, to J. H. Enderson at AOU meeting, 1964) reported seeing an adult peregrine carry food to a young, nonflying falcon on the Mormon Temple in Salt Lake City in 1962, although we can find no corroborative evidence that falcons ever nested there.

#### Cliff Orientation

The ledges on which most Utah peregrines nest are in extensive mountain ranges which lie in a north-south direction. The escarpments of these mountains provide east- and west-facing cliffs, while their side canyons provide both north- and south-facing cliffs (Fig. 12). As illustrated in Figure 16, most peregrine eyries in the state were found in east- and north-facing cliffs. Although the escarpment along the Wasatch Mountains provided cliffs which faced all directions (Fig. 12), 10 of 12 eyries, for which data are available, were at sites facing northward (five eyries) and eastward (five eyries); three of the 12 faced slightly westward (NNW and NW), four faced southward (ESE and SE), one faced directly west, and one faced directly south. This suggests a directional orientation by the peregrine to the sun's exposure. Cliffs facing north or east should provide the eyrie

better protection from the hot afternoon sun than would those facing south or west.

These findings tend to corroborate those of Nelson (1969), who has documented the death of nestling Golden Eagles (*Aquila chrysaetos*) due to direct exposure to the hot rays of the sun. He considers the peregrine to be more sensitive to the extremes of temperature and to the direct rays of the sun than the Prairie Falcon. He has pointed out that the later nesting of the peregrine, compared to that of the Golden Eagle and Prairie Falcon makes the peregrine's young more vulnerable to heat and sun than are the young of either of the other two species. McGahan (1968) found a preference by the Golden Eagle in Montana for southern exposures. He suggested that nest site preference was influenced by the direction of the sun and noted that exposure should be important when temperatures are below freezing as well as during the warmer months of June and July.

In Alaska, Cade (1960) found that peregrines nesting along the Yukon River preferred cliffs facing an easterly direction and that this orientation had some relation to the sun. He noted no such correlation, however, for eyries along the Colville River and hypothesized that the Yukon eyries faced eastward because of strong prevailing summer winds, whereas the lack of special orientation along the Colville was due to the absence of such winds.

On the other hand, in Great Britain, where the climate is more moderate, Ratcliffe (1962) found that suitable cliffs faced all directions and that British peregrines are indifferent to directional facing. He argues further that more intensive ice action on shaded north and east slopes have resulted in more extensive development of cliffs or crag ranges on these slopes. Hence, he concludes that cliff exposure is unlikely to influence the deliberate choice of a nesting cliff or site.

Our data and those of Cade's (1960) suggest that sun and wind exposure in the harsh extremes of climate such as those in the desert and in the Arctic may, indeed, elicit a deliberate choice of nesting sites. In Great Britain peregrine eyries probably are not subjected to such harsh extremes of climate, and thus, peregrines have less need for making deliberate choices there.

#### Rock Type, Cliff Size, and Eyrie Height

The physical characteristics of the cliff play an important role in their use by the peregrine as a nesting site. The geological formation, involving type of rock and height of cliff, contributes to the suitability of the cliff as a nesting site. Thirty peregrine eyries in Utah were

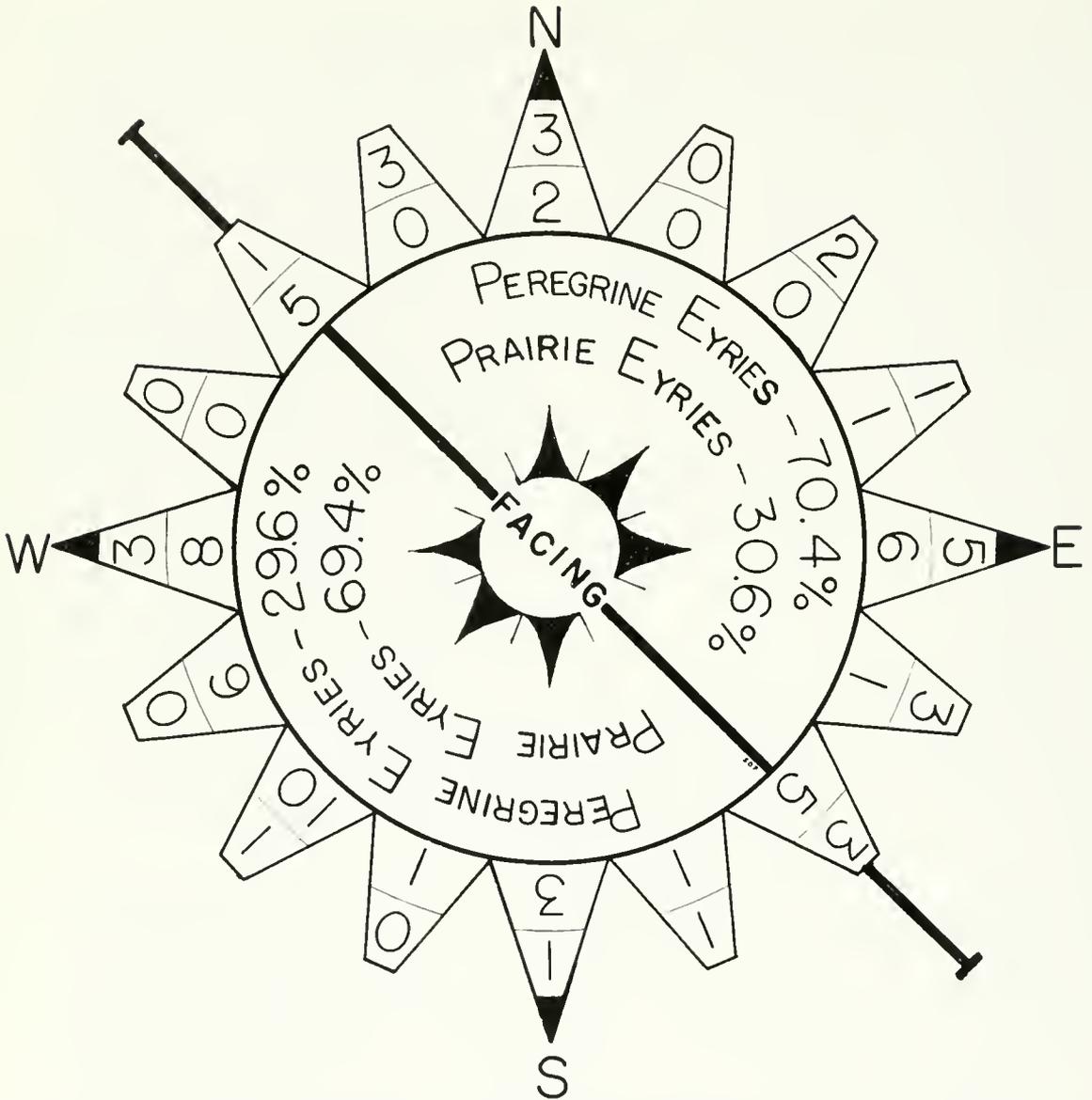


Fig. 16. Directional facings of Peregrine Falcon and Prairie Falcon eyries in Utah, both in areas of sympatry and in areas of allopatry. The values in the outer ring are for the peregrine; those in the inner ring are for the Prairie Falcon. The directional relationships shown here were statistically significant at  $p < 0.01$  ( $X^2$  test; calculated  $X^2$  value, 7.37, 1 df) for the Prairie Falcon and  $p < 0.05$  ( $X^2$  test; calculated  $X^2$  value, 4.48, 1 df) for the Peregrine Falcon.

situated on cliffs composed principally of four types of rocks: limestone, nine eyries; sandstone, nine eyries; quartzite, six eyries; and volcanic rock, three eyries. One additional eyrie each was located on volcanic agglomerate, granite, and metamorphic gneiss.

According to Hickey (1942), the height of the cliff is involved in the species' fidelity at the eyrie site over many generations of occupancy, and this concept is supported by Ratcliffe (1962, 1969) in Great Britain; Fischer (1967) has discussed the concept for eyries elsewhere in Eu-

rope. Hickey (1942), on the basis of height and continuity of use, classified cliffs in the eastern United States into three classes. Bond (1946) believes Hickey's (op. cit.) classification to be an oversimplification in the western United States.

Peregrines in Utah selected a wide variety of eyrie sites. Although the history of occupancy of individual eyries in Utah is largely unknown, there is some evidence to support Hickey's (op. cit.) hypothesis, at least in regards to height. Eyrie sites on the low, marginal cliffs were the first to be abandoned in Utah, whereas several

that were situated high up, on massive cliffs that were difficult to climb, have the longest histories of occupancy.

A frequency distribution of heights of cliffs which supported nesting peregrines in Utah are given in Table 3. These cliffs ranged from 40 to 400 feet (12.2-122 m) in height. The mean height of 21 such cliffs in Utah was 178 feet (54.3 m). An additional cliff, first noted by Treganza early in this century and reported by Woodbury et al., (unpubl. ms), was in excess of 1,000 feet (304.8 m) in height (Figs. 1 and 7; Table 1, site 8). We excluded it from our calculations so as to not disturb unduly the more normal range of heights (see footnote, Table 3).

For 14 eyries the distance from the base of the cliff to the eyrie site averaged 105.5 feet (32.2 m) and ranged from 25 to 330 feet (8.5-100.6 m). These measurements do not include the talus slope and mountain side. If these distances were included, the values given above would be considerably higher for most sites, especially those on the escarpment of the Wasatch Mountains. Ratcliffe (1962) has discussed the importance of the steep slopes as a relevant factor in attracting peregrines to the cliff.

From the brink of the cliff to the eyrie sites below, the distance averaged 68.6 feet (20.9 m) and ranged from 12 to 250 feet (3.7-76.2 m) for 13 eyries.

The values given here for cliff heights average somewhat higher than those reported by Cade (1960) for the Yukon River in Alaska,

and by White and Cade (1971) for the Colville River. Distances from the base of cliffs to the nest sites in Utah, however, averaged nearly twice those reported by Cade (1960) in the Arctic.

*Hunting Sites*

Marshes apparently play an important role in the breeding ecology of the peregrine in Utah (Figs. 12, 17, and 18), because nearly all peregrine eyries are situated near them. We measured the distances from each of 20 known eyrie sites in the Great Salt Lake and Utah Lake valleys to the closest nonflowing surface water, to the closest marsh 320 acres (130 ha) or larger, and to the closest marsh with no regard to size. The surface areas of the closest nonflowing water and the size of the closest marsh were also determined. Measurements were taken from U.S. Geological Survey topographic maps which were constructed from aerial photographs taken between 1945 and 1956; they are summarized in Table 4.

Of the 4,500 sq miles (11,655 km<sup>2</sup>) surrounding and including these two lakes, marshes covered about 100 sq miles (259 km<sup>2</sup>), while open water comprised about 1,443 sq miles (3,737 km<sup>2</sup>). With exclusion of the Utah and Great Salt lakes, with their surface areas of about 138 sq miles and 1,661 sq miles (358 km<sup>2</sup> and 4,302 km<sup>2</sup>), respectively, the surface area of water would be 80 sq miles (207 km<sup>2</sup>). If the three large impoundment lakes (surface area, about 55 mi<sup>2</sup>; 142 km<sup>2</sup>) at the Bear River

Table 3. Frequency distribution of heights of cliffs containing Peregrine Falcon and Prairie Falcon eyries in Utah and the vertical distances of eyrie sites above bases of the cliffs.

Distance in Feet	CLIFFS				EYRIES				Distance in meters
	Peregrine		Prairie		Peregrine		Prairie		
	n	Percent	n	Percent	n	Percent	n	Percent	
0-24	0	0.0	1	2.3	0	0.0	10	19.6	0.0-7.5
25-49	1	4.5	11	25.0	3	21.4	19	37.3	7.6-15.1
50-74	1	4.5	10	22.7	3	21.4	8	15.6	15.2-22.8
75-99	4	18.2	8	18.2	3	21.4	7	13.7	22.9-30.4
100-124	4	18.2	5	11.4	0	0.0	2	3.9	30.5-37.9
125-149	1	4.5	0	0.0	1	7.1	0	0.0	38.0-45.6
150-199	3	13.6	3	6.8	2	14.3	2	3.9	45.7-60.9
200-249	1	4.5	2	4.5	0	0.0	1	2.0	61.0-76.1
250-299	1	4.5	1	2.3	1	7.1	1	2.0	76.2-91.3
300-349	2	9.1	2	4.5	1	7.1	0	0.0	91.4-106.6
350-399	1	4.5	0	0.0	0	0.0	0	0.0	106.7-121.8
400-449	2	9.1	0	0.0	0	0.0	0	0.0	121.9-137.0
450-499	0	0.0	0	0.0	0	0.0	1	2.0	137.1-152.3
500 ≥	1	4.5	1	2.3	0	0.0	0	0.0	152.4 ≥
Totals:	22	99.7	44	100.0	14	99.8	51	100.0	
$\bar{x}$	178.0 ft <sup>a</sup> (54.3 m)		101.7 ft (31.0 m)		105.5 ft (32.2 m)		64.2 ft (19.6 m)		
Range:	40-400 ft (12.2-121.9)		7-500 ft (2.1-152.4 m)		28-330 ft (8.5-100.6 m)		2.5-450 ft (0.76-137.2 m)		

<sup>a</sup>Excludes one ground nester and one eyrie on a 1,000 ft (305 m) cliff



Fig. 17. Saltgrass (*Distichlis stricta*) marsh at Ogden Bay Refuge, Black-necked stilts (*Himantopus mexicanus*), a prey species of the peregrine, in the foreground. Photo by R. D. Porter, 1953.



Fig. 18. View to the west toward Promontory Mountains from Ogden Bay Waterfowl Management Area. Marshes in foreground are typical of those adjacent to Great Salt Lake from which peregrines and prairies nesting along the Wasatch escarpment and adjacent mountains obtained their major food source. Photo by R. J. Erwin, August 1972.

Table 4. Distances from peregrine eyrie sites in the Great Salt Lake Valley and Great Basin Desert to open, nonflowing water and marsh hunting areas and the size of these areas in relation to distance (measured from U.S. Geological Survey topographic maps which were constructed from aerial photographs taken between 1946 and 1956). Values in parentheses represent metric equivalence in kilometers or hectares.

Area & Statistic	MARSHES			SURFACE WATER <sup>1</sup>		
	Mi. to closest marsh (km)	Mi. to closest marsh ≥ 320 acres (130 ha)	Acres in closest marsh (ha)	Mi. to closest water (km)	Mi. to closest water ≥ 320 acres (130 ha)	Number of acres in closest water (ha)
<b>Wasatch Mountains (Utah &amp; Great Salt Lake valleys)</b>						
<i>n</i>	19	19	17 <sup>2</sup>	19	19	14 <sup>3</sup>
$\bar{x} \pm SD$	3.3 ± 2.6 (5.3 ± 4.2)	7.6 ± 5.1 (12.2 ± 8.2)	17.5 ± 20.6 (7.1 ± 8.3)	2.5 ± 2.0 (4.0 ± 3.2)	5.2 ± 4.3 (8.4 ± 6.9)	59.6 ± 34.4 (24.1 ± 13.9)
Range	0.19-9.7 (0.31-15.6)	0.19-18.6 (0.31-29.9)	3.7-82.6 (1.5-33.4)	0.10-6.7 (0.16-10.8)	0.10-13.6 (0.16-21.9)	1.2-188.8 (0.49-76.4)
<b>Desert, Great Basin</b>						
<i>n</i>	3	3	3	3	2 <sup>4</sup>	3
$\bar{x} \pm SD$	1.3 ± 1.3 (2.1 ± 2.1)	1.3 ± 1.3 (2.1 ± 2.1)	7,302 ± 10,396 (2,955 ± 4,207)	1.7 ± 2.0 (2.7 ± 3.2)	4.0 (6.4)	406 ± 701 (164 ± 284)
Range	0.19-2.8 (0.31-4.5)	0.19-2.8 (0.31-4.5)	640-19,281 <sup>5</sup> (259-7,803)	0.19-4.0 (0.31-6.4)	4.0-4.0 (6.4-6.4)	1.0-1,216 (0.40-492)

<sup>1</sup>nonflowing waters; lakes and ponds. <sup>2</sup>excludes two large marshes; one 5,598 acres (2,266 ha), the other 1,114 acres (451 ha). <sup>3</sup>closest water to five eyries was either Utah Lake or Great Salt Lake; hence, they were excluded. <sup>4</sup>data for one desert eyrie, which was nearly 100 miles (161 km) from large body of water, was excluded. <sup>5</sup>Nelson (1966) gives 4,700 acres (1,900 ha) for Clear Lake Waterfowl Management Area, but topographic maps show an additional 14,581 acres (5,901 ha), contiguous with the management area, and a total of 53,000 acres (21,449 ha) are shown within about 20 miles radius of the Clear Lake eyrie.

Refuge were also excluded, the amount of surface water would be reduced to 25 sq miles (65 km<sup>2</sup>). If both surface waters, exclusive of the Utah and Great Salt lakes, and marshes were divided equally by the 20 known peregrine eyries for the area, each pair of birds at these eyries would use prey species from 4.0 sq miles (10.4 km<sup>2</sup>) of water, 5.0 sq miles (13.0 km<sup>2</sup>) of marsh, and 9.0 sq miles (23.3 km<sup>2</sup>) of the two combined. Nelson (1966), on the other hand, reports that there are 234 sq miles (606 km<sup>2</sup>) of managed marshlands surrounding the Great Salt Lake (see Fig. 19), to which may be added several sq miles of unmanaged marshes controlled by duck clubs. The disparity between Nelson's measurements and ours probably is due to the fact that we used only marsh areas as shown on topographic maps and excluded mud flats and water, whereas Nelson's measurements probably include all lands and water within the Waterfowl Management Areas.

Marshes were the dominant features near three eyries in the Great Basin desert (Figs. 1 and 20, Table 1, sites 4, 23, and 25), and Twomey (1942) reported the use of the Ashley Creek marshes by peregrines nesting in Uintah County. The desert eyrie in the Colorado Plateau reported by White and Lloyd (1962) was by a river (Fig. 9). Figure 21 gives an aerial view of a river site in the desert of northern Arizona, typical of those in parts of Utah, and Figures

22 and 23 show marshes near eyrie sites in the Great Salt Lake Desert.

Peregrines nesting along the Wasatch escarpment traveled long distances to obtain shore and marsh birds, which made up the bulk of the food items found in their nests (Table 4), and the marshes where they hunted were rather extensive. In general, the Great Basin desert eyries were closer to marshes and to open water than were the Wasatch escarpment eyries (Table 4). One marsh supporting an eyrie in the Great Salt Lake Desert is only about a square mile (2.6 km<sup>2</sup>) in extent, and is only about a mile (1.6 km) from the eyrie (Fig. 20). It is about the same size as the Ashley Creek marsh (Stewart Lake Waterfowl Management Area, Nelson, 1966) near the eyrie found by Twomey (1942). The marsh at one other eyrie in the Great Salt Lake Desert covers about 2¼ square miles (5.8 km<sup>2</sup>) and is less than a mile from the eyrie site. An additional eyrie site (Woodbury et al., unpubl. ms) was 2.8 miles (4.5 km) from a marsh that covered over 30 square miles (78 km<sup>2</sup>) (Table 4). The surface area of fresh water at two of the desert sites is only a few acres in extent (Fig. 23), whereas that at the additional site was about 2 square miles (5.2 km<sup>2</sup>) in extent.

Of the 40 eyries and suspected eyries in Utah for which we have data, three were along rivers with marshes, streams, or lakes; five were

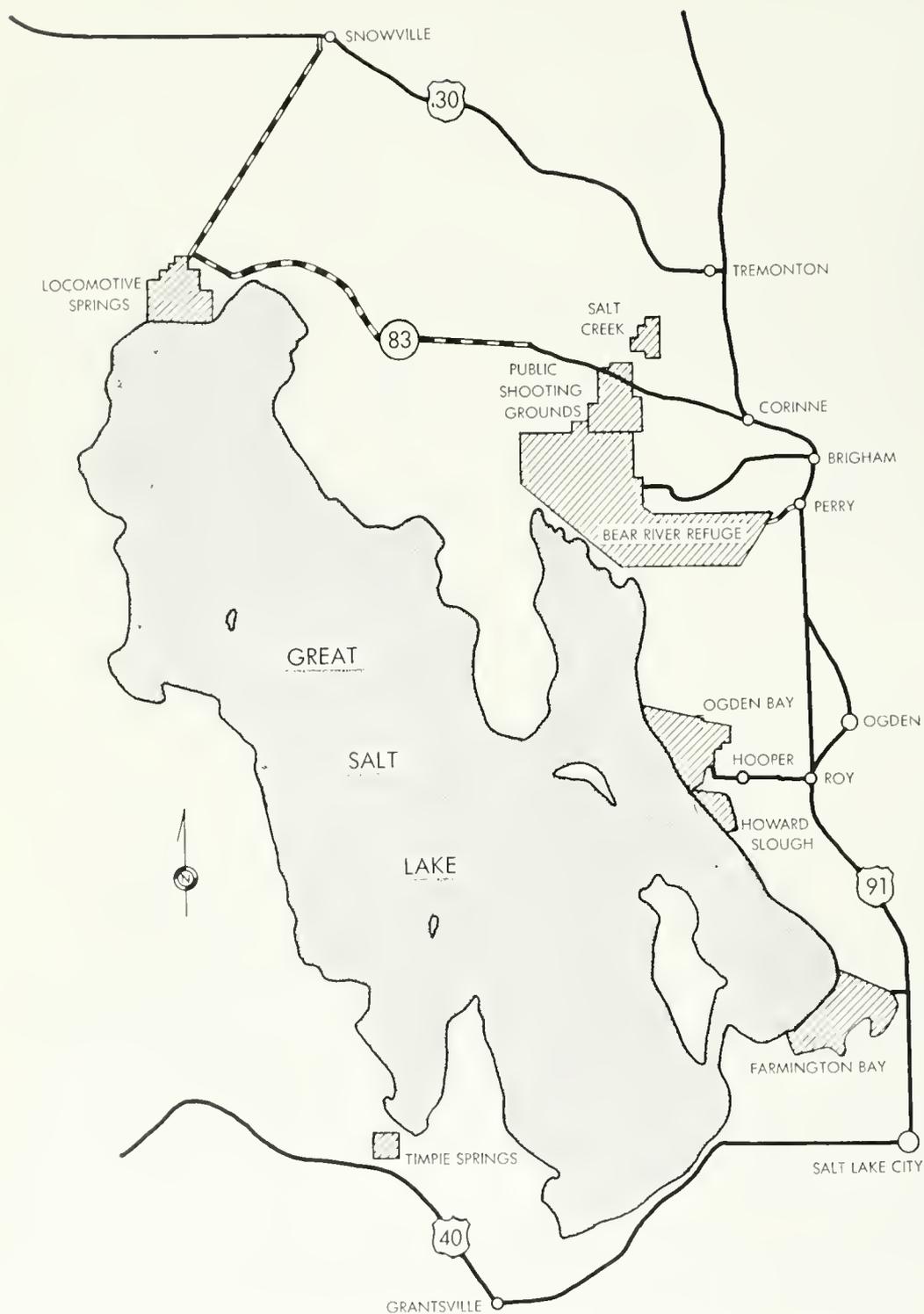


Fig. 19. Distribution of managed marshlands concentrated around the Great Salt Lake region. Photo by permission of Utah Division of Wildlife Resources, in Nelson, 1966.



Fig. 20. View across a marshy area adjacent to an eyrie in the Great Basin at the edge of the Great Salt Lake Desert. R. D. Porter is standing in foreground and is about 1 mile (1.6 km) east of the eyrie shown in Figure 44. Photo by R. J. Erwin, August 1972.

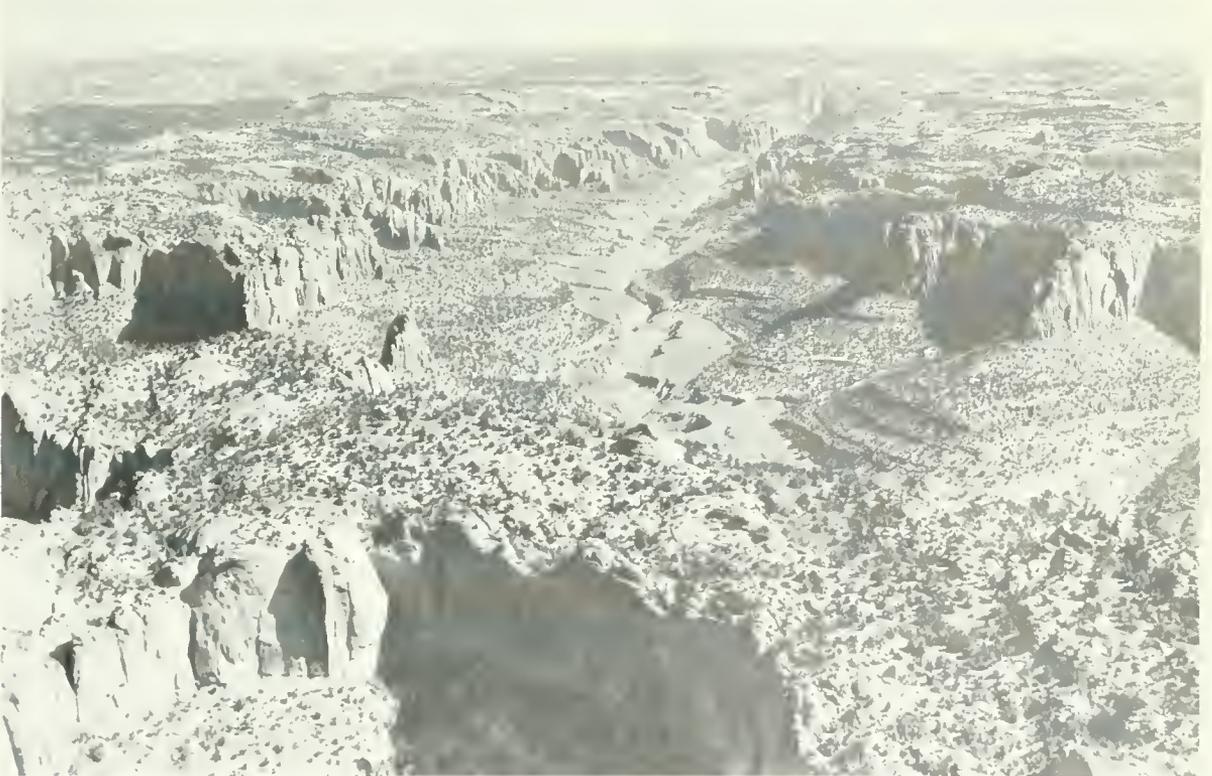


Fig. 21. Aerial view of a river eyrie site in the desert of northern Arizona typical of those in southeastern Utah. View looking NNE. Peregrines nested on the canyon wall on the right hand side of the photo. Photo by G. D. Lloyd, 1960.

along major rivers; 25 were near marshes with lakes and streams; five were along streams only; and there was one each near a marsh and a lake only. All but two of the 21 eyries near the Great Salt Lake were adjacent to a stream, which usually comprised the closest source of water. The smaller passerine birds associated with the streamside vegetation provided the peregrines with a source of food which frequently was within the immediate area of the eyrie.

The marshes originate from desert springs, from the overflow of rivers and creeks, from deltas at the junctions of rivers and lakes, and in more recent times, from artificial damming of streams or from the formation of ponds resulting from the drilling of wells. Bulrush (*Scirpus* sp.), saltgrass (*Distichlis stricta*) (Figs. 17 and 18), and cattail (*Typha* sp.) (Fig. 12) are the principal plants in these marshes.

The marshes supply food for peregrines during all seasons of the year, but are especially important during nesting season. The presence of an abundant food supply in the marshes at Ogden Bay undoubtedly was the major ecological factor responsible for the groundnesting of a peregrine there. Several easily accessible eyries that were mentioned by Beebe (1960) in the Queen Charlotte Islands may have been due to an abundant source of prey and to the absence of mammalian predators.

The combination of marshes adjacent to suitable cliffs for nesting may be considered an "ecological magnet" (Hickey, 1941) for the peregrine in Utah, especially along the Wasatch escarpment, where extensive marshes border the Utah and the Great Salt lakes. Here, marshes are formed at the deltas of three major rivers that flow into the lake (Fig. 19). Typical of



Fig. 22. Eyrie site near the eastern limits of the Great Salt Lake Desert. The eyrie, when first located by Porter in the early 1950s, was on a small cliff in the left foreground which does not show in this photo because it was removed to make a road bed. The peregrines were last seen using the cliffs near the top right of the photo. Prairie Falcons also used the same eyrie that was last used by the peregrines at least three years after the peregrines were last seen there. Photo by R. J. Erwin, August 1971.

their vegetation is that at the delta of the Weber River (Ogden Bay), which, from salt flats to river channels, consists mainly of glasswort (*Salicornia* sp.), saltgrass, alkali bulrush (*S. paludosus*), hardstem bulrush (*S. acutus*), cattail (*T. latifolia* and *T. angustifolia*), and sago pondweed (*Potamogeton pectinatus*) (Nelson, 1954). For a more comprehensive description of plant ecology in Utah marshes, see Nelson's (1954) studies of a marsh near the Great Salt Lake (Ogden Bay) and Bolen's (1964) discussion of a spring fed marsh in the Great Salt Lake Desert (Fish Springs).

Numerous remains of nine species of waterbirds, including grebes, ducks, rails, avocet, gulls, and terns, from anthropological sites at the northwest side of the Great Salt Lake, some dating back at least 8,350 years (Harper and Alder, in press), suggest that marshes were present in the Great Salt Lake valley long before the arrival of the white man. Some of the early hunters and explorers to enter the valley reported the presence of numerous waterfowl and shorebirds. Father Escalante, who visited Utah Lake in 1776, wrote that the lake "abounds in many kinds of fish and in geese and waterfowl" (Harris, 1909). Osborne Russell, a trapper, saw "miriads of Swans, Geese Brants, and Ducks which kept up a continuous hum day and night . . ." at Bear River marshes on 2 April 1842 (Haines, 1955). Fremont (1845), who visited the

Bear River Delta on 3 September 1843, mentioned the thunderous noise made by multitudes of waterfowl in the marshes and described the area as being covered with rushes and canes. Captain Stansbury (1852) made similar observations on 22 October 1849 from a vantage point on the east side of Promontory Point. He recorded that ". . . thousands of acres, as far as the eye could reach, were covered with them [waterfowl]. . . ." Fremont (1845) reported that "the stillness of the night [8 September 1843] was enlivened by millions of waterfowl," this time at the mouth of the Weber River near Little Mountain; and on 9 September he reported that the shallow delta of the river was "absolutely covered with flocks of screaming plover." Stansbury (1852) noted innumerable flocks of ducks, geese, white swan, and long-legged plover around the shallows at the mouth of the Jordan River on 4 April 1850. It is probable that the "plover" were mostly American Avocet (*Recurvirostra americana*), Black-necked Stilt (*Himantopus mexicanus*), and Willet (*Catoptrophorus semipalmatus*).

Vegetation at the river sites was comprised mostly of cottonwoods (*Populus fremontii* in the Lower Sonoran desert areas; *P. angustifolia* in the Upper Sonoran areas) and willows (*Salix exigua* was most frequently present, with *S. lutea*, *S. gooddingi*, and *S. caudata* occasionally present also). Other plant species known to oc-



Fig. 23. View from hillside below cyrie in Figure 22. Brackish marsh can be seen in the midground, and salt flats from the Great Salt Lake can be seen in the background. Photo by R. J. Erwin, August 1971.

cur with the cottonwoods and willows include: squawbush (*Rhus trilobata*), wildrose (*Rosa* sp.), tamarix (*Tamarix ramosissima*), Joshua tree (*Chrysoyucca brevifolia*), box elder (*Acer negundo*), ash (*Fraxinus* sp.), baccharis (*Baccharis emoryi*), hackberry (*Celtis douglasii*), and even scrub oak (*Quercus gambelii*). The presence or absence of the latter species is dependent upon altitude, latitude, and local ecological conditions.

#### Food Niche

Little has been published on the diet of the peregrine in the intermountain region. Wetmore's (1933:49-50) account of the hunting tactics of the peregrine on the Bear River marshes has been quoted elsewhere (Bent, 1938). It is repeated here because it gives a remarkably vivid picture of the peregrine in its native haunts along marshes of the Great Salt Lake earlier in the present century.

The birds [falcons] at rest perched in low willows, or on logs or bits of drift, where they had clear view of the teeming bird life about them. When hungry, they dashed across the open flats at high speed, striking ruthlessly at any birds that appeared, from small sandpipers to large ducks.

Their appearance in the air was always the signal for chattering cries of alarm from blackbirds and avocets that put all their bird neighbors on the watch. These warnings had little effect, however, as the duck hawk, killing practically at will, was truly despot of this realm.

I have seen this falcon dash through closely massed flocks of flying sandpipers, striking out two or three with as many thrusts of the claws, allowing each bird to drop and then wheeling swiftly to seize the falling prey in mid-air before it reached the ground. Again, I have seen one in a stoop, swift almost as light, knock a redhead duck to the ground, where it landed with a broken wing and other injuries.

On one occasion a pair of duck hawks harried a helpless nighthawk, stooping at it playfully until one in passing gave it a quick squeeze with one foot. It then allowed the nighthawk to fall, when it was seized by the other duck hawk. Then the pair flew away, and the one with the booty at intervals dropped it, so that it could be seized in air by its mate.

Food items found in several Utah eyries are summarized in Tables 5 and 6. We collected 107 individual prey items representing 20 species of birds and at least one species of mammal from two eyries along the escarpment of the Wasatch Mountains between 1943 and 1957. The American Avocet was represented in the greatest numbers (Fig. 24). It, the Mourning Dove (*Zenai-*



Fig. 24 Avocet at nest. This species was the most important food species found in the eyries of the peregrine in the valley of the Great Salt Lake and also the most frequent shorebird species in the eyries of the Prairie Falcon in the same locality. Photo by R. J. Erwin, 8 June 1959.

Table 5. Prey species in Peregrine Falcon and Prairie Falcon eyries in areas of sympatry along the escarpment of Utah's Wasatch Mountains<sup>1</sup>, facing the marshes of the Great Salt Lake.

Prey species	Weight class in grams <sup>2</sup>	n	Peregrine Falcon		n	Prairie Falcon	
			Percent of total	Percent of biomass		Percent of total	Percent of biomass
Duck sp. (yng.) <sup>2</sup>	150	3	2.80	2.75	2	2.63	2.60
Killdeer ( <i>Charadrius vociferous</i> )	106	2	1.87	1.29	9	11.84	8.26
Willet ( <i>Catotrophorus semipalmatus</i> )	203	10	9.35	12.38	5	6.58	8.79
Greater Yellow-legs ( <i>Totanus melanoleucus</i> )	165	3	2.80	3.02	—	—	—
Long-billed Dowitcher ( <i>Limnodromus scolopaceus</i> )	86	2	1.87	1.05	—	—	—
Sanderling ( <i>Crocethia alba</i> )	63	—	—	—	1	1.32	0.55
American Avocet ( <i>Recurvirostra americana</i> )	281	22	20.56	37.10	6	7.89	14.60
Black-necked Stilt ( <i>Himantopus mexicanus</i> )	152	1	0.93	0.93	—	—	—
Wilson's Phalarope ( <i>Steganopus tricolor</i> )	58	6	5.61	2.12	—	—	—
Franklin's Gull ( <i>Larus pipixcan</i> )	295	1	0.93	1.80	—	—	—
Shorebird and Gull Subtotal		50	43.92	59.69	21	27.63	32.20
California Quail ( <i>Lophortyx californicus</i> )	198	—	—	—	1	1.32	1.71
Ring-necked Pheasant ( <i>Phasianus colchicus</i> )	807	—	—	—	2	2.63	13.97
Gallinaeous Bird Subtotal		—	—	—	3	3.95	15.68
Mourning Dove ( <i>Zenaidura macroura</i> )	115	13	12.15	9.12	2	2.63	1.99
Rock Dove ( <i>Columba livia</i> )	318	5	4.67	9.70	1	1.32	2.75
Dove Subtotal		18	16.82	18.82	3	3.95	4.74
Red-shafted Flicker ( <i>Colaptes cafer</i> )	137	8	7.48	6.69	1	1.32	1.19
Western Kingbird ( <i>Tyrannus verticalis</i> )	42	—	—	—	1	1.32	0.36
Horned Lark ( <i>Eremophila alpestris</i> )	29	—	—	—	1	1.32	0.25
Scrub Jay ( <i>Aphelocoma coerulescens</i> )	77	1	0.93	0.47	—	—	—
Robin ( <i>Turdus migratorius</i> )	82	2	1.87	0.99	7	9.21	4.97
Bohemian Waxwing ( <i>Bombycilla garrula</i> )	56	2	1.87	0.68	—	—	—
House sparrow ( <i>Passer domesticus</i> )	26	—	—	—	9	11.84	2.03
Western Meadowlark ( <i>Sturnella neglecta</i> )	89	9	8.41	4.89	18	23.67	13.87
Redwinged Blackbird ( <i>Agelaius phoeniceus</i> )	54	4	3.74	1.32	—	—	—
Brewer's Blackbird ( <i>Euphagus cyanocephalus</i> )	68	3	2.80	1.24	1	1.32	0.59
Unidentified blackbird	61	5	4.67	1.86	1	1.32	0.53
Green-tailed Towhee ( <i>Chlorura chlorura</i> )	30	2	1.87	0.37	—	—	—
Rufous-side Towhee ( <i>Pipilo erythrophthalmus</i> )	37	—	—	—	2	2.63	0.64
Passerine Subtotal		28	26.16	11.82	40	52.63	23.24
Big brown bat ( <i>Eptesicus fuscus</i> )	18	1	0.93	0.11	—	—	—
Unidentified bat	10	2	1.87	0.12	—	—	—

Table 5 (Continued)

Uintah ground squirrel ( <i>Citellus armatus</i> )	250	-	-	-	2	2.63	4.33
Rock squirrel ( <i>Citellus variegatus</i> )	696	-	-	-	2	2.63	12.04
Unidentified ground squirrel ( <i>Citellus</i> sp)	400	-	-	-	1	1.32	3.46
Meadow mouse ( <i>Microtus</i> sp)	60	-	-	-	1	1.32	0.52
Mammal Subtotal		3	2.80	0.23	6	7.90	20.35
Totals		107	99.98	100.00	76	100.01	100.00
			20 species			21 species	

<sup>1</sup>Most prey items for both species originated from the Peregrine Falcon and Prairie Falcon eyries at site 7 (Table 1, Fig. 1); hence, for the most part, they represent prey species from a common resource.

<sup>2</sup>Weights of all avian species, with exception of the common pigeon, were obtained from Porter, Bushman, and Behle (unpubl. ms.); the value for the common pigeon was obtained from Roxie Laybourne, of the U. S. Bureau of Sport Fisheries and Wildlife; weights of mammalian species were estimated from those given by Hall (1946). Those of unidentified bats, ground squirrels, and young ducks were estimated by the authors.

<sup>3</sup>Weight of the young ducks is estimated; young pintails (*Anas acuta*) not yet feathered were in the peregrine eyrie on 13 and 14 June 1947.

*dura macroura*), Willet (Fig. 25), Western Meadowlark (*Sturnella neglecta*), Red-shafted Flicker (*Colaptes cafer*), Wilson's Phalarope (*Steganopus tricolor*), Rock Dove (*Columba livia*), and two species of blackbirds (*Agelaius phoeniceus* and *Euphagus cyanocephalus*) made up nearly 79 percent of the food items at the eyries. However, in both total biomass (59.7 percent) and in numbers (43.9 percent), the shorebirds comprised the largest segment of the diet, of which the avocet (37.5 percent biomass) (also see White, 1963) and Willet (12.4 percent biomass) were by far the most frequent. This is probably a reflection of the availability of shorebirds in the Great Salt Lake marshes.

Aside from being common, both avocet and Willet may have some conspicuous behavior that makes them easy to capture and that accounts for the numbers taken by the falcons. Tinbergen (1940) has shown that various behavioral peculiarities of certain passerine birds enhance their vulnerability to predation, and F. and J. Craighead (1956), based on the study of the food remains at 20 peregrine eyries, have suggested that the flash patterns of meadowlarks, redwings, and the Blue Jay (*Cyanocitta cristata*) and the conspicuous flight of flickers may increase the vulnerability of these species to predation by the peregrine. This hypothesis may be applicable to the Willet and avocet, both of which have conspicuous flash patterns.

Mourning Doves and Rock Doves were important columbiforme items (18.8 percent of biomass and 16.8 percent of total items). Passerines, woodpeckers, and bats were represented in smaller numbers and biomass (Table 5).

The use of bats for food by peregrines has been reported from Texas by Stager (1941), and desert nesting Shaheen Falcons (*Falco pelegrinoides babylonicus*) of the Middle East, which are either peregrines or are very closely related

to them (Vaurie, 1961; White, 1968b; Brown and Amadon, 1968), reportedly hunt bats at dusk (Dementiev, 1951 and 1957). In Indonesia, Mees (1949) reports that wintering tundra falcons seem to be specialized for feeding on bats. He saw one falcon kill seven bats one after another. Fischer (1968) reports that the subspecies of peregrine (*F. p. ernesti*) indigenous to Indonesia also hunts bats.



Fig. 25. Willet (*Catoptrophorus semipalmatus*) on nest. The Willet was an important prey species in peregrine eyries of the Great Salt Lake Valley. This species is inconspicuous while on nest but in flight it, like the stilt and avocet, shows a striking flash pattern. Photo by R. J. Erwin 1959.

Table 6. Prey species in two Peregrine Falcon eyries in Utah's desert (sites 4 and 28, Table 1, Figs. 1, 9, and 22).<sup>o</sup> C=Colorado Plateau, GB=Great Basin.

	Weight class in grams	No.	Percent of total	Percent of biomass
Chukar ( <i>Alectoris graeca</i> ) (C) <sup>oo</sup>	520	1	5.26	26.52
American Coot ( <i>Fulica americana</i> ) (GB) <sup>oo</sup>	365	1	5.26	18.60
Mourning Dove ( <i>Zenaidura macroura</i> ) (C, GB)	115	2	10.53	11.73
Common Nighthawk ( <i>Chordeiles minor</i> ) (GB) <sup>oo</sup>	62	1	5.26	3.16
Ash-throated Flycatcher ( <i>Myiarchus cinerascens</i> ) (C) <sup>oo</sup>	29	2	10.53	2.96
Say's Phoebe ( <i>Sayornis saya</i> ) (C) <sup>oo</sup>	21	1	5.26	1.07
Horned Lark ( <i>Eremophila alpestris</i> ) (C, GB) <sup>oo</sup>	29	3	15.79	4.44
Pinon Jay ( <i>Gymnorhinus cyanocephala</i> ) (C) <sup>oo</sup>	116	1	5.26	5.92
Western Meadowlark ( <i>Sturnella neglecta</i> ) (GB)	89	1	5.26	4.54
Yellow-headed Blackbird ( <i>Xanthocephalus</i> )				
<i>xanthocephalus</i> ) (C) <sup>oo</sup>	92	3	15.79	14.07
Redwinged Blackbird ( <i>Agelaius phoeniceus</i> ) (C, GB)	54	2	10.53	5.51
Lark Sparrow ( <i>Chondestes grammacus</i> ) (GB) <sup>oo</sup>	29	1	5.26	1.48
Unidentified Passerines (C)				
Passerine Subtotal		14	73.68	39.99
Desert Totals		19	99.99	100.00

12 species

<sup>o</sup>See footnote for Table 5.<sup>oo</sup>Not recorded in Wasatch Mountain eyries (see Table 5).

Eyries adjacent to the Great Salt Lake contained no full-grown waterfowl despite the abundance of waterfowl in the adjacent marshes, although the peregrine has been observed eating or pursuing full-grown ducks of several species during the breeding season. These include the Gadwall (*Anas strepera*) (observed 5 May 1938, field notes of R. G. Bee), a teal (H. Austin, pers. comm.), a teal on 10 April 1948 at Ogden Bay (Porter), and the Redhead (*Aythya americana*) (Wetmore, 1933). Calvin Wilson (pers. comm.) has watched peregrines from an eyrie in the Wasatch Mountains eating Ruddy Duck (*Oxyura jamaicensis*), Cinnamon Teal (*Anas cyanoptera*), Pintail (*Anas acuta*), and American Coot (*Fulica americana*) on dikes of a nearby marsh. R. J. Erwin (unpubl. data) flushed a peregrine from the side of a highway in Grand County in April 1958, where it had just captured an adult Mallard (*Anas platyrhynchos*).

Cade, White, and Haugh (1968), on the other hand, found that waterfowl constituted nearly 50 percent (biomass) of the food items in the eyries of the Alaskan taiga peregrine (*F. p. anatum, sensu lato*). Utah peregrines are smaller, however, than those of interior Alaska. The absence of ducks in the Wasatch Mountain eyries may possibly be explained on the basis of the weight of the prey item in relation to the distance that peregrines must carry it to their eyries. A full-grown duck may be too heavy for peregrines to carry the several miles from the Great Salt Lake marshes to eyries along the Wasatch escarpment.

Shorebirds were not present in two desert eyries. One eyrie was located near a marsh in

the Great Basin and the other near a river in the desert of the Colorado Plateau. The availability of a variety of marsh and shorebirds to the peregrines at the desert eyries in the Great Basin (Table 6) accounts for the presence of the coot. The coot in the Great Basin desert eyrie probably came from a pond (desert spring) which was only about 1,200 yards (1,097 m) from the eyrie site. Since its weight (400 g) is about the same as that of a duck, it is possible that its absence from the Wasatch Mountain eyries may have been for the same reason that ducks were missing from these eyries. The small sample-size of food items probably accounts for the absence of shorebirds in this desert eyrie.

At a Wasatch Mountain eyrie, observed by R. D. Porter (site 7, Table 1) for the first two weeks after hatching, only one, and at most, two, prey items were found each day in the nest; these usually consisted of Redwinged Blackbirds, Mourning Doves, Willets, and meadowlarks. But as the nesting season progressed, a greater number of species and items were brought to the nest. On 28 June 1952, for example, about three weeks after hatching of the young falcons, the female returned with a young Willet at 11:00, a robin-sized bird at 11:50, and an unidentified item at 17:20. The male returned with a young avocet at 15:20 and a leg of a young avocet at 15:45. The next day the male brought a Wilson's Phalarope to the nest and the female an avocet. Other items found in the nest on 29 June were Scrub Jay (*Aphelocoma coerulescens*), unidentified blackbird, big brown bat (*Eptesicus fuscus*) and one adult and one immature Wilson's Phalarope. Of the shore-

birds brought to the young at this eyrie (site 7, Table 1) during the years it was observed, 33 percent were partially fledged young of the season. Peregrines nesting along the face of the Wasatch Mountains traveled several miles to obtain the marsh and shorebirds (Table 4); other species were obtainable much closer to the eyries.

Despite the peregrine's reported antipathy to capturing food on or near the ground (Bond, 1936a), mammalian prey species such as the brush rabbit (*Sylvilagus bachmani*) (Bond, 1936c), rats (*Rattus* sp.) (White, et al., 1973), and certain gallinaceous birds (ptarmigan, *Lagopus* sp.) (Cade, 1960; White and Cade, 1971) also are taken for food occasionally. Bond (1946) reported that peregrines commonly brought Horned Larks to their small young. The Horned Lark, which is essentially a ground-dwelling species, is one of the most abundant birds in Utah's salt desert scrub vegetation. It was present in peregrine eyries in both the Colorado Basin and Great Basin deserts of Utah (Table 6).

Much of the desert lowlands and foothills of Utah are vegetated with desert scrub and with pigmy conifer forests, respectively, yet the peregrine was not known to nest far from water in those areas where the Horned Lark of necessity would have been an important item in its diet. Jays (*Aphelocoma* and *Gymnorhinus*), kingbirds (*Tyrannus*), Ash-throated Flycatcher (*Myiarchus cinerascens*), Lesser Nighthawks, Red-shafted Flickers, Robins, Mourning Doves, and Black-throated Gray Warbler (*Dendroica nigrescens*), some of which are known to be used as prey by the peregrine, are available in the pigmy forests, yet the peregrine nests in these areas

only when water or marshes are nearby.

A more intensive study of the peregrine's food habits in Utah during nesting season undoubtedly would have revealed a much wider variety of prey species, especially the smaller passerines. In terms of biomass, however, the smaller species of birds probably would not have altered appreciably the percentages of each category of birds.

The abundance of doves in Utah eyries is not surprising, despite the availability of marsh and shorebirds, since the domestic pigeon has been found to be a favorite prey species of the peregrine, not only in the eastern United States, but also in many other areas of the peregrine's cosmopolitan distribution (Hickey and Anderson, 1969).

The Utah peregrines utilize a wide variety of prey species (at least 29 species, see Tables 5 and 6) during the nesting season, and in this respect their diet is more comparable to that of populations elsewhere in North America than to that of populations in the Queen Charlotte Islands, where Beebe (1960) found them limited mostly to one and not more than four prey species during the nesting season. On Amchitka in the Aleutian Islands, White, Emison, and Williamson (1973, in press) list 32 species in the peregrine's diet, most of which were found in the nests, and comprised principally marine birds, waterfowl, gulls, and shorebirds. Shorebirds were represented frequently in the eyries of peregrines along the Colville River of Alaska (White and Cade, 1971). Cade, White, and Haugh (1968) reported 49 prey species in eyries located in the taiga zone of the Arctic, and Cade (1960) found 21 species in nests located in the tundra zone.

## NESTING BEHAVIOR IN UTAH

### History of Nesting at a Wasatch Mountain Eyrie

Eyrie sites of the Peregrine and Prairie Falcon at a cliff on the escarpment of the Wasatch Mountains (Table 1, site 7; Fig. 26) were observed by R. D. Porter, R. J. Erwin, and others from 1943 through 1952, exclusive of two war years, 1944 and 1945. We obtained data at this cliff on interspecific competition between the two species and on productivity, incubation periods, and reproductive failure for the peregrine, all of which will be discussed under separate headings.

The cliffs were composed of quartzite and faced westerly along the west-facing escarpment of the mountains and southerly along a south-

facing edge of a side canyon. Peregrines were first noted there on 3 April 1943, the year the cliff was first under our observations, by R. J. Erwin and J. F. Poorman, and again that year by J. F. Poorman and R. L. Porter on 15 April. A nest containing three eggs was found on 26 April. Prairie Falcons were also first noted at this cliff in 1943. A summary of the reproductive history of the peregrines at this site is given in Table 7. The physical characteristics of the various peregrine and Prairie Falcon sites utilized during the period of study are given in Table 8. The photographs represented by Figures 27-39 were taken in 1947, 1948, and 1952.

In 1949 the peregrines defended a nesting

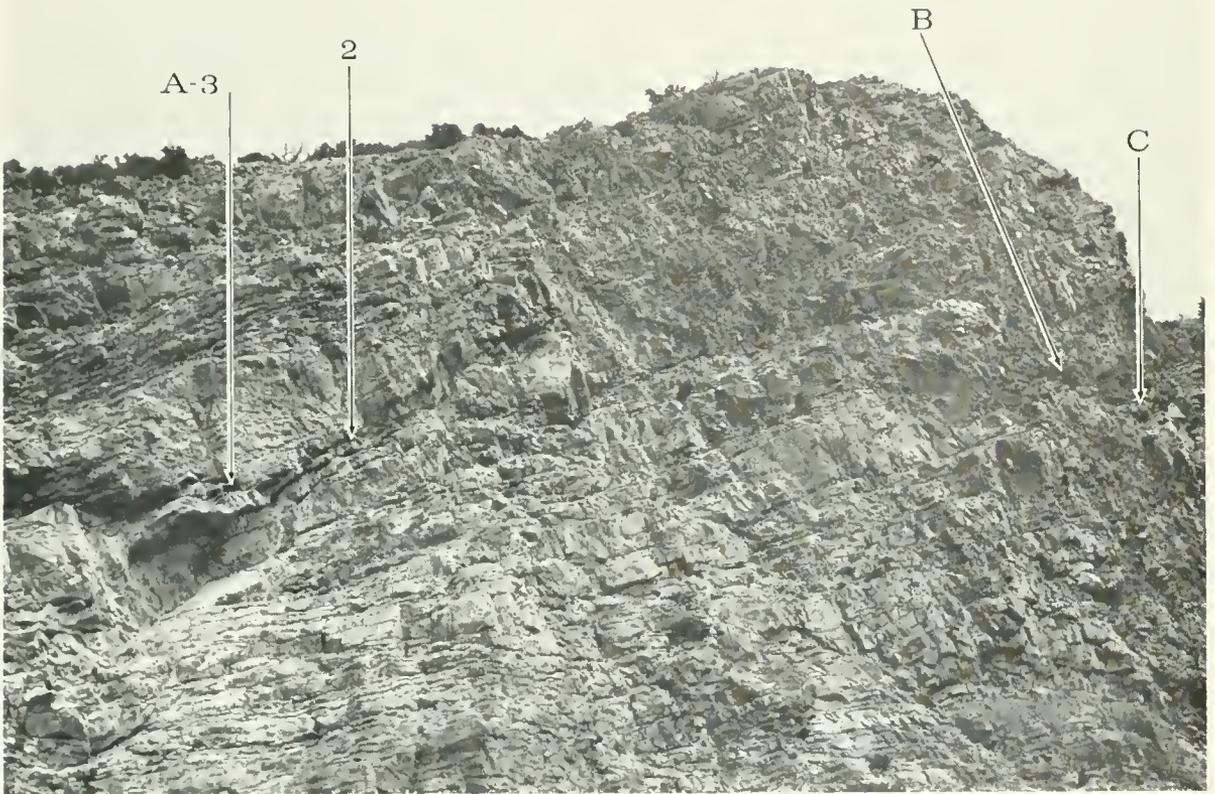


Fig. 26. A cliff along the escarpment of the Wasatch Mountains which contained eyries of both the Peregrine Falcon and the Prairie Falcon (Table 1, site 7). The Peregrine Falcons used site A-3 in 1943, 1952, and 1953; site B in 1946 and 1947; and site C in 1948 and 1951. The Prairie Falcons used site 2 in 1948; site A-3, 1949; and site 1, to the north (not shown in photograph) of site A-3, in 1943 and 1950. Sites B and C faced south, sites 1, 2, and A-3 faced west. Photo by R. J. Erwin, 1972.

ledge, which contained two nest scrapes, but apparently laid no eggs. They defended several sites on the cliff in 1950 but with less tenacity than usual. Although they made 20 to 25 scrapes along several hundred feet of ledge, no eggs were found. Between 4 March and early June the cliffs were searched for an eyrie 10 times without success. The behavior of the birds suggested the presence of a nest at numerous places along the cliff. However, each new section of cliff was defended with nearly equal spirit.

In 1952, the two young at site A (Fig. 26 and Tables 7 and 8) were measured and weighed from date of hatching until 13 August. They were removed from the nest on 5 July. R. J. Erwin banded three young peregrines at the 1943 site in 1953. He obtained no information on egg number or occurrence of Prairie Falcons.

A new female peregrine nested at alternate site A in 1952. She still had some immature



Fig. 27. Five-egg clutch of Peregrine Falcon (eyrie site 7-B, Table 1, 1947). Note the wood rat (*Neotoma* sp.) scat on ledge and about the eggs. Photo by R. D. Porter.



Fig. 28. Female peregrine entering eyrie. Photo by R. D. Porter and R. J. Erwin, 1948.



Fig. 29. Female peregrine settling down over nestlings which are only a few days old (Table 1, site 7, alt. site C). Photo by R. D. Porter and R. J. Erwin, 1948.

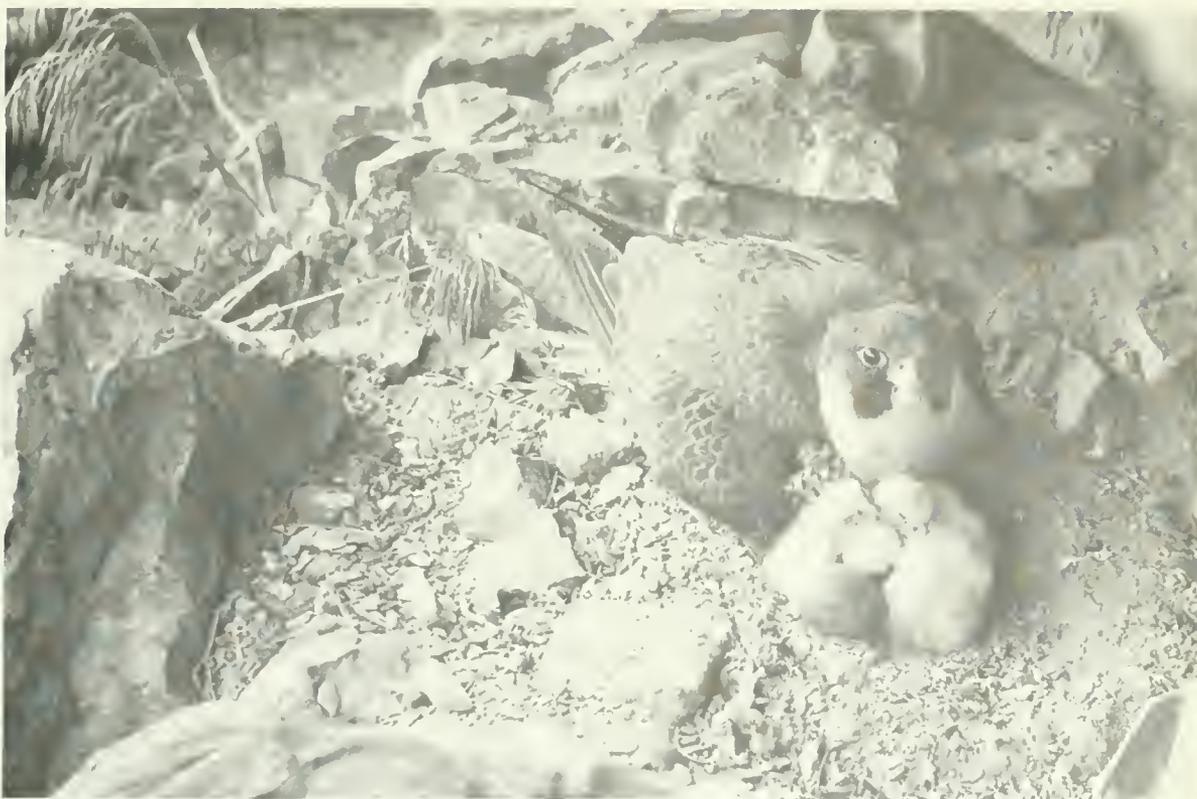


Fig. 30. Female peregrine brooding young. Note addled egg. Photo by R. D. Porter and R. J. Erwin, 1948.



Fig. 31. Female peregrine with young, in defensive attitude. Photo by R. D. Porter and R. J. Erwin, 1948.



Fig. 32. Female peregrine feeding young. Photo by R. D. Porter and R. J. Erwin, 1948.



Fig. 33. Female peregrine feeding young which were nearly 3 weeks old (eyrie site 7, alt. site B, Table 1). Photo by R. D. Porter, 1947.



Fig. 34. Young peregrines at approximately 4 weeks of age (eyrie site 7, alt. site C). Photo by R. D. Porter and R. J. Erwin, 1948.



Fig. 35. Young peregrines about 6 weeks of age, nearly old enough to fledge (eyrie site 7, alt. site C). Photo by R. D. Porter, 1947.

Table 7. Reproductive history of the peregrines at a Wasatch Mountain eyrie (site 7, see Tables 1 and 8, and Figs. 26-29).

Year	Alternate site location	Dates recorded	EGGS			NESTLINGS			
			No.	Probable date of 1st egg	Incubation period (in days)	No.	Dates hatched	Other dates of record	Misc. Data
1943	A	26 April	3	-	≤37 (3rd egg)	3 <sup>1</sup>	unknown	31 May	
1946	B	-	-	-	unknown	4	unknown	26 June	Young nearly fledged, two taken
1947	B	26 April 17 May	3 5 <sup>2</sup>	21-22 April	35-37 (3rd egg)	3	unknown	31 May	Downy young
1948	C	16 April 19 April 27 May	3 4 5	11-12 April	42-44 (3rd egg) 39-41 (4th egg)	4	28-29 May	29 May  29 June 5 July 17 July	5 eggs, 1 pipped 27 May; 4 young + 1 addled egg, 29 May 4 young, 2 taken <sup>2</sup> young fledged <sup>2</sup> young full grown <sup>2</sup>
1951	C	2 May 3 May 13 May 19 May	3 3 2 0		unknown	0	-		
1952	A	29 April 1 May 27 May 31 May 1 June	1 <sup>3</sup> 1 <sup>3</sup> 3 3 3	29 April	37 (egg 1)	0 <sup>1</sup> 2	- 5 June, 07:00	4 June 5 June 7 June	2 eggs pipping 1 hatched, 1 <sup>3</sup> nearly hatched both hatched
1953	A	-	-	-	unknown	3	-	-	

<sup>1</sup>Three young were about ready for flight when two were taken for falconry sometime in early July. <sup>2</sup>29 June: 4 young, 2 males, 2 females; females taken for falconry: oldest male, tail half grown, flew from nest. 5 July: 1 young male, still on nest ledge, flew at approach of observer, first male to leave nest on rock above nest. 17 July: females taken from nest about full grown. <sup>3</sup>Marked with a numeral 1 in India ink. <sup>4</sup>Two eggs pipping, one with small hole (egg 1), other barely dented, young peeping inside both eggs, loudest in egg marked with numeral 1; marked egg weighed 47 g, other pipped egg, 50 g, and unpipped egg, 48 g. <sup>5</sup>Shell around abdomen and legs; it probably hatched on 6 June; third egg addled.

feathers (see Figs. 36-38), and was undergoing a molt as evidenced by the fact that on 28 June the upper surface of the wings had just begun to molt into the adult plumage. The molt on the back (capital and spinal feather tracts) and the lower breast (ventral tracts) was nearly complete, while that of the primaries and retrices had only begun. The capital tracts of the head were only partially molted. While the female was in flight, it was noted that at least one primary was missing on each wing as well as at least one retrix on each side of the tail.

The plumage condition of this bird indicates that she probably was no more than three years of age. Records of breeding peregrines while still in their immature plumage are not common. Beebe (1960) noted no instances of mated pairs in immature plumage, or even in plumage showing traces of immaturity, in a rather large sample of pairs along the northwest Pacific Coast. However, Herbert and Herbert (1965) pointed out two instances of immature-plumaged females occupying an eyrie, neither of which was found to lay eggs. Hickey (1942) reported on three immature, one-year-old females that failed to lay eggs and a fourth that brooded a clutch of two eggs, making a total of only one first-year female out of 34 falcons

over a two-year-period in New York. A report by Herbert of two females believed by him to be two-year-old birds, both of which laid only two eggs in different years, also was mentioned by Hickey (1942). White and J. R. Haugh (pers. obser.) found one female, out of 17 pairs breeding on the Yukon River in 1966, that was essentially still in the streaked brown immature plumage. Therefore, it was thought to be but one year old. She laid two fertile eggs, one of which hatched.

#### Egg Laying

At the alternate site A eyrie (Table 1, site 7) egg laying began between 12 and 29 April (1943-1952) as estimated by counting back from known dates certain eggs were laid (Table 7). Published records for the state range from about 22 March (counting back from 30 March as given by Johnson, 1899) to the second or third week in May (counting back from 20 May given by Bee and Hutchings, 1942). The first egg of a three-egg clutch found by White and Lloyd (Table 1, site 28) was probably laid around 6 May, as indicated by the date of hatching. At the aforementioned eyrie in the Wasatch Mountains (Table 1, site 7), 3.8 eggs (range 3-5) on the average were laid per year during the five



Fig. 36. A view of female peregrine with unmolted immature plumage. Her two young are about 3 weeks old (eyrie site 7, alt. site A). Photo by R. D. Porter, 1952.



Fig. 37. Same female as in Fig. 36. This bird is certainly not more than three years old because of the amount of immature plumage retained. Note that most of the tail, secondary wing feathers, and greater wing coverts are immature feathers. Photo by R. D. Porter, 1952.

Table 8. Physical characteristics of eyrie sites at a cliff in the Wasatch Mountains (Table 1, site 7, see Figs. 26-39) used by both peregrines (Pe) and Prairie Falcons (Pr). Values in parentheses represent metric equivalents.

Alt. site	Approx. dist. in ft (m) from site A to site	Species <sup>1</sup> and year used	Cliff height, ft (m)	Eyrie height, ft (m)	Direct facing	Ledge length, inches (m)	Ledge width, inches (m)	Dist. Eyrie below overhang, inches (m)	Nest area ft <sup>2</sup> (m <sup>2</sup> )	Dia. nest scrape, inches (m)	Depth soil, inches (m)
A-3 <sup>2</sup>	0	Pe 1943 1952 1953 Pr 1949	110 (34)	85 (26)	W	72 (1.8)	62 (1.6)	20 (0.51)	7.42 (0.69)	6.9 (0.18)	2 (0.051)
B	320 (98)	Pe 1946 1947	135 (41)	90 (27)	S	120 (3.0)	60 (1.5)	18 (0.46)	6.45 (0.60)	-	-
C	350 (107)	Pe 1948 1951	135 (41)	90 (27)	S	156 (4.0)	48 (1.2)	35 (0.89)	6.55 (0.61)	6.4 (0.16)	-
1 <sup>3</sup>	300 (91)	Pr 1943 1950	110 (34)	-	W	-	-	-	-	-	-
2 <sup>2</sup>	55 (17)	Pr 1948	110 (34)	95 (29)	W	61 (1.5)	90 (2.3)	21 (0.53)	21.8 (2.0)	-	2 (0.051)

<sup>1</sup>Prairie Falcons were not recorded in 1947, 1952, and 1953, were seen, but no nest was found in 1951.

<sup>2</sup>All values were obtained by direct measurements at eyrie sites; all other values given in the table, except cliff and eyrie heights, distances between eyrie sites, are approximations from photographs, using a peregrine's egg or the adult peregrine as a unit of measurement.

<sup>3</sup>Exact eyrie site was not reached

years that eggs were found (see Fig. 27), and 2.4 of the eggs (range 0-4) on the average hatched. The eyrie produced a total of 19 young during the seven years it was known to have been active, for an average of 2.7 young per

year. Although the number of fledged young was not ascertained, no young were known to have died in the nest. Eight young, however, were removed for falconry when nearly fledged.

These values approach those for the peregrine



Fig. 38. A close-up of same female as in Fig. 36. Photo by R. D. Porter, 1952.

in eastern North America, where Hickey (1942) found the average clutch size to be 3.72 and the average number of downy young to be 3.0. For western North America, Bond (1946) reported an average clutch size of 3.7 and Cade (1960) recorded an average of 2.7 eggs per clutch in northern Alaska and 3.1 eggs per clutch in other locations in the Arctic.

### Incubation

The eggs are laid usually at two-day intervals, and occasionally at three (Cade, 1960; Herbert and Herbert, 1965; Demandt in Fischer, 1967). On the Hudson River, incubation generally began on the fifth day with the laying of the third egg and averaged 32–33 days from time of commencement until the hatching of the last egg (Herbert and Herbert, op. cit.). The incubation period is determined best by checking the time between the last egg laid and the last young hatched (Nice, 1954), providing that all eggs hatch. Although the incubation period in the peregrine is said to be 28–29 days (Witherby, et al., 1939; Dementiev, 1951; Herbert and Herbert, 1965), there is still some uncertainty regarding its exact length, as suggested also by Nelson (1972), who believes it to be closer to 32 to 34 days in *F. p. pealei*. If the incubation period for the fifth egg is 28 to 29 days, and not more than two days elapse between the laying of each egg, the period between laying of the fourth egg and the hatching of the fifth egg would be 30 to 31 days; between the laying of the third egg and the hatching of the fifth, 32 to 33 days; between the second and the fifth, 34 to 35 days; and between the first and the fifth egg, 36 to 37 days. In four-egg clutches, the intervals between the laying and hatching of the third and fourth egg would be 30 to 31 days; between the second and the fourth egg, 32 to 33 days; and between the first and fourth egg, 34 to 35 days. For three-egg clutches, the intervals between the laying of the second and third eggs would be 30 to 31 days; and between first and third eggs, 32 to 33 days. If, as reported by Nelson (ibid.), the incubation period is 32 to 34 days, 4 to 6 additional days must be added to each of the above values.

At the Wasatch Mountain eyrie (Tables 1 and 7, site 7), the incubation period in 1947 and

1952 was close to that given by Nelson (op. cit.) for *pealei*. In 1948, however, it seemed to have lasted abnormally long. The period from laying to hatching was about 40 days (39 to 41) for the fourth egg and at least 42 days (42 to 44) for the third egg, which is about 10 days longer than that expected using the 28 to 29 day period. This could be explained if the first clutch was destroyed within a day or so after the fifth egg was laid and if the first egg of a new clutch was laid a day or two later. This would increase the observed incubation period by about 10 days. This phenomenon has been reported in captive American Kestrels (*Falco sparverius*) (Porter and Wiemeyer, 1972).

In 1952, the period between the laying and hatching of marked egg number one was about 37 days. It likely was laid the day it was first found or the day before. Unfortunately, the period of 36 to 37 days corresponds closely to the expected incubation period for the first egg of a five-egg clutch, if the incubation period is 28 to 29 days, as well as that expected for the first egg of a three-egg clutch if the incubation period is 32 to 34 days.

The 32- to 34-day period seems to fit our data better than does the 28- to 29-day period. Additional observations are needed to resolve this problem.

Two days elapsed between the pipping of the first egg to hatch and the fourth egg to hatch (a fifth egg did not hatch) in 1948. Only one day elapsed between pipping and hatching of egg number one in 1952 and the same was probably true of the second egg as well. This appears to agree with Hall's (1955) observation in 1943 on the Sun Life peregrines, which hatched two eggs on each of two successive days. Porter and Wiemeyer (1972) reported a two-day interval between the hatching of the first and the last egg of five-egg clutches of captive kestrels. The kestrels frequently began incubation with the laying of the fourth egg. Unlike the peregrines of the lower latitudes, those in the Arctic reportedly initiate incubation with the laying of the first egg (Cade, 1960; Dementiev, 1951). Cade (1960) reported as much as a week's difference between the ages of the youngest and oldest nestlings in four-egg clutches in the Arctic.

## PEREGRINE DECLINE IN UTAH

The peregrine in Utah, as elsewhere in the United States and in Europe (Hickey, 1969), declined precipitously in the past two decades.

To our knowledge, only two or three of the 29 eyries known to occur in Utah over the past several decades are still active. Nelson (1969)

reported that before 1942, 50 percent of the "9 or 10" (9, Nelson, pers. comm. 1969, see Table 1) eyries located by him between 1939 and 1942 around the Great Salt Lake were taken over by Prairie Falcons, and by 1948 only three or four of them were left. White (1963), however, noted that five of these eyries (Table 1, sites 4, 7, 8, 10, and 13) were still active as late as 1952, and two additional eyries (sites 17 and 18) are known to have been active in 1952 (C. Ward, pers. comm.), indicating that some of them were overlooked by Nelson (1969) or else previously unoccupied eyries were reactivated later. However, White's (1969b) report of the occupancy by peregrines in 1954 of an eyrie which earlier in the century (1927) was used by Prairie Falcons (Wolfe, 1929) suggests that the reverse situation also may have taken place.

The usurpation of peregrine eyries by Prairie Falcons may not have been permanent, as suggested by our observations of the two species utilizing one another's eyries in Utah. Nelson (1969) indicates that he was unaware of the utilization of alternate nesting sites by the peregrine between 1939 and 1942, which increases the possibility that some of the peregrine locations believed to have been taken over by Prairie Falcons at that time were still being utilized by peregrines nesting at alternate eyries.

By 1956, only four of the 20 known eyries along the Wasatch Front were active. No young have been known to fledge from any of these eyries since then (White, 1963), although one adult was seen at each of two eyries in 1969 (Table 1, sites 8 and 18), and a third is reportedly still active. Only two or three eyries were believed to have been active by 1969 in the entire state, which represents only about 10 percent of the total known to occur earlier. On the other hand, there are vast areas in Utah with seemingly appropriate ecological conditions that have remained virtually unexplored for falcons. It is possible that 10 or more eyries exist in these areas. It is interesting to note that the eyries in the more remote parts of Utah remained active nearly a decade longer than did those in the more populous and more intensively cultivated areas.

#### Climatic Change Hypothesis for Peregrine Decline

Nelson (1969) has hypothesized that the reduction in numbers of active eyries in Utah was caused by a combination of rising average temperature and drastically reduced precipitation, starting about 1870. He suggested that these changes resulted in the drying up of small lakes

and ponds and the lowering of the surface water areas of larger lakes, causing a critical reduction in the habitat for the prey species of the peregrine in Utah and in other areas of the northwestern United States. According to Nelson (*ibid.*) by 1961 the drought gave way to more moderate conditions resulting in habitat changes more suitable to the peregrine.

Besides the drought conditions reported by Nelson (1969), river waters were diverted for irrigation and the vegetation adjacent to the marshes was overgrazed by livestock (Behle, 1958). By 1910, thousands of once productive acres of heavily vegetated marshlands along the shores of the Great Salt Lake, with their smaller lakes, ponds, and channels of fresh water, became mud flats with stagnant pools of alkaline water. Ultimately these changes caused the death of thousands of ducks, shorebirds, and marshbirds due to botulism (Wetmore, 1915, 1918; Behle, 1958). It was not until after the completion of the Bear River Migratory Waterfowl Refuge between 1932 and 1935 and the Ogden Bay and Farmington Bay refuges in about 1941 that these marshes regained much of their former vitality and productivity.

Some changes took place as late as the early 1950s in the marshes further removed from the lake. Weller, Wingfield, and Low (1958), for example, recorded a drastic change in the size of the Knudson Marsh, four miles west of Brigham City, Utah, between 1950 and 1955. They attributed the changes to a deepening of the water channel entering Bear River Refuge, an increased demand for irrigation waters, a below average rainfall between 1952 and 1954, and overgrazing by cattle. The change in size of the Knudson Marsh resulted in a decline of one-third in the number of species and two-thirds in the number of birds nesting there.

By 1960, the total acreage of marshland in Utah was reduced by nearly 50 percent (Smith, 1961) of the 1,174,400 acres (475,279 ha) known to exist originally (Low, 1966). Smith (1961) reported the existence in 1960 of 600,000 acres (242,820 ha) of wetland habitat in Utah of variable value to wildlife. Of this acreage, 83,000 (33,590 ha) were owned by the U.S. Fish and Wildlife Service and 60,000 (24,282 ha) were owned and operated by the State Fish and Game Department. The remaining acreage was in private ownership, either as managed clubs or as unmanaged natural wetlands. Unfortunately, the effects of these environmental changes on the peregrine were never documented adequately.

Morlan Nelson (Hickey, 1969: 96) has suggested that in 1965 there was only enough

habitat left in the Bear River marshes to support one pair of peregrines. This would seem to be an underestimation, since we know of several eyrie sites in the western United States where peregrines have bred successfully adjacent to marshes much smaller and much less productive than are the Bear River marshes.

In discussing the decline of the peregrine in Utah, Nelson (1969) indicated that the peregrines nesting in 1939 at the U1 site (site 11, Table 1) adjacent to the Bear River Migratory Bird Refuge did not return to nest by 1941 because the drought dried up their hunting sites. So that we might critically assess Nelson's implication, we measured the extent of the marshes and open waters within a five-mile (8 km) radius of the U1 eyrie, using U. S. Geological Survey topographic maps (aerially photographed, 1953-1956). The resulting measurements tend to weaken Nelson's argument, since there were still 16.6 sq miles (43 km<sup>2</sup>) of marsh and 5.8 sq miles (15 km<sup>2</sup>) of open water within the five-mile radius. Moreover, the Bear River Refuge, with its extensive marshes, was only seven miles away. However, this is based on the assumption that these marshes did not increase appreciably in size between 1941 and 1956. We cannot comment on the latter premise because we have no information on the extent of these marshes for the early 1940s.

Since we consider the cliff at the U1 site to be marginal in terms of accessibility to humans and predators, we believe that human disturbance may have been the major factor causing the abandonment of this eyrie, although habitat change and competition with the Prairie Falcon probably played a subordinate role.

Further evidence which tends to weaken Nelson's climatic change hypothesis was obtained from Noland F. Nelson, manager of the Ogden Bay State Waterfowl Management Area. Nelson spent many hours at the Bear River and Ogden Bay marshes prior to the completion of the refuges. He noted that there was not a dearth of shorebirds and marshbirds at these marshes before the dikes were constructed (N. F. Nelson, pers. comm., 1971) and that the development of the Ogden Bay area increased the numbers of nesting and migrant shorebirds (Nelson, 1954). Nevertheless, he does believe that the shorebird populations at Ogden Bay have declined in the past several years (N. F. Nelson, pers. comm., 1971).

Furthermore, it is of interest to note that Noland Nelson observed fewer peregrines at Ogden Bay in the 1950s than in the 1940s. He saw them there occasionally in the 1940s (Nelson, 1954), but rarely after the early 1950s (N.

F. Nelson, pers. com., 1971). The occasional observation of peregrines at Ogden Bay during the 1940s is about all one would expect, considering that these marshes were supporting at most only three pairs of active eyries during these years. These observations correspond with the reduction of breeding pairs along the Wasatch escarpment between 1940 and the 1950s.

The Great Salt Lake has been subject to major cyclic fluctuations in size twice historically, and perhaps many times in the past several thousand years. Early historical evidence indicates that in 1850, when the Great Salt Lake was first surveyed by Captain Howard Stansbury, it was much reduced in size compared to earlier and later reports. James Clyman, who with a party of trappers first circumnavigated the Great Salt Lake in a bullboat in 1826, wrote the following in his journal on 1 June as he passed through the Great Salt Lake Valley in 1846 on a trip east from California.

proceeded nearly east to the point of a high mountain [Oquirrh Mountains] that Bounds the Southern part of the great salt lake I observed that this lake like all the rest of this wide spread Sterility has nearly wasted away one half of its surface since 1825 [1826] when I floated around it in my Bull Boate and we crossed a large Bay of this lake with our horses which is now dry . . . (Korns, 1951:36).

Four years later when the lake was surveyed by Stansbury (1852), it covered 1,750 sq miles (4,433 km<sup>2</sup>) (Powell, 1879). By 1869, the lake had increased in size to 2,166 sq miles (5,610 km<sup>2</sup>) (ibid.), and by 1870 to 2,400 sq miles (6,216 km<sup>2</sup>) (Bue, 1963 in Nelson, 1969). By 1961, the Great Salt Lake had receded to an unprecedented low (950 mi<sup>2</sup>; 2,461 km<sup>2</sup>) following several decades of drought (ibid.), and by 1971 it had risen about seven feet (2.1 m) above its historic low, with a surface area of 1,461 sq miles (3,784 km<sup>2</sup>) (U.S. Geol. Survey, 1971). Powell (1879) considered the lake to be at its highest level in 1869, which exceeded a level to which it had long been subjected, and that its old mean area was 1,820 sq miles (4,714 km<sup>2</sup>). A drawing of the lake in 1850 by Stansbury (Powell, 1879) is a near duplicate of the size and shape of the lake shown on U.S. Geological Survey topographic maps constructed from photographs taken in 1953. Anthropological studies in Utah by Antevs (1948) and Harper and Alder (in press) and the studies of Blackwelder (1948) suggest that the lake probably was subjected to fluctuations in size many times prior to written history; this will be taken up in more detail under a separate heading.

Despite these periods of drought and their corresponding changes in aquatic habitat, the

peregrine persisted until the late 1950s. Although the relationship between the changes in climate and concomitant fluctuations in the size of the lake and the effects of these changes on peregrine populations of the area may never be fully understood, it is clear that never before had these populations been so adversely influenced by the activities of man as in the past century.

Data from Utah Lake also do not seem to fully support Nelson's (1969) hypothesis. Data on the fluctuations of water surface and compromise levels have been plotted for the period 1883 to 1960 (from several sources, including Bureau of Reclamation and Utah State Fish and Game). The lake oscillated around the compromise level (4,488.95 ft; 1,368.23 m) between a plus and minus five feet (1.5 m) through 1925. Between 1925 and 1930, the lake remained around the minus five-foot (1.5 m) level, and starting in 1930 the lake level gradually lowered to its lowest level, slightly below minus 10 feet (3.0 m), in 1934 and 1935. There was a slow regain, remaining near the minus five-foot (1.5 m) level through the mid-1940s, until it reached above the compromise level in 1952. However, the lake has remained below the compromise level since then. At its lowest level (1934-35) about 37 percent of the surface area was lost (data through D.A. White from the Utah Lake Research Station). Presumably many marshes around the edge of the lake dried up during this low period, thereby reducing shorebird and water bird habitat. However, this may not be a totally satisfactory index to the availability of marshes. Many areas formerly covered by water but apparently dry during the low water years, such as Provo Bay, were fed by springs and doubtless maintained some habitat for the prime avian prey species. Some of these areas were situated opposite active peregrine eyries. Thus, the impact of the drought years on peregrines is difficult to evaluate. Even so, it is clear that it was not until well after the drought years and after the 1950s that some of the eyries around Utah Lake became inactive (Table 1, sites 17 and 18, for example).

As mentioned earlier, the number of peregrines wintering in the marshes adjacent to the Great Salt Lake declined steadily from 1939 ( $p < 0.01$ , linear regression analysis), the year Nelson (1969) located his first eyries in Utah, until the early 1960s when the species disappeared as a resident in the marshes (Fig. 11). The decline correlated closely in time with the abandonment of local eyries. The desertion of some eyries during the early 1940s and perhaps earlier in the century is explainable on the basis of Nelson's (ibid.) climatic change hypothesis. How-

ever, the magnitude of the decline which followed later in the decade and on into the late 1950s is not, since management methods by then had brought about stability to the marshes and a concomitant increased population of prey species. If climate had been the sole cause of the decline in Utah, one should have expected the reactivation of eyries by the early 1950s following the development of the migratory waterfowl refuges in Utah, yet this did not happen.

(Additionally, a reported increase in nesting peregrines since 1939 in Arizona at the expense of the Prairie Falcon is still unexplained [Phillips, Marshall and Monson, 1964].)

We do not question the validity of Nelson's (op. cit.) climatic change hypothesis for Idaho and elsewhere in the Northwest, where peregrine food producing marshes and waters disappeared. We do believe, however, that the more permanent nature of the Great Salt Lake marshes greatly lessened the impact of these climatic changes in Utah, resulting in the abandonment of a few marginal eyries (Table 1, sites 11 and 25) that were situated near smaller and less permanent marshes or that were located on small, relatively accessible cliffs. However, the number of eyries, if any, that disappeared prior to Nelson's (1969) 1939-1948 observations in Utah is not known. Furthermore, a 10-year reversal of the prolonged drought of the preceding half century which purportedly caused the peregrine decline has not yet resulted in an appreciable recolonization of old eyrie sites or the establishment of new sites.

Nelson (op. cit.) also suggested that Utah's peregrines may have made altitudinal adjustments during periods of drought to compensate for the changes in climate. Our data show no indication whatever of shifts in the species nesting populations from lower to higher elevations (see Table 2). Only one known eyrie (site 36, Table 1) and two suspected eyries (sites 27 and 29, Table 1) in Utah were above 6,000 feet (1,829 m) in elevation. Two of these were known earlier in the century (early 1900s and middle 1930s), whereas the third is of more recent observation in an area that was not investigated biologically earlier in the century.

### Pesticide Hypothesis for Peregrine Decline

#### *Pesticide Syndrome in Utah Peregrines*

Because climatic change did not appear to be the complete answer to the peregrine decline in Utah, we have investigated the possibility that pesticides may have been involved during the later stages of the decline.

Abnormal behavior and increased reproductive failure were recorded at several Utah eyries during the period following World War II (Table 1).

As mentioned earlier, the birds at site 7 in the Wasatch Mountains either failed to lay in 1949 and 1950 or if they laid, their eggs were destroyed and the adults showed little inclination to defend their nests during these years. In 1951 the eyrie contained three eggs, but they disappeared one by one over a 17-day period, and in 1952 the nesting female at the eyrie was a new one (see Table 7).

A pair of peregrines at an eyrie which was located several miles away (Table 1, site 13), reacted similarly when they were first observed on 20 May 1951. An adult male and immature female dived at us only halfheartedly once or twice, otherwise they circled, screamed, or just perched. A third falcon which flew by at this time elicited no response from either bird. A pair was seen there again on 1 June 1952 by R. J. Erwin. Although they apparently had no eggs, they responded more normally to human intrusion than they had the previous year.

The occurrence of immature females at these two eyries suggests the possibility of a breakdown in the normal ratios of adult to immature peregrines during the early 1950s. The two aforementioned eyries were visited again by us in 1961, but no falcons were seen.

One of the four eggs in a Great Basin desert eyrie (Table 1, site 4) was partially caved in on one side and contained a small hole about one-fourth inch (0.64 cm) in diameter when the nest was first located on 13 May 1954. The male was not seen at this time, but the female displayed little if any of the expected aggressiveness toward our intrusion (Porter, et al., unpubl. ms). When the eyrie was next visited on 24 June, only one youngster was present, and both adults screamed incessantly at the observer. The eyrie was still active in 1954 (White). It was last observed to be active in 1957 or 1958 by a local falconer, who trapped the adults after a complete clutch of eggs was said to have disappeared.

White and Lloyd (1962) found two freshly killed peregrines, about 28 days old, at an eyrie in the desert of the Colorado Plateau (Table 1, site 28, Figs. 9 and 10). The two young were located near their nest, 70 feet (21 m) from the top of a 400-foot (122 m) vertical cliff composed of smooth Navajo sandstone on 7 July 1961. The back, portions of the thoracic organs, and parts of the neck and wings of each had been eaten. They attributed the death of the two young to predation by a Ringtail (*Bassariscus*

*cus astutus*), because of the presence of fresh Ringtail seats along the ledge and because of the nature of the wounds on the young.

When next visited on 6 July 1962, the adults screamed, using the "wailing" call described by Hagar (*in Bent*, 1938). The female then left the area, while the male flew back and forth but remained silent. The following year both adults were present, but they remained perched and made no noise. Only one adult was seen in May 1964 and none in May of 1965.

Later, White re-examined the young peregrines, which had been preserved (Univ. Utah collection) and could find no chewed off feathers so characteristic of fox-killed peregrines and other mammalian predation observed subsequently by him in the Arctic. Furthermore, the feathers appear to have been plucked from the young as though by a bird, suggesting that their death may have been the result of predation by the parent birds or an avian predator rather than a mammalian predator. As suggested by Morlan Nelson (*pers. comm.*, 1971), the deaths of these two young could have been caused by Great Horned Owls (*Bubo virginianus*), or some raptor other than the adult peregrines. (See Fischer 1967, for a more complete assessment of owl and other avian predation on peregrines.)

The phenomenon of egg breakage and egg disappearance may not be restricted to the peregrine. A Prairie Falcon eyrie north of the Bear River marshes observed by R. D. Porter, R. L. Porter, and Jack Hagan on 6 May 1951 contained a single egg which was slightly cracked on the small end. The female was not seen on the nest, nor did she react defensively towards her nest. The egg was absent on our next visit to the nest on 13 May. Moreover, many of the Prairie Falcon eyries that were present around the Great Salt Lake were abandoned during the past two decades, while those farther removed from the marshes, occupied by pairs living mostly on rodent diets, have persisted.

The pattern of reproductive failure described here is similar to, and synchronous with, that associated with the drastic declines which afflicted the peregrine elsewhere in the United States, in Great Britain, and in northern Europe (Hickey, 1969) beginning early in the 1950s.

The pattern of reproductive failure in Great Britain, where the documentation is the most complete, was characterized by a marked increase in the number of eggs that were broken in the nests, in the number of eggs that disappeared, and in the number of eggs eaten by the parent birds. This pattern was followed by the disappearance of one or both of the adult birds and finally by the complete abandonment of the

cyrics (Ratcliffe, 1958, 1963, 1965, 1967b, 1969). It was determined later that the eggshells of the peregrine in both Great Britain (Ratcliffe, 1967a, 1970), and in the United States (Hickey and Anderson, 1968) had experienced a marked decrease in thickness starting about 1947. Ratcliffe (1967a, 1970), who was the first to recognize and document this phenomenon, attributed eggshell thinning to the chlorinated hydrocarbons.

These reproductive abnormalities have been duplicated experimentally in the American Kestrel (Porter and Wiemeyer, 1969), the Mallard (Heath, Spann, and Kreitzer, 1969), and Black Duck (*Anas rubripes*) (Longcore, Samson, and Whittendale, 1971) by giving them low dietary levels of organochlorine pesticides. The mode of action of these chemicals on avian reproduction has been investigated (Peakall, 1969, 1970, 1971; Bitman, Cecil, and Fries, 1970), and the effects of DDT on the structure and chemistry of the eggshell are now being studied (McFarland, Garrett, and Nowell, 1971; Longcore et al., 1971).

Experimental studies which indicate that DDT delays ovulation in the Bengalese Finch (*Lonchura striata*) (Jefferies, 1967) and also in American Kestrels (Porter and Wiemeyer, unpubl. data), suggest that this phenomenon may have occurred in wild peregrines as well. The laying date of the first egg in 1952 at cyric number 7 (Tables 1 and 7) (29 April) was two and one-half weeks later than in 1948 (approximately 11-12 April), and a week later than in 1947 (about 21-22 April). However, this may be a reflection of the change in females that was known to have taken place at the cyric in 1952, or of an adjustment to a change in weather, rather than to a pesticide-induced delay in ovulation.

Direct mortality of adult birds due to DDE-poisoning cannot be discounted as a factor in the decline of the peregrine, since Porter and Wiemeyer (1972) have demonstrated that dietary levels of only 2.8 ppm (wet weight basis) *p,p'*-DDE were lethal to 8 percent of male captive American Kestrels after one year on dosage. The effects were most pronounced during molt and immediately following nesting season—a period when the fat cycle of the kestrel was at its lowest point. They have also shown (Porter and Wiemeyer, in preparation) that kestrels dosed at both low (0.28 ppm dieldrin; 1.1 ppm DDT) and high (0.84 ppm dieldrin; 4.7 ppm DDT) (wet weight basis) dosage levels of DDT and dieldrin in combination are more susceptible to death following stress of weather than are non-dosed kestrels.

### *Residues of Pesticides in Peregrine Prey Species*

We will now consider the quantity of organochlorine pesticides in the tissues of some of the peregrine's prey species in Utah, since many of the principal prey of the peregrine are known to contain high levels of these chemicals. Cade, White, and Haugh (1968), and Enderson and Berger (1968), for instance, determined that DDT, DDD, DDE, and dieldrin were present in greater quantities in the tissues of migrant sandpipers than in any other of the peregrine's prey species in the Arctic. Some contained DDE in their tissues in quantities of sufficient magnitude to be cause for concern (see Porter and Wiemeyer, 1969, and Wiemeyer and Porter, 1970).

DDE is considered to be the most inimical to avian reproduction of the metabolites of DDT. Relatively high DDE residues were present in the eggs and in tissues of Short-billed Dowitchers (*Limnodromus griseus*), Killdeer (*Charadrius vociferus*), American Avocets and Black-necked Stilts in California (Keith and Hunt, 1966). Surprisingly high residues of *p,p'*-DDE (expressed in average and extreme ppm, wet weight basis) were found in the eggs of Black-necked Stilts (4.92, range 1.0-13.7), American Avocets (4.43, 1.5-12.0), and Franklin's Gulls (0.92, 0.5-2.2) collected at the Bear River marshes in 1968 (unpubl. data, Denver Wildlife Research Center). The whole body tissues of two Lesser Yellowlegs (*Totanus flavipes*) contained on the average 10.95 (range 5.1-16.8) ppm *p,p'*-DDE (wet weight basis); four Long-billed Dowitchers (*Limnodromus scolopaceus*), 13.25 (0.7-49.20); one avocet, 3.4; nine White-faced Ibis (*Plegadis chihii*), 2.55 (0.1-6.5); and three Marbled Godwits (*Limosa fedoa*), 6.01 (0.15-17.8). Dieldrin in the tissues of these birds ranged from 0.1-0.86 ppm in the ibis, 0.2 ppm in the Lesser Yellowlegs, 0.05-0.50 ppm in the godwits, and 0.68 ppm in the avocet. Many of the DDE values are greater than the 2.8 ppm (wet basis) of DDE that caused eggshell thinning (Wiemeyer and Porter, 1970) and adult mortality (Porter and Wiemeyer, 1972) in American Kestrels. Residues of PCB's were found in four of the dowitchers and two of the yellowlegs. They averaged 3.75 ppm (1.5-10.0) and 4.5 ppm (3.0-6.0), respectively.

### *Mosquitocide Usage in Utah*

The chemical DDT was used as a mosquitoicide in the marshes along the Great Salt Lake as early as 1917 in Weber (Ogden Bay State Waterfowl Management Area) (Benge and Fronk, 1970) and Box Elder counties (K. L. Josephson, pers. comm., 1971) and on an experi-

mental basis in Salt Lake County (Salt Lake City Mosquito Abatement District) in 1945 (Graham and Rees, 1958). This chemical was used at Ogden Bay until 1961, at which time the use of parathion was initiated (Benge and Fronk, op. cit.). Davis County probably began the use of DDT in 1951 or 1952, since mosquito control was initiated there in 1951 (Stewart, 1954; Nielson, 1962). The quantities of DDT used in the early years probably were not great, since it was applied by means of foggers and hand-operated sprayers. However, beginning in 1949, DDT was applied to the extensive marshes bordering the Great Salt Lake by means of aircraft (for additional history of mosquitoicide usage in Utah, see Appendix. The utilization of DDT increased with the use of airplanes as a vehicle for application. It is interesting to note that reproductive failure in the peregrine was most pronounced in the years coincident with, and immediately following, the initiation of aerial spraying, although this may be an unrelated coincidence.

Between 1947 and 1961 many thousands of pounds of DDT were deposited on agricultural crops, and more importantly, directly on the marshes and waters in the Great Salt Lake Valley where nesting peregrines obtained much of their food. The quantities applied by mosquito abatement districts were greatest along the marshes of the Great Salt Lake, where no peregrine eyries are known to have been active after 1957, and least in Utah County, where several peregrine eyries apparently remained active until the late 1960s.

Data on the quantities of organochlorine insecticides used for agricultural purposes in the area surrounding the Utah and Great Salt lakes were unavailable to us, but chlorinated hydrocarbon pesticides probably were used in large quantities, judging from a recent survey of pesticides in Utah (Warnick, 1971). However, they were applied to farm crops, farm animals, and buildings, and not directly on the marshes where the peregrine obtained its food. Unfortunately, little is known regarding the movements of these chemicals from agricultural lands to the marshes.

We have no direct evidence linking these chemicals with the sharp reduction in active peregrine eyries along the Wasatch Mountains during the critical years between 1945, when the chemicals were first used, and 1957, when the species was last known to breed in the area. Nor do we know the extent of the environmental contamination at that time by other chemicals such as the polychlorinated biphenyls (PCBs). We do not know the effects of PCBs on raptor

reproduction, although some PCBs (1245) in small dietary concentrations do not seem to affect reproduction in Mallards, Pheasants (*Phasianus colchicus*) (Heath et al., 1972), and Ring Doves (*Streptopelia risoria*) (Peakall, 1971) in the same way as does DDE.

We can only speculate regarding the residues of chlorinated hydrocarbons present in the tissues of either the peregrine or its prey species during the period of its decline in Utah. Most of the peregrine's prey species were migratory in nature. Thus, part of the insecticide residues acquired by them were from areas other than Utah and the Great Salt Lake valleys. We are unable, therefore, to establish an absolute cause and effect relationship between the quantities of chlorinated hydrocarbons used and the decline of the peregrine in Utah, although one is suggested by the experimental, ecological, and behavioral evidence which we have presented.

#### Disease Hypothesis for Peregrine Decline

White (1963) referred to 27 cases of botulism (*Clostridium botulinum*) in peregrines that were found in the Great Salt Lake marshes between 1943 and 1958. Ralph B. Williams (pers. comm., 1972) also found several affected peregrines on marshes around Utah Lake in the mid-1940s. The disease was most prevalent between late July and early October, and it appeared to affect adults more than young, and females more than males. Botulism undoubtedly has taken its toll of peregrines during the past several decades and perhaps, sporadically, for many hundreds of years. Its effects, historically, on the local peregrine population cannot be assessed because the fluctuations in numbers of active peregrine eyries in Utah are not known. We cannot evaluate the effects of botulism toxins combined with those of pesticides, since knowledge of the effects of pesticides on the susceptibility of birds to various diseases and the interactions of botulism toxins with the chlorinated hydrocarbons are poorly understood. However, any mortality of adult birds due to disease during periods of reproductive failure would tend to accelerate the decline.

#### Human Activity Factors in the Decline of the Peregrine

A number of human activities, besides the agricultural practices already mentioned, may have adversely affected the peregrine in Utah, particularly in combination with the inimical effects of organochlorine pesticides, botulism poisoning, and changes in the climate. (See an

earlier analysis by White (1969b) of the effect of human pressures.)

The impact of nest robbing, which started earlier in the century with egg collecting and later in the century, starting about 1939, with the utilization of the nestlings for falconry, are difficult to evaluate, although there is no evidence that these activities per se were responsible for the sharp increase in abandoned eyries in the state. Some peregrine eyries in Europe were robbed of their young for many hundreds of years without apparent harmful effects (Fischer, 1967; Ratcliffe, 1969).

Photography at eyrie sites also may have caused some birds to abandon their eyries, although to our knowledge only one nest in Utah (Table 1, site 7) was harassed in this way and the eyrie site was known to have been active subsequently.

The reported collection of an adult falcon from the Pelican Point eyrie (Table 1, site 3) in 1935 (Bee and Hutchings, 1942) apparently had little impact on this eyrie, since it was still occupied as late as 1939 (notes of R. G. Bee). The removal of the adults from eyrie site 4 (Table 1) in 1957 or 1958 by a falconer probably hastened the abandonment of that eyrie by only a few years, since what seems to us to have been the pesticide syndrome was already in strong evidence there.

The cliff at Pelican Point (site 3, Table 1, Fig. 6) became a limestone quarry in recent years and the eyrie site was destroyed, as was an eyrie site in southwestern Utah (site 37, Table 1). Lower portions of the cliff near one of the most inaccessible peregrine eyries in the state (Table 1, site 8) were blasted away during the 1960s. Some of the earlier observations of peregrines in Utah were near this site. A bird was noted there in 1969 (C. M. White), but not in 1971 (R. J. Erwin).

A recreation area, established after 1968, is situated below one eyrie in east-central Utah (Table 1, site 28). When the eyrie was visited in May 1971, several motorcycle clubs were using the area as a point of rendezvous and all day and night the roar of motorcycles echoed through the canyon. Although fresh excreta was seen along a ledge running adjacent to the old eyrie site, no falcons were seen in two days

of observations. This eyrie had shown evidence of the pesticide syndrome as early as 1961, however. The extent of the damage to the above site is not known.

Depredation of the species by hunters is a mortality factor which is frequently overlooked. Utah's marshes, which in the past were frequented by peregrines in the fall and winter, have been used by increasingly greater numbers of waterfowl hunters in recent years. This is especially true of areas around the Great Salt Lake since the establishment of state and federal waterfowl refuges between 1930 and the early 1940s. Often hunters kill raptors and other birds indiscriminately. This could be a contributory factor to the peregrine decline, since peregrines frequenting the marshes during hunting season probably were from local eyries. However, the significance of depredation by hunters is difficult to assess since the peregrine is noted for its ability to withstand this type of persecution and destructive treatment by man (Ferguson-Lees, 1957; Cade, White, and Haugh, 1968; Ratcliffe, 1962, 1969).

In the past two decades, the construction of human dwellings on the high foothills of the Wasatch Mountains below certain eyrie sites may have had an adverse affect on these eyries (see White, 1969b), and the effects of the activities at a nearby rifle range on one such eyrie also are unknown. One can only speculate what the construction of homes near eyrie sites will do to these sites, since there is already a precedent set for peregrines nesting above railroad tracks, on bridges, and in heavily populated urban centers (Hickey, 1942; Olivier, 1953). The extent to which some individuals of the species persist, despite the presence of human populations near their eyries, is illustrated by the peregrines at one eyrie that tolerated for over a century the activities of a village of two hundred people at the base of the cliff that housed the falcon eyrie (Hickey, 1942).

To sum up, pollution, shooting, nest site and habitat destruction, human disturbance, and climatic changes have contributed singly and jointly to the near demise of the peregrine in Utah. Of these, pollution and climatic change appear to have played the dominant roles.

## FACTORS INFLUENCING PEREGRINE DISTRIBUTION AND ABUNDANCE IN UTAH

To more fully understand the various factors involved in the distribution of the peregrine in Utah prior to its catastrophic decline, we have

attempted to examine the impact on the species of various ecological factors, both past and present.

### Water, Food, and Nesting Sites as Limiting Factors

Bond (1946) has reported that in the western United States the peregrine seldom nested more than one half mile (0.8 km) from water in which to bathe. Exceptions to Bond's (*ibid.*) observations are few. Gabrielson and Jewett (1940), for example, tell of a pair that nested in Oregon on an isolated rock far from water (11 mi.; 17.7 km., Bond, 1946), and Thomas Ray (*pers. comm.*) located an active eyrie far from water in arid western New Mexico.

The peregrine's affinity for free water probably is associated more with its needs to bathe and to obtain food than with its needs to drink. Bartholomew and Cade (1963) point out that the larger predatory birds obtain adequate quantities of water from their food under most circumstances. They cited instances of several falcons, including the peregrine, maintaining weight for many months without free water.

Beebe (1960) concluded that because 11 of 13 young peregrines taken from nests in the Pacific Northwest and raised in Denver died of dehydration, humidity rather than nearness of free water was perhaps a critical factor in brood success in areas of the West other than the Northwest Pacific coast. Since these nestlings died despite having been supplied with drinking water, Beebe (*ibid.*) hypothesized that peregrines were more or less restricted to nesting sites near water because of high humidity rather than the presence of free water.

An important question appears to be whether or not the young mentioned by Beebe were acclimatized to the cool, humid climate of the Northwest before being transferred to the arid intermountain area. Nelson (*pers. comm.*, 1971) has suggested that these birds may have died of malnutrition rather than dehydration. He raised and trained one of them and encountered no difficulty with dehydration. Other nestling peregrines from British Columbia and the Aleutian Islands, similarly transferred to Utah, have not been affected in this manner. Nestlings taken from Utah eyries have not appeared to suffer greatly from dehydration nor has there been any evidence of moisture loss among young peregrines cared for in the nest by their parents.

This affinity for high humidity, if it exists, may be an inherited physiological characteristic of the *pealei* race, which is less pronounced in the peregrine populations of the arid Intermountain West (see also, White, 1968b, for further documentation of this problem). Furthermore, other populations of falcons, such as those of the *Shahen*, exist and breed in the deserts of

the Middle East under the harshest conditions known (Bartholomew and Cade, 1963).

Food availability appears to be a major criterion influencing the distribution and abundance of the peregrine in arid regions of the West. Density and distribution of peregrine populations in Utah appear to correlate best with the abundance of the food supply. Peregrine populations are most dense in the area surrounding the Utah and Great Salt lakes where the preferred prey species, particularly shorebirds and marshbirds, are most abundant. Here, the marshes have historically supplied food for 10 to 20 eyries during a single nesting period. Hunting areas for isolated pairs of peregrines elsewhere in the state were supplied by smaller, less extensive marshes or by narrow tongues of streamside vegetation. Usually, isolated pairs survived and reproduced where adequate food was available.

Food availability apparently is an important factor in the distribution and abundance of the peregrine in more humid and mesic regions as well as in arid regions. Beebe (1960) has attributed an unusually high breeding density of peregrines in British Columbia to the extremely high concentrations of four or five species of colonial seabirds occurring there. These small pelagic birds apparently were especially suited as prey species for the peregrine.

Ratcliffe (1962) considered the geographic variation of food supply as the most obvious factor associated with population density of the peregrine in Great Britain. He has correlated size of territory and density of peregrine populations in Britain with the nature of the food supply.

The same factor generally appeared to be operative in Utah, although peregrine density in the Great Salt Lake Valley of Utah probably was not limited by the size of the prey populations. However, the species may be limited by the distance (up to 17 mi., 27.4 km; Table 4) it must fly to reach the marshes where it obtains its preferred prey species.

Peregrines may select easily accessible nesting sites in areas containing an abundance of suitable prey species, as occurs in the Queen Charlotte Islands (Beebe, 1960). Such sites are seldom utilized in areas containing less favorable food supplies. This is illustrated in Utah by the occurrence of the ground-nesting peregrines at Ogden Bay.

Hickey (1942, 1969) considered the cliff on which peregrines nest as the dominant feature of their ecological niche. He considered extremely high cliffs as "ecological magnets" which attract peregrines regardless of nesting success.

Cade (1960), on the other hand, has argued that the ability of the pair to breed effectively is a result of a strong pair bond, and that the strength of the bond is a more important consideration than the size of the cliff. He argued that the pair bond would be dissolved and that the eyrie would become inactive indefinitely if both the male and female disappeared from the eyrie. Ratcliffe (Hickey, 1969), in support of Hickey (1942, 1969), has cited examples of several eyrie sites which were consistently reoccupied following the deaths of both adults. This also has been noted in the Arctic by White (unpubl. data). (See Fischer, 1967 for additional documentation.)

In Utah, selection of eyrie sites by peregrines is associated with the availability of suitable sites near a readily available supply of preferred prey species. The preferred prey species usually are closely associated with a marsh or stream. These two factors combined, then, constitute the most important aspect of the peregrine's nesting economy in the state.

#### Interspecific Competition During Nesting Season

Cade (1960) has discussed competition between the peregrine and the Gyrfalcon (*Falco rusticolus*). White and Cade (1971) have discussed competition among several species of raptorial birds in the Arctic, and White (1968b) has discussed this problem as concerns peregrine distribution and its relation to large congeners over broad distributional areas. These papers give a valuable basis for the evaluation of the competition between the peregrine and other raptors whose range and habitat in Utah are sympatric. In our discussion of interspecific competition, we prefer the more restricted definition of the term "interspecific competition" as given by Birch (1957) and as discussed by Cade (1960). That is, competition results when more than one species requires a resource that is in short supply.

Competition for food and/or nesting sites between the peregrine and other species of raptors, particularly the Prairie Falcon and the Golden Eagle, may be factors contributing to the relative paucity of peregrines in the arid Intermountain West.

Where relatively abundant, the Golden Eagle may be a competitive factor limiting the density of the peregrine in the more arid regions of Utah. Bond (1946) has watched the peregrine strike at Golden Eagles and R. J. Erwin and J. F. Poorman (unpubl. notes) have made a similar observation in Utah. Dixon (1937) tells of one instance when a pair of Golden Eagles in

California usurped a cliff that had been occupied by peregrines for years. The eagles persistently outfought the peregrines, forcing them to leave. Cade (1960) found that the peregrine was quicker and more persistent in its attacks on Golden Eagles than on any other raptor discussed. Ratcliffe (1962, 1963) reported that in many districts in Scotland, where there is a surplus of suitable cliffs, the density of Golden Eagles is high while the densities of the peregrine and the Common Raven (*Corvus corax*) are low. In these situations apparently the eagle replaced the peregrine as the chief nesting predator in the Scottish Highlands.

In Utah, peregrines and eagles were found nesting concurrently on the same set of cliffs only once. The eagles nested one mile (1.6 km) (Morlan Nelson, pers. comm., 1971) from active peregrine and Prairie Falcon eyries (see Nelson, 1969), but on the opposite side of the mountain (north). The eagles apparently foraged northwardly, while the peregrines foraged southwardly. No aggression was noted between the eagles and the falcons (Nelson, pers. comm.). A cliff formerly occupied by peregrines in Utah (site 15, Table 1) contained an active Golden Eagle's nest in the spring of 1971, and the presence of two old eagle nests (R. J. Erwin) suggests a long period of occupancy by the eagles. The cliff also had been occupied by as many as three pairs of Prairie Falcons simultaneously during some of the intervening years (Nelson, pers. comm., 1971).

The food habits of the eagle and peregrine are sufficiently diverse in Utah so as to negate a strong competition for food. Additionally, the eagle seems to attain its greatest abundance in the more arid regions of the state, where it more likely would compete with the Prairie Falcon for nesting sites than with the peregrine, although the abundance of eagles in the deserts of Utah may be one of the reasons why the peregrine seldom occurs there. This latter postulation, however, appears unlikely because of an absence of the food niche preferred by the peregrine.

The Common Raven has been shown by White and Cade (1971) to compete rather extensively with Gyrfalcons for nest sites in the Arctic, though it seems to have only limited competitive effect on Arctic peregrines using the same cliffs. In Utah, where the raven is common, only three cliffs with peregrines were known to house ravens. Like the situation in the Arctic, ravens probably had "no" effect on Utah peregrines, although Porter observed peregrines at site number 4 pursuing ravens on 8 April 1954. Ravens may, however, have a considerable

modifying effect on Prairie Falcons, as will be discussed in a later section. (See also Ratchliffe, 1962, for a consideration of raven-peregrine interaction in Great Britain.)

The Prairie Falcon (Fig. 39), on the other hand, is more closely related phylogenetically, is more similar in size, and is more equivalent in ecological function to the peregrine, than is either the eagle or raven. Hence, it likely would be a more serious competitor of the peregrine and it probably would be a more important factor limiting peregrine populations in areas of sympatry.

The Prairie Falcon is a true desert falcon. It undoubtedly evolved in the arid West, and therefore is probably better adapted than is the peregrine for Utah's arid environment. The Peregrine Falcon is separated from the Prairie Falcon and the Gyrfalcon at the subgeneric level. The two species are of similar size, although the peregrine is somewhat heavier than the Prairie Falcon (See Table 9 and Webster, *in* Beebe and Webster, 1964).

The peregrine, which is nearly cosmopolitan in its geographic distribution, has a breeding range which completely overlaps that of the Prairie Falcon geographically but not ecologically. The Prairie Falcon breeds from central British Columbia, southern Alberta, southern Saskatchewan, and North Dakota, south to Baja California, and northern Mexico (See AOU Checklist of N. Am. Birds, 1957). The peregrine is most abundant north of its zone of sympatry with the Prairie Falcon.

According to Bond (1946), the Prairie Falcon may be quite common up to 6,000 or 7,000 feet (1,829 or 2,134 m) in suitable localities and at elevations where trained Prairie Falcons, with their much greater surface to weight ratio, clearly outfly trained peregrines, which are their superiors at sea level. Morlan Nelson (*pers. comm.* 1971), who has tested Bond's (1946) hypothesis on several occasions with captive falcons, considers that it is more a matter of individual variation within both species than it is a factor of

elevation.

Actual contact between the two species occurs where their ecological niches overlap. To our knowledge, there is no locality in Utah where peregrines nest which is not also inhabited by Prairie Falcons, but not the reverse. The peregrine's proclivity to nest near water or marshes where both its food and nesting requirements are met is not shared by the more curvaceous Prairie Falcon which may fulfill these requirements both near water and in the desert many miles from water.

As discussed previously, the several peregrine eyries found in the deserts of Utah were situated within easy access of marshes, desert springs, ponds, streams, or rivers. Perhaps this reflects the differences in hunting methods and food habits of the two species, as well as the proclivity of the peregrine to bathe in water as discussed by Bond (1946) and Cade (1960). Both species can be dust bathers in captivity (Nelson, *pers. comm.*), although the Prairie Falcon is less dependent on water than is the Peregrine Falcon.

#### Some Factors Modifying Competition and Success

Before examining the kinds of competition that may affect Utah peregrines, a general discussion is in order. There are many ways that falcons can exploit their respective environments. Their success, that is, the total number of young that become breeding adults in the next generation, depends upon the effectiveness of this exploitation.

Frequently ecologists use the terms "generalist" and "specialist" to describe a species in terms of the manner in which it utilizes certain resources. Most frequently this pertains to the manner in which the food or habitat niche is exploited, or to the modes of hunting certain species of prey.

Although the specialist has a narrower habitat tolerance, it usually compensates by being more competitive (see, for example, Cade,

Table 9. Weights (in grams) of Peregrine Falcons and Prairie Falcons from various North American populations.

Species and Population	MALES			FEMALES		
	n	$\bar{x}$	range	n	$\bar{x}$	range
PEREGRINE FALCONS						
(White, 1968a & b)						
<i>F. p. tundrius</i> <sup>1</sup>	12	610.9	550-647	19	952.0	825-1,094
<i>F. p. anatum</i> <sup>2</sup>	5	678.0	675-682	5	1,038.0	870-1,201
PRAIRIE FALCONS <sup>1</sup>						
(Enderson, 1964)	15	554.0	500-635	31	863.0	760-975

<sup>1</sup>Weights are from adult birds

<sup>2</sup>From population in western United States

1960). When the optimal requirements for the specialist are present, it tends to capitalize on or "monopolize" the resources or conditions to receive maximum benefit, often to the exclusion of the generalist or other specialists. It is the existence of a specific or optimal set of conditions that allows the specialist to be successful. The generalist might also successfully exploit the precise conditions. However, because of competition with the specialist, it may alter the manner in which it uses the conditions by partitioning the resource, or it may be forced into suboptimal conditions because of the dominance of the specialist. In the absence of the specialist, the generalist obtains even greater benefit by the use of the specific combination of resources or conditions that the specialist would have used.

The generalist tends to be more widespread geographically and often more common than the specialist. Moreover, when two closely related species with similar ecological niches occupy the same geographic area, one tends to assume the role of the "specialist" and the other the role of the "generalist," depending upon their individual needs. Gyrfalcons, for instance, are specialists on the Arctic Slope of Alaska, where they have specific nesting requirements and where they specialize on ptarmigan for food, while the sympatric peregrine is the generalist, having rather broad requirements for nesting and feeding (White and Cade, 1971). The Gyrfalcon seemingly has the advantage and appears to outcompete the peregrine for certain resources. However, because the peregrine is a generalist, it has less precise requirements and therefore is able to occur over a much broader geographic range in Alaska, such as the taiga regions. Then, too, it is probably more numerous when considering its entire range.

Even though the peregrine is probably a generalist over much of its cosmopolitan range, it becomes a specialist in the Aleutian Islands, where it has a narrower food niche consisting mostly of marine birds of the family Alcidae and of the order Procellariiformes. Thus, the role of the species is modified by the conditions in a given locality.

Prairie Falcons have been thought of as specialists because they are able to exploit very arid climates where a limited number of food species are present. They often occur where other large falcons are unable to survive. Because they are able to concentrate on the prey species most available, Prairie Falcons may have a rather highly specialized food niche, especially in the more arid regions where a limited number of food species occur. Their ability to

"specialize" on what is available enables them to live successfully in a wide variety of ecological situations.

If one considers the Prairie Falcon's entire geographic and ecological range, it is narrowly selective in its exploitation of the climatic conditions available to it (i.e. a near obligate of xeric conditions), but it is broadly selective in its exploitation of food and nesting sites. Additionally, where the geographic ranges of the two species overlap, Prairie Falcons are much more common than are peregrines. Because of the Prairie Falcon's seemingly narrow climatic tolerance during the breeding season, climate may be a major factor limiting its geographic distribution.

Peregrines, unlike prairies, are broadly selective in their exploitation of climatic conditions over their entire geographic range. However, they are narrowly selective in their exploitation of food and nesting sites in the arid West where they must compete with the sympatric Prairie Falcon. Moreover, they are much less common than are Prairie Falcons, where the ranges of the two species are sympatric. Their specialized food requirements (generally "water-type" birds) and restrictive methods of capturing prey (not prone to capture prey on the ground), are the major factors limiting the expansion of their geographic and ecological ranges in Utah and probably elsewhere in the arid West.

The presence of surface water in the arid West may dramatically alter the environment. For certain species it may even act as a limiting factor. Water creates a food niche which apparently is optimal for the peregrine, providing an abundance of aquatic birds in these localized areas. Hence, the peregrine does better in the presence of surface water. This is especially evident at the margin of the species' ecological range in the arid parts of Utah. With the presence of these "oases" of aquatic habitat in an otherwise unexploitable environment, the peregrine assumes the role of specialist; and, where the peregrine and prairie occur together in Utah, the prairie seemingly assumes the role of the "generalist." The broad spectrum of food, habitat, and nesting sites which the prairie selects overlaps and surpasses the requirements of the peregrine. The requirements of the peregrine are more limited and restrictive, yet it may do better competitively than its congener when the optimal conditions prevail.

#### Competition with the Prairie Falcon for Food

Where the two species occur together along the escarpment of the Wasatch Mountains and adjacent to the Great Salt Lake, their food ap-

pears to be quite similar (Table 5), although there are some marked differences. In this region of joint occupancy, the Prairie Falcon utilizes a much wider variety of vertebrate species than does the peregrine. As illustrated in Table 5, the Prairie Falcon is more prone to feed on rodents and on ground-dwelling birds, such as quail, pheasants, meadowlarks, and passerine birds in general, and is less inclined to feed on pigeons, doves, and flickers than is the peregrine (also see Bond, 1936a, b, and c).

Prairie Falcons also feed on reptiles. For instance, at one Prairie Falcon eyrie in the Great Basin, not far from a peregrine eyrie, adults were observed carrying large whiptail lizards (*Cnemidophorus* sp.) to the eyrie.

The Prairie Falcon exploits a different food resource in the allopatric parts of its geographic range than in those that are sympatric with the peregrine. A case in point is the high plateau country of Utah NNW of the Uinta Mountains (6,800 feet elevation; 2,073 m) where only the Prairie Falcon occurs, although one would expect peregrines also to occupy the habitat. Food items taken from several nests between 1961 and 1964 in this region of allopatry consisted of 61 percent mammals, about 90 percent of which was the Uintah Ground Squirrel (*Citellus armatus*), although another species of ground squirrel, a chipmunk (*Eutamias* sp.), and a vole (*Microtus* sp.) also occurred. Birds made up the remaining 39 percent, with Mourning Doves being the principal avian food, though the Brewer's Blackbird (*Euphagus cyanocephalus*), Flickers (*Colaptes* sp.), Horned Larks, Starling (*Sturnus vulgaris*), and the Mountain Bluebird (*Sialia currucoides*) also occurred. Thus, about 75 percent of the total food was made up of two species, one mammal and one bird. In this case, and those cited by Enderson (1964), with an absence of peregrines in both localities, the Prairie Falcon tended to fill the role of a "specialist" in food habits; and to a large extent the species was mammivorous (mammal-eating). (See Bond, 1936b). The avivorous (bird-eating) peregrine, on the other hand, consumes few mammals and fewer, if any, reptiles.

Ground-nesting birds and rodents are important items in the diet of the Prairie Falcon in areas other than Utah. For example, Enderson (1964) found remains of the ground-nesting Horned Lark and of the Richardson's ground squirrel (*Citellus richardsonii*) most often, and sometimes exclusively, in the nests of Prairie Falcons in eastern Wyoming and Colorado. Ogden (1971) considered the Townsend's ground squirrel (*Citellus townsendi*) to be the most important food species, followed by Horned

Larks, Meadowlarks, and whiptail lizards in Prairie Falcon eyries along the Snake River of southwestern Idaho. The antelope ground squirrel (*Citellus leucurus*) was also present, but in smaller numbers.

The Horned Lark was also a staple item in the winter diet of Prairie Falcons in Utah and in the prairies of Wyoming, Colorado, and New Mexico, where it influences the falcon's seasonal movements and distribution (Enderson, 1964).

An overlap in the food niches of the peregrine and Prairie Falcon is evident in the area along the Wasatch Mountains (Table 5). In terms of biomass, aquatic birds comprised the largest category of prey species in the Wasatch Mountain eyries of both species, but they were much more predominant in the eyries of the peregrine than in those of the Prairie Falcon.

The avocet was the major aquatic species in the eyries of both falcons (see Frontispiece and Fig. 39). The importance of the avocet as a prey species of the Prairie Falcon was apparent also at two eyries in the Great Basin, northwest of Great Salt Lake, where the adult Prairie Falcons brought avocets and Antelope Ground Squirrels to their young almost exclusively in 1962 (C. M. White, unpubl. data) and commonly in 1969 (Platt, 1971). This, however, was in the apparent absence of competition with the peregrine.

The presence of the avocet in the diets of both species is probably a reflection of the local abundance of this shorebird and the ease with which it may be captured. The avocet likely did not represent a resource in short supply and undoubtedly was an important item in the diet of the peregrine long before the first white settlers arrived in the western United States. In 1871 Allen (1872) found it very abundant along the shores of Great Salt Lake, where he noted flocks containing several thousand individuals from 1 September to 8 October, and a quarter of a century earlier (4 April 1850), Stansbury (1852) observed innumerable flocks of long-legged plovers, many of which probably were avocets, Willets, and stilts. The avocet predated white man in the Great Salt Lake area by many thousands of years, as evidenced by its presence among the bird remains dating back nearly 8,500 years B.P. in the early strata of Hogup Cave, just north of the Great Salt Lake (Harper and Alder, in press).

The White-faced Ibis was an additional marshbird upon which both species of falcons apparently preyed. Weller et al. (1958) indicated that the peregrine killed White-faced Ibis in the Knudson marshes near Brigham City,

and R. D. Porter (unpubl. data) observed a Prairie Falcon feeding on an ibis at the Bear River marshes on 5 June 1951. Since the ibis was not found in the cyries of either species, it was probably too heavy for the falcons to carry to their cyries. The weight of an adult female ibis as determined by Porter et al. (unpubl. ms) is 517 grams, whereas the weights of two adult female avocets average 281 grams.

In Prairie Falcon cyries along the Wasatch Mountains, shorebirds, passerines, rodents, and gallinaceous birds were nearly equally represented; whereas in the cyries of the peregrine, shorebirds predominated and gallinaceous birds and rodents were absent (Table 5). The ducks present in the cyries of the Prairie Falcon (Table 5) were about half grown and probably inca-

pable of flight. Hence, they probably were either captured on the water or on the ground and were sufficiently light in weight that they could be carried by the falcons.

We have no data for comparison of the food habits of the peregrines nesting in the desert (Table 6) with those of desert-nesting Prairie Falcons in the same region. A comparison of this kind is needed to fully evaluate the competition for food by the two species. Cade (1960) found that the overlap in food species of the peregrine and Gyrfalcon were least in the areas of contact and greatest in areas where ranges were not sympatric. A comparison of this kind between the peregrine and Prairie Falcon would be difficult to make, since in Utah the Prairie Falcon occurs in the same geographic area as the peregrine. Nevertheless, one would expect



Fig. 39. Prairie Falcon feeding its young a downy avocet (peregrine site 7, alt. prairie site 2, see Fig. 26). Photo by R. J. Erwin and R. D. Porter, 1948.

less rather than more overlap in food habits in areas of allopatry than in areas of contact. The isolated peregrine's eyrie in Oregon, which was situated far from water (Gabrielson and Jewett, 1940), contained birds usually preyed upon by Prairie Falcons, and an adult peregrine at an eyrie in Zion Canyon was observed by Grater to carry a squirrel into a crag (Woodbury et al., unpubl. ms.).

In Utah, then, the Prairie Falcon has a wider versatility in taking prey species than does the peregrine, which would seem to lessen the competition between the two species for food. Hence the role played by the Prairie Falcon in Utah is similar to that of the peregrine in the Arctic (Cade, 1960; White and Cade, 1971), and that played by the peregrine in Utah is similar to that of the Gyrfalcon in the Arctic.

According to White and Cade (1971), there is no evidence to suggest that density of breeding peregrines is influenced in any way by availability of food in the Colville valley of Alaska. This generally is not applicable to the peregrine in Utah, but in the region surrounding the Great Salt Lake it is difficult to surmise how the density of the peregrine could have been limited by availability of food, considering the superabundance of prey species in the Great Salt Lake marshes. Nevertheless, extensive distances from eyrie sites (Table 4) to hunting sites in the marsh may have limited their density.

### Competition with the Prairie Falcon for Eyrie Sites

#### *Directional Exposure Preferences*

In Utah the peregrine's preference for cliffs with northerly or easterly exposures (Fig. 16) would tend to lessen the competition for nesting sites between it and the Prairie Falcon if the Prairie Falcon had a preference for south-facing cliffs similar to that reported for Colorado and Wyoming by Enderson (1964). We investigated this hypothesis by examining the directional facing of the 49 eyrie sites of the Prairie Falcon in Utah for which we had available data. As shown in Figure 16, 69.4 percent of these eyries faced south and west and 30.6 percent faced north and east. This relationship was statistically significant at  $p < 0.01$  ( $X^2$  test; calculated  $X^2$  value, 7.37, 1 df). Conversely, 70.4 percent of 27 peregrine eyries in Utah faced north and east and 29.6 percent faced south and west, and this relationship was significant at  $p < 0.05$  ( $X^2$  test; calculated  $X^2$  value, 4.48; 1 df).

When the two species nested in close juxtaposition on the same set of cliffs, as at site 7 in the Wasatch Mountains, the Prairie Falcon

seemingly selected the sites more exposed to the afternoon sun (west-facing sites) than did the peregrine (see History of Nesting at a Wasatch Mountain Eyrie, Table 7 and Fig. 26). As a general rule, the Prairie Falcon eyries on the escarpment of the Wasatch Mountains were situated directly on the west face, whereas those of the peregrine, as discussed previously, usually were on cliffs in the side canyons with northerly or easterly exposures. For example, three of the Prairie Falcon eyries were situated on west-facing cliffs (see Figs. 26 and 39-42). At each of these sites, peregrines had been seen in the side canyons, although not always concurrently with the nesting of the Prairie Falcon (sites 7, 8, and 16, Table 1). In 1943, a Prairie Falcon nested in one of the canyons (near peregrine site 16, Table 1), but at a west-facing site in an easily accessible Red-tailed Hawk's nest.

Morlan Nelson (pers. comm., 1971) noted a similar orientation between the eyries of the two species at the UI site in northern Utah (site 11, Table 1), where he observed the two species in aerial combat (Nelson, 1969). The peregrine eyrie was on a ledge facing east and the Prairie Falcon eyrie was in a pothole (cave-like recess) in the side of the west-facing cliff, less than half a mile away (1,320 ft; 402 m; Nelson, pers. comm., 1971). Potholes probably provide greater protection from the hot afternoon rays of the sun than do exposed ledges.

These data suggest that both species may select eyrie sites on the basis of directional exposure to the sun, and that such a preference by these two species tends to lessen competition between them for eyrie sites. Nevertheless, this phenomenon needs further investigation, both in Utah and elsewhere, since some studies suggest that the Prairie Falcon in some parts of its range selects eyrie sites on the basis of availability of suitable cliffs rather than directional facing. For example, Leedy (1972) investigated the directional facing of 49 Prairie Falcon eyries in Montana during 1970 and 1971 and compared them with the directional facing of the available cliffs. He found that 72 percent of the eyries faced south (33 percent) or east (39 percent), 8 percent faced north, and 20 percent faced west. Of the 45 available cliffs in Leedy's study area, 71 percent faced south (31 percent) or east (40 percent), 7 percent faced north, and 22 percent faced west—a near duplication of the directional facing of the eyrie sites. Similarly, Tyler (1923) reported that most Prairie Falcon eyries examined by him in southern California had northern exposures because in the region where he made his observations the north ends of the ridges

broke off abruptly into cliffs that faced north. Nevertheless, a few of his eyries were on west-facing cliffs; one was on an east-facing cliff; and none were on south-facing cliffs.

#### Height Preference for Cliffs and Eyrice Sites

The Prairie Falcon in Utah may use nesting sites of a quality inferior to those normally used by the peregrine in Utah. Judging from Bond's (1946) observations, this may be typical of the behavior of the two species wherever their geographic ranges overlap.

Three of nine Prairie Falcon eyries found in Utah by Porter and Erwin between 1950 and 1952 were at locations that were easily accessible to both humans and mammalian predators. Two were situated in potholes, one of which was located only 30 inches (76.2 cm) from the base of a small sandstone cliff and the other was only 36 inches (91.4 cm) from the base and 48 inches (121.9 cm) from the top of an outcropping of limestone. A third eyrie was located in 1943 by R. L. Porter and J. F. Poorman in an old Red-tailed Hawk's nest that was situated on a small pinnacle of rock which required no climbing to reach. One found in 1958 by F. Welch and G. L. Richards was on a large rock about 15 feet (5 m) above the ground and 6 feet (2 m) below the top of the rock. It probably could have been reached by a good climber without the aid of a rope. In southwestern Utah the Prairie Falcon has nested in a stick nest in the top of a 20-foot (6 m) juniper tree (*Juniperus* sp.) (Williams and Matteson, 1948).

In Utah peregrine eyries were a greater distance from the base of the cliffs, on the average, than were those of the Prairie Falcon. They were on higher cliffs, on the average, and they were on relatively more inaccessible ledges than were the eyries of their congener (Table 3). Moreover, the peregrine eyries averaged a greater distance below the brink of the cliff ( $\bar{x}$  = 68.6 ft, 21 m; range, 25-250 ft, 8-76 m;  $n$  = 13) than did those of the Prairie Falcon ( $\bar{x}$  = 25.3 ft, 7.7 m; range, 4-175 ft, 1-53 m;  $n$  = 41).

The average height of the Prairie Falcon eyries in Utah (64 ft; 20 m) was greater than that recorded by Enderson (1964) in Colorado and Wyoming (34.7 ft; 11.1 m), and less than that reported by Leedy (1972) in Montana (80 ft; 24.4 m). The average cliff height of 101.7 feet (31 m) for the Prairie Falcon in Utah is nearly twice that recorded by Enderson (1964) for this species in Colorado and Wyoming, and about 25 feet (7.6 m) less than that recorded by Leedy (1972) in Montana. Table 3, which compares the heights of cliffs and eyrie sites of the Prairie Falcon with

those of the peregrine, illustrates the difference in height preferences between the two species.

The more marginal sites, including those on the smaller or more accessible cliffs at sites such as 1, 3, 11, and 20 (Table 1), probably were abandoned by the peregrine earlier in the century. Both their sizes and locations made them marginal sites. Several investigators (Hickey, 1942; Ratcliffe, 1962) have indicated that the marginal sites were the first to become inactive following the advent of early settlers.

#### Eyrie Type Preferences

The Prairie Falcon uses a wider variety of nesting situations than does the peregrine (see Figs. 39-45). For example, nearly half (45.8 percent) of 72 Prairie Falcon nesting sites in Utah were in potholes and crevices (Figs. 42-44) in the face of a cliff, whereas only a third of them (31.9 percent) were on an open ledge of a cliff (Fig. 39). An additional third of the eyries were in the



Fig. 40. The Prairie Falcon eyrie that was situated on an old Common Raven's (*Corvus corax*) nest and was later reclaimed by the raven. Note the accumulation of fecal material and detritus suggesting that the eyrie had been used by the falcons for a long period of time (eyrie site faces southwest). Photo by R. D. Porter, 1951.

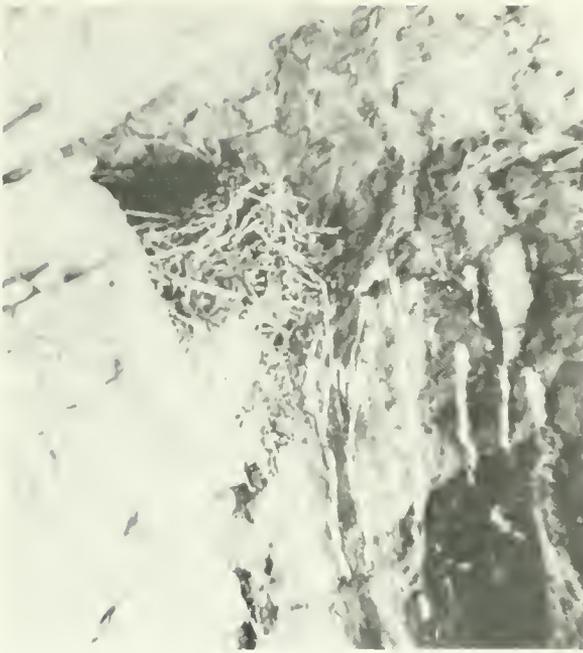


Fig. 41. Raven's nest built upon prairie eyrie (shown in Fig. 40). Photo by R. D. Porter, 1951.

nests of other species of raptors and Common Ravens, which suggests that these species may be beneficial to the Prairie Falcon by providing additional nesting sites. Table 10 gives the kind of nesting situations used by Prairie Falcons in Utah.

Sometimes these competitors may preempt their old nests from the Prairie Falcon. An oc-

Table 10. Percentage use of various categories of eyrie sites by Prairie Falcons in Utah (see photos by Wolfe, 1928)<sup>1</sup>

Kind of Site	Usage of eyrie types	
	n	Percent
Potholes <sup>2</sup>	26	36.1
Open cliff ledges	23	31.9
Crevices	7	9.7
Stick nests	16	22.2
Red-tailed Hawk's on cliff face	7	9.7
Common Raven's on cliff face <sup>3</sup>	5	6.9
Tree nests	2	2.8
Golden Eagle's on cliff face	1	1.4
Unknown species of hawk	1	1.4
Totals	72	99.9

<sup>1</sup>From unpublished data of authors, fieldnotes of R. G. Bee, A. B. Boyle, and R. J. Erwin, and from ornithological literature for the state.

<sup>2</sup>Five or 6.9 percent of the eyries were in old ravens' nests located within potholes.

<sup>3</sup>Including the five that were in old ravens' nests within potholes, a total of 10 or 13.8 percent were in old ravens' nests.

currence of this kind took place at an eyrie in Weber County observed by Porter and Erwin. The falcons were using an old raven's nest which apparently had been occupied for many years by falcons, since it was almost entirely buried in excrement (Fig. 40). Without the old raven's nest as a base, a falcon's eyrie would have been impossible. When first located on 5 June 1950, five fully grown young were present in the nest. The following year the eyrie contained three fresh eggs on 7 April. When it was next visited on 8 May, a raven flushed from the eyrie site, exposing six raven eggs in a newly constructed stick nest over the old prairie eyrie (Fig. 41). The whereabouts of the previous tenants was not determined.

Peregrines apparently were more restrictive in the selection of their eyrie sites. They used predominantly open ledges or shelves which usually were under an overhung portion of the cliff (See Figs. 26-38). Only two Utah eyries, to our knowledge, were situated in potholes on the sides of cliffs [sites 4 (alternate) and 23, Table 1 (See Fig. 44)]. We have no evidence of a beneficial relationship between the peregrine and other cliff-nesting species similar to that previously discussed for the Prairie Falcon.

Both species of falcon apparently prefer to nest under overhangs. Although our data on the



Fig. 42. Prairie Falcon eyrie in crevice on face of west-facing cliff. Peregrines nested up side canyon (site 8 Table 1). Much of the wood in the crevice was carried there by wood rats (*Neotoma* sp.). Photo by R. D. Porter, 1951.



Fig. 43. A cliff used alternately by Prairie Falcons and ravens. Nesting site is situated in a pothole similar to that shown in Figure 46. Cliff is less than 2 miles (2.6 km) from the peregrine eyrie shown in Figure 22, and this cliff may also have been used historically by peregrines. Photo by R. J. Erwin, August 1972.

Prairie Falcon are incomplete in this regard, all but one of 36 Prairie Falcon eyries in Colorado and Wyoming reported by Enderson (1964) were directly overhung by a portion of the cliff

#### Size Preference for Nesting Area

The Prairie Falcon appears to be less selective than the peregrine in the size of its nesting or egg-laying area. White (unpubl. data), for instance, observed a Prairie Falcon nesting in a pothole that was apparently too small for a large family of young because before the young had fledged, all but one were forced from the eyrie to an untimely death on the talus below (Figs. 45-46). This nest was used for five consecutive years. The female laid five eggs each year and each year only one young fledged. The eyrie was then abandoned. We have also, however, seen prairies successfully fledge large broods from ledges equal to or smaller than the site mentioned above.

The aforementioned Prairie Falcon eyrie in Weber County that was taken over by ravens

had a total nesting area of only about 310 sq inches (2,000 cm<sup>2</sup>) (measured from photographs). A Prairie Falcon eyrie in Box Elder County, found by Erwin, was in a crevice in the face of a cliff which was only 20 inches (51 cm) wide at the point where the eggs were laid. The crevice was over 50 inches in depth (ca. 200 cm) and nearly high enough for a man to stand in (measured from a photograph).

In the Wasatch Mountains, peregrines usually laid their eggs on wider ledges with a relatively more spacious nesting area (frequently with grass on them) than did the Prairie Falcon. The area and/or volume available for nesting on open ledges and within potholes used as eyrie sites in Utah are given in Tables 9 and 11. The average available nesting area for peregrine eyries in Utah is nearly twice that of prairie eyries (Table 11).

The wider variability in size and height of the Prairie Falcon's nesting sites would appear to be advantageous to the Prairie Falcon in its competition with the peregrine. If the better quality sites were already utilized, one of lesser quality,

Table 11. Size of area available for nesting at Prairie and Peregrine Falcon eyrie sites in Utah.<sup>1</sup>

Types of sites and units of measure	PRAIRIE FALCONS			PEREGRINE FALCONS		
	n	$\bar{x}$	range	n	$\bar{x}$	range
<b>POTHOLE SITES</b>						
Avail. nest. area						
sq feet	5	11.6	8.0 -18.8	-	—	— —
sq meters	5	1.1	0.74- 1.7	-	—	— —
Volume of potholes						
cubic feet	4	20.2	9.0 -43.7	-	—	— —
cubic meters	4	0.6	0.3 - 1.2	-	—	— —
<b>LEDGE AND POTHOLE SITES, combined</b>						
sq feet	8 <sup>2</sup>	16.3	2.2 -38.8	7 <sup>3</sup>	27.8	10.0-52.0
sq meters	8 <sup>2</sup>	1.5	0.2 - 3.6	7 <sup>3</sup>	2.6	0.9- 4.8

<sup>1</sup>Data were collected between 1943 and 1972 by R. D. Porter, C. M. White, and R. J. Erwin. See Table 8 for more detailed data on peregrine eyrie site 7.

<sup>2</sup>Two of the eyrie sites were alternate sites at site 7 (Table 1); one was used in common with peregrines.

<sup>3</sup>Data are from four different eyrie sites, including three alternate eyrie sites at site 7 (Table 1, figs. 26-30).

and possibly not suitable for peregrines, could be used, thus giving additional pairs of Prairie Falcons the opportunity to nest. Prairie Falcons nesting in the more arid desert areas of Utah frequently use sites which probably would not be used by the peregrine.

**Aggressive Interactions between Peregrines and Prairie Falcons**

Nelson's (1969) reported decline in active peregrine eyries around the Great Salt Lake probably involved the use by Prairie Falcons of abandoned peregrine eyries (Nelson, pers. comm., 1971), and as mentioned earlier, the peregrine also is known to have occupied an eyrie which earlier in the century was used by Prairie Falcons (see White, 1969b).

No direct competition between the two species for nesting sites was recorded during the years that the earlier mentioned Wasatch Mountain eyries (Table 1, site 7) were under observation by Porter and Erwin, despite the fact that the eyrie sites were only about 300 feet (91 m) apart (Figs. 22 and 23), and that the peregrines frequently flew within 100 yards (91 m) or so of the prairie's eyrie. Neither of the eyries were visible from the other (see Fig. 22). White and Cade (1971) found peregrines and Gyrfalcons nesting on the same cliffs simultaneously and successfully. They postulated that perhaps peregrines and Gyrfalcons can coexist in close juxtaposition if their nests are not visible to one another and if their schedules or routes of going to and from their nests to hunt are different.

Other instances of amicable interspecific co-existence between the peregrine and the prairie have been reported. Bond (1946), for example, tells of the two species nesting peaceably only a

few hundred feet apart. Pettingill and Whitney (1965) noted the nesting of a pair of peregrines and prairies 400 yards (366 m) apart in South Dakota without apparent conflict. French (1951) found the two species nesting 200 yards (183 m) apart, but not in view of each other. He watched the peregrines attack the prairies at least three times, but only during one of several visits to the eyrie. It is possible that his disturbance of the prairies at their eyrie helped provoke the attack by the peregrines. Lanner Falcons (*Falco biara-*



Fig. 44. Cliff in Great Basin desert (site 23, Table 1). Peregrine eyrie was situated near the horse-shoe-shaped depression, "pothole," at the center of the cliff indicated by arrow. Photo by R. J. Erwin, August 1972.



Fig. 45. Prairie Falcon eyrie in pothole on side of sandstone cliff. Photo by Gary D. Lloyd and C. M. White, 1958.

*micus*) and peregrines in Sicily have been reported by Mebs (in Fischer, 1967) to nest only 500 meters apart with no apparent conflict during the nesting period.

On the other hand, Nelson (1969) watched a pair of Prairie Falcons in aerial combat with a pair of peregrines in Utah near the nesting site of the latter (Table 1, site 11); the two pairs nested about one-fourth mile (402 m) apart (Nelson, pers. comm., 1971). In discussing the aerial battles between the two species, Nelson (1969), indicated that the Prairie Falcons seemed to win them. Later in the paragraph he writes, "The battles were not definite and always ended in sort of a draw, with observers deciding that the Prairie Falcons won." He also noted that although the Prairie Falcons had command of the air, when the two species parted they returned to their respective sites. Hence, he did not consider the aggression to result in the abandonment of eyries by either species. Webster (in Beebe and Webster, 1964) gives a vivid account of an aerial attack in Colorado by a female Prairie Falcon on a peregrine presumably carrying food to its young in which the Prairie Falcon robbed the peregrine of its prey. The Prairie Falcon nested nearby, but the location of the



Fig. 46. Young Prairie Falcon in pothole eyrie illustrated in Fig. 43. Photo by Gary D. Lloyd and C. M. White, 1958.

peregrine's eyrie was not ascertained by the observer.

Not all encounters between the two species are won by Prairie Falcons. Ogden (1972) sighted an adult female peregrine along the Snake River of southwestern Idaho on 31 March and 6 April 1972. Although unmated, she forced a pair of Prairie Falcons to abandon their established territory and clutch of eggs following about two weeks of conflict between the two species (Ogden, pers. comm., 1972). The female peregrine remained and defended the cliff through the remainder of the nesting season and on several occasions she made reproductive overtures toward male Prairie Falcons (ibid.). Richard Fyfe (pers. comm., 1972) made an observation similar to Ogden's on 11 April 1972 in Alberta, Canada. A pair of Prairie Falcons was well established and the female was about to lay eggs in a "pothole" eyrie on a high dirt river bank at the time that the female peregrine arrived at that eyrie on 11 April. The male peregrine preceded her arrival by a few days. Within a matter of hours on the day of her arrival, the peregrines had driven the prairies away and usurped the pothole.

Despite these observations of conflict, both species are able to establish and hold an eyrie site in close proximity to its congener. The near equality in size and strength between the two

species seems to reduce their dominance over each other. This is unlike the competition between the peregrine and the Gyrfalcon in the Arctic, where the larger and stronger Gyrfalcon, due to its earlier nesting and superiority to the peregrine in aerial combat, is able to establish and hold the most propitious nesting sites (Cade, 1960).

Both peregrines and prairies may use one another's alternate nesting sites, the availability of which may enable the two species to nest in closer proximity to each other than would two pairs of peregrines or two pairs of Prairie Falcons. Mebs (*in Fischer, 1967*) reported a similar relationship between the Lanner Falcon, a near ecological equivalent of the Prairie Falcon, and the peregrine in Sicily. A nesting cavity (hole) under his observation for three years was occupied in 1957 by lanners and in 1958 and 1959 by peregrines.

In some instances, the Prairie Falcon may occupy sites which otherwise would be used by additional pairs of peregrines—as well as the reverse—thus possibly limiting each other's breeding density.

Each species is known to maintain distances between eyries in parts of its geographic range not occupied by the other species which are much less than the distances between their eyries along the Wasatch escarpment. Few of the distances, however, averaged less than the distance between the alternate nesting sites used by the peregrine and Prairie Falcon at site 7.

Hickey (1942), for example, mentions that two pairs of peregrines nested only a half mile (805 m) apart in Canada, and Rateliff (1962) gives an instance in Great Britain of four pairs breeding on a mile (1.6 km) stretch of cliff. White and Cade (1971) found peregrines nesting a quarter of a mile (1.40 km) apart in the Arctic, but this was the exception, not the rule. Beebe (1960) noted five to eight pairs nesting on a linear mile (1.6 km) of cliff in the Queen Charlotte Islands, the highest density known for the peregrine.

The highest Prairie Falcon density, to our knowledge, is along the Snake River in southwestern Idaho, where in 1971 Ogden (1971) found 74 active nest locations along a 53 mile (85.3 km) stretch of river, for an average of 1.4 occupied areas per linear mile (1.6 km). The eyrie sites averaged less than one mile (1.6 km) apart (one pair/3,771 ft; 1,149 m).

#### Date of Egg Laying as a Competitive Factor

We have observed in Utah that the Prairie Falcon generally initiates egg laying earlier in

the spring than does the peregrine, and Nelson (1969) also noted this relationship between the two species. In Utah, peregrines have initiated egg laying as early as 22 March and as late as the second week in May. We have records of Prairie Falcon clutches in the Great Salt Lake area containing three eggs on 7 April, four eggs on 10 April (R. L. Porter and J. F. Poorman, unpubl. notes), and five eggs on 22 April. Newly hatched young were present on 13 May; young capable of flight were present on 10 June. A nest in extreme northern Utah found by Erwin in 1969 contained fully fledged young on 1 June. Woodbury et al. (unpubl. ms) recorded 51 sets of eggs from Tooele, Salt Lake, and Utah counties collected from 3 March to 15 June 1939. The average date of collection for 16 of the clutches, for which sufficient dates are available, was 20 April (range: 3 April-22 May). This did not, however, represent the dates of the laying of the first eggs. Wolfe (1928) records complete clutches of Prairie Falcon eggs in Utah from 5 to 20 April. The average nesting date for 36 records in Utah County was 18 April (range: 3 March-15 June) (data from Bee and Hutchings, 1942).

An earlier nesting date would give the Prairie Falcon first choice of eyrie sites. We have very little precise information for Utah on the arrival dates of either species at their eyrie sites, although White has seen Prairie Falcons at cliffs where eyrie sites were situated in February and early March and Porter has recorded them at a nesting cliff in the west desert of Utah as early as 3 February (1953) (Porter, Bushman and Behle, unpubl. ms). Wolfe (1928) noted the first appearance of Prairie Falcons in the Salt Lake Valley about the middle of March, and earlier farther south. He indicated that in some of the warmer valleys many of the falcons probably remain during the entire winter. Morlan Nelson (pers. comm., 1971) has seen this species at its desert eyries in Utah the year around. He believes that only the young leave the area of the nesting site (*ibid.*), although Enderson (1964) recorded the earliest arrivals in northern Colorado on 22 February in 1961 and observed that most adults became associated with the cliffs by mid-March.

Judging from the observation of adult male peregrines at eyries the year around in New Mexico (T. Smylie, pers. comm., 1971), it is quite possible that peregrines remain at or near some of the Utah eyries the year around, particularly the desert sites. Paul Newey (pers. comm., 1952) observed peregrines chasing his pigeons near the Wasatch Mountains during

the last week in January 1950 and again on 18 February 1950. The falcons were probably from a nearby eyrie. The nesting cliff was climbed on 25 February by R. D. and R. L. Porter, but no falcons were seen. Both peregrines and Prairie Falcons, however, were seen by 4 April.

### Reproductive Potential as a Competitive Factor

The Prairie Falcon appears to have a greater reproductive potential than does the peregrine. This, however, among other things such as food availability and winter mortality of young, may be a reflection of the greater vulnerability of

the Prairie Falcon's eggs and young to predation due to its selection of eyries at sites which are more easily accessible to predators. The average clutch size for the Prairie Falcon is 4.5 for 55 completed clutches in Wyoming and Colorado (Enderson, 1964), 4.3 for 20 nests in western Montana (Leedy, 1972), 4.25 for 31 eyries along the middle Snake River in Idaho (Ogden, 1971), and 4.35 for the 65 clutches from the Utah eyries in the present study. These are compared with an average clutch size of 3.8 for peregrines in Utah, 3.7 for peregrines elsewhere in the United States (Hickey, 1942; Bond, 1946), and 2.9 for peregrines in northern Alaska (Cade, 1960).

## PLEISTOCENE AND PREHISTORIC PEREGRINE AND PRAIRIE FALCON DISTRIBUTIONAL RELATIONSHIPS

Although Nelson's (1969) climatic change hypothesis probably is not the complete answer to the recent reduction in active eyries in Utah, it has a great deal of merit on a long-term basis. Perhaps the peregrine's present distribution in Utah can be elucidated best by an examination of the possible distribution of the peregrine and prairie falcon during prehistoric and Pleistocene times.

### Pleistocene Distributional Records

Both the peregrine and the Prairie Falcon are known from late Pleistocene deposits in western North America (Howard, 1962b; Miller, 1943). Hence, both species probably were present in Utah during the late Pleistocene. White and Cade (1971) suggest that the peregrine may have originated in midlatitude regions of Eurasia, then spread northward into the Arctic, and from there into North America (White 1968b). The Prairie Falcon apparently evolved *in situ* in western North America.

Both species were present in the Los Angeles area of California contemporaneously (Howard, 1962b) throughout much of the late Pleistocene period covered by fossils found in the La Brea Tar Pits. The fossils in these pits are believed to range from 5,000 to 40,000 years old (Berger and Libby, 1966; Ho, Marcus, and Berger, 1969; and Downs and Miller, 1971).

Pit 16 contained fossils of three each of both the peregrine and the Prairie Falcon. Fossil wood from two depths, 6½ and 12 feet (2-3.7m), in this pit has been dated back  $\geq 40,000$  years by radiocarbon dating (Berger and Libby, 1966).

The occurrence of these two species together in this and other pits (Howard, 1962b) suggests a long association between the two species. Since there is, however, a considerable variation in the ages of the fossils from the various pits and from the various depths of each pit, and since the greatest depths have not always yielded the oldest fossils (pit 9, Berger and Libby, 1966), the exact age of the peregrine fossils is not known. In addition, Howard's (1962b) published account of the fossils present in the various pits does not indicate the depths from which the fossils were obtained nor if the fossils of the two species discussed here intermixed within the same depth. Therefore, a more definitive interpretation regarding the duration of a sympatric association between the two species and the age of their fossil remains must await carbon dating of the actual peregrine and Prairie Falcon fossils.

Additional specimens of the Prairie Falcon from Pleistocene deposits are known from Smith Creek Cave in Nevada (Howard, 1952), from Rocky Arroyo (Wetmore, 1932) and Howell's Ridge Cave (Howard, 1962a) in New Mexico, from Lubbock Reservoir in Texas (Brodkorb, 1964), and from Nuevo Leon in Mexico (Miller, 1943). Specimens of the peregrine also have been found at Potter Creek Cave and at McKittrick in California (Miller, 1911 and 1927), Shelter Cave in New Mexico (Howard and Miller, 1933), and at American Falls in Idaho (Brodkorb, 1963). Vertebrate fossils from the late Pleistocene American Falls bed B, where this latter specimen apparently originated, have been dated as having an age greater than 29,700 B. P. (*ibid.*).

### Post-Pleistocene Distributional Records

The Prairie Falcon was distributed widely during prehistoric times. It is known from Oregon (Miller, 1957; <8,000 B. P.), California [(Howard, 1929;  $\leq$ 1,000 B. P.) and (DeMay, 1942;  $\leq$ 500 B. P.)], Arizona (Miller, 1932; 1,000 A. D.), and Utah [(Harper and Alder, in press;  $\leq$ 8,500 B. P.) and (Steward, 1937; remains not dated, but probably very recent)]. The peregrine, on the other hand, has been found, to our knowledge, only at prehistoric sites in California (Howard, 1929;  $\leq$ 1,000 B. P.) and Utah (Steward, 1937; remains not dated, but one of the two specimens probably was very recent; the other may have been somewhat older; one apparently was within strata containing artifacts of the Promontory culture).

These records suggest that both species were rather widely distributed geographically during the late Pleistocene, and that the peregrine probably was more common then than now; but following the Pleistocene period, the relative distribution and abundance of the two species probably were much the same as they have been historically.

### Lake Bonneville and Peregrine Distribution in Utah

Ancient Lake Bonneville was formed during the thrusts of the most recent Pleistocene glaciers some 60,000 to 70,000 years ago (Blackwelder, 1948, and Antevs, 1948). At its greatest height (the Bonneville level), this lake covered 19,750 sq miles (51,153 km<sup>2</sup>) of Utah's Great Basin (Antevs, 1948) and had a shoreline of 2,550 miles (4,103 km) (Fenneman, 1931). After standing at the Bonneville level for a long period of time, it is believed to have receded below the present level of the Great Salt Lake (Marsell in Durrant, 1952). Then, some 25,000 years ago during the Provo pluvial it rose to the Provo level [Lake Provo, 13,000 mi<sup>2</sup> (33,670 km<sup>2</sup>) area, Antevs (1948)]. It then receded (Antevs, *ibid.*; Marsell, *op. cit.*) after which it again filled back up to the Provo level (Marsell, *op. cit.*). In the last 12,000 years it receded to the present level (*op. cit.*).

A warmer interval of some 4,000 years began about 5,550-4,000 years B. C. (Blackwelder, 1948), at which time the lake receded to a level below that of the Great Salt Lake, with average temperatures distinctly higher than those of the present (Antevs, 1948; Blackwelder, 1948). Beginning about 2,500 years ago, a reduction in mean temperatures and evaporation caused an

expansion of the lake to its historic levels (Antevs, 1948).

The present environmental conditions in the Arctic may be near optimal for the peregrine, judging from its recent distribution and population density there. Climatic conditions in Utah during the late Pleistocene glacial periods probably were much less arid than at present and consequently closer to those presently occurring in the Arctic. According to Blackwelder (1948), temperatures in the Great Basin during the coldest ages probably were 8-12° F below the long-term average, and the rate of evaporation was much slower than at present. The extent of the ecological changes that took place in the southern part of the Great Basin during the latest glacial age are revealed in the dung of extinct ground sloths found in Gypsum Cave of southern Nevada (Laudermilk and Munz, 1935). The dung contained species of plants which now occur 3,000 feet (914 m) higher in the mountain ranges some 20 miles (32.2 km) away.

Recent data collected by Harper and Alder (in press) from an anthropological site in northern Utah, although agreeing in the sequence of events, indicate that the date of the actual onset and termination of these periods may be in error as might the extent of temperature change. At Hogup Cave, which is located just north of the Great Salt Lake, Harper and Alder (in press) found that all but one of the plant species that were present in the 14 feet of deposit dating back 8,500 years presently occur within 40 miles (64 km) of the cave. During this period, the upland areas were dominated by a xeric desert shrub community, although the first 500 years were somewhat more mesic in nature. They (*ibid.*) found that the lowlands had undergone a greater degree of change than had the uplands, as suggested by both plant and animal remains in the deposits. From about 7,800 B. P. to 2,500 years B. P. (except for a brief period about 6,000 years B. P.), the temperature increased at least 1° C and the open water and marshlands decreased. Then some 1,500 years ago and continuing for about a millenium, there was a relative increase in grasses on the uplands [suggesting an increase in rainfall]. Harper and Alder (*ibid.*) believe that the last 500 years were more arid and that the climate around the cave became as dry and inhospitable as at anytime during the past 8,500 years.

Historically, with the utilization for irrigation of the river waters which support the Great Salt Lake and a general increase in mean temperatures and decrease in precipitation during the past several decades, as was discussed ear-

lier, the Great Salt Lake reached its minimum level for historic times in about 1961. Since then it now has risen about seven feet (2.1 m) above its historic low.

The climate and ecological conditions present during the past 8,500 years would not seem to have been sufficiently arid to have eliminated completely the peregrine as a breeding bird in the area surrounding the Great Salt Lake. This is especially so if one considers the apparent extent of the aridity during the past 500 years and the persistence of the peregrine as a breeding bird in Utah despite the dry harsh climate of the past half century.

The occurrence of the Prairie Falcon at the oldest level (at least 8,350 years B. P.), along with numerous remains of nine species of water birds, at a time when ecological conditions probably were more optimal for the peregrine than at present, would suggest that the region surrounding the Great Salt Lake was even at that time an area of sympatry for these two species. The presence of both species in Black Rock Cave, south of Great Salt Lake (Steward, 1937), gives credence to this hypothesis.

The date of the first occurrence of the peregrine in the intermountain area, of course, is not known, but one can speculate that it appeared during one of the pluvial periods when the environmental conditions were most propitious for its survival and for its competition with the Prairie Falcon for food and nesting sites.

It is probable that it was present in Utah during the late Pleistocene, contemporaneously with its occurrence at Rancho La Brea. The presence of this species among fossils at the American Falls bed B, dating back at least 29,700 years, tends to confirm this supposition.

During the Bonneville and Provo pluvials, Lakes Bonneville and Provo, with their extensive shorelines and numerous islands, must have provided innumerable nesting sites, an abundance of prey species, and a near optimal climate for the peregrine. Pleistocene rivers and smaller lakes also must have provided correlative conditions which may account for eyries in areas outside of Bonneville Basin.

If the peregrine was present during the Bonneville and Provo interpluvials, it may have encountered environmental conditions of even greater aridity than at present. It would be of interest to know if peregrine eyries were maintained during these periods of extreme aridity or if, as suggested by Nelson (1969) for present conditions, altitudinal and latitudinal adjustments were made. If the latter were true then

the eyries became reactivated when the lake gradually increased again to its maximum historic level.

The overlap between the breeding distribution of the Prairie Falcon and peregrine in the intermountain area during the cooler, wetter pluvial period was probably dominated by the peregrine, but as the climate slowly ameliorated, populations of the Prairie Falcon likely increased in density and gradually extended northward, probably at the expense of the peregrine. As the environmental conditions became more arid, the peregrine eyries that were near lakes or streams where sufficient food was available may have remained active. Those where the water disappeared probably either were taken over by the better adapted Prairie Falcon or else were deserted. Peregrines at the active eyries may have gradually adapted to the increasing aridity, but they would have been able to compete with the Prairie Falcon only at sites where water was available. This hypothesis seems to be supported by the geographical and ecological distribution of the peregrine in Utah during historic times (Fig. 1). For instance, of the 40 known and suspected eyries in Utah, 26 were located in or near the Bonneville Basin. The greatest concentrations of breeding pairs occurred near the largest remaining bodies of water, particularly in the area surrounding the Utah and Great Salt lakes.

The eyries in the harsh environment of the Great Salt Lake Desert were adjacent to small expanses of marsh (Figs. 20 and 23). Most astounding is that these eyries existed at all, considering the harsh nature of the environment. It is evidence of the adaptability of the species and of the species' tenacity at its eyrie sites. How long these eyries would have remained active in the absence of human interference is a question that may never be answered. The tenacity of peregrines at their eyrie sites as discussed by Cade (1960) and Hickey (1942), and the tendency toward a genetic continuity in eyrie maintenance as proposed by White (1969a) (for a more complete discussion, see White, 1968b) would suggest the possibility that some of the eyrie sites that were active during recent times may have had long histories of activity; some perhaps, even extended back into Lake Bonneville times. This possibility seems especially plausible when one considers the relative recency of some of the later pluvial periods. Thus, the relationship between the Prairie Falcon and peregrine probably extends back many thousands of years, which may be a factor in the relative compatibility of the two species.

Data presented previously regarding the contemporaneity of the two species at Rancho La Brea; the occurrence of the peregrine in a fossil bed at American Falls, Idaho, dating back to at least 29,700 years B. P. (Brodkorb, 1963); the presence of both species at anthropological sites just south of the Great Salt Lake (Steward, 1937; Black Rock Cave); and the climatic and environmental evidences from Hogup Cave in northern Utah (Harper and Alder, in press) tend to corroborate this supposition. The lack of aggression

between them also suggests a long sympatric relationship.

White and Cade (1971) believe that traditional use of an eyrie site will in the long run reduce the total impact of intolerant behavior and promote stability in the peregrine populations of the Arctic. If so, a long history of occupancy at Utah eyries probably would have enhanced the peregrine's competitive position with the Prairie Falcon and thus strengthened the peregrine's hold on its optimal eyrie sites.

## SUMMARY AND CONCLUSIONS

Utah's rugged topography and ecological variability is conducive to its inhabitation by a wide variety of raptorial species. This includes the Peregrine Falcon, which now has virtually disappeared as a breeding bird in the state.

Although sparsely distributed throughout Utah, the species apparently found conditions especially suitable for nesting in the environs of the Great Salt Lake and Utah Lake valleys, where its nesting sites in the adjacent mountains were within flying distance of a plentitude of preferred prey species which inhabited the marshes and shorelines surrounding the two lakes. Despite the aridity of the environment, the 20 eyries that occurred there, when and if they all were active simultaneously, comprised a population comparable to some populations elsewhere in North America where the environment is considered to be more congenial to the peregrine. On the average, there was one eyrie site for every 225 sq miles (583 km<sup>2</sup>) in an area of about 4,500 sq miles (11,655 km<sup>2</sup>) surrounding the Utah and Great Salt lakes. The average distance between 13 eyries along 130 linear miles (209 km) of the Wasatch Mountains was 10.0 miles (16.1 km) (range, 2-20 mi; 3.2-32.2 km).

Elsewhere in the state, the species was more sparsely distributed, and then only at sites where suitable nesting cliffs were adjacent to marshes or rivers. Only nine additional eyries have been verified for the remainder of the state [one pair per 7,732 mi<sup>2</sup> (20,025 km<sup>2</sup>) in area, exclusive of the aforementioned 4,500 mi<sup>2</sup>], although 11 others are suggested by the presence of adult birds and/or young during the nesting season. If all 40 known and suspected eyries are included, there would be about one eyrie for every 2,123 sq miles (5,499 km<sup>2</sup>). If 11 unverified eyries are excluded, there would be about one eyrie for every 2,928 sq miles (7,584 km<sup>2</sup>) of the state.

Peregrines have reproduced successfully in the deserts of Utah's Great Basin and Colorado Plateau under some of the harshest climatic conditions to which the species is subjected. All eyries in Utah's deserts have been situated near marshes, lakes, or rivers. Peregrine nesting sites in the desert generally were closer to extensive marshes than were those along the Wasatch escarpment. The average distance from eyrie to hunting sites in the marshes was only 1.3 miles (2.1 km) (range, 0.19-2.8 mi; 0.31-4.5 km) for three desert eyries. For the nesting sites in the region of the Utah and Great Salt lakes, the distances averaged 3.3 miles (5.3 km) (0.19-9.7 mi; 0.31-15.6 km). Marshes used by peregrines at the desert eyries usually were less than 3 sq miles (7.8 km<sup>2</sup>) in extent (Table 4).

Although the Peregrine Falcon has been known to occur in Utah since the early 1870s, most of our knowledge of its nesting distribution and abundance dates back only three or four decades. The status of the species in Utah prior to the late 1930s is largely unknown. Its past history and present status in Utah, therefore, has been postulated on the basis of all records available to us, both before and after 1939. Data are too sketchy for a thorough understanding of the kinetics of local populations. Eyries that survived the longest are those farthest from areas of intensive agricultural practices and also dense human populations. Those at the poorest quality sites appeared to have been deserted first. Abandonment of active eyries first became apparent in the 1940s. The known breeding population in Utah was reduced by the late 1960s to less than 10 percent of the pre-1940 estimates.

The several factors, in order of relative importance, that may have contributed to these changes are as follows: (1) the inimical effects of DDT, its metabolites, and other chlorinated

hydrocarbons on peregrine reproduction; (2) a drying up of marshes which supported the peregrine's prey species, due to a decline in annual precipitation; an increase in the average daily temperatures; and the diverting of river waters for irrigation purposes; (3) the killing of adult and young falcons with firearms; (4) the death of peregrines due to botulism toxins; (5) the robbing of eyries for their eggs or young; and (6) the destruction of nesting cliffs for mining and construction operations and general human encroachment.

Reproductive failure typical of the pesticide syndrome was recorded at three peregrine eyries and one Prairie Falcon eyrie in Utah during the period following the extensive use of DDT to control mosquitoes and agricultural pests in Utah and elsewhere. All of these factors combined probably have contributed to the near extirpation of the peregrine in Utah, although the use of organochlorine pesticides probably was the most important contributory factor, especially when combined with a prolonged drought which occurred during the first half of the century.

The average clutch size at one peregrine eyrie site in Utah for five years between 1943 and 1952 was 3.8, and an average of 2.4 young hatched during these years; and for seven years between 1943 and 1953 a total of 19 young were produced for an average of 2.7 young per year. This is in close agreement with figures recorded at other eyrie sites in North America at an equivalent latitude. The incubation period at the aforementioned eyrie site was estimated to exceed the 28 to 29 days reported elsewhere by four or five days. An unusually long incubation period of about 40 days in 1948 was explained on the basis of renesting, if based on a 28- to 29-day incubation period.

Nestling peregrines in Utah were given a wide variety of avian prey species. Pairs nesting along the Wasatch Mountains (near the Great Salt Lake) fed their young mostly shore- and marshbirds, many of which were obtainable only from Great Salt Lake marshes up to 17 miles (27.4 km) distant. Avocets and Willets were the species of shorebirds most used. Mourning Doves, Rock Doves, Red-shafted Flickers, and Western Meadowlarks were most used of the nonaquatic prey species. Bats, which were the only mammalian prey species present in Utah eyries, represented less than one percent of the diet. Passerine and gallinaceous prey species were of greater importance and aquatic prey species of lesser importance in the desert eyries. The selection of eyrie sites by peregrines in Utah appears to be associated with the availability of

suitable nesting sites adjacent to a marsh or stream where prey species are available in adequate numbers. The utilization of aquatic prey species as food for nestling peregrines in Utah undoubtedly is a major factor in the species's proclivity for nesting sites near water.

The Golden Eagle and Prairie Falcon are the two species most likely to compete with the peregrine for food and nesting sites. Direct competition between the peregrine and Golden Eagle for food probably is minimal, since mammalian prey species contribute greatly to the eagle's diet, and no direct evidence of competition between the two species for nesting sites has been observed in Utah.

The Prairie Falcon, on the other hand, is a probable competitor, which is expected because both species belong to the same genus, both are basically equivalent in ecological function, and both are approximately equal in size and strength. Although the habitat of the two species overlaps, habitat separations are present. The Prairie Falcon, for example, may nest in the desert many miles from water. In the zone of contact between the two species, its selectivity in habitat and food encompasses and exceeds that of the peregrine. The zone of contact between the two species appears to be restricted only by the paucity of suitable nesting habitat adjacent to an adequate supply of food for the peregrine.

Where they occupy the same habitat their diets are somewhat different, thus mitigating the possibility of strong competition for food, although where they nested side by side in the Great Salt Lake Valley their food niches did overlap considerably. Both species preyed rather extensively on the same two prey species, the avocet and Willet, which probably was a response to the abundance of these two shorebirds. In general, the Prairie Falcon was much less selective in its food requirements in the area surrounding the Great Salt Lake than was the peregrine in the same area, and it was more prone to supplement its diet with rodents, ground nesting birds, and reptiles. Thus, in this respect, it appeared to have an adaptive advantage over the peregrine.

Competition between the two species for food did not appear to have been an important factor in controlling their relative densities along the escarpment of the Wasatch Mountains, especially when populations of avocets, Willets, and other species of shorebirds were sufficiently large to support them both.

We have no data regarding the food niches of the Prairie Falcon in the zones of contact between the two species at river sites in the

desert. However, we would expect a greater overlap in the avian prey of the food niches of the two species in these areas due to the elimination of a great portion of aquatic birds from the diet of the peregrine (see Gabrielson and Jewett, 1940). Our data, however, suggest that the extensive utilization of rodents, particularly ground squirrels (*Citellus* sp.), by the Prairie Falcon in the desert areas would tend to lessen the impact of the competition between the two congeners for avian prey in those regions.

In regions of Utah where the populations of the peregrine were greatest, pairs of Prairie Falcons and peregrines nested much closer together than did pairs of peregrines or pairs of prairies. The two species sometimes even used one another's alternate nesting sites. When they nested close together, their nesting sites were not known to be visible from one another. Although they were observed in aerial combat, neither species appeared to be able to consistently dislodge its congener from its nesting site.

Our data suggest that both species select eyrie sites on the basis of availability, but when given a choice they seemingly select them on the basis of directional exposure to the sun. The peregrine shows a preference for north- and east-facing cliffs, and the Prairie Falcon shows a preference for south- and west-facing cliffs. This relationship between the two species needs additional investigation to further test its validity in Utah and to test its applicability elsewhere in the arid West.

The Prairie Falcon was less selective than was the peregrine in its choice of nesting sites, sometimes selecting sites which were seemingly shunned by the peregrine. The former species, for example, utilized sites that were located on smaller ledges with a smaller total nesting area, as well as sites located on lower cliffs nearer the base of the cliff or otherwise more easily accessible to humans and to mammalian predators, than did the latter species. Furthermore, ravens which are common in Utah, seemingly alter the nesting habitat in a beneficial way for Prairie Falcons by providing additional nests that are frequently used by the falcons, whereas the peregrine apparently is little affected by the presence of ravens.

The Prairie Falcons initiated egg laying earlier in the season, thus giving them first choice of nesting sites; and on the average they laid larger clutches than did the peregrine.

The Prairie Falcon is a true desert species. It apparently evolved in the arid environment of western North America, and as expected, in its association with the peregrine it appears to be

the dominant competitor in the following ways: (1) it has a greater reproductive potential than does the peregrine, based on its larger clutch size; (2) it is less selective than is the peregrine in choice of nest sites and thereby has more nesting situations to choose from; (3) it lays earlier in the season than does the peregrine; thus it may have first choice of cliffs and eyrie sites; (4) it shows less selectivity in its choice of prey species as food for its young; consequently it has a wider range of species to choose from, including birds, mammals, and reptiles; and (5) because of its selection of prey species other than birds, it is not as obligate to open water for food, nor is it as obligate to open water for bathing, and thus it may nest many miles from water.

The Prairie Falcon, then, would appear to have a marked adaptive advantage over the peregrine, especially in marginal areas where the peregrine's ecological tolerance is restricted and where the peregrine's preferred food and/or nesting sites are in short supply. The Prairie Falcon's adaptive advantage over the peregrine may contribute to the restriction of the peregrine to the more optimal aquatic habitats near streams and marshes where food and nesting sites are not in short supply, and where the peregrine competes successfully with its congener.

Some of the reasons the peregrine in Utah is able to compete successfully with the Prairie Falcon for food and quality nesting sites may be: (1) the relative tolerance of the two species for each other while nesting close together; (2) the utilization of one another's alternate eyries, coupled with the inability of either species to consistently gain a dominance over the other in aerial combat, although recent observations by Ogden (1972) and R. Fyfe (pers. comm.) suggest that the peregrine may occupy the most propitious sites because it is capable of forcing the Prairie Falcon from them; (3) the possible partitioning of the nesting cliff with each species having distinct preferences for different types of nesting sites or a wide variability in acceptable nesting situations. There is, for example, the peregrine's preference for open ledges and the Prairie Falcon's acceptance of a wide range of nesting situations, illustrated by its use of potholes in the face of the cliff, open ledges, and old stick nests of other raptorial species. The pothole eyries probably enhance the survival prospects of young reared on west-facing cliffs and probably offer greater protection from predation than do the open ledges; (5) a variation between the two species in the size

of the nesting area and in the height of the cliffs and eyrie sites; (6) the presence, in abundance, of the prey species preferred by the peregrine in areas of Utah where the peregrine was most common, with partial partitioning by the two species of their food niches; and (7) the peregrine's fidelity to the cliff.

We have hypothesized that the peregrine probably invaded the intermountain region during a pluvial period of the Pleistocene, when the environmental conditions favored the peregrine in its competition with the Prairie Falcon. Moreover, the ancient Pleistocene Lakes Bonneville and Provo undoubtedly presented the peregrine with both an abundance of food and a sufficiency of nesting sites. Fossil remains of peregrines from the La Brea Tar Pits dating back 40,000 years or more and from American Falls in Idaho dating back nearly 30,000 years support this hypothesis.

There may have been times during the cooler pluvial periods when the geographic ranges of the two species were mutually exclusive, at least in some localities of Utah. During the drier interpluvials, the Prairie Falcon probably took over nesting sites no longer tenable to the peregrine. However, the peregrine probably persisted at those sites where the ecological conditions were most propitious to its survival and where it gradually adapted to the more arid condition of the interpluvial, as is the present case. The peregrine is noted for its fidelity to certain cliffs over many generations of breeding birds. Traditional occupancy may not be the rule with the Prairie Falcon. Finally, one would expect that the longer the existence of a sympatric relationship between two closely related congeners, the more extensive would be the partitioning of their resources and the greater the reduction in the conflict between them. The partitioning of the resources between the peregrine and prairie seems to be sufficiently defined to suggest that this phenomenon has been in operation for a considerable period of time. The low level of interspecific aggressiveness as well as the palaeontological records suggest that the relationship between the two species is probably of long standing.

Fluctuations in peregrine populations concomitant with fluctuations in height and length of the shoreline of the Pleistocene lakes probably have been of natural occurrence down through the ages. Peregrine populations possibly have been declining slowly in Utah over the past several centuries concurrent with a general amelioration of climate and accompanying reduction in suitable habitat based on climatic and biotic evidence from Hlogup Cave dating

back 8,500 years, while populations of the Prairie Falcon may have slowly expanded to fill the void as suggested by Nelson (1969).

Evidence that the southern extremity of the peregrine's geographic range historically shifted northward along with an associated shift altitudinally (Nelson, 1969) has not been demonstrated for Utah. With the drastic decline in the species' breeding populations that is presently taking place throughout North America, a hypothesis of this kind is difficult to test. A general cooling trend in Utah and elsewhere in the Northwest which started about 1961, however, should result in more suitable ecological conditions for the peregrine. The extent to which old eyrie sites are recolonized should be a test of the validity of Nelson's (1969) climatic change hypothesis for the peregrine decline in the western United States.

The presence of the peregrine at desert sites on the periphery of its ecological range as late as 1959-60 in the Great Basin (Table 1, site 23) and the early 1960s in the Colorado Plateau (Table 1, site 28) emphasizes the species's ability to adapt and its tenacity for survival.

The competitive roles of the peregrine and the Prairie Falcon apparently change according to locality, based on availability of food and nesting sites, and on the behavior and ecology of the raptorial species with which they must compete. For example, in the Arctic the Peregrine Falcon is a generalist, both in terms of its selection of nesting sites and in regards to trophic relationships with its competitors (White and Cade, 1971); there, this species utilizes a wide variety of food, which is not a restrictive aspect of its economy in the Arctic, and a broad selection of nesting sites. Its chief competitors in the Arctic are the Common Raven, the Gyrfalcon, and the Rough-legged Hawk (*Buteo lagopus*). The Gyrfalcon, the peregrine's most closely related competitor, on the other hand, is a specialist in terms of nest site and food selection. The raven and Gyrfalcon have similar nesting requirements, and since both are early nesters they have an earlier choice of eyrie sites. Thus, when the later-nesting peregrines and rough-legs arrive, the late arrivals are more or less limited to the remaining sites. Consequently, the peregrine utilizes "marginal" sites where it may have to compete with the rough-legs. Apparently, however, the peregrine is capable of usurping the rough-legs's nest. In addition, the two species may jointly occupy the same cliffs, thus lessening the competition between them. White and Cade (1971) believe that since ravens and peregrines do not get along well together, the

earlier nesting raven may force the peregrine into "marginal" and "submarginal" sites on those occasions when peregrines try to nest too close to the ravens. They believe that the same thing applies when peregrines attempt to settle too close to Gyrfalcons on the same cliff. The peregrine, nevertheless, does use "optimal" sites in the Arctic when they are available.

In the desert, however, the peregrine's role is the reverse of its role in the Arctic. Here the peregrine is forced into the role of a specialist because the harsh arid environment produces few of the prey species preferred by the peregrine and because the Prairie Falcon competes more successfully for both the former's marginal food niche and its marginal nesting niche. The specialization in the peregrine's food requirements is apparent only when compared with that of the Prairie Falcon in the zones of contact between the two species. Here the utilization by the Prairie Falcon of rodents (especially ground squirrels), reptiles, and birds (to a great extent the same principal shore birds used by peregrines) makes it a generalist in its food habits. In areas of allopatry, as in the deserts, the Prairie Falcon often uses predominantly one or two species of rodents and/or birds and, therefore, in these regions, it is seemingly a specialist.

In its nesting site requirements, the Prairie Falcon is a generalist when both allopatric and sympatric with peregrines. In its selection of nesting sites, it seems to prefer sites which we would consider to be marginal for the peregrine. This more or less limits the peregrine to the more optimal nesting sites and to the role of a specialist. Distribution of free water, and its concomitant supply of suitable prey species, is the most important environmental factor dictating the distribution and abundance of the Peregrine Falcon in the arid West. Conversely, lack of free water and its associated supply of suitable prey species is a limiting factor in the distribution and abundance of this species.

Climate, on the other hand, appears to be a major factor restricting the geographic distribution of the Prairie Falcon as is its strong proclivity to nest on cliffs, thus nearly eliminating the use of tree nests as eyrie sites. In general, however, the selection by the Prairie Falcon of a wide variety of prey species, encompassing three classes of vertebrates, its utilization of several different types of nesting situations, its relatively high reproductive potential, and its ability to exploit successfully the arid environments of western North America points out the extent to which this species has become adapted to its particular environment. With its versatility in selec-

tion of prey species and nesting sites, but more especially the former, the Prairie Falcon is among the better adapted and more successful of North American raptors.

Because of its extensive utilization of rodents for food, its frequent occurrence in areas many miles from water and many miles from civilization, and its relatively nonmigratory nature, the Prairie Falcon is much less likely to become a permanent victim of the indiscriminate use of the chlorinated hydrocarbons than is the peregrine.

The current precarious status of the Peregrine Falcon in Utah is probably a result both of a change in climate and of the inimical effects of man's activities. The future of the species in Utah, as elsewhere, appears bleak. Many of the factors responsible for its decline are still in evidence. DDT and other harmful pesticides are still being used in Utah. In 1969, for example, 7,593 pounds (3,440 kg) of DDT were used in Utah for the control of noxious insects (in the pesticide policy statement of the Utah State Department of Natural Resources) and this was increased to 11,348 pounds (5,140 kg) in 1970 (Work Unit A, Pesticides Applied—State of Utah, Utah State Health Dept., 1970; Stephen L. Warnick). The impact on raptors of polychlorinated biphenyls and of the heavy metals, such as mercury, lead, and cadmium, are still poorly understood, and other chemical hazards of unknown kinds also may be involved.

Although man is still encroaching on the activities and habitat of the peregrine and on its environment, with the construction of artificial lakes such as those formed in Glen Canyon and in the Flaming Gorge and with a general cooling of the climate which is resulting in the re-establishment of certain lakes and marshes, nesting pairs of peregrines may yet be attracted into new and old areas, hopefully away from the harmful activities of man. Inimical environmental factors must first be eliminated. The use of management methods, such as construction of manmade marshes near suitable nesting cliffs or manmade eyrie sites near suitable marshes, has not yet been attempted. Management techniques have worked well with other species, and may prove successful with the peregrine.

The few peregrine eyries still remaining active, as well as the many active Prairie Falcon eyries in the state, should be given the strictest protection and/or management. All peregrine eyries should be guarded zealously that future generations may have the pleasures which have been ours; that is, to see, to study, and to enjoy this magnificent species alive in its native haunts.

### Addendum

After the final manuscript was in press, we learned of two more localities used by peregrines. Ralph B. Williams (pers. comm.) told us of an eyrie that the late Charles Springer of Salt Lake City, an avid birder and falcon enthusiast, located sometime in the late 1930s and early 1940s. The eyrie was west of the general area of the Bear River marshes. From the description of the eyrie it appeared to be about 12 to 15 straight-line miles from eyrie number 9 (Table 1) and within region A as outlined

on Figure 1. It was apparently inactive after the early 1940s since that area was searched for falcons in the mid-1940s. The second locality occupied by a pair of territorial peregrines would also be included in the area of region A but to the east of the boundary lines, as shown in Figure 1. This locality was adjacent to several pairs of Prairie Falcons, but the exact canyon in which it was located could not be determined from a map, as it was located in the late 1930s and details are vague (Morlan Nelson, pers. comm., 1973).

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We would like to dedicate this study to the late Gary D. Lloyd, who was a constant companion to White while working with raptors through the 1950s and early 1960s, and who met an untimely and premature death, along with his wife, while they were working in the falcon country of east-central Utah.

### APPENDIX—ADDITIONAL HISTORY OF DDT USAGE AS A MOSQUITOCIDE IN UTAH

According to Collett (1955), Salt Lake County sprayed 310 acres (125 ha) by airplane in 1949 and in 1950, according to Smith (1951), both Weber and Salt Lake City Mosquito Abatement districts (MAD) hired planes for aerial spray work, and the latter treated more than 1,300 acres (526 ha). From 1950 through 1953 the Salt Lake City district treated 10,680 acres (4,322 ha) by aircraft (Collett, 1955) and Davis County sprayed 3,000 acres (1,214 ha) by aircraft in 1953 (Stewart, 1954). Aerial spraying greatly increased in 1954, according to Graham and Rees (1958). In that year the Salt Lake City district (Collett, 1955) aerially treated 12,128 acres (4,908 ha), of which 2,286 acres (925 ha) were in cooperation with the Davis County MAD. Insecticides used by the Salt

Lake City MAD in 1954 were DDT in number 2 fuel oil, DDT and water emulsion, and heptachlor emulsion in water; DDT was applied at the rate of two gals per acre (19 l/ha), containing 0.4 lbs (181 g) of DDT; heptachlor was applied at the rate of 0.06 lbs/acre (67 g/ha) for larvae and 0.08 lbs/acre (90 g/ha) for adults (Collett, *ibid.*).

The Weber County MAD sprayed over 10,000 acres (4,047 ha) by air in 1952 and 19,825 acres (8,023 ha) in 1953. DDT was applied at 0.2 lbs/acre (224 g/ha) for 15,812 acres (6,399 ha) and at 0.4 lbs/acre (448 g/ha) for 1,793 acres (726 ha) in 1953, for a total of 3,880 lbs (1,760 kg) of DDT applied to 17,605 acres (7,124 ha) of marsh and pasture lands (Fronk, 1954). In 1954 Weber County aerially treated

13,300 acres (5,382 ha) at 0.1 to 0.4 lbs of DDT per acre (112–448 g/ha) (Fronk and Jenne, 1955), while Box Elder County similarly sprayed 5,000 acres (2,023 ha) (Josephson, 1955).

An abatement district was not operative in Utah County until 1963, and the chemicals used were Baytex, parathion (both in pastures), and DDT (where residues were considered to be no problem) (Davis, 1964). DDT was not used by the South Salt Lake County district. Heptachlor was used in this county starting with the inception of the MAD in 1953 (Graham and Rees, 1958; Graham in letter). It was applied at 0.04 lbs per acre (45 g/ha). Dieldrin was

used extensively in this district also at the same concentrations as heptachlor. Other districts then began using heptachlor, and by 1958 it became as commonly used as DDT (Graham and Rees, 1958). Malathion and parathion were used in 1956, and parathion became the insecticide preferred by the Salt Lake County MAD in 1957 when resistance to heptachlor developed in the mosquitoes (Graham and Rees, 1958). By 1962 nearly all mosquito abatement districts in Utah had abandoned the use of DDT because pastures, milk, and food were becoming polluted with residues, and by 1970, only Box Elder County was still using DDT.

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AN ECOLOGICAL SURVEY OF THE  
ALGAE OF  
HUNTINGTON CANYON, UTAH

by

Lorin E. Squires  
Samuel R. Rushforth  
Carol J. Endsley



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# AN ECOLOGICAL SURVEY OF THE ALGAE OF HUNTINGTON CANYON, UTAH

by

Lorin E. Squires,<sup>1</sup> Samuel R. Rushforth,<sup>1</sup> and Carol J. Endsley<sup>1</sup>

## ABSTRACT

A quantitative and ecological study of the algae of Huntington Canyon, Emery County, Utah, was conducted from March 1971 to April 1972. Net plankton, nanoplankton, periphyton, and visible attached algae were studied. Certain physical and chemical parameters in the waters of Huntington Creek and a small pond along its course were also measured.

Huntington Creek contains a wide diversity of genera and species of algae. Diatoms are the main constituent of the flora of this stream throughout the year. *Hydrurus foetidus* is preva-

lent in Huntington Creek from late winter to early summer, and filamentous blue green algae abound in the summer and fall. *Cladophora glomerata*, *Oedogonium* sp., and *Chara vulgaris* are abundant in the creek beyond the mouth of the canyon. Most plankton in Huntington Creek originate on the substrate and in reservoirs on the left fork.

Huntington Creek is a cold, fast-flowing, hard-water mountain stream, and the algal flora of this creek is typical of such a habitat.

## INTRODUCTION

In October 1970 a study of the algae of Huntington Canyon, Emery County, Utah, was initiated (Fig. 1). The need for this study stems from the construction of a coal-fired power-generating station and a 30,000 acre-foot reservoir by Utah Power and Light Company. The generating station is located in lower Huntington Canyon approximately 12 miles northwest of Huntington, Utah, on land formerly owned by the Utah State Division of Wildlife Resources and the Bureau of Land Management (Fig. 2). The Peabody Coal Company will supply coal for the generating station from a mine 2.5 miles southwest of the station, and the electricity will be transmitted south to the Four Corners area and north to Camp Williams (Draft Environmental Statement, 1971). When completed, the station will consist of four generating units. The first unit will generate 430 megawatts of electricity and will be operational in 1974. Thereafter, one unit will be completed during each of three four-year periods. Upon completion, the station will be capable of generating 2,000 megawatts of electricity.

The four generators will be cooled with water taken from Huntington Creek. To insure

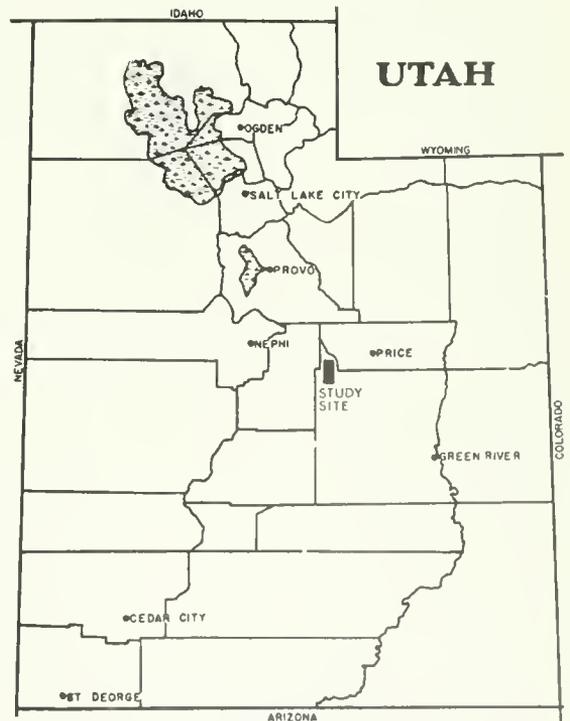


Fig. 1. Index map of the Huntington Canyon study area.

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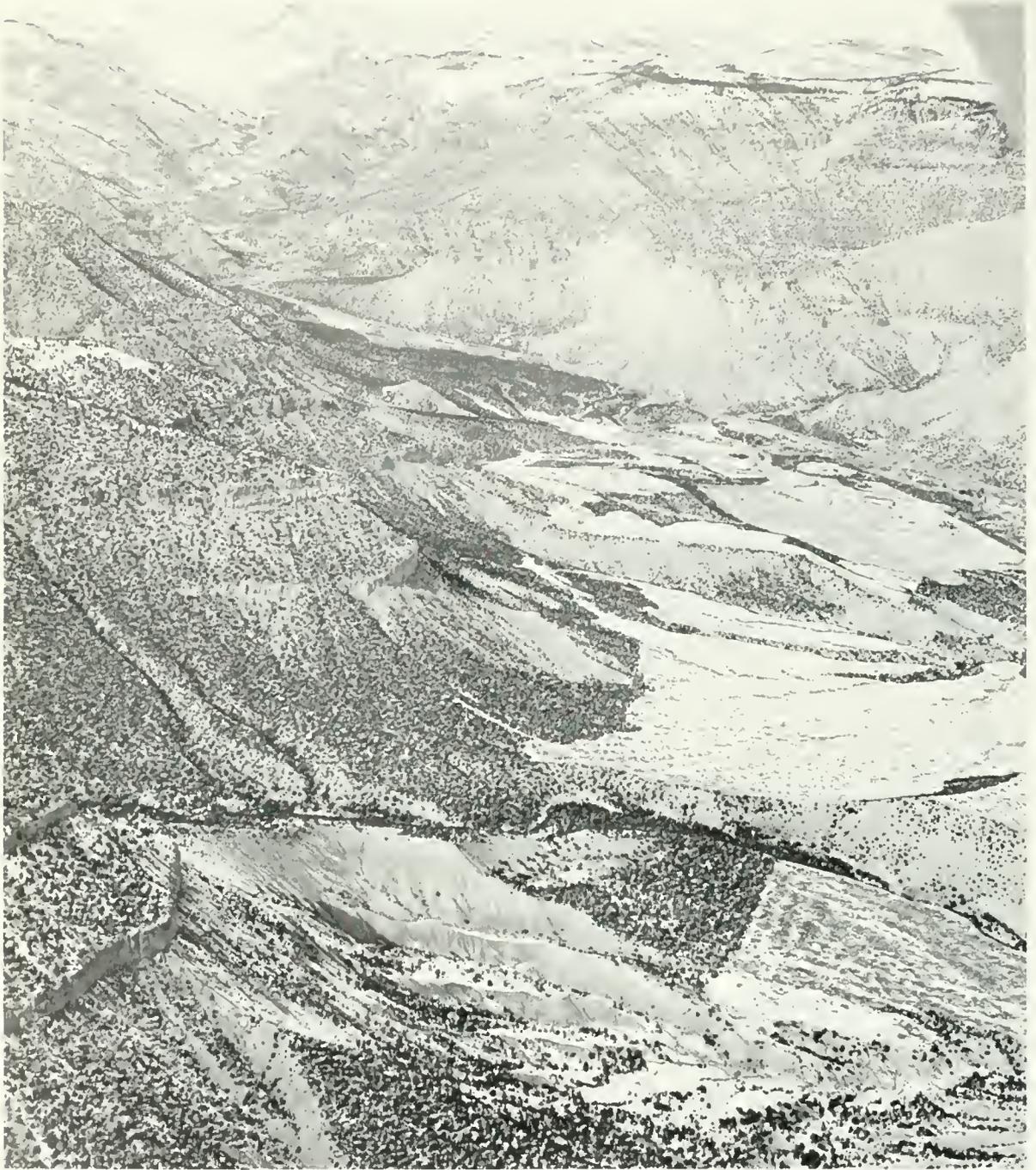


Fig. 2 Mouth of Huntington Canyon on the eastern edge of the Wasatch Plateau. The Utah Power and Light Company Generating Station is located at the right center. Photographed Feb. 7, 1972.

that a continuous supply of water will be available, a new reservoir, called Electric Lake, will be constructed on the right fork of Huntington Creek approximately 20 miles upstream from the generating station near the mouth of Bear Canyon, Emery County, Utah (Fig. 3). The reservoir will be approximately 4.5 miles long and 215 feet deep at the dam (Fig. 4). It will

store water from the spring runoff, which will be released as needed during the summer and fall months. A paved road will allow access to the reservoir, and public recreational facilities will be provided.

Initial impact of this project on the environment of Huntington Canyon will result from the following four factors: (1) the construction



Fig. 3. Locality of the dam for Electric Lake on the Right Fork of Huntington Creek below Bear Canyon. Photographed Nov. 16, 1970.



Fig. 4. Upper drainage of the Right Fork of Huntington Creek. Flat Canyon is at the lower right and James Canyon is at the left center. Photographed Nov. 16, 1970.

of the generating station itself, which necessitates extensive excavation and will infringe on the winter deer range; (2) the scarring of the mountainside during the construction of the dam and the relocation of approximately 15 miles of road through heavily forested regions; (3) the flooding of approximately 4.5 miles of

prime fishing stream on the right fork of Huntington Creek, which currently serves as spawning grounds for brown and cutthroat trout; and (4) the destruction of watersheds along the path of the power lines.

Other less obvious effects may occur, especially in the aquatic environment, which often

becomes a repository for chemical and physical pollutants entering via effluents, drainage from surrounding lands, and directly by rain and snow. The silt load in the creek is an important factor, especially during construction periods, causing abrasion and erosion which can be detrimental to the stream ecosystem. Also, the release of reservoir water into Huntington Creek may cause temporary or permanent temperature, chemical, and/or nutrient changes which will affect the ecological balance of the biota of the stream.

Because of the possible environmental effects of this project, the Center for Health and Environmental Studies at Brigham Young University, with primary funding from Utah Power and Light Company, undertook a comprehensive study of the aquatic environment of the Huntington Canyon region in September 1970. The initial goal of this study was to gather data on physical, chemical, and biological parameters, which may be used to determine future changes in this ecosystem.

Algae are important in such an environmental impact study inasmuch as they are extremely responsive to changes in the environment and thus indicate changes and fluctuations that may occur. For instance, Blum (1957) found a marked change in the benthic algal flora as pollution outfalls entered the Saline River, Michigan. Foerster and Corrin (1970) observed that the presence or absence of certain algae enable one to determine the condition of the water in which they are normally found. Palmer (1961) stated that a knowledge of the algal population of rivers both quantitatively and qualitatively is important if one is to assess their true value in

the ecosystem. Palmer (1961) further stated that ". . . it can be important to know the algal population of a river before any major change is made in the use of the stream. Also, we need to know the algal population of rivers throughout the year and not merely for the summer months."

This paper reports the initial algal studies of Huntington Creek. Future comparative studies will be made during and after construction and operation of the power plant-reservoir complex.

The initial goal of this study was to obtain an overall picture of the entire aquatic algal flora rather than one specific part. Therefore, sampling included water chemistry, quantitative analysis of phytoplankton and attached algae, and a floristic survey.

Plankton are interpreted in this study as all organisms found in the open water (Kofoid, 1908), and only chlorophyll-bearing phytoplankton (Welch, 1935) are considered in this paper. Phytoplankton are divided into net plankton (those forms large enough to be retained by a 67- $\mu$ m mesh plankton net) and nannoplankton (those forms which can pass through the net). Nannoplankton are of primary importance in this study, since diatoms, the dominant algae in most rivers (Ricc, 1938), are included in this group.

Sampling of the attached algae included both microscopic periphyton, defined by Young (1945) as that assemblage of microscopic organisms growing upon free surfaces of submerged objects in water, and the visible attached algae.

Floristic sampling was done to determine the composition and distribution of the algae of the canyon.

## REVIEW OF SELECTED ALGAL STUDIES IN UTAH

Aquatic research in Utah has not been extensive, although it has included several ecological and pollution studies. One significant contribution was made by Clark (1958), who studied the phytoplankton of the Logan River in the Bear River Range of the Wasatch Mountains. Clark's results were valuable for comparison with those of the present study, since the two streams are similar in size and certain other characteristics. A companion study to that conducted by Clark was completed by McConnell (1959), who estimated the algal productivity of the Logan River from chlorophyll extracts of the algae growing on the river bed.

Samuelson (1950) completed a study which illustrated man's influence on the algal floras in two mountain streams in the Wasatch Moun-

tain Range east of Salt Lake Valley, Utah. He observed that livestock grazing and recreation severely damaged the aquatic ecosystem in Emigration Canyon as compared to that of Red Butte Canyon.

Another pollution study (Quinn, 1958) demonstrated that organic wastes from the effluent of a sugar beet factory were detrimental to the algal flora of the Jordan River in Salt Lake County, Utah.

Currently, an algal floristic and ecological investigation is being conducted along the entire length of the Provo River (Lawson, pers. comm.). This study will establish the algal communities in the river and their responses to man's use of the drainage area.

More investigations have been conducted

on insects than on algae in Utah streams. These studies are valuable, since they often include information on the algae in the ecosystem being studied and give general information concerning biological responses to environmental stresses. One such study was conducted by Smith (1959), who included algal samples in his macroinvertebrate study of the Weber River in north central Utah. His results showed that siltation from watershed misuse, habitat destruction from dredging, and stream bottom exposure resulting from irrigation diversion were more destructive to the aquatic biota than organic pollution.

An earlier study by Dustans (1951) on the Provo River also discussed the effects of dredging on aquatic life. He mentioned reduced photosynthesis, loss of marginal vegetation, and the loss of diatoms, desmids, and filamentous algae as primary contributing causes to the reduction of insect benthos in dredged stream channels.

A pollution study was conducted in central Utah on the Price River (Miller, 1959). Although this river, like Huntington Creek, drains the Wasatch Plateau, it is of little value for comparison with the present study, since the extreme silt load in the Price River and organic pollution contributed by towns through which it passes severely restrict biological life. Miller found only rare and limited amounts of *Cladophora* sp. and *Chaetophora elegans* in the river and a noteworthy absence of aquatic vascular plants.

Work has also been done on the plankton

of ponds, reservoirs, and lakes of Utah. These studies include the following: Piranian's (1937) report on the plankton of the Bear River Migratory Waterfowl Refuge; Chatwin's (1956) study of the vertical distribution of phytoplankton in Deer Creek Reservoir, Wasatch County, Utah; Pratt's (1957) investigation of plankton periodicity in Salem Lake, Salem, Utah; and Longley's (1969) discussion of the phytoplankton associations in Flaming Gorge Reservoir. The information provided by these and similar studies is valuable in understanding stream environments and communities, since lentic environments normally exert a definite strong influence on the streams that drain them. Since several reservoirs presently occur on the Huntington Creek drainage, and a new one (Electric Lake) is under construction as of 1972, their management and algal populations need to be considered as factors affecting the physical and biological parameters of Huntington Creek itself.

Mention should also be made of some important taxonomic references concerning Utah algae. The most significant contribution in this regard was made by Dr. Seville Flowers who published mimeographed keys to the common algae of Utah (n.d., a) and to the blue green algae of Utah. (n.d., b). Flowers has also reported on the nonvascular plants of various regions of the state (1959, 1960). Two other taxonomic studies are those by Norrington (1925) and Coombs (1964) of the Wasatch and Uinta Mountains, and the Western Uinta Mountains, respectively.

## DESCRIPTION OF THE HUNTINGTON CANYON DRAINAGE

### Geology

Huntington Creek is one of many streams that drain the Wasatch Plateau of central Utah. This plateau is the northernmost of the plateaus of Utah and is situated in the central part of the state between 30 and 40 degrees north latitude and 111 and 112 degrees west longitude. It merges northward with the higher land of the Uinta Basin and is separated from the Fish Lake Plateau to the south by a 20-mile-wide erosional depression. The Wasatch Plateau, which rises to elevations of 11,000 feet above sea level and 5,000 to 6,000 feet above Castle Valley on the east and Sanpete Valley on the west (Spieker and Reeside, 1925), is essentially a tableland 90 miles long and 20 to 30 miles wide (Figs. 5-6). Strata in the plateau are mostly Late Cretaceous and Early Tertiary in age and lie flat or dip at moderate angles. Re-

sistant rocks alternate with those less resistant, giving cliff, bench, and slope profiles much like those of the Colorado Plateau (Spieker and Billings, 1940). Castle Valley on the east is of erosional origin. The western edge of this valley exhibits a sharp profile, since the eastern edge of the Wasatch Plateau drops abruptly through horizontal strata from one formation to another (Fig. 2). Sanpete and Sevier Valleys, west of the plateau, arose from down folding and faulting, with the western front of the plateau itself being a great monoclinical flexure. Other faults running through the plateau have created irregularities in stratigraphy, and erosion has carved canyon, cliffs, and gullies throughout the area (Dutton, 1880).

The eastern slopes of the Wasatch Plateau are dissected by deep, rocky gorges with fast-flowing streams similar to lower Huntington

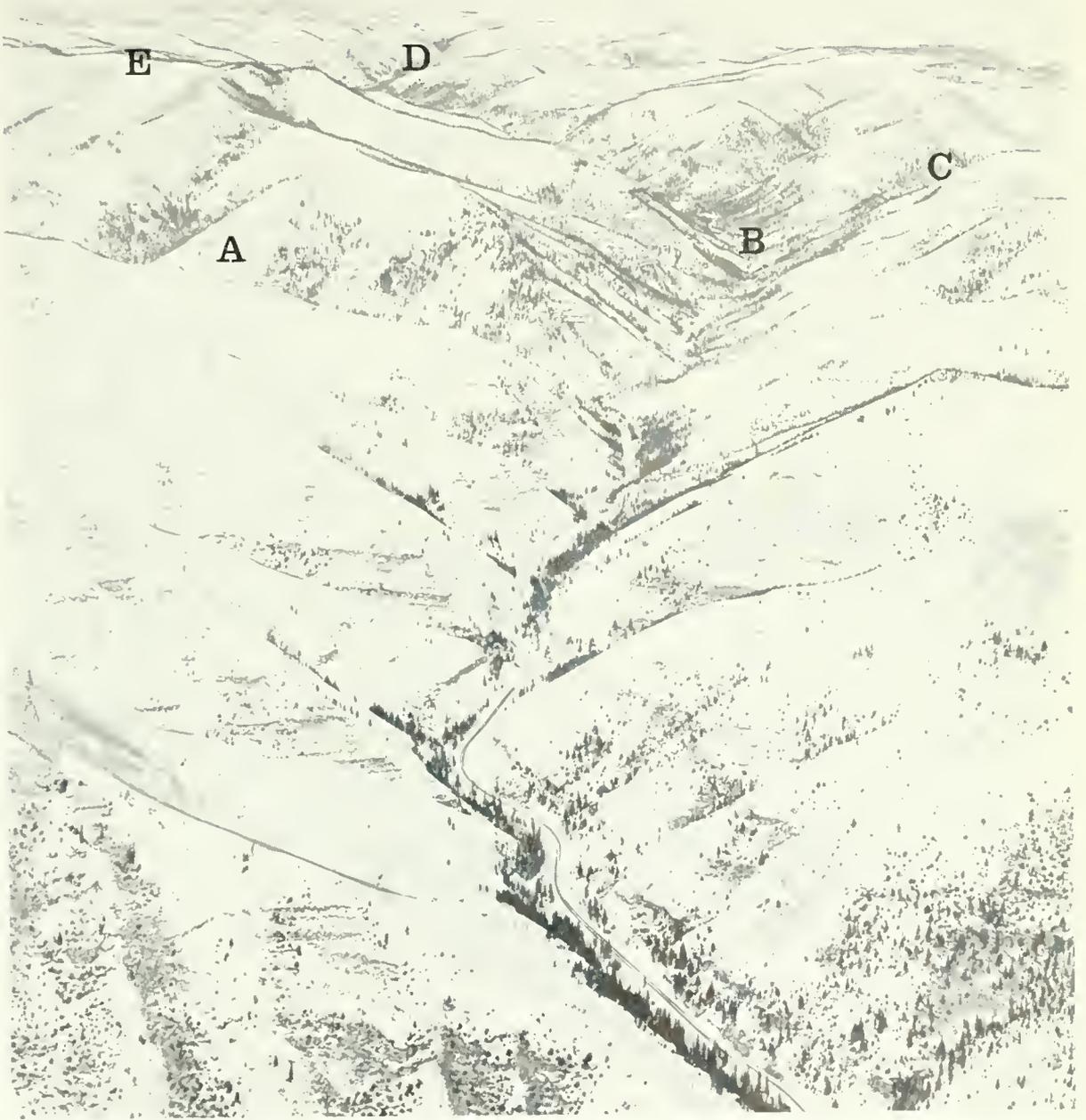


Fig. 5. North central portion of the Wasatch Plateau showing the Huntington Creek drainage. Left Fork of Huntington Creek is at A, Right Fork of Huntington Creek is at B, Nuck Woodward Canyon is at C, North Hughes Canyon is at D and Candland Mountain is at E. Photographed Feb. 7, 1972.

Creek. The eastern face of the plateau consists of sharp cliffs of Starpoint sandstone and rough erosion of the uppermost layers of Mancos shale. From the mouth of Huntington Canyon, Castle Valley extends eastward toward the San Rafael River (Fig. 7), which collects the waters of Huntington Creek and other drainage waters

of the eastern slopes of the plateau. The San Rafael River drains into the Green River, which in turn feeds the Colorado River. Streams of the western slope of the Wasatch Plateau drain into the San Pitch and Sevier rivers.

Spieker and Billings (1940) described the stratigraphy and thickness of each formation



Fig. 6. Eastern edge of the Wasatch Plateau and Lower Huntington Canyon looking eastward toward the San Rafael Swell. The Left Fork of Huntington Creek is at the lower right, the right fork is at the lower left and Tie Fork Canyon is at A. Photographed Feb. 7, 1972.

of the Huntington Canyon section of the Wasatch Plateau as follows:

Paleocene

Flagstaff limestone. Gray, tan, white limestone, with minor amounts of shale and sandstone; lacustrine ..... 300-500'

Upper Cretaceous and Paleocene

North Horn formation. Buff, gray, red sandstone, gray to variegated shale, conglomerate, some limestone; flood-plain and lacustrine in origin ..... 2000'

Upper Cretaceous

Price River formation.  
Upper member: Gray sandstone and conglomerate with minor amounts of shale ..... 600'+

Castlegate sandstone member: Massive, cliff-forming gray sandstone, coarse grained to conglomeratic ..... 300'

Blackhawk formation. Medium-to-fine-grained buff and gray sandstone, gray shale, coal ..... 1500'

Starpoint sandstone. Massive, cliff-forming buff sandstone, medium-to-fine grained; marine ..... 450'

Mancos shale. Gray marine shale (only uppermost part exposed in area described) ..... 4000'+

The upper portion of the Huntington Creek drainage (Fig. 8) is mostly North Horn sandstone and shale with glaciated cirques, moraines, and widened valleys with outwash deposits of



Fig. 7. Mouth of Huntington Canyon looking across Castle Valley toward the San Rafael Swell. Photographed Feb. 7, 1972.

Pleistocene age (Spieker and Billings, 1940). Most cirques occur in Joe's Valley Graben, a vertically displaced fault block in the central part of the plateau. This graben averages 2.5 miles wide and extends south for 60 miles from the north central part of the plateau (Spieker and Billings, 1940). Most glaciers issued eastward from the western edge of the plateau into the graben valley, often coalescing to form large sheetlike moraines. Stream notches in many of these moraines have been dammed in recent years to form storage reservoirs, such as Cleveland and Huntington reservoirs.

The left fork of Huntington Creek drains the northern part of this graben and the slopes that rise from it. The headwaters gather from Spring,

Lake, Rolfson, and Staker canyons, flow across the graben valley, and descend through a rocky gorge approximately 3,000 feet deep (Spieker and Billings, 1940).

The headwaters of the right fork of Huntington Creek arise north of the termination of Joe's Valley Graben, which ends at Cleveland Reservoir. The right fork originates in narrow rocky canyons in the Price River sandstone but flows early into Blackhawk sediments where the stream channel widens into a broad U-shaped valley (Fig. 9). This valley remains prominent to Bear Canyon, where it narrows again to a V-shaped mountain gorge (Fig. 10). This flat-bottomed valley was created by lateral erosive cutting by glaciers in this canyon.

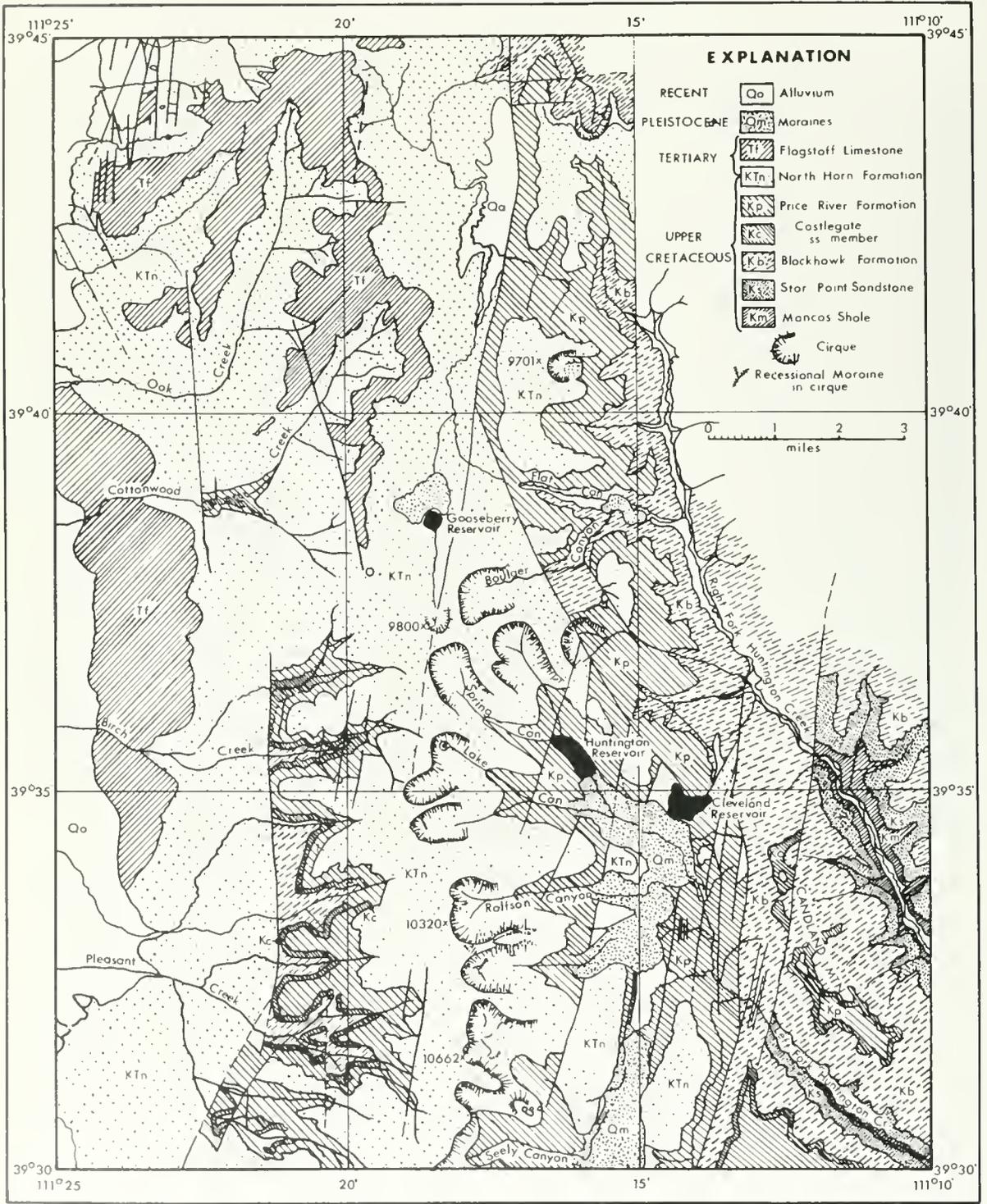


Fig. 8. Geologic map of part of the Wasatch Plateau, Utah (after Spieker and Billings, 1940).

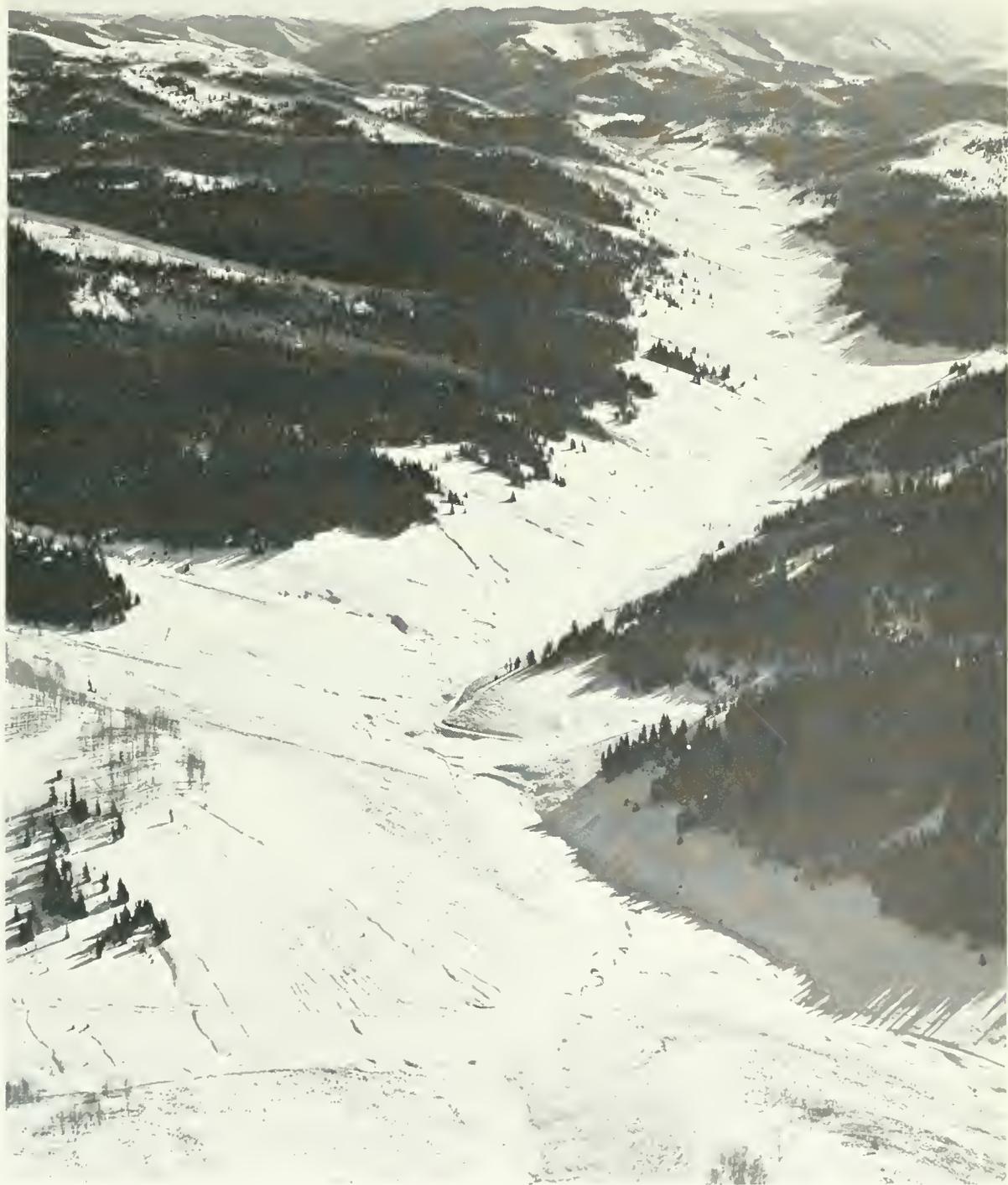


Fig. 9. Glacier cut U-shaped valley in the upper drainage of the Right Fork of Huntington Creek. Northern end of Joe's Valley Graben is at the upper right. Photographed Nov. 19, 1970.



Fig. 10. Deep gorges of Huntington Canyon. Pole Canyon (A), Left Fork (B), Horse Creek Canyon (C), Tie Fork Canyon (D). Photographed Feb. 7, 1972.

#### Climate and Vegetation Zones

The upper part of the drainage of Huntington Creek exists under semihumid montane conditions, with 30 to 40 inches of precipitation annually (Draft of Environmental Statement, 1971). A large snowpack accumulates in this region in the winter, creating a high spring runoff supplying ground water which feeds local springs throughout the year. Aspen-snowberry (*Populus tremuloides*-*Symphoricarpos vac-cinoides*) associations are scattered throughout this upper drainage with populations of sub-alpine spruce (*Picea engelmannii*) on the north-  
 other slopes and in the open valleys (Figs. 11-

12). Wet meadows and willows are common along gently flowing streams and in pockets formed from Pleistocene glaciation.

Lower Huntington Canyon exhibits a semi-arid climate with approximately 12 inches of precipitation annually. Pinyon-juniper (*Pinus monophylla*-*Juniperus osteosperma*) and sage (*Artemisia tridentata*) communities are the dominant vegetation types here, with cottonwoods (*Populus angustifolia*) often lining the streams in the canyon bottoms (Fig. 2).

ern slopes and sagebrush-grass communities on  
 Castle Valley is flat and arid with a few scattered small towns. It provides some pasture



Fig. 11. North Hughes Canyon looking northeast from the Right Fork of Huntington Creek toward the Book Cliffs (in the background) showing spruce-aspen forest cover. Photographed Nov. 16, 1970.



Fig. 12. Right Fork of Huntington Creek at James Canyon. Photographed Nov. 16, 1970.

land and crop land for alfalfa, corn, and other grains, utilizing irrigation water supplied from streams draining the eastern slopes of the Wasatch Plateau. Much of the lower slopes of the eastern face of the Wasatch Plateau and the Castle Valley floor are composed of Mancos shale deposits. Since these rocks are rich in carbonates and other easily dissolved mineral salts, the streams passing through them are greatly influenced and become less desirable for agricultural uses. Because of this, much of the irrigation water used in Castle Valley is obtained via canals from storage reservoirs and streams further up the canyon where the water is of higher quality.

### Description and Uses of Huntington Creek

The present study is mainly concerned with the right fork of Huntington Creek and its main course below the junction of the two forks, since these will be influenced directly by the Utah Power and Light Company project. As mentioned, the upper reaches of the right fork are gentle and smooth flowing, becoming torrential upon descent through deep canyon gorges. From the headwaters of the right fork until it joins the San Rafael River, Huntington Creek is approximately 50 miles long and drains approximately 320 square miles. The length of the creek sampled during this study extended from the mouth of Bear Canyon downstream approximately 35 miles to the town of Lawrence on the western edge of the San Rafael Swell.

The Huntington-Fairview Forest Highway follows Huntington Creek and its right fork rather closely and is paved from its junction with Utah Highway 10 at Huntington to two miles above the junction of the right and left forks. Plans for the future in this area include an all-weather road across the summit, linking Huntington and Fairview (Draft of Environmental Statement, 1971). Many campgrounds and picnic areas presently occur along the creek, and these facilities are well used, especially on summer and fall weekends. The stream and neighboring reservoirs are stocked and managed by the Utah State Division of Wildlife Resources and provide some of the best fishing in eastern Utah. The upper reaches of the right fork provide excellent spawning grounds for German brown and cutthroat trout, and the natural channel of the creek provides good habitat for aquatic insects, which contribute to a productive environment for fish. The upper valleys are also used for summer grazing of cattle and sheep.

Cleveland, Miller's Flat, Rolfson, and Hun-

tington Reservoirs on the left fork of Huntington Creek are maintained and managed by the Huntington-Cleveland Irrigation Company to supply water to the communities and farms of Castle Valley. These reservoirs achieve some control of the spring runoff and allow a constant flow to Castle Valley through the summer and fall dry period. Most of the water released by these reservoirs, as well as water from Huntington Creek proper, is diverted from the creek into a canal by a diversion dam located four miles northwest of Huntington. This canal empties into North Huntington Reservoir northeast of the town of Huntington. The water stored there is used for agricultural purposes in Castle Valley. Below this diversion dam the stream flow is greatly reduced but increases slightly as it gathers drainage waters from the surrounding land and springs along its course. The water in this lower portion of Huntington Creek is greatly affected by this drainage water and is generally of low quality.

Water discharge in Huntington Creek fluctuates greatly with the seasons. Discharge measurements have been made at two localities along the creek. Utah Power and Light Company took readings at the site for Electric Lake on the right fork just below the mouth of Bear Canyon. The U.S. Geological Survey took readings at Station 9-318, located seven miles northwest from the town of Huntington and one mile upstream from Fish Creek. The average yearly flow for the Electric Lake locality was 30.3 cubic feet per second for the period 1968 to 1971. The average monthly mean reached a high over this same time period of 159.7 cfs at spring flood in May and a low of 7.8 cfs in January. Water flow near the mouth of the canyon (U.S.G.S. Station 9-318) showed a yearly average of 100 cfs for the years 1966 to 1971, with the monthly mean being high in May at 309 cfs and low in January and February at 27 cfs. The six-year high was in May 1969, when the discharge was 552 cfs. The six-year low was in February 1966, when the water level dropped to 18 cfs.

Observations of the creek throughout the 1971-72 study period supported the water flow data. Heavy spring runoff began in early April 1971, and reached a peak during May and early June. A significant drop in water flow was noted on June 29, 1971, followed by a gradual decline during the summer and fall to winter lows in January and February 1972. The summer decline in the main creek was less severe than that of the right fork because the natural drainage of the main fork was supplemented with

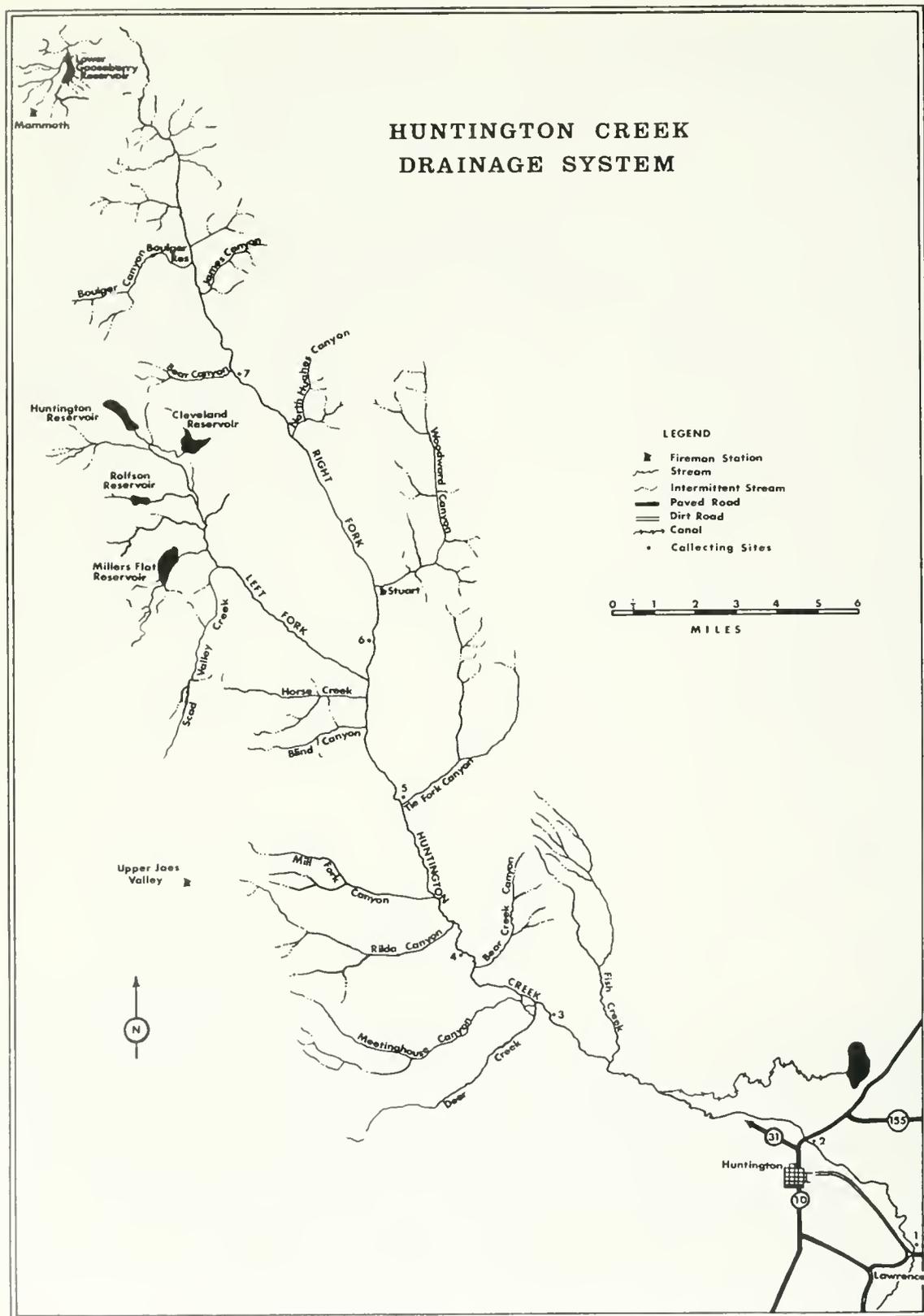


Fig. 13. Index map of Huntington Canyon drainage.

water from the reservoirs on the left fork. The river was completely frozen by December 1971,

but an early thaw opened a major part of the creek channel in February 1972.

## DESCRIPTION OF SAMPLING SITES

Sampling sites were chosen to represent a variety of different ecological niches along the drainage. Seven sites were established for quantitative study, which were numbered beginning downstream at Lawrence and proceeding up Huntington Canyon to the mouth of Bear Canyon (Fig. 13). This was also the general order followed during sampling.

### Lawrence (Site 1)

This site is located on Huntington Creek 4.7 miles southeast of Huntington, Emery County, Utah, and 1.5 miles east of Lawrence, Emery County, Utah. It is approximately nine miles below the main diversion dam on Huntington Creek and was established to monitor effects of agricultural drainage and increased dissolved minerals on the algal flora. The actual sampling site was located in a pasture through which the creek meandered near the intersection of Huntington Creek and a road leading to the San Rafael Swell (Fig. 14). The average width of the creek at this locality was 22 feet during the spring flood and 15 feet during low water periods. Average water depths during the same periods were 22 and 13 inches, respectively. This site included slow-flowing deep water and

swifter-flowing shallow riffles, providing varied algal habitats. A sharp, eroded bank characterized the west side of the stream, whereas the east bank sloped gradually into a pasture. *Populus angustifolia*, *Tamarix pentandra*, *Chrysothamnus nauseosus*, and *Artemesia tridentata* occurred along the banks throughout this area. The stream bed here consisted mostly of silt and sand, with small stones in the riffles, and the water was generally of low quality. In talking with the rancher who owns the land at this locality, he mentioned that over the last few years his cattle will no longer drink the water from the creek unless they have no other source. This is probably due to the diversion of the better quality water upstream, and perhaps to the addition of organic pollutants by Huntington City.

### Highway 10 Bridge (Site 2)

This site is located four miles upstream from Lawrence and is 0.3 mile northeast of Huntington on Utah Highway 10 at the crossing of the creek by the road. Sampling at this site included water chemistry, visible attached algae, and floristics. It was established to augment the data collected at site 1 and was similar to it in most respects. The bottom was silty in the slow areas and rocky in the faster water. The average width was 35 feet in the spring and 16 feet in the summer and winter, and the average depth was 12 to 18 inches and 5 to 7 inches, respectively, during the same periods. Streamside vegetation was similar to that of site 1 except that a large grove of cottonwoods created some shading effect at this site.

### Plant Site (Site 3)

This site is located approximately three miles above the North Huntington Reservoir diversion dam about three-fourths of a mile downstream from the Utah Power and Light generating station, at an altitude of 6,300 feet above sea level. It is approximately 0.3 mile below the entry of Deer Creek, which drains the mountains west of the generating station (Fig. 15). The river at this location was basically deep and fast flowing, although some swift riffles were present. The average depth of the creek at this site was three feet during the spring flood when it was 25 or more feet wide. In the low flow period,



Fig 14. Huntington Creek 4.7 miles southeast of Huntington, Utah. Locality of collecting site 1. Photographed April 28, 1972.

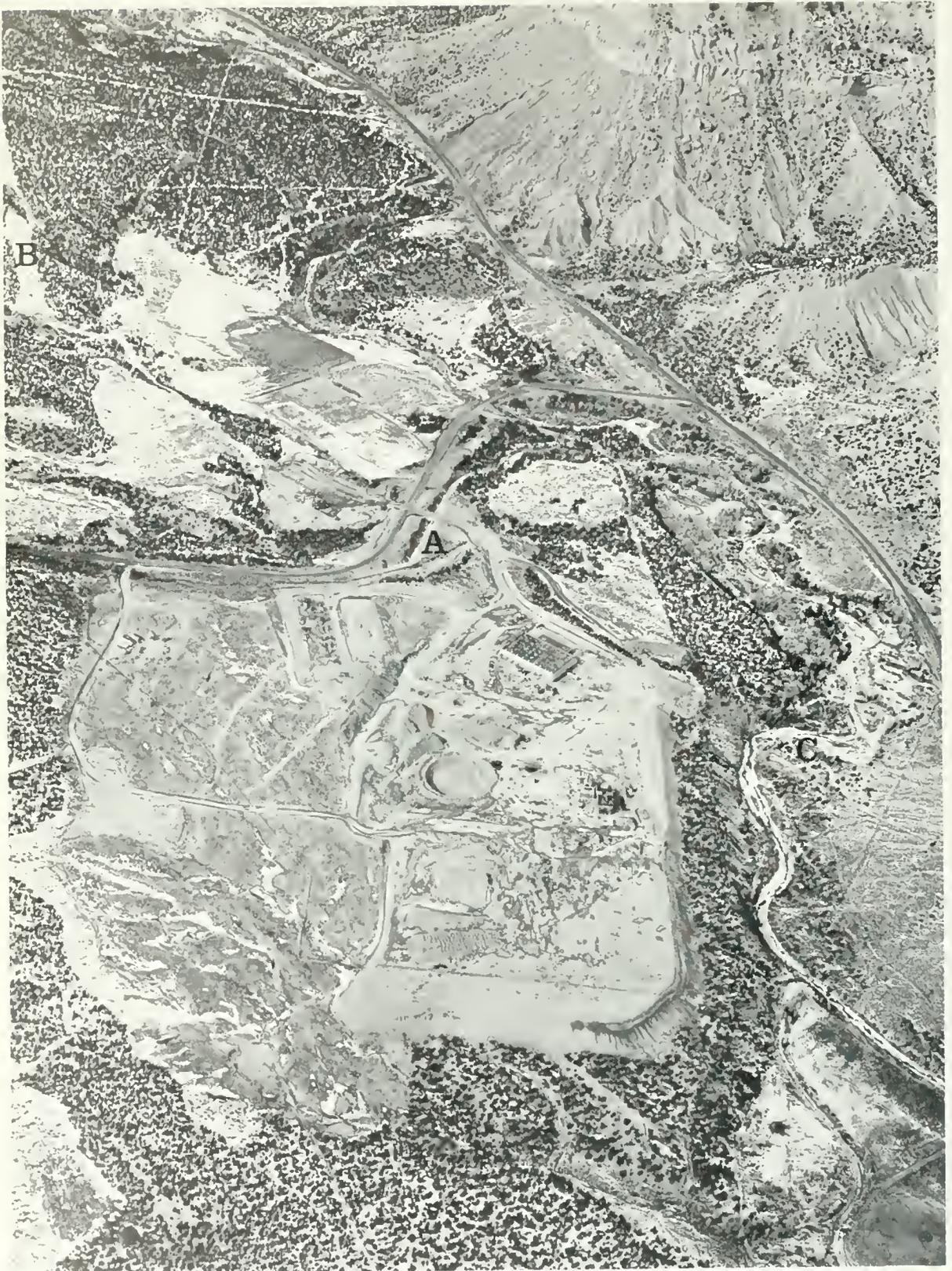


Fig. 15. Utah Power and Light Company Generating Station. Deer Creek (A), transmission lines (B), collecting site 3 (C). Photographed Feb. 7, 1972.

it was usually less than 1.5 feet deep and about 20 feet wide. The bottom was strewn with large and small stones, and many large boulders protruded from the water. This site often showed siltation resulting from construction, and pollution from Deer Creek, which carried coal dust and other pollutants originating from mines above the generating station. The water here was often turbid with suspended sediments, and the bottom generally showed coal dust deposits. Terrain surrounding this site included steep banks on the west side of the stream with a more gentle incline on the east. Terrestrial vegetation here was dominated by *Pinus monophylla*, *Juniperus osteospermum*, *Artemisia tridentata*,

with *Populus angustifolia* abundant along the stream channel. This site was established to monitor the effects of construction and operation of the generating station on the algal flora of the creek.

#### Bear-Rilda Campground (Site 4)

This site is located approximately two miles above the generating station between Bear Creek and Rilda Canyons at an elevation of 6,600 feet above sea level (Fig. 16).

The creek at this campground was characterized by a deep-flowing channel, a shallow riffle, and a deep pool, thus providing a variety of

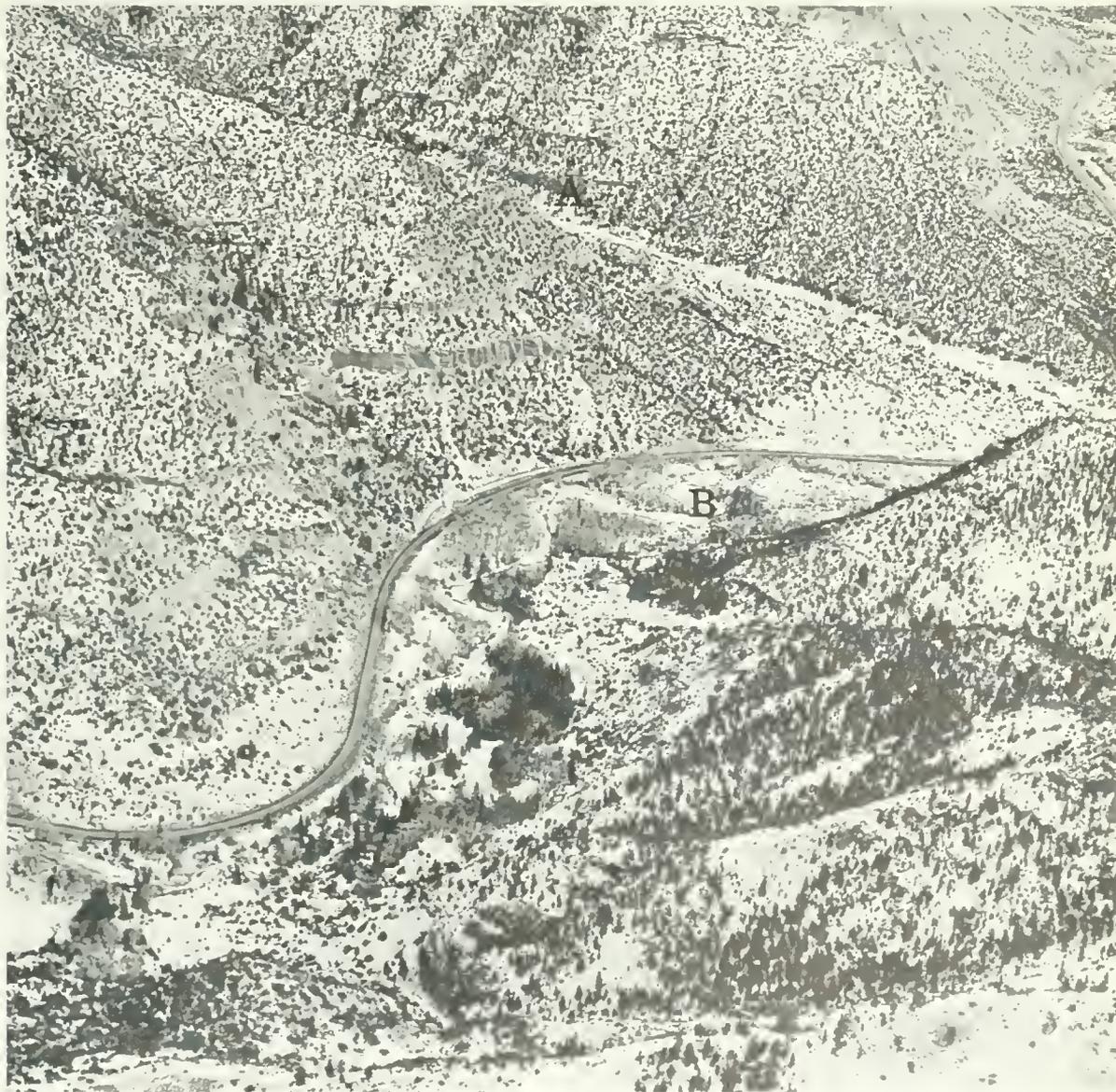


Fig. 16. Huntington Canyon above Bear Creek Canyon (A) showing collecting site 4 (B). Photographed Feb. 7, 1972.

habitats. The stream here was bordered by a broad flood plain and averaged about 2 feet deep and 55 feet wide at spring flood. During low water the riffle area became exposed when the current was limited to a narrow channel. The average width during this period was 11 feet and the depth 1 foot. The pool at this site collected sediment and exhibited a deep accumulation of silt. The bottom over much of the rest of the stream, especially in the riffle, was covered with small stones. Willows (*Salix* sp.) and cottonwoods (*Populus angustifolia*) were abundant on the banks, and a large thicket of Russian Olive (*Eleagnus angustifolia*) was present (Fig. 17). Leaves from these trees contributed to the detritus in the stream during the fall months, and the trees were responsible for some shading throughout the year, particularly in the spring and summer.

#### Tie Fork Pond (Site 5)

This site is a small shallow pond located at the mouth of Tie Fork Canyon at 7,300 feet elevation, six miles upstream from the generating station (Fig. 18). This pond is fed by drainage and seepage from the surrounding hillsides and in turn drains into Huntington Creek via a culvert. This site was established to provide information concerning the composition and seasonal fluctuations of algal populations characteristic of some of the ponds and backwaters occurring along the creek drainage. Heavy growths of *Potomogeten*, *Chara*, and filamentous algae dominated the vegetation in this pond during the summer



Fig. 18. Tie Fork Pond just west of the mouth of Tie Fork Canyon. Photographed April 28, 1972.

months, and a thick accumulation of organic mud from decomposition lined its bottom. The water level here was high in the spring, became quite low during the summer, and rose again in the fall. It was completely frozen from November 1971 to March 1972.

#### Stuart Fire Station (Site 6)

This site is located on the right fork of Huntington Creek 1.5 miles below Stuart Fire Station at an elevation of 7,700 feet (Fig. 19). The creek meandered through this portion of the canyon and was less turbulent than downstream (Fig. 20). The site included a riffle with small stones and a deep-flowing channel with larger rocks providing good habitat for the attachment of visible benthic algae and diatoms. The right fork at this site averaged 25 to 30 feet in width and about 1 foot in depth throughout most of the year. A steep mountain slope covered with sage, grasses, and spruce rose from the southwest bank, whereas the northeast bank was lined with willows and gently rose a few feet to the canyon floor. This was the highest elevation in the canyon that could be reached during winter months.

#### Bear Canyon (Site 7)

This site is located on the right fork near the mouth of Bear Canyon at the present junction of the Huntington-Fairview Forest Highway with the Miller's Flat road (Fig. 21). The elevation here is 8,400 feet. This portion of the



Fig. 17. Huntington Creek at collecting site 4. Photographed Feb. 7, 1972.

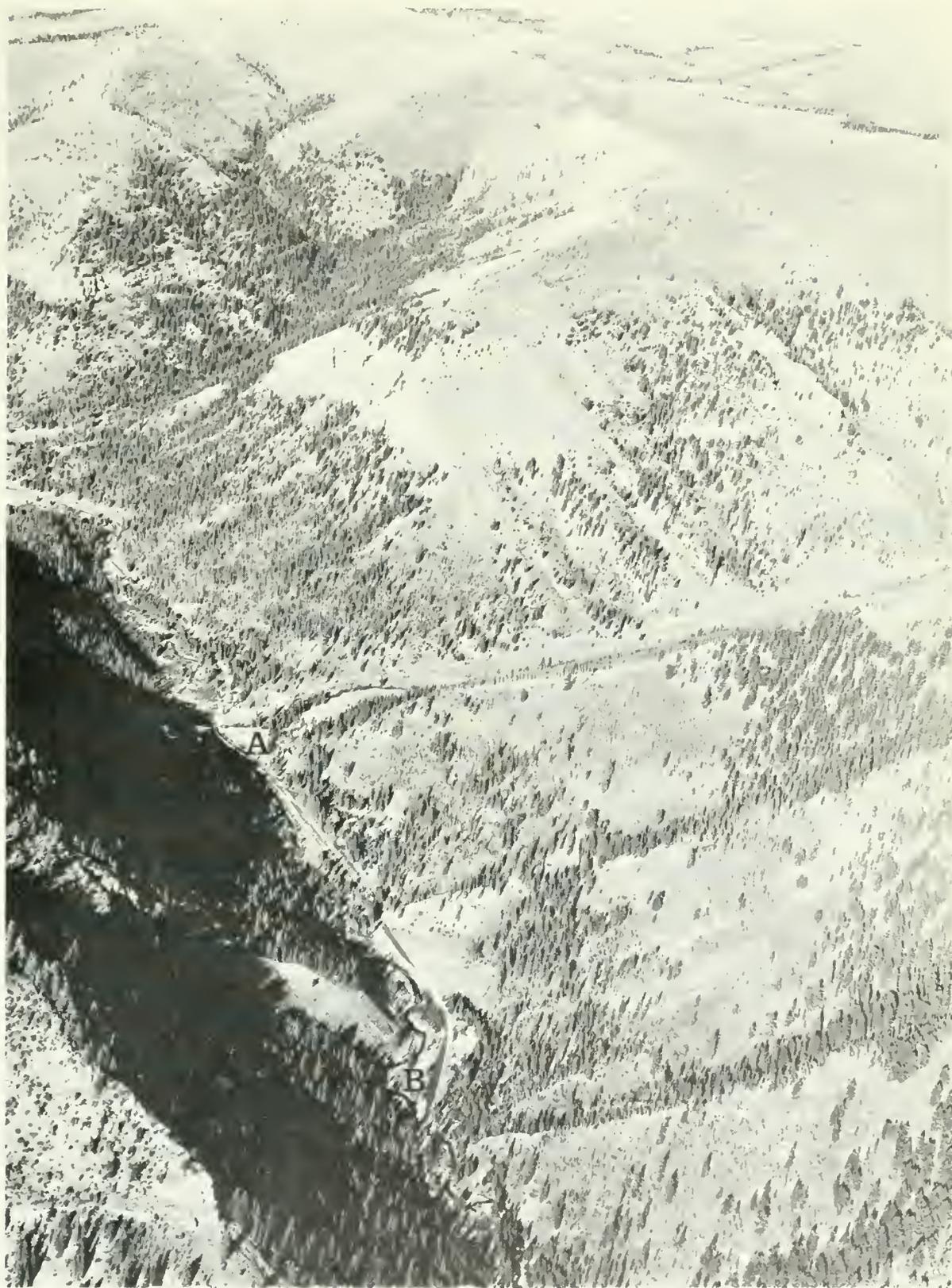


Fig. 19. Right Fork of Huntington Creek. Nuck Woodward Canyon is at the right center of the photograph, Stuart Fire Station is at A and collecting locality 6 is at B. Photographed Nov. 16, 1970.

creek averaged 20 feet wide and less than 2 feet deep throughout the study. The bottom was sandy in slow areas and covered with small stones in the riffles. A clay shelf along part of the channel supported growths of benthic Chlorophyta during much of the growing season. Stream banks at this site were vertical and undercut, rising approximately 10 feet above the stream channel. The creek valley here is wide

with grass-covered low hills rising gently to the mountains. This site is located at the transition zone between the broad U-shaped valleys of the upper drainage and the deep gorges of the lower canyons. It was added to the previous six sites in June 1971 to sample the flora of the upper drainage and for comparison with site 6. From December to June, this site was inaccessible due to snow pack.

## METHODS

### Physical and Chemical Measurements

Physical and chemical sampling was initiated on June 8, 1971, at sites 1, 3, 4, 5, and 6; and sites 2 and 7 on August 20, 1971. Measurements were taken during each collecting trip until the study was terminated in March 1972. However, site 7 became inaccessible after November 1971; and site 5 was frozen from November to March of the study period.

*Temperature.* Water temperature was recorded at each sampling station in degrees centigrade.

*Turbidity.* Turbidity was measured using the colorimeter in a Hach model DR-EL portable water engineer's laboratory. Turbidity was expressed in Jackson turbidity units (JTU) as a measure of the intensity of light scattered by particles suspended in the water.

*Water Chemistry.* The pH was tested using a Sargent-Welch pH meter. All other chemical

tests were run following standard methods (Amer. Public Health Assoc., 1971) using a Hach Model DR-EL portable water engineer's laboratory. Tests were run for the levels of dissolved oxygen, carbon dioxide, nitrate, ortho and meta phosphate, silica, calcium and magnesium hardness, alkalinity, and sulfate.

The amount of oxygen dissolved in the water was tested in the field, since biochemical and chemical oxygen demand can alter the dissolved oxygen content of a stored sample. All other tests were completed in the laboratory upon returning from the field.

### Phytoplankton

Phytoplankton studies were divided into net plankton and nanoplankton. Traditionally this division is determined by the ability of nanoplankton to pass through the meshes of bolting cloth No. 25, which has meshes measuring 0.04 to 0.05-mm square (Ward and Whipple, 1918). This classification will be altered here so that nanoplankton will include all diatoms regardless of size, and other algal forms too small to be adequately sampled with a 0.067-mm mesh plankton net.

*Net Plankton.* Net plankton were collected by filtering 40 liters of water through a 67- $\mu$ m mesh plankton net. The 40-liter sample was collected by scooping an 8-liter bucket of river water from five randomly chosen sections at each sampling site. The concentrated sample was collected in a 30-ml vial attached to the net. Care was taken to wash the net with filtered water to remove any organisms that might cling to it. The vials were transported to the laboratory where net plankton were examined and enumerated. Since it was possible to count net plankton soon after returning to the laboratory, preservatives were not used on these algae.

The 40-liter quantitative sample (Clark, 1958) is similar to the plankton pump method described by Ward and Whipple (1918). This method is superior to plankton net tows used



Fig. 20. View down the Right Fork of Huntington Creek from collecting site 6. Photographed April 28, 1972



Fig. 21. Right Fork of Huntington Canyon at junction with Bear Canyon (A). Collecting site 7 is at B, the dam of Electric Lake is at C and North Hughes Canyon is at D. Photographed Nov. 16, 1970.

by Kofoid (1908), Allen (1920), and others, since a known volume of water is filtered and the chance of error from an uncertain amount of water passing through the plankton net is eliminated.

Enumeration of net plankton was done using a Sedgwick-Rafter counting cell. This counting cell is commonly used for plankton studies (Kofoid, 1908; Allen, 1920), and many different counting procedures have been adapted to it. The counting method used for this study was adapted from Weber (1970). After thoroughly mixing the 30-ml vial of concentrated river water, a 1-ml aliquot was pipetted into the Sedgwick-Rafter cell. The sample was counted at 100 magnifications under the microscope. An ocular micrometer was used to measure a width of 1 mm on the slide, and two or more longitudinal transects across the slide were made. Algae encountered during these transects were identified, and the number of occurrences of each genus or species was recorded. From the total, an average number of organisms per single 50-mm transect was calculated, and from this, the number of organisms per liter of river water was determined.

Occasionally, it was necessary to modify these procedures slightly. During the summer months the density of net plankton at site 5 (Tie Fork Pond) required dilution of the 30-ml concentrate. In September and October the sample size at Tie Fork Pond was reduced from 40 liters to 24 liters in order to reduce algal density in the sample. Because of low frequency and low total number of organisms, samples taken during the winter months were concentrated by centrifugation to 5 or 10 ml to increase sensitivity during counting.

*Nannoplankton.* Nannoplankton were collected by obtaining 1 liter of river water from each of four randomly chosen sections at each site. This sample was placed in a gallon container and returned to the laboratory. Two liters of this sample were then suction filtered through a membrane filter with a pore size of 1.2- $\mu$ m. This filtering process removed all phytoplankton and much extraneous suspended matter from the water. The filters were cleaned using distilled water, and the resulting suspension centrifuged. The excess water was carefully decanted, and the pellet was resuspended in 5 ml of standard formalin-alcohol-acetic acid (FAA) to preserve it or in 5 ml of distilled water, if counting was done immediately.

Nannoplankton were counted using a Palmer nannoplankton counting slide (Palmer and Maloney, 1954). This slide is designed for use with high power dry microscope objectives and

allows for higher magnification and resolution necessary to identify and count nannoplankton genera. All nannoplankton observations and counts were made at 400x. An ocular micrometer was used to measure a 0.25-mm width on the Palmer slide, and the algae encountered in four transects of this width were counted across the diameter of the slide. From the four counts, an average count per transect was then computed. In most cases a new aliquot was used for each count, and the samples were always thoroughly mixed before the aliquot was taken to maximize the chances for uniform distribution of the suspended organisms.

Furthermore, averaging the number of algae encountered in four transects increased the probability of obtaining an accurate representation of algae actually found in the river and reduced abnormal values due to clumping. The number of algae encountered in each transect was tallied separately as a check on the precision of the counts, and, in most cases, relatively little variation occurred between the four counts.

As mentioned previously, all diatoms were included in these nannoplankton investigations, as well as algal forms too small to be adequately retained in the plankton net. Since the original sample was taken directly from the river, net plankton forms were encountered during nannoplankton enumeration. These were not included in the nannoplankton computations, although they did provide a check on net plankton studies.

Turbidity was a noteworthy problem during nannoplankton investigations since most suspended particles were retained by the filters. Silt and sand particles, which were especially prevalent during the spring runoff, often obscured the algal specimens and made it necessary to dilute samples to 10 ml, 15 ml, or 20 ml. In rare cases, higher dilutions were necessary.

Permanent diatom slides were made from the nannoplankton samples from September 1971 to March 1972 so that a permanent record of the plankton flora would be available. Methods have been described by Weber (1970) and Patrick et al. (1954) to count diatoms and characterize diatom floras from prepared slides. Such studies may be undertaken at a future date, and the slides are also valuable to compare with future collections. All diatoms were mounted in Pleurax (Hanna, 1949). This mounting medium has a very high index of refraction (1.770) and greatly facilitates resolution.

### Periphyton

Sampling of the periphyton community has received the attention of many workers in recent

years, and many variations in sampling methods have been attempted. Sládečková (1962) summarized techniques and materials developed in periphyton work. Recent trends have been to submerge artificial substrates at study sites to obtain both a qualitative and quantitative concept of periphyton communities from studying the algae that become attached to these substrates. Materials such as wood, slate, concrete, asbestos, asbestos cement, various sheet metals, plastics, celluloid, styrofoam, and glass have been used. However, smooth glass is most widely used and has given accurate results. Patrick et al. (1954) found that by using glass slides for sampling periphyton they were able to sample 75% to 85% of all species obtained by other collections, and 95% of those species with more than eight individuals per sample. Dor (1970) compared glass slides with basalt and limestone substrates in Lake Tiberia in Israel and found that production on slides was 73% of that produced on natural substrates. Odum (1957) found that succession of algae on glass slides was similar to that on *Sagittaria* plants. In general, Whitford and Schumacher (1963) found that colonization on glass slides was similar to that of rock substrates, although it was somewhat different from colonization observed on living plants.

Under certain conditions, glass may be surpassed by styrofoam as a colonization substrate for periphyton, especially diatoms. Hohn and Hellerman (1963) found that at 16° and 25°C, both substrates gave representative colonies; but at 3°C, diatom species diversity on the glass was reduced as much as 40% while the styrofoam continued to support a representative flora. However, Dillard (1966) reported glass to have higher diatom populations at both high and low temperatures.

The means of attaching slides to the substrate has also resulted in the development of many devices. Butcher (1932), who did a pioneer river study using glass slides to sample periphyton, used a frame attached to the river bed to support his slides. Patrick et al. (1954) developed a special apparatus for holding slides in the water which they called the Catherwood diatometer. This apparatus consists of a plastic rack with attached floats so that it can be suspended at desired depths in the water. Slides are placed vertically in the rack, which allows diatoms to colonize the slides and concurrently reduces silt deposition. Weber and Raschke (1970) described a similar apparatus with styrofoam floats as a standard periphyton sampler for pollution surveillance. In Huntington Creek the current is extremely swift during runoff

and quite low in the summer and fall. In addition, the stream and canyon are heavily used by campers, picnickers, and fishermen; and a periphyton sampling device such as described above is impractical.

Consideration has also been given to the length of time the slides should be left in the water. Patrick et al. (1954) found two weeks to be optimum, since by that time diatom diversity had been established and longer periods had been allowed for excessive silt and debris deposition. Newcombe (1949), on the other hand, suggested 25 days to be the optimum time period. Patrick et al. (1954) found that the accumulation of debris and other organisms on the slides over a long time period made them less favorable for diatom growth, and the more adapted species actually crowded others out. However, a longer time period allows dominant species to become well established on the slides, and this may actually be an advantage in aiding an understanding of relationships between periphyton and the periphyton-influenced plankton assemblages.

Newcombe (1949) discussed the advantages of vertical placement of the slides versus horizontal placement, claiming the latter to be best since production was higher and the results were more reproducible. However, Hohn and Hellerman (1963) reported no appreciable difference due to slide placement, and since silt accumulation on horizontal slides presents a problem, vertical placement is often used. Periphyton slides in the present study were oriented both horizontally and vertically, and no appreciable difference in silt accumulation or diatom populations was observed.

Periphyton sampling techniques used in the present study were similar to those used by Whitford and Schumacher (1963). Clean 1" x 3" microscope slides were fastened to a length of copper or stainless steel wire by means of electrician's tape. The slides were then secured in the river by fastening the wire to submerged sticks, large stones, or other convenient objects. Generally, the slides were allowed to drift freely in the current. Four slides were placed in the water at each site monthly and retrieved the following month. Both sides of the slides were cleaned with distilled water in the laboratory, and the attached algae were preserved in 10 ml of FFA until counting could be done. Samples were counted using a Palmer counting slide, and procedures similar to those used in counting nanoplankton were followed, except that all algal forms encountered were identified and recorded.

In computing the algal totals, an average number of individuals per transect across the Palmer slide was made from four individual counts. Periphyton were computed in number per cm<sup>2</sup>. This counting method was used because it is the most precise commonly used method (Sládečková, 1962) and it correlated with the nannoplankton procedures, thus allowing the establishment of accurate relationships between periphyton and plankton assemblages.

Difficulty was often encountered due to excessive silt deposition on the slide, which apparently was entrapped by mucilage secreted by the algae. Dilutions beyond 10 ml were often necessary for accurate counting, although dilutions were kept as low as possible.

Data presented from periphyton studies were obtained from counts on slides taken as much as possible from one specific location at each site. These data characterize the general periphyton flora of the area but certainly are not representative of every available ecological condition. Slides submerged at site 1 were suspended in slow, evenly flowing water. Those at site 3 were in deep fast-flowing water. Slides from site 4 were in a deep hole where the water was quiet and in a shallow riffle. Slides from site 6 were in a shallow riffle, and slides from the pond (site 5) were submerged just below the water surface in still water.

### Visible Benthic Algae

Visible benthic algae, including such forms as *Cladophora*, *Chara*, and *Hydrurus* were sampled following the methods of Blum (1957) and Dillard (1966), combining quadrat and line transect methods for studying plant communities. Transects were chosen across the stream at right angles to the current flow in areas displaying average growth conditions. The percent coverage of the substrate by each genus encountered was estimated in alternating 10-cm by 25-cm plots along this transect. Macroscopic benthic algae were always most abundant in riffles, and so one or more representative tran-

sects of a riffle were taken at each study site. At sites 1 and 2 slow water also supported significant algal growths. Transects were run in these slow water areas as well as in riffles at these sites, and the results were averaged to give a figure representative of the site as a whole.

From data gathered it was possible to calculate cover, composition, and frequency of each genus on the stream substrate. The frequency percent for each genus was obtained by dividing the total number of quadrats in the transect into those quadrats in which each genus occurred. The cover percent for each genus was determined by assigning coverage classes (Daubenmire, 1968) to the estimation of each genus recorded in the field and then averaging the mid-points of these coverage classes. From the cover percentage, the percent composition of the total community represented by each genus was determined by dividing the total cover into the cover of each genus and multiplying by 100.

This method of estimating cover in each quadrat gave more accurate information than Blum's (1957) method of only recording the presence or absence of a species beneath the plots.

Where the water was deep and swift, this sampling method was not applicable. Turbid waters also hindered its use, although a glass jar submerged in the water enhanced visibility.

### Floristic Sampling

Samples were taken from rocks, twigs, sand, and macroscopic vegetation at fourteen sites along the creek. Seven of these sites corresponded with the seven quantitative sites; and the other sites represented ponds, backwaters and other areas where algae were found growing. Floristic sampling began in October 1970 and continued throughout the study. The algae in these samples were identified to species in the laboratory. Samples of many filamentous algae were preserved in FAA solution, and permanent diatom slides were made.

## RESULTS AND DISCUSSION

Each site in this study was chosen to represent a unique ecological habitat. Consequently, each site was studied with the view in mind to characterize the complete algal community and ecological parameters found under each set of conditions. The following discussion therefore treats the algology and ecology of each site of the study area.

### Lawrence (Site 1)

The algal flora at Lawrence is dominated by macroscopic species including *Cladophora glomerata*, *Oedogonium* sp. and *Chara vulgaris* and by many diatom genera. *Cladophora glomerata* was first recorded from floristic samples in April 1971. By May it was prevalent among the rocks on the stream bottom (Fig. 22). The

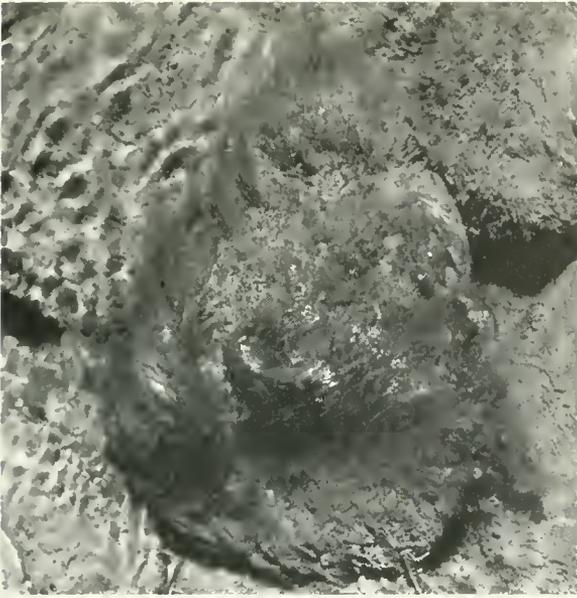


Fig. 22. *Cladophora glomerata* attached to a stone at site 2. This photograph was taken in the spring when *Cladophora* began to be prominent in the flora, and the alga is approximately one half as long as it is at maturity. Photographed April 28, 1972.

first quantitative sample in June showed this alga to cover 35% of the stream bottom in riffle areas. The second sample in June showed a peak development of *C. glomerata* when it covered 43% of the riffle substrate occurring as long deep green streamers from the stones.

*C. glomerata* declined sharply through July and by the end of the month was represented mostly by stubby basal portions of the plant. These fragments have the ability to regenerate (Fritsch, 1906), and many began to do so in September, causing this species to reappear significantly in the flora. However, the fall growth consisted only of heavily encrusted compact mats which lacked the long luxuriant streamers characteristic of spring growth.

This cycle of *Cladophora glomerata* development at Lawrence supports the assumption of Blum (1956) that this alga is sensitive to temperatures approaching 25°C and does very poorly at higher temperatures. The water temperature at this site on June 29, 1971 was 15°C in early morning and approached 25°C by late afternoon. Temperatures through July, August and early September likewise approached 25°C for at least portions of the day.

*Cladophora glomerata* beds at Lawrence provided excellent habitat for development of other organisms. Consequently, they were often full of insects and epiphytic algae. The peak of biological activity of the stream could thus al-

most be said to parallel the peak of *Cladophora* development.

Mats of *Oedogonium* sp. also formed long green streamers intermingled with *Cladophora glomerata*. This alga could be recognized since the mats were generally formed nearer the water surface and their color was yellow green as opposed to the deep green of *Cladophora*. The pattern of development of this genus at Lawrence was similar to that of *C. glomerata*. *Oedogonium* sp. appeared in April and reached a peak of development in June. By July *Oedogonium* sp. was not evident as a visible alga although small filaments were found to colonize glass slides throughout the year and were found in the net plankton until November.

Mats of *Chara vulgaris* began developing in early summer when the water level declined and the water temperature rose. By October *C. vulgaris* dominated the aquatic vegetation covering 64% of the total substrate. *C. vulgaris* occurred in greatest abundance in slow-flowing water, where it reached 85% cover in October. Riffles averaged only 54% *Chara* cover at the same time. The water level was extremely low during this period, and *C. vulgaris* mats literally filled much of the creek channel. By November the plants forming these large mats had begun to die and decompose, and walking through them stirred up a black organic ooze and large amounts of entrapped silt. Visible films of epiphytic diatoms covered the upper filaments of *C. vulgaris*. These diatoms consisted mostly of *Achnanthes minutissima* and *Synedra ulna*. Similar to the *Cladophora glomerata* mats, *Chara vulgaris* beds were the site of a great deal of biological activity.

In December and January extensive decomposition of *C. vulgaris* occurred under the ice cover and the stream bed became very murky with silt and decomposition products. The water was significantly influenced by decomposition during this period. Due to high biological oxygen demand, dissolved oxygen levels during November, December and January fell to 6, 3 and 8 ppm, respectively, from the usual average of 9–10 ppm. Carbon dioxide levels rose concurrently from averages of 2–4 ppm to 6, 24, and 16 ppm for the same three months. The higher CO<sub>2</sub> levels also lowered the pH slightly through this period. It is interesting that a significant amount of *Chara vulgaris* remained viable through the winter months, indicating that sufficient light penetrated the ice and snow to allow photosynthesis and also indicating that *C. vulgaris* is quite resistant to low temperatures.

The ice broke in February 1972 due to an early thaw, and the large mats of *Chara* had

entrapped large amounts of silt. The bottom was black and murky, and the water was extremely turbid from silt stirred up from the substrate. With the rise of the spring flood in March, turbidity became so intense that visibility through the water was reduced to zero as higher and faster water began scouring the stream channel and washing silt deposits downstream.

During late summer and early fall, a prostrate, often encrusted alga became quite evident on smaller stones of the stream bottom. This alga was very difficult to identify accurately due to its growth form, but was suspected to be *Protoderma viride* since this alga was prevalent on periphyton slides collected in September. *P. viride* appears to prefer warm water, since it first appeared in the summer then disappeared as the waters cooled in the fall.

The vascular plant, *Potamogeton* sp. was included in the sampling at Lawrence since it was an important aquatic plant throughout much of the growing season. Interestingly, few epiphytic diatoms were found growing on living *Potamogeton* sp. plants as contrasted to *Oedogonium* sp. and *Cladophora glomerata* which supported large populations of attached diatoms. Hynes (1970) indicated that some species of aquatic plants such as *Potamogeton pectinatus* support a poorly developed periphyton assemblage while living, and apparently this holds true for the *Potamogeton* at Lawrence.

*Potamogeton* sp. first appeared in early July and by late July constituted an important part of the total flora. Small amounts remained present throughout the winter and were still present when the ice broke in February. Most *Potamogeton* plants lasting through the winter were removed by scouring during spring high water.

Net plankton pulses showed a definite correlation with the appearance and development of *Oedogonium* sp. and *Cladophora glomerata* (Fig. 23). *C. glomerata* fragments were a major component of net plankton samples during late spring and early summer but disappeared in July and August. *Oedogonium* sp. appeared in the net samples in May, reached a peak in June when it was also most abundant as a visible benthic form, and fell off sharply in July. Total net plankton occurrence followed much the same curve as *Cladophora glomerata* and *Oedogonium* sp., being highest in the spring and very low throughout the summer and fall. Net plankton at Lawrence increased significantly in February and March 1972 because of the growth of *Ulothrix tenerrima* on the substrate during winter months. Periphyton slides retrieved in December and March likewise had populations of *U. tenerrima* growing on them. Blum (1957)

noted a similar winter growth of *Ulothrix* through the late winter months in the Saline River, Michigan.

Although the Lawrence site is located low on the creek drainage, few true planktonic algae were collected. Clark (1958) likewise found the lower Logan River, Utah, to be low in true phytoplankton. Kofoid (1903) and Whitford and Schumacher (1963) discussed the development of euplankton in rivers and concluded that the water in a stream must be several weeks old before a true river plankton will develop. Thus, the water in Huntington Creek probably takes much less time than this to pass from its origin into the San Rafael River.

Information on diatom populations in this study came from periphyton and nannoplankton investigations. A strong vernal increase in periphyton was evident in April and early May followed by a summer low and a general increase from September through December. Winter lows occurred from January to March and fewer total organisms were present during this time than in the summer. This yearly trend was basically formed by the genera *Navicula*, *Synedra*, *Diatoma*, *Cymbella* and *Surirella* (Fig 24). *Gomphonema* likewise followed this general trend except for a significant increase in September and October. This September-October *Gomphonema* pulse was caused by rapid increase of *G. gracile*. *G. olivaceum*, on the other hand, was more important in the fall and especially in the winter.

*Nitzschia* (mostly *N. palea*) was an important component of the periphyton in early June (30% of the total periphyton). It decreased through the summer until October, when a significant pulse occurred. It then declined again through the winter months. Whitford and Schumacher (1963) classified periphyton into late spring-early fall species and early spring-late fall species. This classification followed their observation that diatoms appearing in late spring usually also showed a high colonization rate in early fall and, likewise, early spring diatoms also were present in large numbers in the late fall. The data on *Nitzschia palea* from Lawrence indicate that this taxon is a late spring-early fall form.

Several diatoms reached their peak of development during summer months. These included *Cocconeis* (mostly *C. pediculus* in June and *C. placentula* in August), *Achnanthes minutissima*, *Cyclotella meneghiniana* and *Pleurosigma delicatulum*. *Cocconeis* constituted approximately 22% of the periphyton from June to August. *Cocconeis placentula* was an especially important epiphyte throughout most of the sum-

Total Net Plankton: I=50 algae I

Selected Genera

I=25 algae I

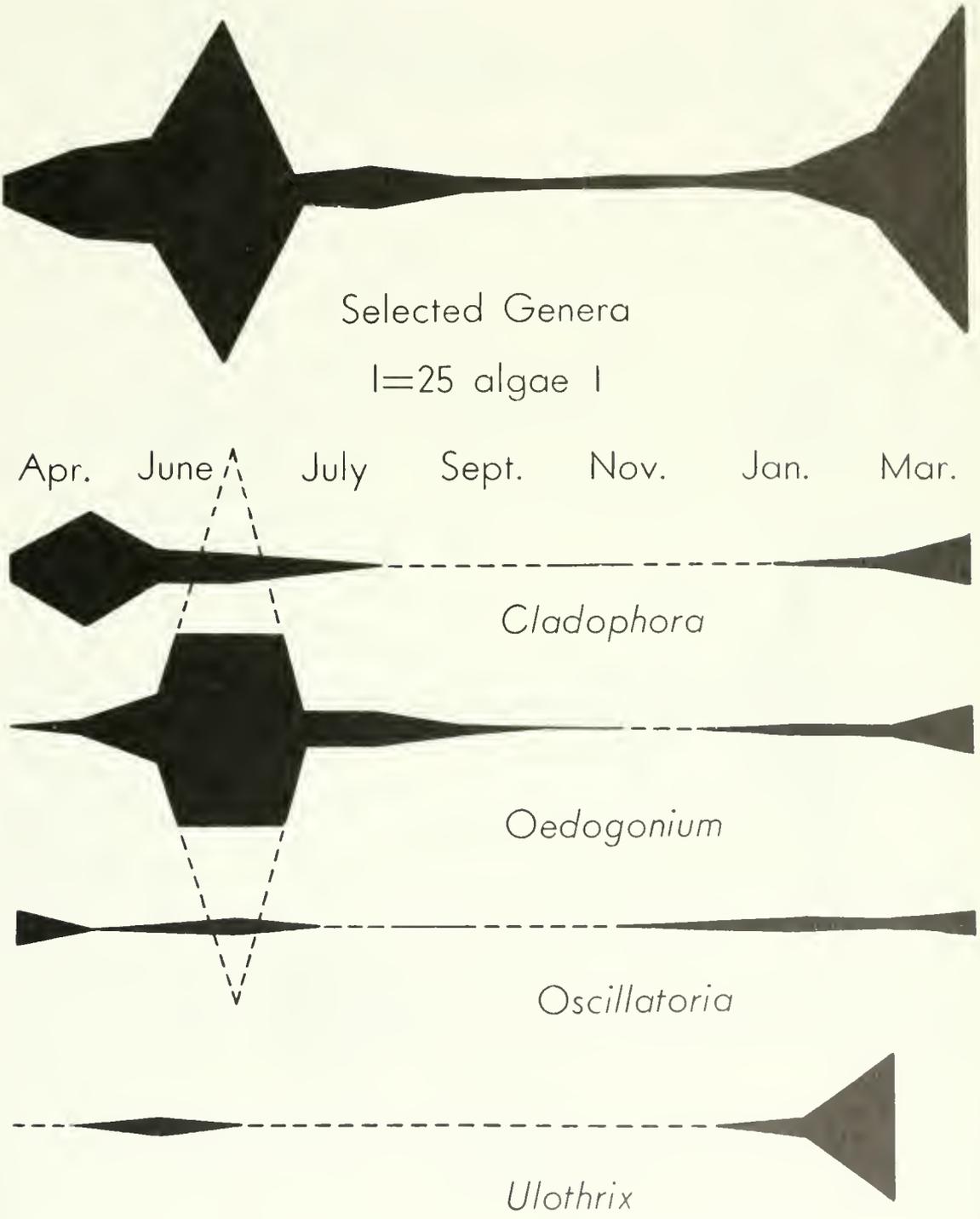
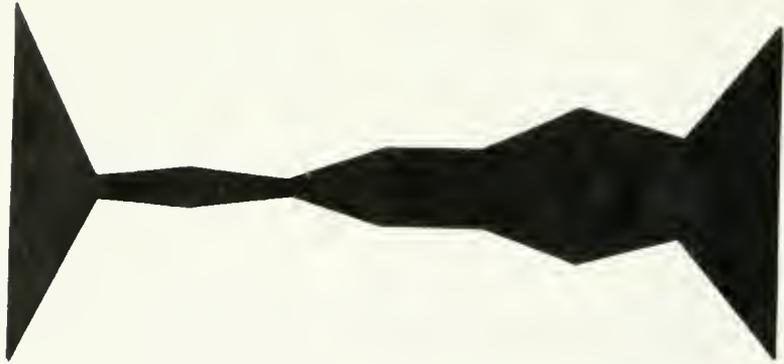


Fig. 23. Seasonal distribution of selected net plankton at Lawrence (site 1).

Total Periphyton: l=10 algae ml



Selected Genera: l=5 algae ml

May      June      Aug.      Oct.      Dec.



*Navicula*



*Synedra*



*Nitzschia*



*Cocconeis*

Fig. 24 Seasonal distribution of selected periphyton at Lawrence (site 1).

mer, and it was not uncommon to collect a filamentous green alga covered with hundreds of specimens of this species. *Pleurosigma delicatulum* was most prevalent in July.

During the August-October period, *Achnanthes minutissima* comprised about 36% of the periphyton. However, this species was absent from the periphyton in October, indicating that colonization decreased sharply during that period.

*Cyclotella meneghiniana* was the only centric diatom prevalent in Huntington Creek. It showed a peak of development in the summer from July to September with a maximum in August.

Nannoplankton in Huntington Creek at Lawrence were high throughout most of the year. The higher nutrient levels in the creek here, and the availability of filamentous green algae as a substrate for diatom growth contributed to the continuously high levels. Some diatom genera, such as *Gyrosigma*, *Cocconeis*, *Cyclotella*, and *Achnanthes* appeared in high numbers in the nannoplankton beginning in July 1971 when spring and fall genera such as *Navicula*, *Surirella*, and *Synedra* became quite low (Fig. 25). These latter genera increased again greatly in late fall when most of the dominant summer genera declined in numbers. A low point for the season in total nannoplankton was reached in October. However, a large pulse occurred in November composed mostly of *Synedra ulna*, which comprised 41% of the total nannoplankton. *Synedra* also actively colonized glass slides during this month, and it grew so profusely on dying *Chara vulgaris* mats that a brown film was visible on each *Chara* plant.

From January to March 1972 a scouring of the stream channel occurred as the early runoff waters riled the silt and decomposition products built up during the fall and early winter season. This scouring process also scoured many of the prevalent winter and spring diatoms from the substrate and from among accumulated plant material, causing extremely high numbers of these diatoms to occur in the nannoplankton. Thus, nannoplankton in February and March exceeded 2 million cells per liter. Important genera during this period included *Synedra*, *Cymbella*, *Surirella* and *Navicula*. Nannoplankton levels were also high in April and May 1971, which was probably caused by renewed colonization following spring scouring.

The flora at Lawrence differed significantly from that of the sites in Huntington Canyon, especially in the growth of *Oedogonium* sp., *Cladophora glomerata*, and *Chara vulgaris*, and the absence of *Hydrurus foetidus* on the stream bed.

The general plankton pattern at this site was similar to that of other sites consisting mostly of diatoms. However, the diatom communities here were much different in structure from those of other sites since *Cocconeis* (mostly *C. placentula*), *Cyclotella meneghiniana*, *Pleurosigma delicatulum*, and *Gyrosigma spencerii* were present in much greater numbers, while *Cymbella* spp. were greatly reduced.

To summarize seasonal community variations at Lawrence, *Cladophora glomerata* and *Oedogonium* sp. dominated the flora in late spring and early summer, with diatoms such as *Navicula*, *Cymbella*, *Synedra*, and *Surirella* occurring in high numbers on stones and macroscopic algae. *Chara vulgaris* dominated the stream bottom from summer through fall and occurred with *Protoderma viride*, *Cocconeis* spp., *Achnanthes minutissima*, and *Cyclotella meneghiniana*. Late summer and early fall allowed maximum development of *Gomphonema gracile* and *Nitzschia* (mostly *N. palea*), while the late fall environment stimulated another general diatom pulse. Net and nannoplankton assemblages were derived largely from cells and filament fragments released from the substrate, and true planktonic algae were rare in the flora.

#### Highway 10 Bridge (Site 2)

Water chemistry and visible attached algal data from this site correlated closely with that from Lawrence and consequently differed from data collected upstream in the canyon. The water at sites 1 and 2 had significantly higher levels of nitrates, phosphates, alkalinity, and especially hardness, silica, and sulfate than the water at site 3, which is the first site located in Huntington Canyon (Table 1).

The same table illustrates that the levels of these chemicals in the water at Lawrence are generally higher than at Highway 10. This is because as the creek leaves the canyon it passes through strata and soils which are extremely rich in carbonates. In addition, the creek here drains both farming and grazing lands which are responsible for the addition of nitrates and phosphates, and passes near Huntington City which

Table 1. Chemical Data for Huntington Creek, December 17, 1971.

	Site 1	Site 2	Site 3
Nitrate mg/l	0.6	0.33	0.3
Phosphate mg l	0.16	0.06	0.08
Alkalinity mg/l	410	370	240
Total hardness mg l CaCO <sub>3</sub>	2000	1300	250
Silica mg l SiO <sub>2</sub>	16	18	2.7
Sulfate mg l	2700	1300	28

Total Nannoplankton: l=100 algae ml



Selected Genera: l=25 algae ml

Apr.    June    July    Sept.    Nov.    Jan.

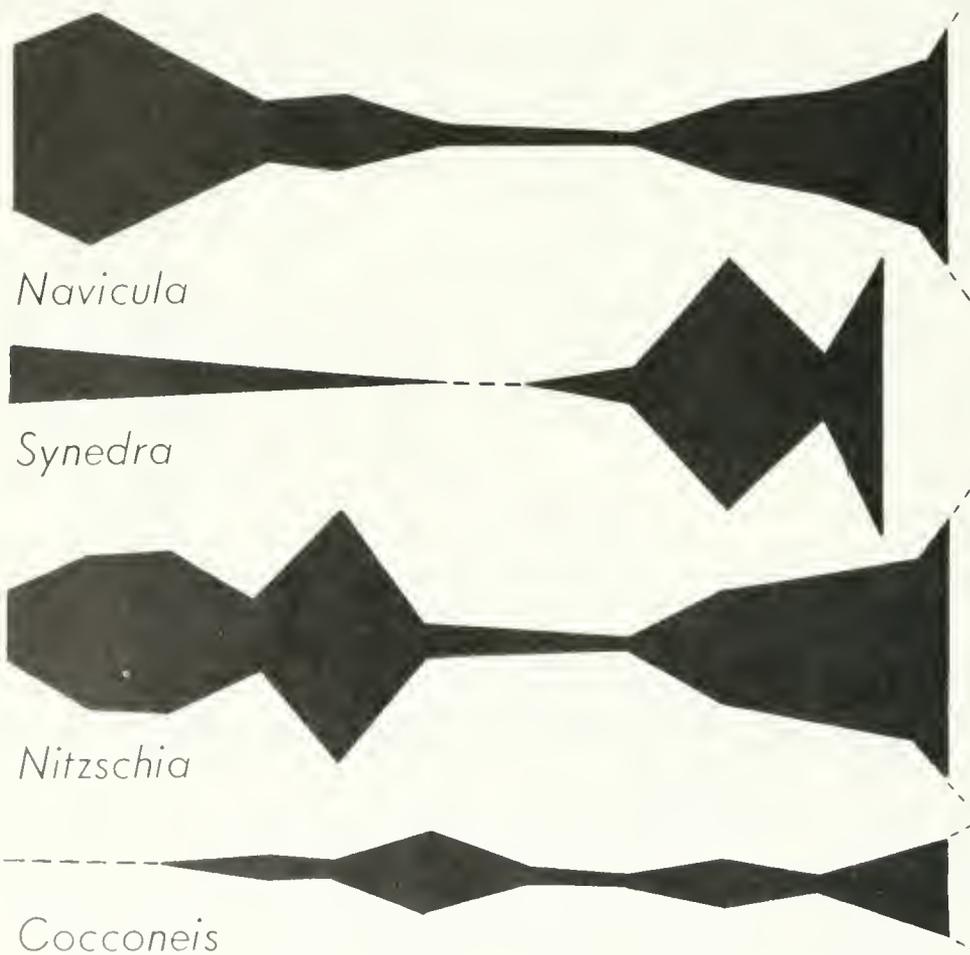


Fig. 25. Seasonal distribution of selected nannoplankton at Lawrence (site 1).

likely also adds nutrients. Due to the removal of water for irrigation and storage above these two localities, the creek is generally low at sites 1 and 2 and thus the addition of these nutrients has a profound effect on water quality.

The algal community at site 2 was very similar to that of site 1 in many aspects, and both resemble that reported by Blum (1957) for the Saline River, Michigan, and appear to be typical of highly calcareous streams in general. *Cladophora glomerata* at Highway 10 demonstrated a late spring-early summer development. This species was prevalent here throughout May and June 1971, covering 25% of the riffle substrate in early June and 57% by late June. By July, *C. glomerata* had apparently stopped growing, but mats of it were still evident attached to stones and streaming in the current.

*Chara vulgaris* appeared in July 1971 and became prevalent in August. This alga was found mostly in slower water rather than in riffles, indicating that the replacement of *Cladophora* by *Chara* in the flora was not a result of direct competition but rather represented seasonal change. Transects to measure visible benthic algae were run in both riffles and slow water at this site, and the results were averaged to characterize overall trends. However, a comparison of the data summarized from each area (Table 2) illustrates some interesting habitat preferences for these two species. *Cladophora glomerata* prefers riffles with fast water and a stony substrate, whereas *Chara vulgaris* prefers slow water and a silty substrate.

*Chara* persisted through the fall and into the winter under the ice cover. However, it did not form the extensive mats which were present at Lawrence since the creek channel was much shallower here and the water faster. As the water level fell late in the season, much of the *Chara* on the creek margins dried from exposure. When the ice melted in February 1972, *Chara* was completely gone from the riffles but still covered 13% of the stream bed in slower areas. However, during the high runoff in March

most of it was displaced and washed downstream by high turbulent water.

From floristic sampling at Highway 10 several trends in population became apparent. In early June and again in October 1971, *Vaucheria geminata* was found intermingled among *Cladophora* filaments and was covered with epiphytic diatoms. Diatoms most abundant in the creek in May and June were *Cymbella parva*, *Amphipleura pellucida*, *Diatoma vulgare*, *Diatoma tenue* and *Synedra ulna*. In late June *Nitzschia* spp. and *Cocconeis placentula* entered the flora in significant numbers. Diatoms decreased generally during the summer months, and the stones became covered with an encrusting cyanophyte and *Protoderma viride*. This crust disappeared in October. In September 1971 large amounts of *Spirogyra* sp. were found here as well as species of *Oscillatoria* and *Lyngbya*. In October *Amphipleura pellucida* showed an increase which was followed in November by an increase in *Synedra ulna* and *Achnanthes minutissima*. The January sample showed these three diatoms to still be important in the flora.

Although floristic trends at this site were similar to those at Lawrence, the total abundance of algae at Highway 10 was considerably lower. This likely resulted from the influence of faster and shallower water here, fewer nutrients present in the water and the shade of the bridge and nearby cottonwood trees reducing the amount of sunlight available for photosynthesis.

### Plant Site (Site 3)

The plant site was the first site located on Huntington Creek in Huntington Canyon proper, and its algal flora was similar in many respects to that of other creek sites in the canyon. The dominant genera at this locality were *Hydrurus*, *Oscillatoria*, other *Oscillatoriaceae*, *Navicula*, *Gomphonema*, *Cymbella*, *Synedra*, *Nitzschia* and *Achnanthes*.

Immediately after the ice broke in February 1972, *Hydrurus foetidus* covered 24% of the stony substrates of this site. It consisted of light brown filaments on stones with scattered patches becoming dark brown. However, it lacked the luxuriant growth evident for this species further upstream. By March 1972 all *H. foetidus* had disappeared except for a few isolated clumps. However, in May and early June of the previous year during the high point of the spring flood, some specimens of this species were observed growing on large rocks close to the water surface or partly exposed.

Net plankton totals for *H. foetidus* at the plant site showed that this May-June period was

Table 2. July-November 1971 averages of the frequency, percent cover and percent composition for *Cladophora* and *Chara* in a riffle and in a slow water area at Highway 10 (Site 2).

	Riffle	Slow water
<i>Cladophora glomerata</i>		
Frequency	76.3	42.4
Cover	7.3	3.7
Composition	62.5	15.1
<i>Chara vulgaris</i>		
Frequency	25.3	86.4
Cover	4.4	42.0
Composition	36.5	84.1

the peak of production for this species in Huntington Creek upstream from the plant site (Fig. 26). Most specimens observed in the net plankton were damaged, indicating that they undoubtedly originated some distance upstream from where they were collected. *H. foetidus* showed a definite downward trend in productivity as the water temperature increased toward 12°C which Zhadin (1961) indicated as the critical temperature for this alga.

Filamentous blue green algae were also especially important in the net plankton from the spring through the summer and into the fall. These algae in Huntington Creek consisted of *Schizothrix fragile*, *Oscillatoria* spp. and other genera of the family Oscillatoriaceae. They usually occurred mixed with diatoms, silt and debris as encrustations on stones and other solid substrate on the creek bottom. Single filaments or clumps of filaments were released into the creek current and were second only to diatoms as a contributor to the total plankton of lower Huntington Creek in the spring and summer.

Periphyton data indicate that blue green algae were most active in colonizing the substrate from late June to October. Floristic samples taken each month revealed that the greatest abundance and diversity of filamentous blue green algae occurred in the summer and early fall. By September a considerable accumulation of blue green algae, diatoms and sediment had accumulated on the stony substrate of the creek. In October 1971 a definite resistant blue green algal encrustation had developed beneath this accumulation, and in November it was easily scraped free. Periphyton data indicate that no cyanophyte colonization occurred during November, which suggests that the onset of winter made conditions unsuitable for these algae.

Net plankton data for the fall months correlate very well with periphyton results. In September small clumps of blue green algae began appearing in the net plankton in significant numbers and by November they comprised 70% of all net plankton indicating that these algae were being readily released from the substrate. Colonization began again during the January-March 1971 period when an active growth of *Oscillatoria amphibia* and *O. agardhii* was noted both under the ice and in open water after the thaw. This recolonization trend was mostly determined from floristic samples taken one to two miles above and below the plant site where *Oscillatoria* spp. were especially abundant.

Green algae occurred only sporadically on periphyton sampling slides at the plant site. However, net plankton data and visual obser-

vation indicated that some species of Chlorophyta were present on the stream bottom. *Ulothrix tenuissima* was most significant in June 1971 and again in March 1972. *Oedogonium* sp. occurred throughout most of the summer, and *Cladophora glomerata* appeared in early summer and again in early fall. This suggests that the approximate temperature preferences for these algae are: *Ulothrix tenuissima* around 10°C; *Cladophora glomerata* close to 15°C; and *Oedogonium* sp. 15°C and higher.

*Spirogyra* sp., *Zygnema* sp., and *Mougeotia* sp., filaments occurred in the net plankton in low amounts in the summer and early fall. These filaments probably originated from quiet side waters or ponds upstream from the plant site.

A few true planktonic algae were noted in the net plankton during the summer months. The most significant of these were *Pandorina morum* which occurred from late June to October and *Ceratium hirundinella* which was collected from August to November (Fig. 26). The source of these algae was likely from lentic environments which drain into Huntington Creek above the plant site. Cleveland, Miller's Flat, Rolfson, and Huntington reservoirs on the upper drainage of the left fork of Huntington Creek were the probable sources of these e-plankters. In addition, these algae may have originated in part from pools, ponds and quiet waters along the creek. The cycle of development of *Pandorina morum* in Tie Fork Pond substantiates this assumption since this alga was prevalent in the pond from July to October, reaching a peak in number in September. This trend correlated with the highest number in the river, both at the plant site and upstream at site 4. Floristic samples taken from Cleveland and Miller's Flat reservoirs in July showed *Pandorina morum* to be present there also, but the presence of this alga in right fork plankton samples discourages the conclusion that these reservoirs are its only source into the creek.

*Ceratium hirundinella* is suspected to originate almost entirely in the reservoirs on the left fork of Huntington Creek. This species has been reported as a dominant summer plankter from other reservoirs in Utah (Chatwin, 1956; Longley, 1969) with large pulses generally occurring in August and September, which were the months of maximum *Ceratium hirundinella* abundance in Huntington Creek. These were also the months of maximum water release from the storage reservoirs on the left fork to provide irrigation water for Castle Valley. Many *C. hirundinella* cells in the plankton were broken, suggesting that they had been transported downstream from the reservoirs.

Total Net Plankton: 1=100 algae l



Selected Genera: 1=50 algae l

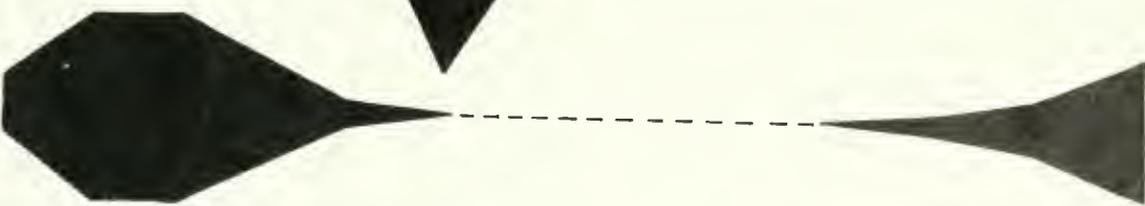
Apr. June July Sept. Nov. Jan. Mar.



*Pandorina*



*Ceratium*



*Hydrurus*



*Oscillatoria*

Fig. 26. Seasonal distribution of selected net plankton at the plant site (site 3).

Nannoplankton samples taken during the summer of 1971 contained three other true planktonic algae, *Dinobryon cylindricum* and the diatoms *Asterionella formosa* and *Fragilaria crotonensis*. These algae were likely also released into the creek from the storage reservoirs. Longley (1969) reported *Dinobryon* to be the dominant phytoplankton in Flaming Gorge Reservoir, Utah, during June and July. Daily (1938) indicated that *Dinobryon* was present in Lake Michigan during most months of the year but that it demonstrated a strong peak of development in July and a lesser peak in November. Pratt (1957) likewise found a similar cycle in Salem Lake, Utah County, Utah, where *Dinobryon* showed a summer pulse from late June to mid-September and another pulse from mid-October to mid-November. *Dinobryon cylindricum* was present in Huntington Creek from early June through November, with July and October being peak months. Maximum development of this alga in Huntington Creek correlated with water release from the left fork reservoirs.

*Asterionella formosa* appears to prefer colder water conditions than *Dinobryon*. Longley (1969) indicated this species to be important in Flaming Gorge Reservoir from September to May, and Pratt (1957) found very high amounts in November and December. Pratt also reported a small pulse in August only on the bottom of the pond where the temperature was approximately 14°C. The cycle of *Asterionella formosa* in Huntington Creek was intimately associated with the management of waters of the left fork reservoirs. These reservoirs are either completely drained or kept at very low levels during late fall and early winter months and are subsequently filled with runoff waters during the late winter and early spring. Consequently, no opportunity exists for the release of euplankton from these reservoirs during this period, explaining why very few euplanktonic species, especially *A. formosa*, were found in the creek during these months. When these reservoirs are filled in the spring, the overflow enters Huntington Creek carrying with it any plankton which may have developed in the reservoir over the winter. This was the probable source of *A. formosa* in the plankton of Huntington Creek, since this diatom was highest in the creek in June 1971 (59,490 colonies per liter on June 8, and 30,250 colonies per liter on June 29). It declined gradually through the summer and then increased slightly in October. This trend was undoubtedly directly correlated with the temperature curve in the reservoirs.

Clark (pers. comm.) studied a similar situa-

tion in Idaho where Henry's Lake drains into the north fork of the Snake River. Blooms of *Asterionella formosa* occurred in Henry's Lake in June and October 1971, and this alga was found in the river plankton for 35 miles below this lake during the time of the bloom. *A. formosa* density was 815,200 colonies per liter at the Lake's outlet and decreased to 32,600 colonies per liter 35 miles downstream from the lake due to the effects of the river current.

A similar reduction in colony number would be expected in Huntington Creek from the reservoirs on the left fork downstream to the plant site, which represents a distance of approximately 18 miles. Only moderate currents are sufficient to cause such a reduction (Allen, 1920) and turbulent currents can often cause extreme reduction in euplankton. For instance, Galstoff (1924) reported a 40% reduction in plankton during an eight-hour passage of the water of the Mississippi River through the Rock Island Rapids.

Many of the *Asterionella formosa* colonies collected in the plankton at the plant site were fragmented, which Brinley (1950) cited as an evidence that they originated in a lentic environment and were not natural stream inhabitants.

*Fragilaria crotonensis* was another euplanktonic diatom present in the nannoplankton at site 3. Clark (per. comm.) mentioned that *Fragilaria crotonensis* was abundant in Island Park Reservoir, Idaho, in October 1971. Likewise, Daily (1938) indicated this species as a dominant form from October to December in Lake Michigan, and Longley (1969) observed the same trend in Flaming Gorge, Utah. *Fragilaria crotonensis* was prevalent at the plant site from September to November, with a large peak in October when its density reached 80,620 colonies per liter. The source of these algae was likely the reservoirs on the left fork.

Other diatoms in the creek were produced largely on the substrate and subsequently released into the current. Thus, understanding trends in periphyton is essential to understanding algal trends in the stream as a whole. Periphyton data demonstrated a rather smooth seasonal colonization curve of diatom development on the substrate. A gradual increase in colonization rate occurred through the spring and early summer until July, after which a decline occurred until December. Dominant genera included *Navicula*, *Cymbella*, *Gomphonema*, *Synedra*, *Nitzschia*, and *Achnanthes*.

As shown by Table 3, the importance of these genera on the substrate correlated rather closely with their importance in the nannoplankton.

Table 3. Percent occurrence of selected genera of periphyton and nannoplankton at plant site (Site 3).

	5/13 1971	6/29 1971	7/30 1971	8/20 1971	10/8 1971	11/15 1971	12/17 1971	2/19 1972
<i>Navicula</i>								
Periphyton	26.4	11.2	18.0	26.8	26.6	14.0	15.9	9.9
Nanno	14.7	17.3	22.4	22.7	14.1	20.7	13.3	13.9
<i>Cymbella</i>								
Periphyton	30.5	44.2	10.9	15.9	13.1	19.5	30.4	26.0
Nanno	19.9	36.1	26.2	24.3	15.4	18.7	17.7	24.6
<i>Gomphonema</i>								
Periphyton	22.0	11.7	3.1	2.6	2.7	7.3	9.1	36.2
Nanno	32.2	6.2	8.7	10.1	5.0	6.7	3.1	20.8
<i>Synedra</i>								
Periphyton	14.0	5.2	1.5	3.5	4.5	11.8	8.4	7.5
Nanno	8.9	3.1	1.2	1.9	8.5	7.6	7.7	8.2
<i>Nitzschia</i>								
Periphyton		6.9	6.2	32.7	36.9	28.7	20.3	10.5
Nanno	16.5	14.3	18.6	20.3	26.4	38.7	25.3	16.7
<i>Achnanthes</i>								
Periphyton	5.0	11.7	57.1	13.7	6.2	5.0	4.1	3.9
Nanno	2.8	6.2	12.3	12.6	5.8	2.2	7.2	4.4
<i>Hannaea</i>								
Periphyton	.6	2.0	.3			1.1		.3
Nanno	.5	4.1	.3		.1			1.1
<i>Diatoma</i>								
Periphyton		.5	.4	1.1	1.4	8.0	5.1	5.7
Nanno	1.9	1.1	2.1	1.7	2.5	1.1	22.1	9.6
Other Diatoms								
Periphyton	1.1	4.1	.8	1.4	3.3	4.5	.8	
Nanno	3.2	12.0	8.0	6.3	22.2	4.4	3.9	.9
Nondiatoms								
Periphyton	.3	2.7	2.0	2.1	6.0		5.8	
Nanno								

A comparison of the total number of algae colonizing periphyton sampling slides with the total nannoplankton at the plant site for the study period is illuminating (Fig. 27). Generally speaking, the nannoplankton were dependent upon the periphyton and the peaks and lows for the two corresponded. However, through the summer, especially in July, the production of periphyton was high due to a heavy colonization

of *Achnanthes* (mostly *A. minutissima*) and *Navicula* spp. This summer periphyton increase was followed by an early fall nannoplankton increase. This nannoplankton pulse was caused by such genera as *Navicula*, *Cymbella*, *Gomphonema*, *Synedra*, *Nitzschia*, and *Achnanthes* (Fig. 28). These genera had developed on the creek bottom throughout the spring and early summer and apparently were released into the stream in

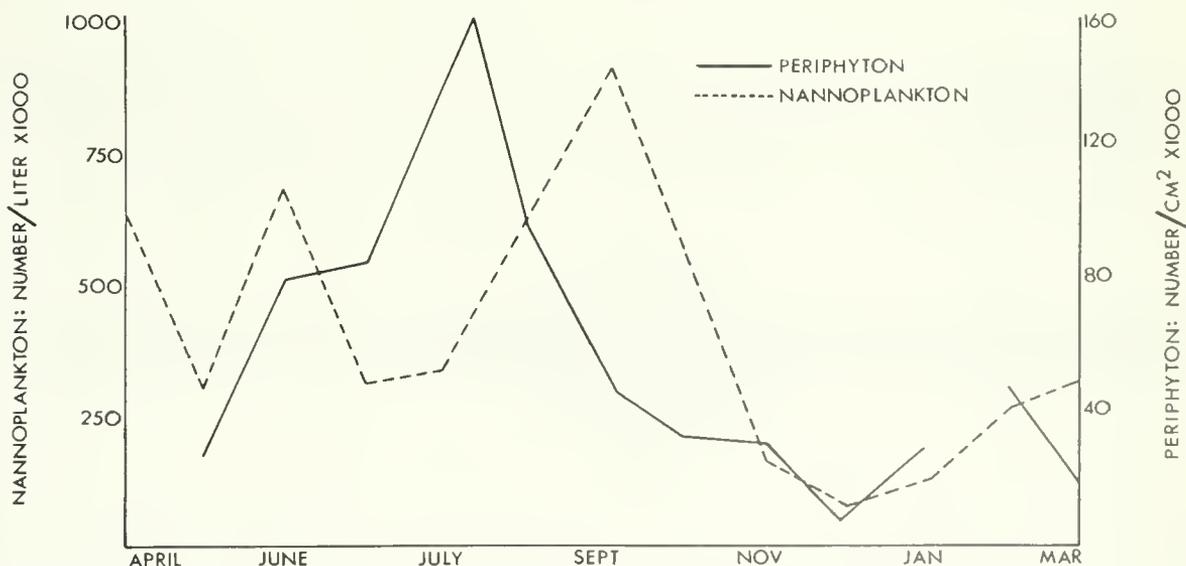


Fig. 27. Density and seasonal distribution of nannoplankton and periphyton at the plant site (site 3).

Total Nannoplankton:  $l=100$  algae ml



Selected Genera:  $l=50$  algae ml

Apr.      June      July      Sept.      Nov.      Jan.      Mar.



Fig. 28 Seasonal distribution of selected nannoplankton at the plant site (site 3).

the late summer due to certain environmental stimuli. This conclusion is supported by decreased colonization rates during the nanoplankton pulse.

*Nitzschia* spp. (especially *N. palea*) were important in the nanoplankton throughout the study period but demonstrated a peak of occurrence from August to October. The yearly high occurred in August, one month later than the *Nitzschia* high at Lawrence and one month earlier than the *Nitzschia* peak from localities further up the canyon.

*Cocconeis placentula* and *Achnanthes minutissima* were predominately summer diatoms at site 3, and *Hannaea arcus* was a late spring-early summer species. *Diatoma vulgare* and *Gomphonema olivaceum* have been reported by Blum (1957) to be important winter colonizers of bare areas. He found *Diatoma vulgare* most abundant in early winter in the Saline River, Michigan, and *Gomphonema olivaceum* most abundant in late winter and early spring. Periphyton data from the plant site show *Diatoma vulgare* to have been most active in colonization in November 1971. *D. vulgare* also occurred in high numbers in the plankton during the fall and winter months. *Gomphonema olivaceum* became most important in the periphyton in January-March 1972. The cells and mucilaginous stalks on which they grow formed an extensive diatom "ooze" on the entire creek substrate during these months. Nanoplankton data from the spring of 1971 and the winter of 1972 indicate that *Gomphonema* spp. were important in the flora throughout the winter and spring.

In summary, the algal flora at site 3 was predominately composed of *Hydrurus foetidus* in the spring, filamentous blue green algae in the summer and diatoms throughout the entire year. Filamentous algae contributed to the net plankton of the river and diatoms comprised nearly the entire nanoplankton. The plankton at site 3 was also influenced by blooms occurring in Miller's Flat and Cleveland Reservoir on the headwaters of the left fork of Huntington Creek. Planktonic algae originating from these reservoirs included *Pandorina morum*, *Asterionella formosa* and *Dinobryon cylindricum* in the late spring and summer and *Ceratium hirundinella* and *Fragilaria crotonensis* in the fall.

#### Bear-Rilda Campground (Site 4)

The campground locality is located three miles upstream from site 3 and exhibited a similar flora. However, certain noteworthy variations between the two floras occurred. These differences are attributed to different ecological con-

ditions at site 4 and the effects of construction and pollution from Deer Creek on site 3.

The creek at site 4 was high from April to early June 1971 with a definite decline in water level in late June. *Hydrus foetidus* appeared here in May on stones in a broad shallow riffle and increased to cover 25% of the substrate in early June. By June 29, 1971, this species had disappeared from the visible benthic algae at site 4, but was still prevalent in the net plankton indicating that it was carried downstream from higher elevations where it persisted later in the season. A light film of *H. foetidus* appeared on the substrate in February but disappeared in March 1972. High water and probable abrasion from ice breakup upstream contributed to the disappearance of this alga at sites 3 and 4 during this period.

The summer and early fall diatom ooze and blue green algal encrustation noted at the plant site were even more apparent at site 4 where the water was shallower, creating more extensive riffles. Algal and sediment buildup began in July and continued through October, when an extensive blue green algal crust was evident under the diatom ooze. In November this crust began flaking off.

It is possible that *Protoderma viride* or another encrusting green alga was a member of this community. However, filamentous blue green algae were definitely the predominant constituents since large amounts of blue green algae were found in the net plankton when the crust began to break up (Fig. 29). Also floristic samples from the campground and further upstream at the junction of the two forks of Huntington Creek showed large amounts of *Schizothrix fragile* and other filamentous Cyanophyta. The presence of these algae in Huntington Creek correlates with the findings of Clark (1958) in the Logan River, Utah, where a blue green encrusting mat was also found on the substrate under the diatom ooze. A new buildup on the substrate was noted in January and February 1972, but it consisted mostly of diatoms. Filamentous blue green algae were present at that time but not in sufficient quantities to create an encrusted mat. During spring flood, the high water and abrasion from its increased silt load usually scoured the stones of much of their periphyton.

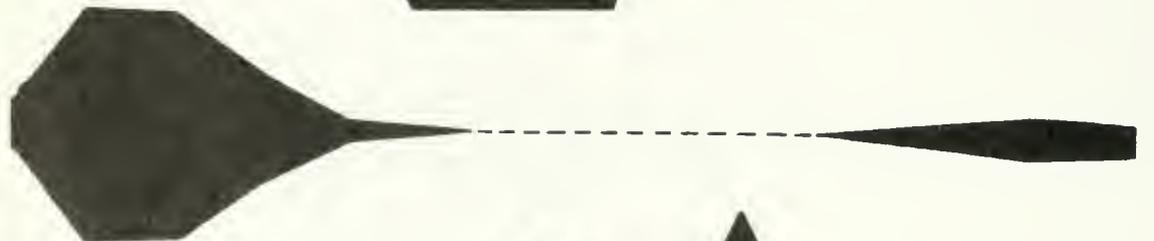
By July, turbulence in the riffle had decreased significantly and many scattered mats of *Oscillatoria* cf. *temis*, together with trapped sediments, occurred on the stream bottom. These were small mats covering only 6.4% of the substrate in shallow water although they oc-

Total Net Plankton:  $I=100$  algae  $I$ Selected Genera:  $I=50$  algae  $I$ 

Apr.    June    July    Sept.    Nov.    Jan.    Mar.



*Ceratiium*



*Hydrurus*



Oscillatoriaceae



*Ulothrix*

Fig. 29 Seasonal distribution of selected net plankton at the campground (site 4).

curred in 77% of the plots observed in transects across the creek. The mats were gone in August but were evident to a lesser extent again in September.

Similar to other sites along the creek, net plankton assemblages at site 4 were directly influenced by the benthic algae. *Oscillatoria* cf. *agardhi* filaments were most abundant in the net plankton in the spring, although they occurred throughout the year. In September and November many small clumps of filamentous Cyanophyta were collected in the net plankton because of the aforementioned breakup of the blue green algal encrustation. *Ulothrix* sp. occurred mostly in May and June, *Cladophora glomerata* from June through August, and *Oedogonium* sp. from May through October. *Spirogyra* sp., *Mougeotia* sp., and *Zygnema* sp. occurred through the summer months, and *Stigeoclonium stagnatile* appeared in the fall.

The same true planktonic algae occurred in the creek at the campground locality as at the plant site (Fig. 30). These included *Ceratium hirundinella* in August and September 1971, *Pandorina morum* in June through October, *Dinobryon cylindricum* from June to November, *Asterionella formosa* from June to December, with highest numbers in June, and *Fragilaria crotonensis* from October to December, with highest occurrence in November. These trends were similar to those at the plant site.

Periphyton colonization trends were similar to those of the plant site. A general increase in periphyton was noted through the spring of 1971 until July, followed by a decline to November 1971. Periphyton data were compiled from slides placed both in a pool and in riffles in order to compare colonization in the two habitats. Both areas showed a general decrease in most genera collected on slides on June 29, 1971, although *Achnanthes minutissima* increased greatly. This species increased from 2,928 cells per cm<sup>2</sup> on June 8, to 23,532 cells per cm<sup>2</sup> on June 29, for slides in the riffle, and from 27,298 cells per cm<sup>2</sup> on June 8, to 123,650 cells per cm<sup>2</sup> on June 29, for slides in the pool (Table 4). From late June to August, *Achnanthes* (mostly *A. minutissima*) was the highest contributor to the

benthic diatom flora in terms of number of cells produced.

Most other diatoms in the periphyton followed the general trend of the total for this site discussed above. The most important genera were *Navicula*, *Cymbella*, *Gomphonema*, *Nitzschia*, and *Synedra*. *Synedra* (mostly *S. ulna*) differed somewhat by nearly disappearing during the warmer months. *Diatoma vulgare* showed good growth in November as it did at the plant site, but *Gomphonema olivaceum* did not show the expected late winter increase. However, nannoplankton data for *G. olivaceum* showed this species to increase in February and May, which correlated with the conclusion drawn from site 3 that this genus is a late winter and early spring form.

*Hannaea arcus* was definitely a late spring diatom, and *Cocconeis placentula* a summer diatom, as indicated by the periphyton and substantiated by nannoplankton data. Certain true plankters were occasionally found on the periphyton sampling slides. These algae became entrapped there as they floated downstream and fell out of the water column.

A comparison of data from slides placed in the pool and the riffle reveals certain differences in colonization in the two habitats. The total number of periphyton and the number of individuals of most genera were much higher in the pool. The only exception to this was *Cocconeis placentula*, which showed a comparable colonization rate in the riffle to that in the pool. The reason for the high colonization rate in the pool was undoubtedly due to reduced removal of periphyton by the stream current while concurrently allowing sufficient water flow for adequate nutrient and gas exchange for rapid algal metabolism.

Periphyton composition percentages for the period May through August 1971 show certain significant differences between the diatoms of the pool and the diatoms of the faster water. The riffle had a higher composition percentage of *Gomphonema* (mostly *G. olivaceum*), *Synedra* (mostly *S. ulna*), *Cymbella* spp., *Nitzschia* (mostly *N. palea*), *Cocconeis* (mostly *C. placentula*), *Ulothrix* sp., and *Hydrurus foetidus* than the pool. Conversely, the pool had a higher percentage of *Navicula* spp., *Achnanthes minutissima*, *Diatoma vulgare* and *Surirella* (mostly *S. ovata*).

From comparing periphyton data with nannoplankton data at site 4 (Fig. 31), it is evident that high periphyton production in June 1971 caused the high nannoplankton levels of the same period and slightly later. The turbulence of high water during this period probably

Table 4. Percent composition of *Achnanthes* on glass slides at the campground, June 8-September 15, 1971.

	6/8	6/29	7/30	8/20	9/15
Slides in riffle	3.2	28.1	54.6	43.2	(NS)*
Slides in pool	12.8	75.8	75.3	14.9	16.0

\*NS—No slide was collected from the riffle in September.

Total Nannoplankton:  $l=100$  algae ml



Selected Genera:  $l=50$  algae ml

Apr.      June      July      Sept.      Nov.      Jan.      Mar.



*Fragilaria*



*Cymbella*



*Asterionella*



*Ceratoneis*

Fig. 9. Seasonal distribution of selected nannoplankton at the campground (site 4).

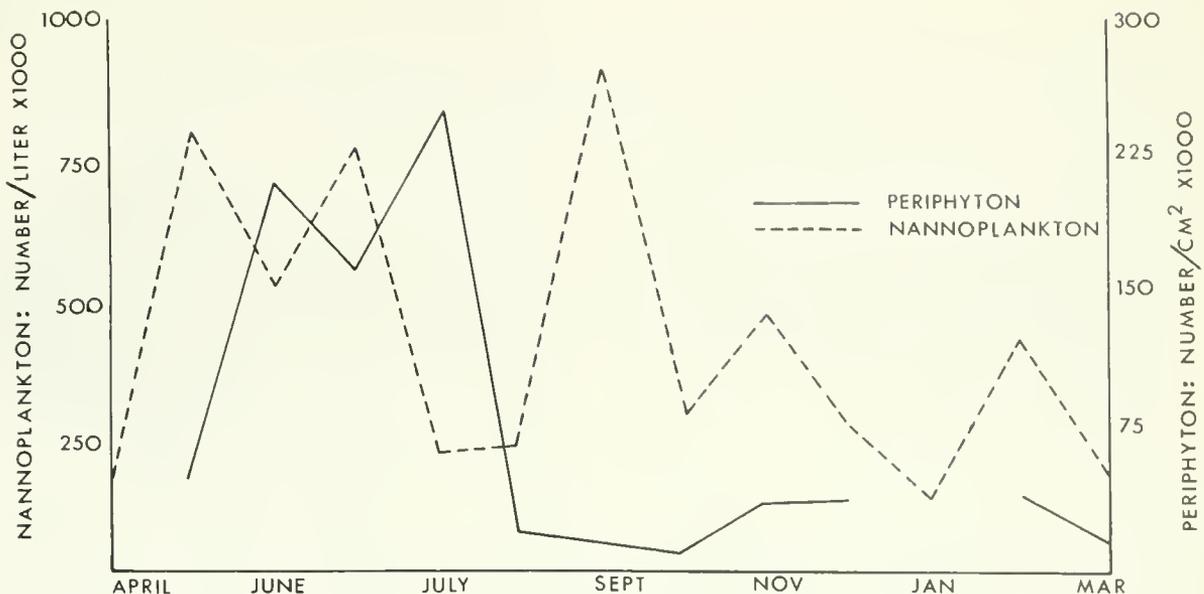


Fig. 31. Density of nannoplankton and periphyton at the campground (site 4).

scoured many diatoms from the substrate into the current. Periphyton production continued to rise in July 1971, when nannoplankton levels dropped, probably because fewer diatoms were removed from the substrate by the current during this period. These periphytic diatoms were subsequently released into the current during early fall when plankton levels increased again. The November nannoplankton increase and subsequent relatively high winter levels were probably due to new colonization, since periphyton levels also rose during this period.

The nannoplankton cycle for site 4 basically followed the trend described for site 3. High diatom levels were evident from April to late June, followed by a summer low, and a high pulse in September (Fig. 32). The decline in plankton in October and subsequent rise in November followed a trend similar to that observed at Lawrence, Stuart Station, and Bear Canyon, although the plant site did not exhibit the November increase. The plant site also had much lower plankton levels on June 29, 1971, than the campground. Turbidity in Huntington Creek

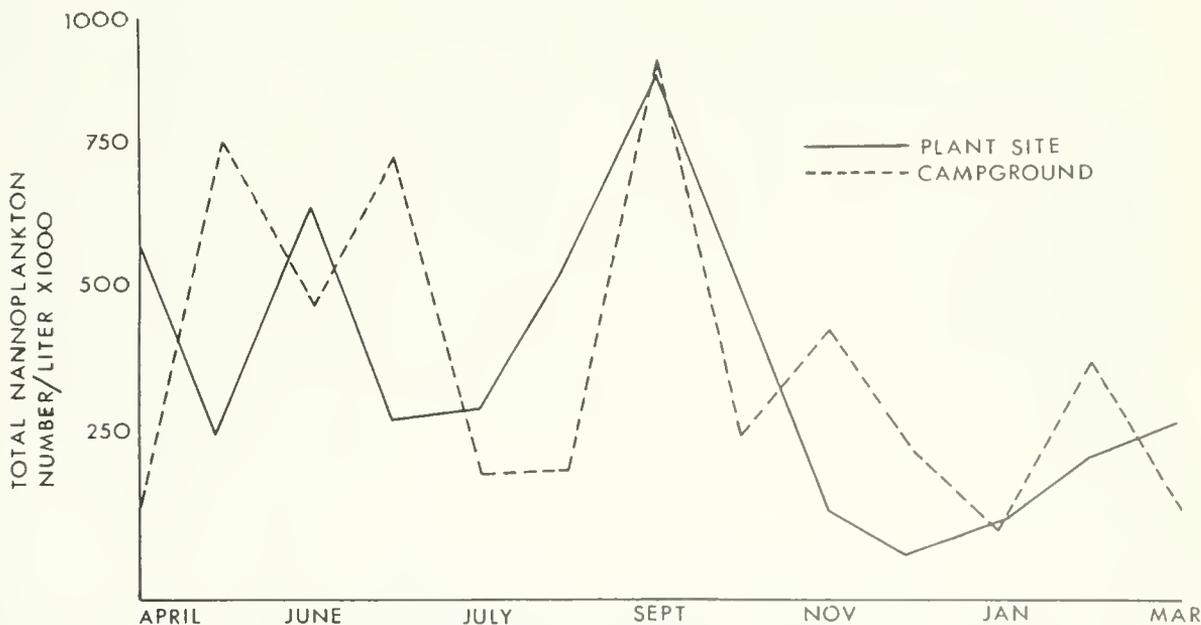


Fig. 32. Seasonal densities of nannoplankton at the plant site (site 3) and the campground (site 4).

at the plant site was 40 JTU on June 29 compared to 15 JTU at site 4. Likewise, on July 5, 1971 turbidity was 25 JTU for site 3 and 11 JTU for site 4 (Wingett, per. com.). The higher turbidity levels were attributed to excavation at the generating station approximately one mile upstream from site 3. Abrasion caused by the extra silt load in the water may have depleted the source of nanoplankton at this site by reducing periphyton populations prior to the June 29 collection, thus accounting for the lower nanoplankton levels here during this period.

The lower nanoplankton levels in November 1971 are attributed to pollution from Deer Creek. This creek flows east from a coal mine across the Utah Power and Light Co. generating station to Huntington Creek. During much of the year its flow was restricted, but during certain periods it flowed freely, carrying an extremely heavy load of coal dust and mining wastes. In October and November the black, soupy water from Deer Creek clouded the clear waters of Huntington Creek and caused heavy coal dust sedimentation on the creek bottom. The effect of this water was probably the main reason for the low November counts here.

In summary, the flora at site 4 was similar to the flora at site 3 in containing large numbers of diatoms both on the substrate and in the nanoplankton. High periphyton production in late spring contributed to corresponding high nanoplankton levels. Production decreased during late summer and increased again in winter. Nanoplankton levels at site 4 fluctuated greatly and differed somewhat from those of site 3. These differences were apparently caused by excavation above site 3, and pollution from Deer Creek. Encrustations of filamentous Cyanophyta were more abundant at site 4 than site 3 in late summer and visible mats of *Oscillatoria* sp. occurred at the campground. *Hydrurus foetidus* grew more profusely at the campground in the spring and greatly influenced the net plankton during this period. Both sites were influenced by euplankton from reservoirs on the upper drainage of the left fork.

#### Stuart Fire Station (Site 6)

The Stuart Fire Station locality is located on the right fork of Huntington Creek approximately 8 miles below the proposed site for the dam creating Electric Lake. This site had considerably less water volume and lacked the influence of reservoirs and artificial flow regulation noted for the left and main Forks of Huntington Creek. However, physical and chemical conditions of the water at site 6 were similar

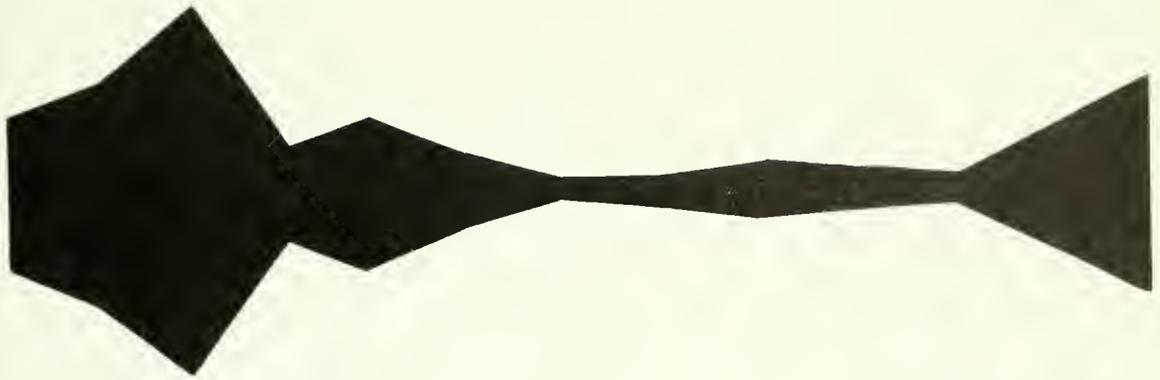
to conditions downstream except for slightly higher silica and alkalinity levels.

Seasonal fluctuations in the algal flora at Stuart Station differed in many respects from those at other sites. This was probably due in large part to the higher altitude and consequent lower temperature and shorter growing season and to the shading effect from the steep walls in this part of the canyon.

*Hydrurus foetidus* was much more prevalent at Stuart Station than lower in the canyon. It was abundant here as early as March in 1971, although the creek was mostly frozen over. It remained present throughout the spring and by June it reached a peak of development forming a prevalent dark covering on most of the stones and rocks of the stream bottom. The quadrat method for estimation of cover and frequency showed this alga to cover 30% of the total substrate and be present in 100% of the plots on June 8, 1971. Visual estimation on the same date of several sites further up the canyon showed *H. foetidus* to be even more abundant there than at Stuart Station. By June 29, this species had declined significantly and soon after disappeared. *H. foetidus* reappeared in December 1971 and became abundant in February 1972 after the ice had melted. This alga usually exhibited more luxuriant growth on larger rocks than on small stones, and it was common to find rich brown filaments trailing in profusion from these rocks. The spring net plankton here was greatly influenced by broken *Hydrurus* filaments, and the peak in net plankton occurred in early June concurrent to the peak of *Hydrurus* production on the substrate (Fig. 33).

Filamentous blue green algae formed an important part of the algal community at Stuart Station. They occurred in all floristic samples and net plankton samples from this site, often occurring in abundance. Maximum development of these algae occurred on the substrate from July to October 1971, when filaments of *Lyngbya* spp., *Phormidium* spp., *Oscillatoria* spp., and *Schizothrix fragile* formed extensive encrusting mats. These filaments were dense and intertwined, and heavily laden with silt particles, diatom mucilage and frustules, and thick deposits of calcium carbonate, which made the exact characterization of this community difficult. However, *Oscillatoria agardhii* was abundant in August and *Schizothrix fragile* and *Lyngbya aerugineo-coerulea* were abundant in October. Fragments of these blue green algae appeared in high numbers in the net plankton from October to November (Fig. 33) similar to sites 3 and 4. *Oscillatoria* cf. *tenuis* also appeared in October as bright blue green filamen-

Total Net Plankton: 1=50 algae l



Selected Genera: 1=25 algae l

Apr. June July Sept. Nov. Jan. Mar.

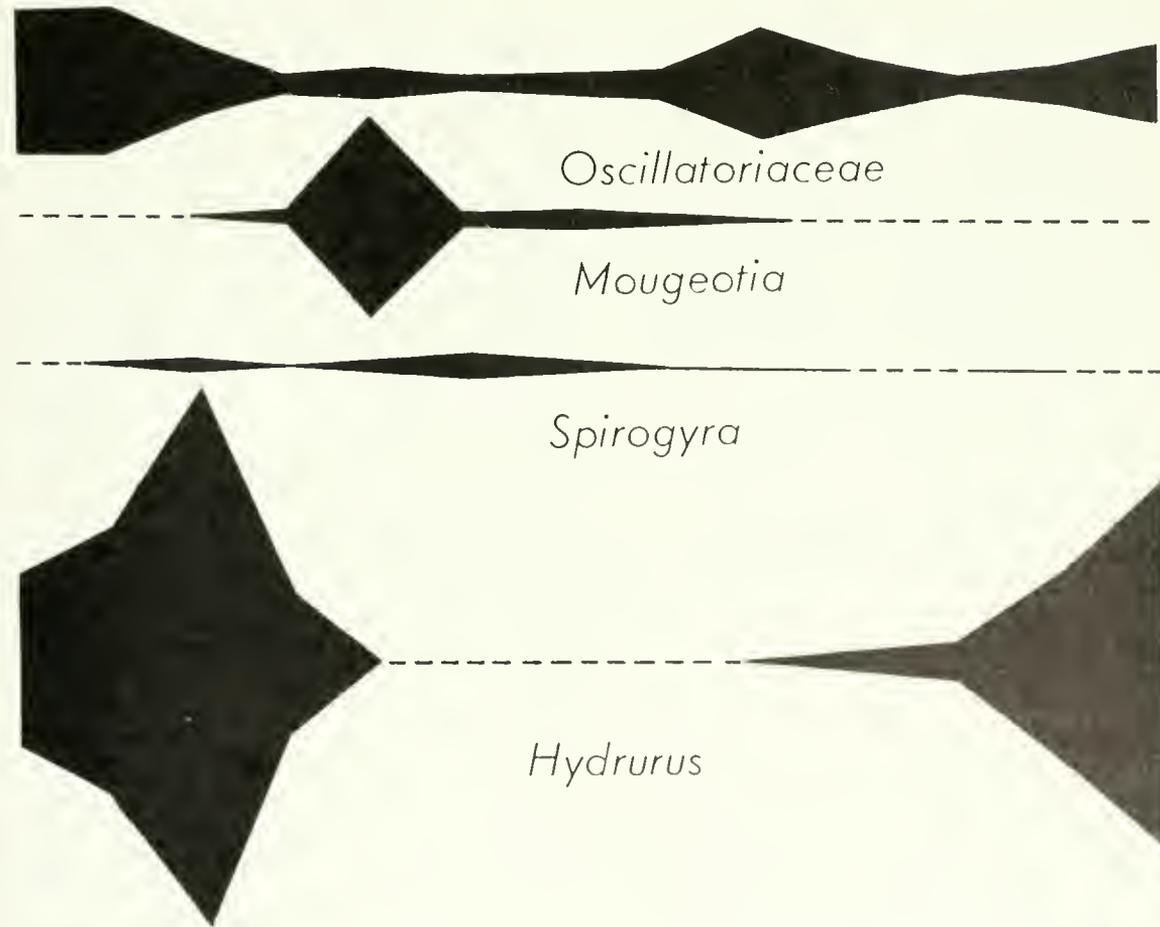


Fig. 33 Seasonal distribution of selected net plankton at Stuart Station (site 6)

tous entanglements similar to those observed at the campground in July.

*O. agardhii* was also abundant in the flora during the winter months. It was prevalent on periphyton slides in November and February and from floristic data it appeared to be widespread on the substrate throughout the November-February period. The high levels of *Oscillatoria* spp. in the 1971 spring net plankton were probably the result of a similar colonization during the winter of 1970-71.

Although this blue green algal community at Stuart Station was very important on the substrate, it was of little significance on the periphyton slides placed in the creek to monitor substrate colonization. Blum (1957) reported a similar situation in the Saline River, Michigan, where a crustose *Schizothrix-Phormidium* community occurred on the river bottom. He found that even after a year's period, sterile rocks placed in the river failed to develop a community structure comparable to the mature *Schizothrix-Phormidium* crust evident in the river. He concluded that a mature crust required a year or more to develop, and that the *Schizothrix-Phormidium* community was a permanent member of the algal flora in the Saline River. A similar situation occurs in Huntington Creek. The basic blue green algal community persists at Stuart Station throughout the year and develops extensively during summer and fall months.

*Cladophora glomerata* likewise did not actively colonize microscope slides at Stuart Station, although it occurred abundantly on the substrate and significantly influenced the net plankton in the spring and fall. This species covered 6% of the substrate in September and 10.5% of the substrate in October 1971. It occurred more on large rocks than on small stones and was covered with epiphytic *Cocconeis placentula*, *Gomphonema olivaceum*, and other diatoms. It was much reduced in November, exhibiting a stubby growth form, but existed through the winter and became heavily encrusted with calcium carbonate and sediment.

In December *C. glomerata* was intertwined with many filaments of *Ulothrix zonata* and *U. aequalis*. *Ulothrix* was otherwise most evident in May and June at this locality.

*Oedogonium* sp. was rare at Stuart Station, although it occurred throughout the summer. *Stigeoclonium attenuatum* and *S. stagnatile* occurred here mostly in the fall months. *Mougeotia* sp., *Spirogyra* sp., and *Zygnema* sp. were of unique importance in the summer net plankton at Stuart Station and were the algae responsible for the steady, relatively high net plankton rates through this period as contrasted to the lower

summer rates at other sites on Huntington Creek. These species occurred mostly from late June to October, but *Spirogyra* sp. was found from early June to February. *Mougeotia* sp. showed a significant increase in July when it comprised 62% of the net plankton, and was the main contributor to the general increase in net plankton during that month (Fig. 33). The creek upstream from Stuart Station contains many regions with slow water and meandering stream channels, as well as springs, pools, and quiet backwaters. These areas supported luxuriant growths of conjugate algae and were undoubtedly the source of these algae in the net plankton at Stuart Station. Algae in these ponds and backwaters probably only entered the creek during runoff from late summer rain storms, but those growing in pools and side waters of the creek itself were constantly released into the channel.

Diatom colonization of the creek substrate at Stuart Station showed peak development in May and November 1971, with lesser peaks in late June 1971 and February 1972. The November-March diatom density was much greater at Stuart Station than that of any period at sites 3 and 4 (Fig. 34), suggesting that the aquatic habitat here was more conducive to diatom production than lower in the canyon. The low colonization rate in early June was likely in part a result of the extensive *Hydrurus foetidus* development during that period. Summer diatom production was low here as it was at sites 3 and 4, although the summer low began in July.

Many diatom genera on the substrate contributed to the total periphyton trends for the study period (Fig. 35). Certain genera such as *Cymbella* (mostly *C. ventricosa* and *C. parva*), *Synedra* (mostly *S. ulna*), and *Diatoma* (mostly *D. vulgare*) demonstrated high numbers on the slides collected on June 29, 1971. These genera were responsible in large part for the general periphyton increase of that period. *Cymbella* spp. were especially abundant in June. Floristic samples taken on June 15, at Stuart Station and selected sites downstream demonstrated extremely high numbers of *Cymbella*. *Diatoma vulgare* was also an important colonizer during this period.

The fall and winter *Diatoma vulgare-Gomphonema olivaceum* increase was much the same at Stuart Station as at sites 3 and 4 down canyon. However, increased *D. vulgare* colonization began in October rather than in November, and *G. olivaceum* colonization began increasing in November rather than later in the winter. *D. vulgare* began forming long prominent zigzag colonies in October which became a dominant part of the periphyton flora in November and

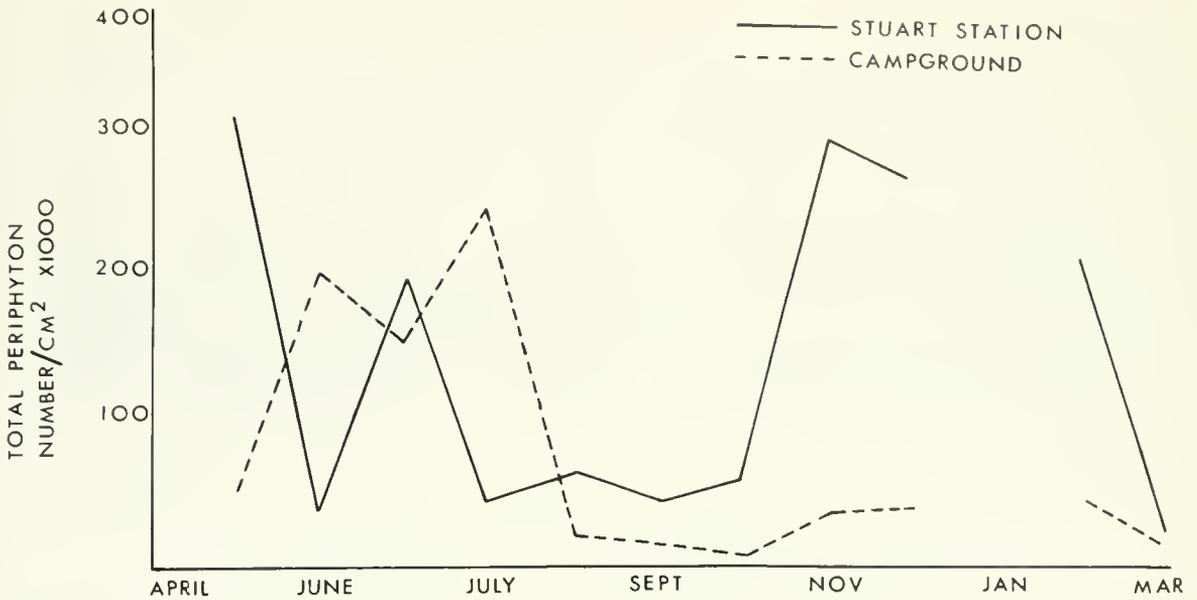


Fig. 34. Density of periphyton at the campground (site 4) and Stuart Station (site 6).

continued dominant through the winter until February 1972. *G. olivaceum* demonstrated a high colonization rate throughout the November-early May period.

*Nitzschia*, as a whole, demonstrated spring and fall highs and a summer low, thus following the general diatom trend. However, *N. acicularis* occurred mostly in the summer and early fall, when it was found in both the periphyton and nannoplankton from late June to November. *Cocconeis placentula* also occurred in greater abundance during the summer and early fall

months. It began colonizing in July and reached a peak in August and September, after which it decreased significantly.

Butcher (1932) described an *Ulvella-Cocconeis* community which was abundant in English calcareous rivers during summer months. An alga similar to *Ulvella*, but identified as *Protoderma viride* (after Prescott, 1962) was found colonizing glass slides at Stuart Station on September 15, 1971. *Protoderma* is a green alga exhibiting a prostate, often encrusted growth habit. In Huntington Canyon it becomes

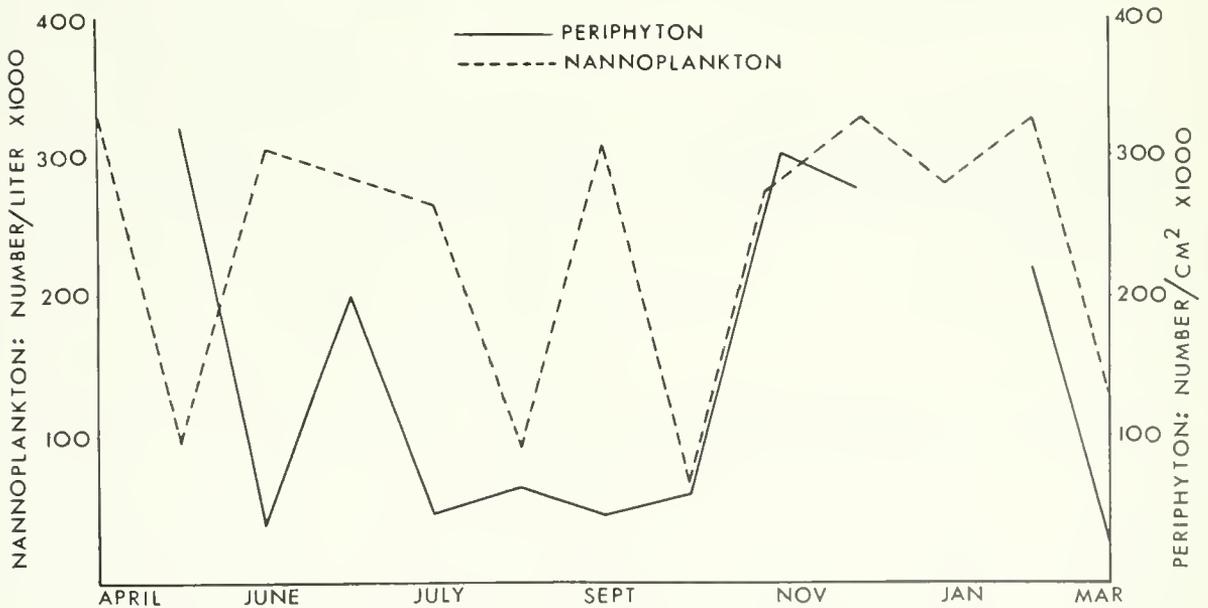


Fig. 35. Density of nannoplankton and periphyton at Stuart Station (site 6).

crusted with calcium carbonate and silt particles, making it difficult to identify except when on periphyton slides. This same species was found abundantly on slides at Lawrence in September and October 1971 and was an important alga in the benthic community there. It was likely also an important constituent of the crusts evident at sites 3 and 4 during this same early fall period, although accurate identification was difficult and *Protoderma* was absent on glass slides at these sites.

Four periphyton slides were retrieved from site 6 in September, and *Protoderma viride* was prevalent in three of the four, covering an estimated 10% to 20% of the surface of each slide. In October *P. viride* was found on only one of three slides and had decreased in importance on that slide. This alga therefore exhibited a short colonization period here and was probably not as effective in colonizing bare surfaces rapidly as some diatoms, such as *Cocconeis* and *Achnanthes*.

Visual observation of the stream bottom throughout the summer indicated that *Protoderma viride* was more prevalent than our data suggest. Such prostrate, often encrusted forms are rare in the plankton (Butcher, 1932), thus eliminating plankton data as a means of monitoring their production on the stream bed. Hence, *Protoderma viride* did not appear in nannoplankton counts from Stuart Station. This represents a weakness in subsampling and illustrates that total numbers of individuals in a flora as determined only by one sampling method may not always convey a true picture of the flora as a whole. *Protoderma viride* mats were few in number on the periphyton slides although each covered a considerable area, making it important in terms of total cover although insignificant in total number of cells when compared to diatoms on the same slide.

*Achnanthes minutissima* and *Cocconeis placentula* illustrate a similar problem of sampling. Table 5 compares the total number of *Achnanthes minutissima* and *Cocconeis placentula* cells per cm<sup>2</sup> and their relative abundance on periphyton slides for the summer and early fall of 1971.

Table 5. Density in cells/cm<sup>2</sup> and relative abundance of *Achnanthes* and *Cocconeis* in the periphyton of Site 6 July-October 1971.

GENUS	7/30	8/20	9/15	8/10
<i>Achnanthes</i>				
Density	29,500	37,290	32,989	5,148
Composition	61.2%	53.1%	61.2%	8.0%
<i>Cocconeis</i>				
Density	2,750	7,900	3,851	762
Composition	5%	11.2%	7.1%	1.2%

These data show both of these genera to be abundant in the summer flora at Stuart Station, although *Achnanthes minutissima* appears to be much more important. However, cells of this species are small and occur on branched mucilaginous stalks, often with many cells appressed together. *Cocconeis placentula*, on the other hand, is larger and grows adnate to the substrate. The microscope slides from this site in September were visually examined prior to cleaning, and *C. placentula* appeared as one continuous sheet of cells covering the substrate. It thus appeared to be more important as a substrate cover than *A. minutissima*, which was present in higher numbers. Therefore, care must be used in sampling, and, whenever possible, subjective description should accompany numerical characterization describing a total flora as it occurs in place.

Nannoplankton at Stuart Station were relatively constant throughout the year except for lows in May, August, and October 1971, and March 1972 (Fig. 36). The high winter and spring nannoplankton levels here were supported by similar high production on the substrate. As periphyton production declined in July and August, the number of nannoplankton also dropped. In September a large number of *Nitzschia* spp. and *Navicula* spp. released from the substrate caused an increase in the number of nannoplankton. An October low occurred at site 6 as it did at site 4.

Generally speaking, nannoplankton levels showed much less fluctuation at Stuart Station than at sites 3 and 4 (Fig. 37), whereas periphyton levels fluctuated more (Fig. 34). Nannoplankton levels were also generally lower at site 6 than at sites 3 and 4 (Fig. 37). This was due to the collection of diatoms in the plankton as the current carried them downstream, thus giving higher levels lower in the drainage. However, many fluctuations and occasional lack of correspondence between nannoplankton and periphyton data suggest that many factors along the stream affect these levels. For instance, many algae, especially nondiatom species, are destroyed as they travel downstream. The abundance of filamentous conjugales at Stuart Station and their paucity at sites 3 and 4 illustrate this fact. Likewise, localized habitat differences are also extremely important in creating differences between floras of different parts of the stream. *Hannaea arcus*, for instance, was important at the plant site and campground, but was almost nonexistent at site 6. A noteworthy lack of euplankton was also evident at Stuart Station.

Successive collections of nannoplankton from

Total Nannoplankton: I=50 algae ml



Selected Genera: I=25 algae ml

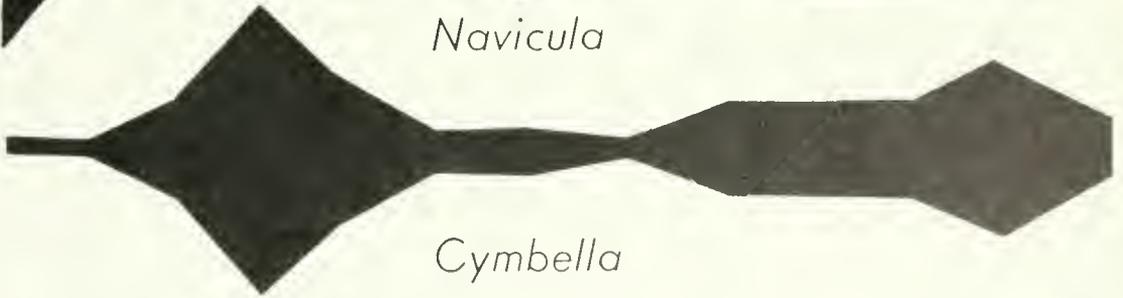
Apr. June July Sept. Nov. Jan. Mar.



*Nitzschia*



*Navicula*



*Cymbella*



*Diatoma*

Fig. 36. Seasonal distribution of selected nannoplankton at Stuart Station (site 6)

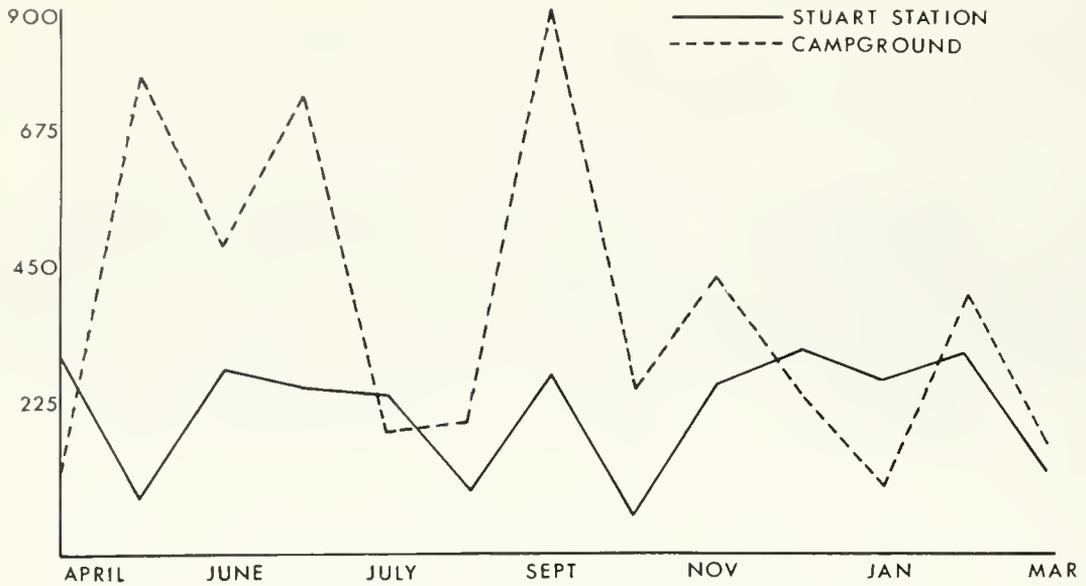


Fig. 37. Density of nannoplankton at the campground (site 4) and Stuart Station (site 6).

Stuart Station were made on February 19 and 23, 1971. The results of these two samples are summarized in Table 6. The close correlation of these two counts supports the reliability of the sampling techniques used and also indicates relatively stable conditions in the creek during this four-day period.

In summary, the flora at Stuart Station demonstrated many species of diatoms on the substrate throughout the year with an *Achnanthes-Cocconeis-Protoderma* community prevalent in summer and early fall. Filamentous blue green algae were important here throughout the year,

especially in the summer-fall period. *Hydrurus foetidus* was abundant in spring and *Cladophora glomerata* was quite prevalent in fall. The dominant diatoms were *Navicula*, *Cymbella*, *Gomphonema*, *Nitzschia*, *Achnanthes*, *Synedra*, *Cocconeis*, *Diatoma* and *Surirella*.

#### Bear Canyon (Site 7)

Sampling at Bear Canyon was conducted from July to November 1971. The stream gradient at this site was not steep and the stream ran clear, usually with lower water flow than at Stuart Station 9 miles downstream. Green and blue green algae were significant in the flora at Bear Canyon. *Ulothrix tenuissima* was highest in the net plankton in June, indicating that it was an active stream bottom colonizer during late spring. *Oedogonium* sp. and *Cladophora glomerata* were prevalent throughout the summer in the plankton, and *Oedogonium* sp. was also abundant on the substrate. Long streamers of this alga were found on stones and a submerged clay shelf in September and October. In September *Oedogonium* sp. covered 12.3% of the substrate and occurred with 79% frequency, and in October it covered 7.2% of the substrate and occurred in 86% of the plots studied. In October *Spirogyra* sp. filaments were intermingled with the *Oedogonium* sp. strands. In November the decrease in abundance of *Oedogonium* sp. was accompanied by the initiation of growth of *Hydrurus foetidus* on the substrate. Much of the creek bottom at Bear Canyon and upstream was sandy and provided little habitat for the attachment of benthic algae, and consequently,

Table 6. Nannoplankton totals for February 19 and February 23, 1972, from Stuart Station.

	February 19, 1972		February 23, 1972	
	No. Per Liter	Percent Composition	No. Per Liter	Percent Composition
<i>Navicula capitata</i>	14,595	4.5	8,340	2.3
<i>Navicula tripunctata</i>	13,900	4.3	18,070	5.0
Other				
<i>Navicula</i>	37,530	11.3	56,990	15.7
<i>Cymbella</i>	115,370	35.2	125,100	34.4
<i>Gomphonema</i>	33,350	10.2	38,225	10.5
<i>Synedra</i>	23,630	7.2	22,935	6.3
<i>Nitzschia</i>	47,955	14.7	47,260	13.0
<i>Achnanthes</i>	24,325	7.1	21,545	6.5
<i>Diatoma vulgare</i>	4,170	1.3	9,730	2.7
<i>Diatoma hiemale</i>	1,390	.4	1,390	.4
<i>Gyrosigma</i>	695	.2	695	.2
<i>Surirella</i>	2,085	.6	4,170	1.1
<i>Cocconeis</i>	4,170	1.3	3,475	1.0
Other diatoms	4,170	1.3	5,500	1.5

the total amount of attached algae was low in these areas.

The seasonal cycle of *Hydrurus foetidus* at Bear Canyon probably was much the same as at Stuart Station. It appeared in the late fall and was likely present throughout the winter, since it was prevalent in the early spring when the ice broke. Because of the high altitude and consequent lower temperature of the water here, *H. foetidus* persisted longer into the summer than at sites lower in the drainage. Thus, this species was abundant in the net plankton as late as June 29, and still present in the July 30, 1971, sample.

Growth of *Cladophora glomerata* was not extensive at Bear Canyon, and when found, it was covered with numerous epiphytic diatoms such as *Cocconeis placentula* and *Gomphonema olivaceum*. Filaments of several conjugate algae were retrieved in net samples during the summer and early fall months. These algae largely originated in protected environments upstream from Bear Canyon where luxuriant mats of *Spirogyra* sp. were observed in October. *Spirogyra* sp. was more prevalent in these samples in the fall while *Mougeotia* sp. and *Zygnema* sp. occurred mostly during the summer.

*Closterium* spp. (mostly *C. moniliferum*) were important in the creek at Bear Canyon. In July their density in the net plankton was 67.5 cells per liter and in August they were present at 42 cells per liter. *Closterium* production in the creek occurred in the substrate in protected areas, among mats of filamentous algae and in partially submerged streamside vegetation. These same habitats were also the site of production for *Trachelomonas robusta*, which appeared in the creek in August, September, and November.

Nannoplankton samples were taken during the August-November period. The total numbers varied somewhat from the figures obtained at Stuart Station and in general were more stable and quite consistently high (Table 7).

One reason for the stability in nannoplankton levels at Bear Canyon was a large occurrence of *Nitzschia palea* and *Gomphonema olivaceum* in September, even though most other genera decreased in numbers during this period. A similar *Nitzschia* sp. pulse contributed to the Stuart Station nannoplankton in September, but the numbers of most other genera increased as

well, thus producing a large pulse. This September increase at Stuart Station was followed by a yearly low in October, which also occurred at sites 1, 4, and Bear Canyon. A November nannoplankton pulse was noted at Bear Canyon as well as at other sites, caused by a general increase in the numbers of most diatom genera.

A second reason for the plankton stability in the upper drainage of Huntington Creek is attributed to the terrestrial environment. The terrain upstream from Bear Canyon consists of large grassy valleys and rolling mountains. Consequently, late summer storms have less effect on the right fork here than in the canyon immediately above Stuart Station where the mountain sides are steep and easily eroded during storms, thus raising the water level rapidly and increasing the silt load in the creek. This increased silt load and high water is likely responsible for scouring diatoms from the substrate and thereby altering nannoplankton counts.

#### Tie Fork Pond (Site 5)

The lentic environment of Tie Fork Pond provided a habitat uniquely different from that of the swift flowing Huntington Creek, and thus the flora here contained many algae which did not occur in the creek. In addition, the cycles of occurrence of some genera common to both environments were very different.

Physical and chemical properties of the water in Tie Fork Pond differed in several important aspects from that of the neighboring portion of Huntington Creek. Silica fluctuated from levels below to levels above those found in the creek waters. Hardness was usually greater in the pond, with magnesium hardness being much higher and calcium hardness being somewhat lower than in the creek. Total alkalinity in the pond was higher and carbonate alkalinity was usually present along with bicarbonate alkalinity. Turbidity was also higher in the pond because of abundant planktonic algal growth, and water temperature was usually 5–10°C higher since the small pond was easily and rapidly warmed by the sun.

The pond was completely frozen during the winter. On March 11, 1972, it had begun to thaw, but neither visible benthic algae nor plankton were evident. A nannoplankton sample taken from the pond yielded only a few diatom frustules which appeared to be left from the previous year.

In April 1971, the pond was completely thawed, and the remains of the previous year's *Chara* mat were evident on the bottom. Filamentous algae such as *Oedogonium* sp., *Spiro-*

Table 7. Nannoplankton totals in cells per liter for Stuart Station and Bear Canyon for August-November 1971.

	Aug.	Sept.	Oct.	Nov.
Stuart Station	116,741	310,271	66,435	282,768
Bear Canyon	215,576	218,223	112,295	265,056

*gyra* sp., and *Microspora* sp. were already floating on the surface of the pond, indicating that spring colonization is rapid. The plankton during this month were predominately diatoms including *Navicula*, *Cymbella*, *Gomphonema*, *Synedra*, *Nitzschia*, *Achnanthes* and *Cocconeis*.

Filamentous algae developed throughout the summer (Fig. 38). By June a new growth of *Chara vulgaris* was evident on the bottom and *Spirogyra* spp. filaments were abundant throughout the pond. *Mougeotia* spp. and *Zygnema* sp. mats were abundant near the south shore of the pond where a culvert drained under the highway into the creek. In July *Potamogeton* sp. was abundant in the pond and the *Potamogeton-Chara* association completely covered the bottom. *Mougeotia* (mostly *M. genuflexa*) development reached a climax during this month and thoroughly saturated the water when it formed bright green fluffy "clouds" throughout the pond. This summer development of *Mougeotia* correlated closely with its appearance in the net plankton of the creek throughout the canyon, indicating that the same developmental cycle occurred in other habitats supporting *Mougeotia* growth. *Spirogyra* spp. development occurred mostly in late summer and early fall in the pond, similar to other localities.

By August the water level in Tie Fork Pond had fallen considerably and very little free water above the *Chara-Potamogeton* cover was present. Consequently, the filamentous green algae declined considerably and generally became restricted to narrow channels near the culvert. Conditions in September were much the same except that a new bloom of *Mougeotia* (mostly *M. genuflexa*) and *Spirogyra* sp. occurred in the limited free water in the pond. The late summer environment of August and September allowed the rapid development of *Oscillatoria limosa* and *O. tenuis* and, to a lesser extent, *Lyngbya major* and *L. aeruginoso-coerulea*.

The water level rose again in October and by November, a 1-inch layer of ice covered the pond. Extensive decomposition of the summer aquatic vegetation began beneath the ice, making the water black and putrid.

Tie Fork Pond supported a large population of diatoms throughout the study, although several genera, such as *Gomphonema*, *Synedra*, *Achnanthes*, and *Cymbella*, declined in the summer months. Other genera, such as *Nitzschia* (including *N. palea*, *N. sigmoidea*, and *N. linearis*), *Epithemia* (mostly *E. gibba*), *Fragilaria crotonensis*, and *F. virescens*, were very abundant in the summer (Fig. 39). *Nitzschia* spp. fluctuated throughout the study period from April to October. *Epithemia* (including *E. gibba*,

*E. turgida*, and *E. argus*) showed a maximum of 159,750 cells per liter occurring in July.

*Fragilaria crotonensis* and *F. virescens* occurred throughout the summer. *F. crotonensis* occurred in highest numbers in late June and *F. virescens* in July. The bloom of *F. crotonensis* was apparently much earlier here than in the reservoirs on the left fork of Huntington Creek, where the bloom occurred in October.

The many nondiatom species present in the nanoplankton and the large number of net plankton during the summer in Tie Fork Pond are characteristic of fresh water lentic environments. True plankters in the nanoplankton here included: *Trachelomonas robusta*, which increased in density throughout the summer to a peak in October; *Scenedesmus* (mostly *S. bijuga*), which was most abundant in July (113,125 colonies per liter) but persisted in the flora until October; *Nephrocytium lunatum*, which appeared in high numbers in July, declined in August and September, and was essentially gone by October; the desmid *Sphaerosoma* sp., which composed 25% of the flora in August and September, appearing mostly as single cells rather than in its typical colonial form; *Cosmarium* sp., which occurred throughout the season and pulsed slightly in July and August; and *Staurastrum* sp., which occurred from June 29 to October 8, being highest in July and August. These last two genera were of minor importance in relation to the entire flora, never comprising more than 3% of the total nanoplankton.

True plankters in the net plankton included: *Paudorina morum*, which increased from July to a maximum density in September of 400 colonies per liter; *Euglena* spp., which were prevalent throughout the season, occurring in greatest numbers in August and September when they reached 2,750 cells per liter; *Closterium* (mostly *C. moniliferum*), which appeared occasionally after May; planktonic Chroococcales (Cyanophyta) which occurred from July to October; and species in Pyrrophyta (mostly *Peridinium cinctum*), which appeared in low numbers in July, August, and October. Most of these algae were not significant in numbers. Desmids, for instance, were generally rare in Tie Fork Pond and throughout the drainage since they are more adapted to softwater and acid habitats (Prescott, 1962) than to calcareous waters such as those of Huntington Canyon.

Many euplanktonic algae were also found on periphyton slides. Most of these probably settled out of the water onto the slides and became a part of the community developing there. For instance, *Scenedesmus* was quite prevalent on the slides throughout the summer. Butcher (1932)

Total Net Plankton  
I=2500 algae l



Selected Genera  
I=2000 algae l

Apr. June July Sept.

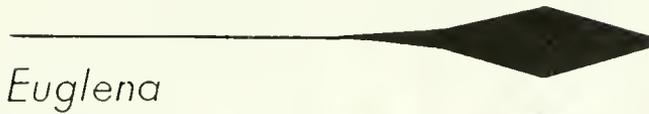
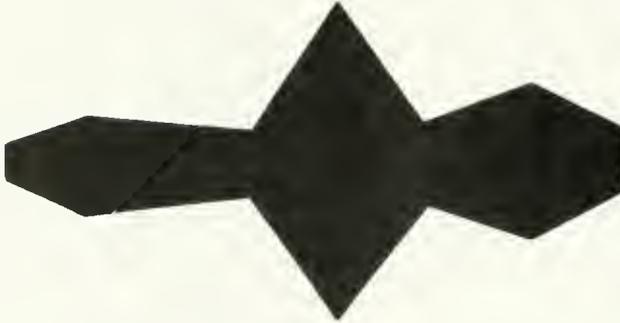


Fig. 38. Seasonal distribution of selected net plankton at Tie Fork Pond (site 5)

Total Nannoplankton  
1=100 algae ml



Selected Genera  
1=25 algae ml

Apr. June July Sept.



*Nitzschia*



*Epithemia*



*Scenedesmus*



*Fragilaria*

FIG. 50. Seasonal distribution of selected nannoplankton at Tie Fork Pond (site 5).

discussed *Scenedesmus* and other algae such as *Pediastrum* and *Cyclotella* that are cosmopolitan in distribution and usually found on the bottom of ponds, ditches, and slow-flowing streams where they live and reproduce until they are disturbed and become a part of the plankton.

Production of diatoms on glass slides in Tie Fork Pond was generally less than in Huntington Creek, but since no current continually washed the diatoms downstream, numbers in the plankton of the two habitats were comparable.

Trends similar to those observed in Tie Fork Pond occurred in other ponds throughout the Huntington Canyon drainage. One such pond is located adjacent to site 2. This pond maintained an extensive mat of *Chara vulgaris* throughout the year, with continual production and decomposition adding to the 2 feet of black organic mud on the bottom.

A pond located about 2 miles east of the plant site was filled with moss rather than *Chara*. In May this pond contained *Microspora* sp. much as Tie Fork Pond and a bloom of *Fragilaria virescens* which continued through early June. *Microspora* sp., *Mougeotia* sp. and *Spirogyra* sp. were abundant here in the early spring, and *Oscillatoria limosa* and *O. tenuis* became abundant in late June. *Epithemia gibba* was present from May to July and *Navicula* sp. and *Nitzschia* sp. were abundant in early summer. Green algae declined generally through the summer, while filamentous blue green algae, especially *Oscillatoria tenuis* and *O. limosa*, in-

creased greatly. Desmids were more abundant in this pond than in any other habitat sampled in Huntington Canyon. The dominant desmid was *Closterium moniliferum*, common from July to October.

A similar mossy pond is located one mile above Stuart Station (Fig. 40). The spring flora of this pond included *Vaucheria geminata*, *Mougeotia parvula*, and *Ulothrix tenuissima*. In June, *Spirogyra dubia* occurred and *Vaucheria geminata* disappeared. *Draparnaldia plumosa* was abundant in June, as were *Chlamydomonas* sp., *Closterium moniliferum*, *C. erhenbergii*, and *C. rostratum*. These desmids, along with *Cosmarium* sp., were also collected throughout the summer in floristic samples. *Mougeotia genuflexa* bloomed in July and *Spirogyra dubia* and *Oedogonium* sp. bloomed in August. *Euglena* (including *E. acus*) was often present in the *Spirogyra* mats. *Epithemia* sp. (mostly *E. gibba*) was present throughout the season in this pond and was most prevalent in August. Filamentous algae became rare by October except for *Oedogonium* sp. *Spirogyra dubia* became prevalent again in November and was accompanied by a bloom of *Synedra* (mostly *S. ulna*).

The third pond is adjacent to the Bear Canyon sampling site. Its flora consisted of *Spirogyra* sp., abundant throughout most of the season except for July, *Nitzschia* sp. and *Cymbella* sp. in June, and *Zygnema* sp. in July and August. *Epithemia gibba* was also abundant in August, as were several species that were also found in Tie Fork Pond, including *Oscillatoria limosa*, *O. tenuis*, and desmids. *Staurastrum custephanum*, especially, was common here in July-September.

In September and October *Amphipleura pelucida* appeared abundantly in this pond, and *Epithemia gibba* continued abundant. Early fall filamentous algae included *Spirogyra* sp., *Zygnema* sp., *Mougeotia* sp., and *Vaucheria geminata*. *Tolypothrix lanata* was prevalent in September and *Oscillatoria tenuis* became abundant in October. *Chara vulgaris* was present in this pond during the summer and fall season but did not form the extensive mats found in Tie Fork Pond.

#### Algal Flora of Huntington Canyon

Huntington Creek is a cold, clear, fast-flowing, calcareous stream, which supports a diverse algal flora adapted to these conditions. Diatoms are the most abundant algae present, occurring throughout the year on the substrate and in the plankton. The dominant genera are *Navicula*, *Cymbella*, *Gomphonema*, *Nitzschia*, *Synedra*, *Achnanthes*, and *Diatoma*. Diatoms show maxi-



Fig. 40. Shallow pond adjacent to the Right Fork of Huntington Creek. These small ponds represent one source of euplanktonic algae in the flora of Huntington Creek. Photographed April 28, 1972.

num production on the substrate in late spring and early summer and in late fall and early winter.

Benthic diatoms are the main contributors to the nannoplankton, and the composition and seasonal fluctuations of the nannoplankton are largely determined by similar fluctuations on the substrate. Water level fluctuations, water temperature changes, and mechanical disturbances also appear to be factors influencing nannoplankton levels.

Periphyton colonization is higher in the right fork of Huntington Creek than lower in the canyon, and nannoplankton amounts increase as the water moves downstream. However, the increase is not entirely cumulative since destruction of cells occurs in the turbulent water.

True planktonic algae, including *Asterionella formosa*, *Fragilaria crotonensis*, *Dinobryon cylindricum*, *Pandorina morum*, and *Ceratium hirundinella* occur in the plankton of Huntington Creek. These algae are thought to originate in reservoirs on the upper drainage of the left fork of Huntington Creek, and their occurrence in the creek basically correlates with algal cycles in these reservoirs.

Filamentous algae are also important constituents of the Huntington Creek algal flora. *Hydrurus foetidus* grows profusely from late winter to early summer, especially in the upper reaches of the canyon, forming thick mucilaginous growths on stones and rocks on the stream bed. Blue green algae are present on the creek substrate throughout the year, but show highest production during summer and fall when encrusted communities form on the stony substrate. Other filamentous algae present in the canyon include *Ulothrix tenuissima*, *U. zonata*, and *Stigeoclonium stagnatile*, which occur mostly in the spring, and *Mougeotia* spp., *Spirogyra* spp., *Zygnema* spp., and *Vaucheria geminata*, which grow in backwaters, pools, and ponds along the creek through the summer and fall.

Fragments from these filamentous algae are an important source of net plankton. *Hydrurus foetidus* fragments are prevalent in the plankton in the spring, and filaments of blue green algae occur in large quantities during October and November. Most filamentous green algae occur during the summer months, and they are most prevalent in the right fork where protected areas along the stream channel allow for their de-

velopment (Fig. 41). Most of these filamentous algae are quickly destroyed as they are carried downstream by the current.

*Cladophora glomerata* and *Oedogonium* sp. also occur in significant numbers in Huntington Creek. *C. glomerata* is most abundant in the lower reaches of the right fork during the fall, and *Oedogonium* sp. is most abundant in the upper right fork during the same period. These genera are likewise prevalent in the lower Huntington Creek as it flows through Castle Valley, where they form long streamers from the stones during late spring and early summer.

*Chara vulgaris* occurs in lower Huntington Creek from July to December, forming large mats and sometimes filling large sections of the stream channel.

Diatoms important in the flora of the lower Huntington Creek include *Navicula*, *Nitzschia*, *Diatoma*, *Gomphonema*, *Synedra*, *Surirella*, *Cymbella*, *Cocconeis*, *Achnanthes*, and *Cyclotella*.

Ponds in the drainage support abundant summer algal floras. Filamentous algae, desmids, and such motile genera as *Chlamydomonas*, *Euglena*, and *Trachelomonas* are common constituents of these floras.

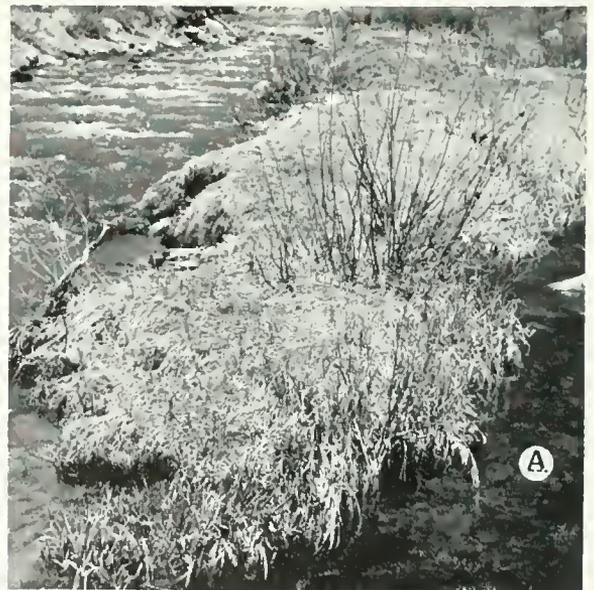


Fig. 41. A small tributary of Huntington Creek (A) with profuse growths of *Microspora willeana* and *Cladophora glomerata*. Photographed April 28, 1972.

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APPENDIX I

NET PLANKTON, NANOPLANKTON, PERIPHYTON, AND  
VISIBLE BENTHIC ALGAL TABLES

Table 8. Number of organisms per liter and relative abundance of net plankton at Lawrence (Site 1)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Chroococcales	—	—	18.5 12.1%	—	—	3.8 5.9%	2.9 14.1%	—	—	—	—	—	—
<i>Oscillatoria</i>	23.0 59.7%	—	3.9 2.5%	7.5 1.4%	—	—	1.9 9.2%	—	—	4.5 59.2%	4.1 16.3%	3.8 2.9%	15.0 3.2%
Other Oscillatoriaceae	—	—	—	—	—	—	3.0 14.8%	1.9 23.6%	20.0 87.3%	.6 7.8%	.5 2.0%	2.5 1.9%	—
<i>Chlamydomonas</i>	—	—	43.0 28.1%	—	—	—	1.9 9.2%	—	—	—	—	—	—
<i>Pandorina morum</i>	—	—	—	53.5 10.5%	—	—	.6 3.0%	—	—	—	—	—	—
<i>Pediastrum</i>	—	—	—	15.0 2.8%	—	—	—	—	—	—	—	—	—
<i>Clothrix</i>	—	—	7.7 5.0%	—	—	—	—	—	—	—	14.4 57.4%	109.7 84.7%	246.0 51.7%
<i>Stigeoclonium</i>	—	—	—	—	—	—	—	—	—	.6 7.8%	—	—	—
<i>Oedogonium</i>	—	7.7 5.8%	49.0 32.0%	423.0 80.3%	25.5 69.4%	22.5 35.3%	2.5 12.3%	.6 7.8%	—	1.9 25.0%	4.1 16.3%	5.0 3.9%	36.0 7.6%
<i>Cladophora glomerata</i>	15.5 40.3%	86.0 64.9%	18.5 12.1%	18.0 3.4%	3.8 10.2%	—	—	1.7 21.5%	—	—	—	5.5 4.2%	36.0 7.6%
<i>Spirogyra</i>	—	—	—	—	—	—	—	.6 7.8%	—	—	—	3.0 2.3%	15.0 3.2%
<i>Zygnema</i>	—	—	—	—	—	—	—	—	—	—	1.5 6.0%	—	—
<i>Closterium</i>	—	7.7 5.8%	—	3.8 .7%	3.8 10.2%	—	—	—	—	—	—	—	—
<i>Cosmarium</i>	—	—	—	—	—	7.5 11.7%	—	—	—	—	—	—	—
<i>Staurastrum</i>	—	—	—	—	—	—	.6 3.1%	1.3 15.8%	—	—	—	—	—
<i>Pleurotaenium</i>	—	—	—	—	—	—	—	.6 7.8%	—	—	—	—	—
<i>Euglena</i>	—	31.0 23.4%	12.4 8.1%	3.8 .7%	3.8 10.2%	—	—	.6 7.8%	1.7 7.4%	—	5 2.0%	—	—
<i>Phacus</i>	—	—	—	—	—	—	—	—	1.3 5.4%	—	—	—	—
<i>Ceratium hirundinella</i>	—	—	—	—	—	30.0 47.1%	6.7 33.0%	—	—	—	—	—	—
<i>Vaucheria</i>	—	—	—	—	—	—	—	.6 7.8%	—	—	—	—	22.5 4.7%
<i>Hydrurus foetidus</i>	—	—	—	—	—	—	—	—	—	—	—	—	105.0 22.0%
Total Algae	38.5	132.4	153.0	526.5	36.8	63.8	20.1	7.9	23.0	7.6	25.1	129.5	475.5

Table 9. Number of organisms per liter and relative abundance of nanoplankton at Lawrence (Site 1)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
<i>Cyclotella</i>	—	—	1,042 .4%	4,180 2.9%	46,200 11.8%	79,250 36.4%	25,716 13.9%	15,567 18.6%	11,620 2.9%	5,560 2.0%	22,240 2.8%	48,650 2.5%	27,800 1.2%
<i>Diatoma tenuis</i>	4,010 1.1%	4,170 1.3%	4,170 1.6%	4,170 .7%	—	—	—	—	—	—	—	58,380 2.9%	69,500 3.0%
<i>Diatoma vulgare</i>	1,390 .4%	8,060 2.4%	5,550 2.1%	696 .5%	—	—	—	—	—	695 .2%	11,120 1.4%	—	13,900 .6%
<i>Fragilaria</i>	798 2%	—	—	—	—	—	—	—	—	—	—	—	—
<i>Meridion</i>	798 2%	—	—	—	—	—	—	—	—	—	—	—	—
<i>Synedra cf. pulchella</i>	6,344 1.7%	12,230 3.7%	9,720 3.7%	5,560 3.9%	—	—	—	—	6,670 1.6%	—	—	—	—
<i>Synedra cf. ulna</i>	30,126 8.3%	20,570 6.1%	9,312 3.6%	11,120 7.9%	4,180 1.1%	348 .2%	1,668 .9%	20,961 25.1%	160,015 41.2%	41,700 14.8%	278,000 35.2%	497,000 24.5%	291,900 12.7%
<i>Achnanthes</i>	6,344 1.7%	—	1,390 .5%	696 .5%	8,360 2.1%	35,500 16.3%	44,500 24.0%	13,900 16.6%	29,190 7.2%	20,850 7.4%	48,920 6.2%	136,220 6.7%	97,300 4.2%
<i>Cocconeis</i>	798 .2%	—	—	4,338 3.1%	5,560 1.4%	52,500 24.1%	9,035 4.9%	5,837 7.0%	23,240 5.7%	11,676 4.1%	44,480 5.6%	136,220 6.7%	194,600 8.4%
<i>Rhoicosphenia</i>	—	1,390 .4%	—	—	—	—	—	—	—	1,390 .5%	5,560 .7%	—	—
<i>Amphiprora</i>	—	—	348 .1%	696 .5%	348 .1%	—	—	696 .8%	2,780 .7%	695 .2%	—	—	—
<i>Gyrosigma- Pleurosigma</i>	1,589 .4%	2,780 .8%	4,448 1.7%	4,448 3.1%	89,250 22.8%	4,170 1.9%	1,390 .8%	2,780 3.3%	7,505 1.9%	4,726 1.7%	11,120 1.4%	29,190 1.4%	13,900 .6%
<i>Navicula cf. truncata</i>	15,888 4.4%	11,120 3.3%	3,057 1.2%	1,042 .7%	10,700 2.7%	2,085 1.0%	—	—	—	—	—	—	83,400 3.6%
Other <i>Navicula</i>	88,959 24.3%	139,000 41.7%	97,300 37.1%	36,488 25.8%	40,387 10.4%	15,919 7.3%	12,075 6.5%	6,550 7.8%	50,040 12.4%	65,886 23.3%	111,200 14.1%	369,740 18.3%	333,600 14.5%
<i>Pinnularia</i>	—	—	—	—	—	—	—	—	—	—	—	9,730 .5%	—
<i>Gomphonema gracile</i>	—	—	—	—	—	—	68,805 37.1%	7,060 8.3%	26,062 6.4%	7,506 2.7%	—	77,840 3.8%	27,800 1.2%
<i>Gomphonema ohvaceum</i>	23,543 6.5%	6,670 2.0%	1,390 .5%	3,480 2.5%	11,275 2.9%	1,668 .8%	4,865 2.6%	2,780 3.3%	348 .1%	7,505 2.7%	71,160 9.0%	194,600 9.6%	542,100 23.5%
<i>Cymbella</i>	109,611 30.0%	1,390 .4%	2,367 1.0%	2,088 1.5%	8,360 2.1%	3,750 1.7%	1,668 .9%	—	3,335 .8%	2,085 .7%	33,360 4.2%	68,180 3.4%	180,700 7.8%
<i>Epthemia</i>	—	—	—	—	—	—	—	—	—	—	—	—	13,900 .6%
<i>Nitzschia arcularis</i>	—	—	2,780 1.1%	6,950 4.9%	3,480 .9%	696 .3%	1,390 .8%	1,668 2.0%	2,085 .5%	—	—	—	—
<i>Nitzschia denticula</i>	—	—	—	—	—	1,042 .5%	1,168 .6%	1,042 1.2%	4,170 1.0%	—	—	—	55,600 2.4%
Other <i>Nitzschia</i>	16,760 12.8%	94,520 28.3%	104,250 40.9%	41,800 29.5%	163,000 41.7%	18,632 8.6%	10,508 5.7%	2,780 3.4%	65,330 16.2%	92,296 32.7%	115,640 14.6%	291,900 14.4%	305,800 13.3%
<i>Suriella</i>	22,874 6.3%	31,690 9.5%	13,900 5.3%	3,480 2.5%	—	—	1,390 .8%	348 .4%	12,510 3.1%	20,015 7.1%	37,800 4.8%	107,030 5.3%	55,600 2.4%
Other Pennales	4,168 1.2%	—	—	11,120 7.8%	—	—	—	—	—	—	—	—	—
<i>Scenedesmus</i>	—	—	—	—	—	348 .2%	—	—	—	—	—	—	—
Total Algae	364,000	333,590	261,024	139,224	391,100	215,908	184,178	81,969	404,900	282,586	790,600	2024,680	2307,400

Table 10. Number of organisms per cm<sup>2</sup> and relative abundance of periphyton on glass slides at Lawrence (Site 1)

Algae	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	2/19 1972	3/11 1972
<i>Cyclotella</i>	810 .3%	—	304 .7%	2,045 10.0%	20,900 21.6%	6,075 5.7%	6,281 3.2%	1,523 1.2%	2,574 .6%	304 3.7%	288 1.1%
<i>Diatoma</i>	9,320 1.9%	204 .7%	102 .2%	—	1,020 1.1%	52 .1%	206 .1%	1,235 .9%	48,392 11.0%	—	536 2.1%
<i>Fragilaria</i>	404 .1%	—	—	—	—	206 .2%	309 .1%	—	—	—	—
<i>Synedra</i> cf. <i>pulchella</i>	293,211 60.9%	7,157 24.9%	10,000 21.8%	—	—	—	—	—	—	—	—
<i>Synedra</i> cf. <i>ulna</i>	18,800 3.9%	1,132 3.9%	849 1.9%	479 2.4%	1,624 1.7%	2,368 2.2%	7,619 3.8%	49,999 38.2%	115,833 26.3%	2,317 27.8%	4,530 17.6%
<i>Achnanthes</i>	19,411 4.0%	204 .7%	3,090 6.7%	68 .3%	26,000 26.9%	51,996 49.0%	—	27,594 21.1%	62,292 14.1%	309 13.0%	412 1.6%
<i>Cocconeis</i>	—	—	10,400 22.7%	3,889 19.0%	22,100 22.9%	5,910 5.6%	5,354 2.6%	2,183 1.7%	5,150 1.2%	1,081 3.7%	535 2.1%
<i>Anphiprora</i>	2,030 .4%	—	102 .2%	—	—	—	103 .1%	—	2,059 .5%	—	—
<i>Gyrosigma</i> - <i>Pleurosigma</i>	38,822 8.1%	808 2.9%	204 .4%	4,727 23.0%	—	—	618 .3%	288 .2%	515 .1%	—	700 2.7%
<i>Navicula</i>	69,610 14.5%	6,152 21.4%	3,218 7.0%	5,309 26.0%	8,108 8.4%	4,223 4.0%	16,268 8.2%	17,009 13.0%	56,115 12.7%	927 11.1%	6,177 24.0%
<i>Gomphonema</i> <i>gracile</i>	—	—	—	—	—	—	17,297 8.7%	—	—	309 3.7%	—
<i>Gomphonema</i> <i>olivaceum</i>	4,040 .8%	1,886 6.6%	1,320 2.9%	34 .2%	2,130 2.2%	25,638 24.0%	2,368 1.2%	10,996 8.4%	41,185 9.3%	1,236 15.3%	5,231 20.4%
<i>Cymbella</i>	810 .2%	2,216 7.7%	2,150 4.7%	625 3.0%	—	247 .2%	1,441 .7%	1,359 1.0%	2,574 .6%	309 3.7%	1,770 6.9%
<i>Nitzschia</i>	—	8,186 28.5%	4,422 9.6%	2,238 11.0%	4,060 4.2%	4,716 4.5%	133,851 67.4%	15,650 12.0%	80,311 18.2%	1,081 13.0%	3,583 13.9%
<i>Surirella</i>	14,127 2.9%	486 1.8%	304 .7%	34 .2%	—	—	—	2,347 1.8%	14,930 3.4%	463 5.6%	1,235 4.8%
Other Pennales	1,210 .3%	304 1.1%	2,250 4.9%	138 .7%	—	—	—	—	—	—	124 .5%
Chroococcales	4,860 1.0%	—	—	—	408 .4%	—	—	—	—	—	—
<i>Oscillatoria</i>	3,240 .7%	—	812 1.8%	410 2.0%	—	—	—	124 .1%	515 .1%	—	288 1.1%
Other Oscillator- iaceae	—	—	—	—	9,300 9.6%	—	—	—	—	—	—
<i>Ulothrix</i>	—	—	—	—	—	—	—	—	3,604 .8%	—	288 1.1%
<i>Protoderma</i>	—	—	—	—	—	3,192 3.0%	3,706 1.9%	—	—	—	—
<i>Stigeoclonium</i>	—	—	—	—	—	—	—	—	3,089 .7%	—	—
<i>Oedogonium</i>	—	—	2,040 4.4%	150 .7%	812 .8%	1,071 1.0%	2,578 1.3%	412 .3%	1,544 .3%	—	—
<i>Cladophora</i>	—	—	849 1.9%	—	204 .2%	—	618 .3%	—	515 .1%	—	—
Other Filamen- tous Chlorophyta	—	—	2,040 4.4%	—	1,220 1.3%	—	—	—	—	—	—
<i>Closterium</i>	—	—	612 1.4%	50 .2%	—	—	—	—	—	—	—
<i>Cosmarium</i>	—	—	—	—	—	52 .1%	—	—	—	—	—
<i>Euglena</i>	1,210 .3%	—	406 .9%	175 .9%	—	—	—	—	—	—	—
Total Algae	481,915	28,735	45,474	20,372	97,886	105,746	198,617	130,719	441,197	8,341	25,697

Table 11. Number of organisms per liter and relative abundance of net plankton at plant site (Site 3)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Chroococcales	—	15.5	3.9	—	11.2	165.0	3.5	2.3	—	—	—	—	—
	—	3.0%	1.0%	—	4.2%	17.6%	1.0%	1.5%	—	—	—	—	—
<i>Oscillatoria</i>	69.5	233.0	—	3.8	45.0	18.2	15.8	10.5	120.0	3.1	5.2	5.5	17.5
	40.7%	45.4%	—	1.4%	18.8%	1.9%	4.4%	6.9%	22.9%	20.7%	14.0%	7.1%	8.2%
Other Oscilla- toriaceae	—	—	—	—	—	11.2	64.7	47.0	367.0	5.7	7.6	4.3	9.8
	—	—	—	—	—	1.2%	17.9%	30.7%	70.0%	38.0%	20.5%	5.5%	4.6%
<i>Anahacna</i>	—	—	—	—	—	—	—	1.8	—	—	—	—	—
	—	—	—	—	—	—	—	1.1%	—	—	—	—	—
<i>Chlamydomonas</i>	—	—	—	—	—	—	1.8	1.8	—	—	—	—	—
	—	—	—	—	—	—	.5%	1.1%	—	—	—	—	—
<i>Pandorina</i> <i>morum</i>	—	—	—	15.0	67.5	78.0	78.7	10.5	—	—	—	—	—
	—	—	—	5.6%	28.0%	8.3%	21.7%	6.9%	—	—	—	—	—
Other Volvo- caceae	—	—	—	—	—	3.8	—	—	—	—	—	—	—
	—	—	—	—	—	.4%	—	—	—	—	—	—	—
<i>Ulothrix</i>	—	—	96.0	30.0	3.8	7.5	—	3.5	—	—	1.5	3.8	11.0
	—	—	25.3%	11.3%	1.6%	.8%	—	2.3%	—	—	4.0%	4.8%	5.2%
<i>Stigeoclonium</i>	—	—	—	—	—	—	—	—	22.5	—	2.6	—	1.3
	—	—	—	—	—	—	—	—	4.3%	—	7.0%	—	.6%
<i>Oedogonium</i>	—	—	3.9	37.5	—	3.8	54.2	28.0	—	—	1.0	.6	2.5
	—	—	1.0%	14.1%	—	.4%	15.0%	18.3%	—	—	2.7%	.8%	1.2%
<i>Cladophora</i> <i>glomerata</i>	—	—	7.7	44.9	15.0	18.0	—	9.3	7.5	.6	—	1.3	1.3
	—	—	2.0%	16.9%	6.3%	1.9%	—	6.1%	1.4%	4.0%	—	1.6%	.6%
<i>Mougeotia</i>	—	—	—	—	7.5	—	—	1.8	—	—	—	—	—
	—	—	—	—	3.1%	—	—	1.1%	—	—	—	—	—
<i>Spirogyra</i>	—	—	—	—	—	11.2	7.0	11.0	3.8	3.1	—	.6	2.5
	—	—	—	—	—	1.2%	1.9%	7.2%	.7%	20.7%	—	.8%	1.2%
<i>Zygnema</i>	—	—	—	15.0	—	—	—	3.0	—	1.9	.5	—	—
	—	—	—	6.3%	—	—	—	2.0%	—	12.7%	1.3%	—	—
Other Filamen- tous Chloro- phyta	23.2	15.5	11.6	—	—	3.8	7.0	—	—	.6	6.1	—	—
	13.6%	3.0%	3.1%	—	—	.4%	1.9%	—	—	4.0%	16.4%	—	—
<i>Closterium</i>	—	—	—	—	22.5	3.8	1.8	1.8	—	—	1.0	.6	1.3
	—	—	—	—	9.4%	.4%	.5%	1.1%	—	—	2.7%	.8%	.6%
<i>Cosmarium</i>	—	—	—	—	3.8	—	—	—	—	—	—	—	—
	—	—	—	—	1.6%	—	—	—	—	—	—	—	—
<i>Staurastrum</i>	—	—	7.7	—	22.5	93.7	—	1.8	—	—	—	—	—
	—	—	2.0%	—	9.4%	9.9%	—	1.1%	—	—	—	—	—
<i>Euglena</i>	—	—	—	—	—	3.8	—	1.8	—	—	—	—	—
	—	—	—	—	—	.4%	—	1.1%	—	—	—	—	—
<i>Ceratium hir-</i> <i>undinella</i>	—	—	—	—	—	17.4	127.7	7.0	7.5	—	—	—	—
	—	—	—	—	—	5.0%	35.3%	4.6%	1.4%	—	—	—	—
Other Pyrrho- phyta	—	—	3.9	—	—	—	—	8.7	—	—	—	—	—
	—	—	1.0%	—	—	—	—	5.6%	—	—	—	—	—
<i>Hydrurus</i> <i>foetidus</i>	78.0	248.0	244.0	135.0	25.5	—	—	—	—	—	11.6	62.0	165.0
	45.7%	48.4%	64.0%	50.7%	10.7%	—	—	—	—	—	31.3%	80.1%	77.5%
Total Algae	170.7	512.0	378.8	266.2	239.3	939.2	362.2	151.6	528.3	15.0	37.1	78.7	212.2

Table 12. Number of organisms per liter and relative abundance of nannoplankton at plant site (Site 3)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
<i>Cyclotella</i>	—	—	2,780	—	3,127	2,780	—	—	—	695	—	—	—
	—	—	.4%	—	.9%	.5%	—	—	—	.8%	—	—	—
<i>Asterionella</i>	—	—	59,490	30,250	13,344	6,115	3,335	6,096	—	—	—	—	—
	—	—	8.7%	9.6%	3.9%	1.0%	.4%	1.2%	—	—	—	—	—
<i>Hannaea arcus</i>	—	1,390	47,260	13,066	1,042	—	—	695	—	—	1,668	2,780	3,892
	—	.5%	6.9%	4.1%	.3%	—	—	.1%	—	—	1.2%	1.1%	1.3%
<i>Diatoma hiemale</i>	—	1,390	2,780	695	—	—	—	—	—	—	—	—	973
	—	.5%	.4%	.2%	—	—	—	—	—	—	—	—	.3%
<i>Diatoma tenue</i>	—	—	—	—	—	—	—	—	—	18,348	6,960	21,545	8,757
	—	—	—	—	—	—	—	—	—	20.2%	4.9%	8.5%	2.9%
<i>Diatoma vulgare</i>	3,475	4,170	2,780	3,475	7,086	10,286	11,120	13,100	1,737	1,668	4,450	2,780	1,946
	.5%	1.4%	.4%	.9%	2.1%	1.7%	1.2%	2.5%	1.1%	1.8%	3.2%	1.1%	.6%
<i>Fragilaria</i>	—	—	—	1,390	—	1,390	2,780	80,620	3,474	1,390	1,042	695	973
	—	—	—	.5%	—	.2%	.3%	15.4%	2.2%	1.5%	.7%	.3%	.3%
<i>Meridion</i>	—	—	—	695	1,042	1,390	—	—	—	—	—	—	—
	—	—	—	.2%	.3%	.2%	—	—	—	—	—	—	—
<i>Synedra</i>	90,350	26,130	28,910	9,730	4,170	11,125	25,020	44,480	11,812	6,950	15,985	20,850	25,298
	14.1%	8.9%	4.2%	3.1%	1.2%	1.9%	2.8%	8.5%	7.6%	7.7%	11.3%	8.2%	8.3%
<i>Achnanthes</i>	3,475	8,340	19,460	19,460	42,600	75,500	29,745	30,580	3,474	6,533	6,255	11,120	18,487
	.5%	2.8%	2.7%	6.2%	12.3%	12.6%	3.2%	5.8%	2.2%	7.2%	4.4%	4.4%	6.1%
<i>Cocconeis</i>	—	2,780	—	—	5,004	14,400	2,780	4,170	1,737	695	1,042	695	1,946
	—	.9%	—	—	1.4%	2.4%	.3%	.8%	1.1%	.8%	.7%	.3%	.6%
<i>Amphipleura</i>	—	—	—	—	—	—	695	2,085	—	347	—	—	973
	—	—	—	—	—	—	.1%	.4%	—	.4%	—	—	.3%
<i>Navicula cf. capitata</i>	—	1,390	1,390	695	—	—	—	—	—	—	4,450	1,390	973
	—	.5%	.5%	.2%	—	—	—	—	—	—	3.2%	.5%	.3%
<i>Navicula cf. rhyncocephala</i>	—	—	—	695	4,170	10,286	44,505	15,290	1,737	—	—	—	—
	—	—	—	.2%	1.2%	1.7%	4.9%	2.9%	1.1%	—	—	—	—
<i>Navicula cf. tripunctata</i>	—	—	—	18,070	13,344	32,500	43,085	13,900	15,287	—	5,560	13,205	18,487
	—	—	—	5.7%	3.9%	5.4%	4.7%	2.5%	9.8%	—	3.9%	5.2%	6.1%
Other	104,250	41,700	115,650	35,305	59,826	93,144	120,930	45,035	15,287	12,093	15,568	20,850	35,028
<i>Navicula</i>	16.2%	14.2%	15.8%	11.2%	17.3%	15.6%	13.4%	8.7%	9.8%	13.3%	11.1%	8.2%	11.5%
<i>Stauroneis</i>	—	—	—	—	—	—	—	—	—	—	348	695	—
	—	—	—	—	—	—	—	—	—	—	.3%	.3%	—
<i>Gomphonema</i>	139,000	94,520	116,760	19,460	30,024	60,500	65,330	26,400	10,425	2,780	15,985	52,820	75,894
	21.6%	32.2%	17.0%	6.2%	8.7%	10.1%	7.2%	5.0%	6.7%	3.1%	11.3%	20.8%	24.8%
<i>Cymbella</i>	205,520	58,380	150,120	113,980	90,375	145,500	216,505	80,620	29,187	15,985	25,993	62,550	65,191
	32.0%	19.9%	21.9%	36.1%	26.2%	24.3%	23.8%	15.4%	18.7%	17.7%	18.4%	24.6%	21.3%
<i>Nitzschia acicularis</i>	—	—	—	695	5,004	2,084	2,362	2,362	—	—	—	—	—
	—	—	—	.2%	1.4%	.4%	.3%	.4%	—	—	—	—	—
Other	86,175	46,980	129,550	44,420	59,175	119,416	328,038	136,220	60,462	22,935	34,333	42,395	44,758
<i>Nitzschia</i>	13.4%	16.5%	18.9%	14.1%	17.2%	19.9%	36.1%	26.0	38.7%	25.3%	24.3%	16.7%	14.6%
<i>Surirella</i>	10,425	4,170	1,390	695	1,042	2,780	9,730	3,335	1,737	347	696	—	1,946
	1.6%	1.4%	.2%	.2%	.3%	.5%	1.0%	.6%	1.1%	.4%	.5%	—	.6%
Other	—	1,390	7,230	3,335	1,042	—	695	—	—	—	696	695	—
Pennales	—	.9%	1.1%	1.1%	.3%	—	.1%	—	—	—	.5%	.6%	—
<i>Dinabryon</i>	—	—	1,390	1,390	3,127	8,900	695	20,016	—	—	—	—	—
	—	—	.2%	.4%	.9%	1.5%	.1%	3.8%	—	—	—	—	—
Total Algae	642,670	292,730	686,940	317,501	344,544	598,096	907,350	525,004	156,356	90,766	141,031	255,065	305,522

Table 13. Number of organisms per cm<sup>2</sup> and relative abundance of periphyton on glass slides at plant site (Site 3)

Algae	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	2/19 1972	3/11 1972
<i>Cyclotella</i>	—	—	—	—	204	—	62	—	—	—	—
	—	—	—	—	.2%	—	.2%	—	—	—	—
<i>Asterionella</i>	—	445	850	202	612	—	62	—	—	—	—
	—	.5%	1.0%	.1%	.6%	—	.2%	—	—	—	—
<i>Hannaea arcus</i>	154	445	1,740	496	—	—	—	371	—	154	309
	.6%	.5%	2.0%	.3%	—	—	—	1.1%	—	.3%	1.6%
<i>Diatoma hiemale</i>	—	51	—	—	204	—	—	—	—	—	—
	—	.1%	—	—	.2%	—	—	—	—	—	—
<i>Diatoma tenue</i>	—	—	—	—	—	—	—	—	—	2,625	1,081
	—	—	—	—	—	—	—	—	—	5.1%	5.7%
<i>Diatoma vulgare</i>	—	51	406	598	847	1,544	474	2,595	407	309	154
	—	.1%	.5%	.4%	.9%	3.2%	1.4%	8.0%	5.1%	.6%	.8%
<i>Fragilaria crotonensis</i>	—	—	—	—	—	—	350	247	—	—	154
	—	—	—	—	—	—	1.1%	.7%	—	—	.8%
<i>Meridion</i>	—	51	—	—	—	—	—	—	—	—	—
	—	.1%	—	—	—	—	—	—	—	—	—
<i>Synedra</i>	3,855	2,062	4,530	2,393	3,420	762	1,503	3,830	678	3,861	1,081
	14.0%	2.5%	5.2%	1.5%	3.5%	1.6%	4.5%	11.8%	8.4%	7.5%	5.7%
<i>Achnanthes</i>	1,390	3,960	10,300	94,100	13,340	15,589	2,060	1,606	325	2,008	618
	5.0%	4.8%	11.7%	57.1%	13.7%	32.3%	6.2%	5.0%	4.1%	3.9%	3.3%
<i>Cocconeis</i>	103	—	—	596	305	1,174	144	—	—	—	—
	.4%	—	—	.4%	.3%	2.4%	.4%	—	—	—	—
<i>Amphipleura</i>	—	—	—	—	64	52	206	864	—	—	154
	—	—	—	—	.1%	.1%	.6%	2.7%	—	—	.8%
<i>Navicula</i> cf. <i>tripunctata</i>	—	1,167	4,530	5,335	6,997	556	2,471	1,831	407	1,390	463
	—	2.0%	5.2%	3.2%	7.2%	1.2%	7.5%	5.7%	5.1%	2.7%	2.4%
Other <i>Navicula</i>	7,258	5,255	5,136	24,265	18,973	3,913	6,322	2,707	868	3,707	772
	26.4%	6.4%	5.9%	14.8%	19.6%	8.1%	19.1%	8.3%	10.8%	7.2%	4.1%
<i>Gomphonema</i>	6,067	14,415	10,300	5,050	2,501	3,027	885	2,348	732	18,688	7,877
	22.0%	17.5%	11.7%	3.1%	2.6%	6.3%	2.7%	7.3%	9.1%	36.2%	41.5%
<i>Cymbella</i>	8,408	35,382	38,755	18,000	15,400	8,175	4,324	6,301	2,441	13,437	2,317
	30.5%	43.0%	44.2%	10.9%	15.9%	17.0%	13.1%	19.5%	30.4%	26.0%	12.2%
<i>Nitzschia acicularis</i>	—	—	—	920	406	206	—	—	—	—	—
	—	—	—	.6%	.4%	.4%	—	—	—	—	—
Other <i>Nitzschia</i>	—	17,649	6,062	9,240	32,094	12,397	12,335	9,267	1,627	5,406	3,861
	—	21.4%	6.9%	6.2%	32.7%	25.7%	36.9%	28.7%	20.3%	10.5%	20.3%
<i>Surirella</i>	201	303	536	503	204	154	144	371	68	—	—
	.7%	.4%	.6%	.3%	.2%	.3%	.4%	1.1%	.8%	—	—
Other Peonales	—	294	2,183	—	—	52	62	—	—	—	—
	—	.3%	2.5%	—	—	.1%	.2%	—	—	—	—
<i>Dinobryon</i>	—	203	—	—	—	—	62	—	—	—	—
	—	.2%	—	—	—	—	.2%	—	—	—	—
<i>Oscillatoria</i>	—	—	2,040	1,056	—	412	—	—	203	—	154
	—	—	2.3%	.6%	—	.2%	—	—	2.5%	—	.8%
Other Oscillatoriaceae	93	—	—	1,151	1,877	103	1,853	—	203	—	—
	.3%	—	—	.7%	1.9%	.9%	5.6%	—	2.5%	—	—
<i>Anabaena</i>	—	—	—	95	64	—	—	—	—	—	—
	—	—	—	.1%	.1%	—	—	—	—	—	—
<i>Ulothrix</i>	—	—	—	95	—	103	—	—	—	—	—
	—	—	—	.1%	—	.2%	—	—	—	—	—
<i>Stigeoclonium</i>	—	—	—	—	—	—	—	—	68	—	—
	—	—	—	—	—	—	—	—	.8%	—	—
<i>Oedogonium</i>	—	—	—	—	—	52	—	—	—	—	—
	—	—	—	—	—	.1%	—	—	—	—	—
Other Filamentous Chlorophyta	—	—	—	738	—	—	144	—	—	—	—
	—	—	—	.4%	—	—	.4%	—	—	—	—
<i>Closterium</i>	—	—	85	—	61	—	—	—	—	—	—
	—	—	.1%	—	.1%	—	—	—	—	—	—
<i>Euglena</i>	—	51	—	—	—	—	—	—	—	—	—
	—	.1%	—	—	—	—	—	—	—	—	—
<i>Hydrurus foetidus</i>	—	51	247	95	—	—	—	—	—	—	—
	—	.1%	.3%	.1%	—	—	—	—	—	—	—
Total Algae	27,529	82,285	87,700	161,928	97,576	48,271	33,463	32,338	8,027	51,585	18,995

Table 14. Number of organisms per liter and relative abundance of net plankton at campground (Site 4)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Chroococcales	—	—	—	—	—	97.5	22.5	8.7	—	—	—	—	—
	—	—	—	—	—	13.5%	1.2%	10.8%	—	—	—	—	—
<i>Oscillatoria</i>	93.0	123	3.9	7.5	3.8	15.0	30.0	7.7	33.7	4.5	3.1	2.5	7.5
	60.0%	21.2%	.8%	2.4%	2.9%	2.1%	1.6%	9.6%	5.8%	14.6%	9.5%	4.4%	14.5%
Other Oscillatoriaceae	7.7	54.0	—	—	—	30.0	385.0	5.2	502.5	21.9	10.3	1.9	3.8
	5.0%	9.3%	—	—	—	4.1%	19.9%	6.5%	87.0%	69.9%	31.4%	3.3%	7.2%
<i>Anabaena</i>	—	7.7	—	—	—	—	—	—	—	—	—	—	—
	—	1.3%	—	—	—	—	—	—	—	—	—	—	—
<i>Chlamydomonas</i>	—	—	—	—	15.0	—	—	1.8	—	—	—	—	—
	—	—	—	—	11.5%	—	—	2.2%	—	—	—	—	—
<i>Pandorina morum</i>	—	—	—	—	11.4	45.0	232.5	3.5	—	—	—	—	—
	—	—	—	—	8.6%	6.2%	11.9%	4.4%	—	—	—	—	—
Other Volvocaceae	—	—	—	—	—	3.8	—	3.5	—	—	—	—	—
	—	—	—	—	—	.5%	—	4.4%	—	—	—	—	—
<i>Ulothrix</i>	—	46.5	161.0	7.5	7.5	3.8	—	2.6	3.8	—	1.0	2.5	—
	—	8.0%	32.0%	4.0%	5.8%	.5%	—	3.2%	.6%	—	3.1%	4.4%	—
<i>Stigeoclonium</i>	—	—	—	—	—	—	—	—	22.5	3.9	1.5	—	2.5
	—	—	—	—	—	—	—	—	3.9%	12.6%	4.6%	—	4.8%
<i>Oedogonium</i>	—	15.5	3.9	11.2	3.8	—	127.5	20.3	—	—	.5	—	—
	—	2.7%	.8%	6.0%	2.9%	—	6.5%	25.3%	—	—	1.5%	—	—
<i>Cladophora glomerata</i>	—	—	11.6	15.0	15.0	15.0	—	4.4	—	.6	1.0	.6	—
	—	—	2.3%	8.0%	11.5%	2.1%	—	5.4%	—	1.9%	3.1%	1.1%	—
<i>Mougeotia</i>	—	—	—	—	—	7.5	—	.9	—	—	—	—	—
	—	—	—	—	—	1.0%	—	1.1%	—	—	—	—	—
<i>Spirogyra</i>	—	—	7.7%	—	—	—	—	7.7	—	—	—	.6	—
	—	—	1.5%	—	—	—	—	9.6%	—	—	—	1.1%	—
<i>Zygnema</i>	—	—	—	—	33.0	3.8	—	.9	—	—	1.0	—	—
	—	—	—	—	25.3%	.5%	—	1.1%	—	—	3.1%	—	—
Other Filamentous Chlorophyta	7.7	—	3.9	—	—	—	—	—	—	—	2.0	.6	—
	5.0%	—	.8%	—	—	—	—	—	—	—	6.1%	1.1%	—
<i>Closterium</i>	—	23.0	—	—	26.2	3.8	7.5	2.6	3.8	—	—	.6	.6
	—	4.0%	—	—	20.2%	.5%	.4%	3.2%	.64%	—	—	1.1%	1.2%
<i>Staurastrum</i>	—	—	—	—	—	72.0	7.5	—	3.8	—	—	—	—
	—	—	—	—	—	9.9%	.4%	—	.64%	—	—	—	—
<i>Euglena</i>	—	—	—	—	—	3.8	—	.9	—	—	—	—	—
	—	—	—	—	—	.5%	—	1.1%	—	—	—	—	—
<i>Ceratium hirundinella</i>	—	—	—	—	—	423.0	1110.0	7.0	7.5	—	—	—	—
	—	—	—	—	—	58.4%	57.6%	8.7%	1.3%	—	—	—	—
Other Pyrrophyta	—	—	—	—	—	—	7.5	—	—	—	—	—	—
	—	—	—	—	—	—	.4%	—	—	—	—	—	—
<i>Hydrurus foetidus</i>	46.5	310.0	309.0	146.8	15.0	—	—	—	—	—	12.4	48.0	37.5
	30.0%	53.5%	62.0%	78.3%	11.5%	—	—	—	—	—	37.8%	84.7%	72.3%
<i>Vaucheria</i>	—	—	—	—	—	—	—	2.6	—	—	—	—	—
	—	—	—	—	—	—	—	3.2%	—	—	—	—	—
Total Algae	154.9	579.7	501.0	188.0	130.7	724.0	1930.0	80.3	578.2	30.9	32.8	57.3	51.9

Table 15. Number of organisms per liter and relative abundance of nanoplankton at campground (Site 4)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
<i>Cyclotella</i>	—	—	—	4,170	—	1,668	—	—	—	1,042	—	—	—
				.5%		.7%				.4%			
<i>Asterionella</i>	—	—	46,425	88,950	13,200	2,357	1,390	2,085	2,085	1,042	—	—	—
			9.0%	11.6%	6.1%	1.0%	.2%	.8%	.4%	.4%			
<i>Hannaea arcus</i>	6,960	16,680	27,105	27,800	2,362	348	695	—	1,390	3,058	1,390	4,170	3,475
	6.1%	2.1%	5.3%	3.6%	1.1%	.2%	.1%		.3%	1.1%	1.1%	1.0%	1.9%
<i>Diatoma hiemale</i>	2,432	—	4,170	3,335	—	—	—	—	—	—	696	—	1,390
	2.1%		.8%	.4%							.5%		.8%
<i>Diatoma tenue</i>	—	—	1,390	—	—	—	—	—	—	—	348	4,170	5,560
			.3%								.3%	1.0%	3.1%
<i>Diatoma vulgare</i>	5,912	12,510	2,085	8,895	2,780	1,668	15,845	3,335	20,016	4,865	4,450	9,730	4,865
	3.1%	1.6%	.4%	1.2%	1.3%	.7%	1.7%	1.2%	4.3%	1.8%	3.5%	2.3%	2.7%
<i>Fragularia</i>	—	—	2,780	695	—	696	695	104,805	10,285	8,340	1,042	1,390	695
			.5%	.1%		.31%	.1%	37.7%	2.2%	3.1%	.8%	.3%	.4%
<i>Meridion</i>	—	12,510	6,950	2,780	—	—	—	—	—	347	—	1,390	—
		1.6%	1.4%	.4%						.1%		.3%	
<i>Synedra</i>	6,602	46,702	11,675	22,795	7,200	5,560	20,850	9,730	20,850	10,703	17,653	33,360	8,340
	5.8%	6.0%	2.3%	3.0%	3.3%	2.5%	2.5%	3.5%	4.5%	4.0%	13.7%	7.8%	4.6%
<i>Achnanthes</i>	1,740	37,530	22,240	61,150	18,725	26,000	49,650	9,730	43,090	22,935	6,960	18,070	15,290
	1.5%	4.8%	4.3%	8.0%	8.6%	11.5%	5.4%	3.5%	9.2%	8.5%	5.4%	4.2%	8.5%
<i>Cocconeis</i>	1,390	—	695	1,390	696	6,255	6,096	—	2,780	3,058	1,668	2,780	695
	1.2%		.1%	.2%	.3%	2.8%	.7%		.6%	1.1%	1.3%	.7%	.4%
<i>Rhoicosphenia</i>	—	1,042	1,390	695	—	—	—	—	—	—	—	—	—
		.1%	.2%	.1%									
<i>Amphipleura</i>	—	—	—	—	—	—	—	—	695	695	—	1,390	—
									.1%	.2%		.3%	
<i>Gyrosigma</i>	—	—	—	—	—	—	—	695	—	—	—	1,390	—
								.3%				.3%	
<i>Navicula cf. capitata</i>	695	1,042	—	695	—	—	—	695	—	—	2,085	8,340	2,085
	.6%	.1%		.1%				.3%			1.6%	2.0%	1.2%
<i>Navicula cf. rhynoccephala</i>	—	—	2,780	2,085	—	3,052	45,035	1,390	5,560	1,042	—	—	4,865
			.5%	.3%		1.4%	4.9%	.5%	1.2%	.4%			2.7%
<i>Navicula cf. tripunctata</i>	—	—	—	18,070	10,007	7,225	56,155	7,505	19,460	9,313	5,838	18,070	13,205
				2.4%	4.6%	3.2%	6.1%	2.7%	4.2%	3.4%	4.5%	4.2%	7.3%
Other <i>Navicula</i>	11,468	141,760	67,550	94,290	36,585	33,323	107,010	11,120	72,280	59,353	10,842	52,820	15,985
	10.1%	18.2%	13.0%	12.4%	16.8%	14.4%	11.5%	4.0%	15.5%	22.0%	8.5%	12.4%	8.9%
<i>Pinnularia</i>	—	1,042	—	—	—	—	—	—	—	347	—	—	—
		.1%								.1%			
<i>Stauroneis</i>	—	—	—	—	—	—	—	—	695	—	—	—	695
									.1%				.4%
<i>Gomphonema</i>	13,553	194,737	79,785	69,500	16,675	23,259	54,210	10,285	53,375	21,545	17,653	76,450	20,155
	11.9%	25.0%	15.5%	9.1%	7.6%	10.3%	5.8%	3.7%	11.3%	8.0%	13.7%	17.9%	11.2%
<i>Cymbella</i>	38,920	159,584	115,925	230,740	73,250	73,250	215,450	33,915	90,350	64,218	31,970	102,860	46,565
	34.2%	20.5%	22.5%	30.2%	33.6%	32.4%	32.2%	12.2%	19.4%	23.7%	24.8%	24.1%	25.9%
<i>Epithemia</i>	—	1,042	—	—	—	—	—	—	—	—	—	—	—
		.1%											
<i>Nitzschia acicularis</i>	—	—	6,115	1,390	2,780	3,052	6,096	2,362	2,780	—	—	1,390	—
			1.2%	.2%	.7%	1.4%	.7%	3.5%	.6%			.3%	
Other <i>Nitzschia</i>	20,880	133,440	85,345	102,960	26,250	30,250	337,770	43,590	113,980	56,990	23,908	86,180	34,055
	18.4%	17.1%	16.6%	13.5%	12.6%	13.3%	36.4%	13.0%	24.5%	21.1%	18.5%	20.2%	18.9%
<i>Surrella</i>	348	9,172	2,780	4,170	1,390	348	9,730	1,390	4,170	1,390	2,363	2,780	2,085
	.3%	1.2%	.5%	.6%	.2%	.2%	1.1%	.5%	.9%	.5%	1.8%	.7%	1.2%
Other Pennates	5,210	4,170	5,560	16,000	—	1,042	—	—	—	—	—	—	—
	4.6%	.6%	1.1%	2.1%		.5%							
<i>Dinobryon</i>	—	—	15,290	1,390	6,255	6,550	—	35,305	2,085	—	—	—	—
			3.0%	.2%	2.9%	2.9%		12.7%	.4%				
Total Algae	116,110	772,963	514,150	763,795	218,145	225,903	926,677	277,937	465,925	270,283	128,866	426,730	180,005

Table 16. Number of organisms per cm<sup>2</sup> and relative abundance of periphyton on glass slides in a pool at campground (Site 4)

Algae	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971
<i>Cyclotella</i>	—	—	—	—	—	52	62	—
	—	—	—	—	—	.2%	.5%	—
<i>Asterionella</i>	—	—	85	1,020	102	103	—	—
	—	—	.1%	.4%	.4%	.5%	—	—
<i>Hannaea arcus</i>	1,020	5,459	648	304	—	—	—	206
	2.0%	2.6%	.4%	.1%	—	—	—	.6%
<i>Diatoma hiemale</i>	—	607	242	—	—	—	—	—
	—	.3%	.2%	—	—	—	—	—
<i>Diatoma tenue</i>	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—
<i>Diatoma vulgare</i>	810	1,213	909	1,522	—	206	762	1,441
	1.6%	.6%	.5%	.6%	—	1.0%	6.4%	3.9%
<i>Fragilaria crotonensis</i>	—	—	—	—	—	—	62	3,532
	—	—	—	—	—	—	.5%	9.5%
<i>Meridion</i>	—	—	—	—	102	—	—	—
	—	—	—	—	.4%	—	—	—
<i>Synedra</i>	2,677	7,919	85	304	—	154	762	1,544
	5.2%	3.7%	.1%	.1%	—	.7%	6.4%	4.2%
<i>Achnanthes</i>	2,677	27,298	123,650	196,100	3,685	3,398	412	4,602
	5.2%	12.8%	76.0%	75.3%	14.9%	16.0%	3.5%	12.4%
<i>Cocconeis</i>	243	—	648	102	1,020	1,853	268	31
	.5%	—	.4%	.1%	4.1%	8.7%	2.3%	.1%
<i>Navicula</i> cf. <i>capitata</i>	102	2,426	—	—	—	—	—	—
	.2%	1.2%	—	—	—	—	—	—
<i>Navicula</i> cf. <i>rhyncocephala</i>	—	—	85	890	304	968	—	—
	—	—	.1%	.3%	1.2%	4.6%	—	—
<i>Navicula</i> cf. <i>tripunctata</i>	—	—	3,006	3,583	890	1,133	618	1,133
	—	—	1.6%	1.4%	3.6%	5.3%	5.2%	3.5%
Other <i>Navicula</i>	21,210	20,606	4,674	10,684	3,690	2,255	2,821	4,221
	41.0%	9.7%	2.9%	4.1%	15.0%	10.6%	23.8%	11.4%
<i>Gomphonema</i>	4,633	30,861	3,583	3,152	2,224	350	1,235	1,205
	9.0%	14.5%	2.2%	1.2%	9.0%	1.6%	10.4%	3.2%
<i>Cymbella</i>	14,932	70,784	19,770	29,948	2,224	2,265	2,327	9,915
	29.0%	33.3%	12.0%	11.5%	9.0%	10.6%	19.7%	26.6%
<i>Nitzschia acicularis</i>	—	—	—	890	102	—	—	—
	—	—	—	.3%	.4%	—	—	—
Other <i>Nitzschia</i>	3,033	40,032	2,887	10,600	3,920	8,237	2,327	7,279
	5.9%	18.8%	1.8%	4.1%	15.9%	38.7%	19.7%	19.6%
<i>Surirella</i>	152	607	85	—	304	52	62	103
	.3%	.3%	.1%	—	1.2%	.2%	.5%	.3%
Other Pennales	102	3,642	648	—	—	—	—	31
	.2%	1.7%	.4%	—	—	—	—	.1%
<i>Dinobryon</i>	—	—	—	—	102	—	—	—
	—	—	—	—	.4%	—	—	—
<i>Oscillatoria</i>	—	—	536	1,190	406	151	—	206
	—	—	.3%	.5%	1.6%	.7%	—	.6%
Other Oscillatoriaceae	—	—	—	—	5,644	—	62	1,514
	—	—	—	—	22.9%	—	.5%	4.1%
<i>Ulothrix</i>	—	1,213	—	102	—	52	62	31
	—	.6%	—	.1%	—	.2%	.5%	.1%
<i>Stigeoclonium</i>	—	—	—	102	—	—	—	31

(Table 16 continued on p. 66)

	—	—	—	.1%	—	—	—	.1%
<i>Oedogonium</i>	—	—	—	—	—	52	—	—
	—	—	—	—	—	.2%	—	—
<i>Cladophora</i>	—	—	536	—	—	—	—	72
	—	—	.3%	—	—	—	—	.2%
<i>Closterium</i>	—	—	—	204	—	—	—	31
	—	—	—	.1%	—	—	—	.1%
<i>Euglena</i>	51	—	—	—	—	—	—	—
	.1%	—	—	—	—	—	—	—
<i>Hydrurus</i>	—	—	536	—	—	—	—	—
	—	—	.3%	—	—	—	—	—
Total Algae	51,642	212,667	162,613	260,697	24,719	21,284	11,842	37,128

Table 17. Number of organisms per cm<sup>2</sup> and relative abundance of periphyton on glass slides in a riffle at campground (Site 4)

Algae	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	2/19 1972	3/11 1972
<i>Cyclotella</i>	—	—	318	—	—	—	—
	—	—	.4%	—	—	—	—
<i>Asterionella</i>	—	102	318	812	—	—	—
	—	.1%	.4%	2.2%	—	—	—
<i>Hannaea arcus</i>	324	1,719	1,590	406	—	6,075	—
	.5%	1.9%	2.0%	1.1%	—	12.7%	—
<i>Diatoma hiemale</i>	—	—	318	—	—	103	154
	—	—	.4%	—	—	.2%	.9%
<i>Diatoma tenue</i>	—	—	—	—	—	3,295	1,287
	—	—	—	—	—	6.9%	7.9%
<i>Diatoma vulgare</i>	486	708	636	—	204	206	154
	.7%	.8%	.8%	—	.2%	.5%	.9%
<i>Fragilaria crotonensis</i>	—	—	—	—	—	—	51
	—	—	—	—	—	—	.3%
<i>Meridion</i>	—	102	—	—	—	103	—
	—	.1%	—	—	—	.2%	—
<i>Synedra</i>	7,113	4,040	1,272	—	204	7,928	1,493
	11.0%	4.5%	1.6%	—	.2%	16.5%	9.2%
<i>Achnanthes</i>	1,375	2,928	23,532	20,400	43,200	2,780	1,184
	2.1%	3.2%	28.1%	54.6%	43.2%	5.8%	7.3%
<i>Cocconeis</i>	81	—	—	3,248	1,624	103	—
	.1%	—	—	8.7%	1.6%	.2%	—
<i>Navicula</i> cf. <i>rhynoccephala</i>	—	—	318	204	1,020	—	—
	—	—	.4%	.5%	1.0%	—	—
<i>Navicula</i> cf. <i>tripunctata</i>	—	1,617	6,678	406	3,040	1,544	—
	—	1.8%	8.0%	1.1%	3.0%	3.5%	—
Other <i>Navicula</i>	7,923	5,982	10,540	2,028	10,276	4,015	1,184
	12.1%	6.6%	12.5%	6.5%	10.3%	8.4%	7.3%
<i>Gomphonema</i>	15,131	24,015	2,226	2,670	2,670	2,574	1,287
	23.3%	26.6%	2.7%	7.1%	2.7%	5.4%	7.9%
<i>Symbella</i>	24,099	33,963	18,762	3,490	16,510	5,354	5,714
	37.2%	37.6%	22.4%	9.3%	16.5%	11.1%	35.0%
<i>Nitzschia acicularis</i>	—	—	—	406	812	—	—
	—	—	—	1.1%	.9%	—	—
Other <i>Nitzschia</i>	8,080	13,820	12,720	1,886	17,503	8,546	3,088
	12.5%	15.3%	15.2%	5.0%	17.4%	17.8%	18.9%
<i>Surirella</i>	—	102	—	—	204	—	103

(Table 17 continued on p. 67)

	—	.1%	—	—	.2%	—	.6%
Other Pennales	81	943	1,908	204	—	2,162	—
	.5%	1.0%	2.3%	.5%	—	4.5%	—
<i>Dinobryon</i>	—	102	—	—	—	—	—
	—	.1%	—	—	—	—	—
Chroococcales	—	—	—	612	—	—	—
	—	—	—	1.6%	—	—	—
<i>Oscillatoria</i>	81	—	1,272	—	406	103	—
	.5%	—	1.6%	—	.4%	.2%	—
Other Oscillatoriaceae	—	—	—	—	2,228	103	—
	—	—	—	—	2.2%	.2%	—
<i>Ulothrix</i>	81	—	—	—	—	—	51
	.5%	—	—	—	—	—	.3%
<i>Closterium</i>	—	—	—	204	—	—	—
	—	—	—	.5%	—	—	—
<i>Hydrurus</i>	—	203	1,272	—	—	2,986	566
	—	.2%	1.6%	—	—	6.2%	3.5%
Total Algae	64,855	90,346	83,680	36,976	99,901	47,980	16,316

Table 18. Number of organisms per liter and relative abundance of net plankton at Tie Fork Pond (Site 5)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971
<i>Chroococcales</i>	—	—	12.4	—	540.0	876.0	250.0	288.0
	—	—	1.3%	—	4.2%	8.3%	.8%	5.0%
<i>Lyngbya</i>	—	—	19.0	10.5	36.0	195.0	300.0	45.0
	—	—	2.0%	.4%	.3%	1.8%	.9%	.8%
<i>Oscillatoria</i>	86.0	39.0	291.0	25.5	90.0	2,100.0	2,000.0	275.0
	15.6%	9.0%	30.3%	.9%	.7%	20.0%	6.3%	4.8%
<i>Anabaena</i>	—	39.0	15.5	4.5	—	45.0	200.0	—
	—	9.0%	1.6%	.2%	—	.4%	.6%	—
<i>Calothrix</i>	—	—	—	—	—	—	150.0	—
	—	—	—	—	—	—	.5%	—
<i>Chlamydomonas</i>	—	—	—	—	330.0	186.0	2,750.0	87.5
	—	—	—	—	2.5%	1.7%	8.7%	1.5%
<i>Pandorina</i>	—	7.7	—	—	246.0	276.0	400.0	70.0
	—	1.8%	—	—	1.9%	2.5%	1.3%	1.5%
Other Volvocaceae	—	—	—	—	—	—	—	37.5
	—	—	—	—	—	—	—	.7%
<i>Gloeocystis</i>	—	—	—	—	—	—	—	38.0
	—	—	—	—	—	—	—	.7%
<i>Oedogonium</i>	—	85.0	127.0	—	156.0	780.0	250.0	137.5
	—	19.6%	13.2%	—	1.2%	7.4%	.8%	2.4%
<i>Cladophora</i>	—	—	7.7	10.5	81.0	22.5	700.0	200.0
	—	—	.8%	.4%	.6%	.2%	2.2%	3.5%
<i>Ankistrodesmus</i>	—	46.7	—	—	—	—	—	—
	—	10.8%	—	—	—	—	—	—
<i>Mougeotia</i>	93.0	—	193.0	1,335.0	11,250.0	4,710.0	15,555.0	4,275.0
	16.9%	—	20.1%	45.3%	86.4%	44.8%	49.0%	73.8%
<i>Spirogyra</i>	46.5	7.7	147.0	1,345.5	66.0	255.0	6,750.0	100.0
	8.5%	1.8%	15.3%	45.7%	.5%	2.4%	21.3%	1.7%
<i>Zygnema</i>	—	39.0	43.5	120.0	30.0	705.0	450.0	—
	—	9.0%	4.5%	4.1%	.2%	6.7%	1.4%	—
Other Filamentous Chlorophyta	185.0	69.5	61.5	100.5	120.0	7.5	—	—
	33.6%	16.0%	6.4%	3.4%	.9%	.1%	—	—
<i>Closterium</i>	—	7.7	23.0	—	—	37.5	50.0	12.5
	—	1.8%	2.4%	—	—	.3%	.2%	.2%
<i>Euglena</i>	139.5	85.0	7.7	4.5	45.0	315.0	1,850.0	187.5
	25.4%	19.6%	.8%	.2%	.3%	2.9%	5.8%	3.2%
Pyrrophyta	—	—	—	—	30.0	7.5	—	12.5
	—	—	—	—	.2%	.1%	—	.2%
<i>Ophiocytium</i>	—	7.7	—	—	—	—	—	25.0
	—	1.8%	—	—	—	—	—	.4%
<i>Vaucheria</i>	—	—	12.4	—	—	—	—	—
	—	—	1.3%	—	—	—	—	—
Total Algae	550.0	434.0	960.7	2,946.0	13,020.0	10,518.0	31,655.0	5,791.0

Table 19. Number of organisms per liter and relative abundance of nanoplankton at Tie Fork Pond (Site 5)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	3/11 1972
<i>Cyclotella</i>	—	—	7,645	—	—	—	—	—	—
	—	—	3.8%	—	—	—	—	—	—
<i>Asterionella</i>	—	—	2,780	2,088	5,004	—	—	—	—
	—	—	1.3%	1.3%	.6%	—	—	—	—
<i>Diatoma</i>	—	3,476	9,035	1,042	12,525	348	2,780	348	1,043
	—	1.3%	4.3%	.7%	1.5%	.2%	.7%	.2%	16.7%
<i>Fragilaria crotonensis</i>	—	—	7,228	40,310	23,775	4,875	2,780	2,363	—
	—	—	3.5%	25.5%	2.8%	2.4%	.7%	1.5%	—
<i>Fragilaria virescens</i>	5,143	—	1,390	4,448	85,950	4,444	9,730	6,533	—
	6.2%	—	.7%	2.8%	10.5%	2.3%	2.5%	4.1%	—
<i>Meridion</i>	—	4,170	—	—	—	—	—	—	—
	—	1.6%	—	—	—	—	—	—	—
<i>Synedra</i>	4,448	16,680	26,828	6,255	13,350	348	5,560	5,838	1,043
	5.4%	6.4%	12.9%	4.0%	1.6%	.2%	1.4%	3.7%	16.7%
<i>Achnanthes</i>	5,143	7,505	17,375	2,088	4,170	1,042	4,170	1,390	—
	6.2%	2.9%	8.3%	1.3%	.5%	.5%	1.1%	.9%	—
<i>Cocconeis</i>	13,733	1,589	—	—	1,042	4,875	1,390	348	—
	16.6%	.6%	—	—	.1%	2.5%	.4%	.2%	—
<i>Amphiptleura</i>	—	—	3,475	1,390	—	—	2,085	348	—
	—	—	1.7%	.8%	—	—	.5%	.2%	—
<i>Gyrosigma</i>	—	696	—	348	—	—	1,390	1,043	1,043
	—	.3%	—	.2%	—	—	.4%	.7%	16.7%
<i>Navicula</i>	19,734	34,611	9,175	6,185	19,852	4,170	9,035	12,510	2,085
	23.8%	13.0%	4.4%	3.9%	2.4%	2.1%	2.3%	7.9%	33.4%
<i>Pinnularia</i>	2,084	—	695	1,042	2,084	348	695	3,475	—
	2.5%	—	.3%	.7%	.2%	.2%	.2%	2.2%	—
<i>Stauroneis</i>	2,084	1,589	—	1,390	3,127	348	695	1,043	—
	2.5%	.6%	—	.8%	.4%	.2%	.2%	.2%	.7%
<i>Gomphonema</i>	348	69,500	1,042	2,432	7,086	—	1,390	3,085	—
	.4%	26.1%	.5%	1.5%	.8%	—	.4%	2.0%	—
<i>Cymbella</i>	2,084	67,275	3,058	4,686	5,004	1,042	2,362	4,865	—
	2.5%	25.2%	1.5%	3.0%	.6%	.5%	.6%	3.1%	—
<i>Epithemia</i>	1,390	696	696	5,837	159,750	37,585	82,010	7,228	—
	1.7%	.3%	.3%	3.7%	19.5%	19.2%	20.7%	4.6%	—
<i>Nitzschia acicularis</i>	4,868	—	13,900	696	2,084	—	8,895	2,780	—
	5.9%	—	6.7%	.4%	.3%	—	2.2%	1.8%	—
Other <i>Nitzschia</i>	12,507	45,035	39,968	25,397	85,950	6,550	36,695	24,603	1,043
	15.2%	16.9%	19.1%	16.0%	10.5%	3.4%	9.3%	15.6%	16.7%
<i>Surirella</i>	—	3,335	—	348	1,042	—	—	348	—
	—	1.3%	—	.2%	.1%	—	—	.2%	—
Other Pennales	—	10,575	696	696	—	—	—	—	—
	—	4.1%	.3%	.4%	—	—	—	—	—
Chroococcales	—	—	2,710	41,282	91,160	—	22,795	—	—
	—	—	1.3%	26.1%	11.1%	—	5.7%	—	—
<i>Anabaena</i>	—	—	695	—	8,340	1,042	—	—	—
	—	—	.3%	—	1.0%	.5%	—	—	—
<i>Ankistrodesmus</i>	—	—	2,362	—	—	5,140	6,950	—	—
	—	—	1.1%	—	—	2.6%	1.8%	—	—
<i>Closteriopsis</i>	—	—	—	—	—	20,475	—	—	—
	—	—	—	—	—	10.5%	—	—	—
<i>Nephrocytium</i>	—	—	—	—	84,000	11,120	34,750	695	—
	—	—	—	—	10.2%	5.7%	8.8%	.4%	—

(Table 19 continued on p. 70)

<i>Scenedesmus</i>	1,390	—	—	2,362	113,125	23,620	29,745	11,398	—
	1.7%	—	—	1.5%	13.8%	12.1%	7.5%	7.2%	—
<i>Cosmarium</i>	1,042	—	—	2,780	9,225	5,987	2,085	1,043	—
	1.3%	—	—	1.8%	1.1%	3.1%	.5%	.7%	—
<i>Closterium rostrata</i>	—	—	—	—	—	1,390	—	—	—
	—	—	—	—	—	.6%	—	—	—
<i>Euastrum</i>	—	—	348	—	16,725	—	—	—	—
	—	—	.2%	—	2.0%	—	—	—	—
<i>Sphaeroszoma</i>	—	—	—	—	57,075	49,500	101,470	5,838	—
	—	—	—	—	6.8%	25.4%	25.6%	3.7%	—
<i>Staurastrum</i>	—	—	—	5,560	4,170	1,390	—	348	—
	—	—	—	3.5%	.5%	.7%	—	.2%	—
Other desmids	—	—	—	—	—	4,444	—	3,475	—
	—	—	—	—	—	2.3%	—	2.2%	—
<i>Phacus</i>	—	—	—	—	—	—	2,780	—	—
	—	—	—	—	—	—	.7%	—	—
<i>Trachelomonas</i>	6,533	—	6,533	—	5,004	5,175	23,630	41,978	—
	7.9%	—	3.1%	—	.6%	2.7%	6.0%	26.7%	—
<i>Peridinium</i>	—	—	—	—	—	—	—	14,873	—
	—	—	—	—	—	—	—	9.4%	—
<i>Dinobryon</i>	—	—	50,735	—	—	—	695	—	—
	—	—	24.3%	—	—	—	.2%	—	—
Total Algae	82,513	266,732	208,369	158,562	820,619	195,258	396,562	157,793	6,257

Table 20. Number of organisms per cm<sup>2</sup> and relative abundance of periphyton on glass slides at Tie Fork Pond (Site 5)

Algae	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971
<i>Cyclotella</i>	— —	51 .2%	— —	— —	612 1.0%	52 .1%	— —	— —
<i>Asterionella</i>	— —	1,964 6.1%	— —	— —	— —	— —	— —	— —
<i>Diatoma tenue</i>	— —	363 1.1%	— —	— —	— —	15,856 36.0%	412 1.5%	793 20.8%
Other <i>Diatoma</i>	— —	— —	102 .6%	— —	102 .2%	— —	— —	— —
<i>Fragilaria crotonenses</i>	— —	707 2.3%	699 3.8%	151 .8%	— —	103 .2%	— —	206 5.4%
<i>Fragilaria virescens</i>	2,420 3.7%	607 1.8%	204 1.1%	656 3.4%	1,280 2.2%	9,267 21.1%	1,380 5.0%	165 4.3%
<i>Meridion</i>	— —	— —	— —	— —	— —	— —	— —	26 .7%
<i>Synedra</i>	4,213 6.4%	4,751 14.9%	1,319 7.1%	254 1.3%	406 .7%	865 2.0%	3,098 11.2%	124 3.3%
<i>Hannaea arcus</i>	— —	— —	— —	— —	— —	52 .1%	— —	— —
<i>Achnanthes</i>	2,992 4.5%	6,308 19.7%	1,624 8.7%	51 .3%	304 .5%	247 .6%	62 .2%	206 5.4%
<i>Cocconeis</i>	242 .4%	— —	102 .6%	850 4.4%	612 1.0%	206 .5%	62 .2%	— —
<i>Rhoicosphenia</i>	— —	— —	— —	— —	— —	103 .2%	— —	— —
<i>Amphipleura</i>	— —	505 1.6%	102 .6%	— —	— —	— —	144 .5%	— —
<i>Gyrosigma</i>	1,133 1.7%	51 .2%	— —	— —	— —	247 .6%	474 1.7%	— —
<i>Navicula cf. tripunctata</i>	— —	1,108 3.5%	608 3.3%	243 1.3%	102 .2%	1,236 2.8%	144 .5%	51 1.3%
Other <i>Navicula</i>	27,652 41.9%	3,375 10.6%	1,330 7.0%	451 2.3%	597 1.1%	103 .2%	2,059 7.5%	258 6.8%
<i>Pinnularia</i>	3,420 5.2%	243 .7%	— —	102 .5%	204 .4%	247 .6%	350 1.3%	— —
<i>Stauroneis</i>	— —	— —	102 .6%	— —	102 .2%	350 .8%	144 .5%	— —
<i>Gomphonema</i>	324 .5%	445 1.4%	204 1.1%	406 2.1%	486 .8%	1,544 3.5%	268 1.0%	51 1.3%
<i>Cymbella</i>	972 1.5%	1,108 3.5%	1,105 6.0%	306 1.6%	— —	556 1.3%	762 2.8%	165 4.3%
<i>Epithemia</i>	890 1.3%	607 1.9%	486 2.6%	1,224 6.3%	3,220 5.6%	206 .5%	1,442 5.2%	26 .7%
<i>Nitzschia</i>	6,308 9.6%	4,893 15.3%	1,976 10.6%	1,581 8.1%	3,248 5.6%	6,837 15.3%	12,293 44.5%	1,416 37.1%
<i>Surirella</i>	161 .2%	— —	— —	— —	— —	52 .1%	556 2.0%	— —
<i>Ophiocytium</i>	242 .4%	— —	304 1.7%	— —	— —	— —	— —	— —
<i>Dinobryon</i>	— —	2,730 8.5%	204 1.1%	— —	— —	— —	62 .2%	— —
Chroococcales	242 .4%	102 .3%	1,376 7.4%	2,011 10.3%	7,745 13.4%	247 .6%	762 2.8%	— —
<i>Lyngbya</i>	— —	— —	— —	243 1.3%	5,450 9.4%	— —	62 .2%	— —

(Table 20 continued on p. 72)

<i>Oscillatoria</i>	9,300	—	204	102	—	515	272	—
	14.1%	—	1.1%	.5%	—	1.2%	1.0%	—
Other Oscillatoriaceae	—	—	—	—	102	52	—	—
	—	—	—	—	.2%	.1%	—	—
<i>Anabaena</i>	—	505	204	1,020	304	52	474	—
	—	1.6%	1.1%	5.2%	.5%	.1%	1.7%	—
<i>Calothrix</i>	—	—	—	—	406	—	—	—
	—	—	—	—	.8%	—	—	—
<i>Chlamydomonas</i>	—	102	—	510	1,624	313	—	—
	—	.3%	—	2.6%	2.8%	.7%	—	—
<i>Pandorina</i>	—	—	—	1,326	486	—	—	26
	—	—	—	6.8%	.8%	—	—	.7%
Other Volvocaceae	81	—	—	204	—	—	—	—
	.1%	—	—	1.0%	—	—	—	—
<i>Oedogonium</i>	648	363	2,960	—	1,280	154	247	226
	1.0%	1.1%	15.9%	—	2.2%	.4%	.9%	6.1%
<i>Cladophora</i>	—	—	102	—	—	412	—	51
	—	—	.6%	—	—	.9%	—	1.3%
<i>Rhizoclonium</i>	—	—	204	—	—	—	—	—
	—	—	1.1%	—	—	—	—	—
<i>Characium</i>	242	—	408	812	—	—	—	—
	.4%	—	2.2%	4.2%	—	—	—	—
<i>Pediastrum</i>	—	—	102	306	—	—	—	—
	—	—	1.1%	1.6%	—	—	—	—
<i>Ankistrodesmus</i>	—	152	304	—	—	—	206	—
	—	.5%	1.7%	—	—	—	.7%	—
<i>Nephrocytium</i>	—	—	—	969	1,624	—	—	26
	—	—	—	5.0%	2.8%	—	—	.7%
<i>Scenedesmus</i>	648	—	102	2,428	15,600	154	206	—
	1.0%	—	.6%	12.4%	27.0%	.4%	.8%	—
<i>Mougeotia</i>	—	505	—	1,323	972	247	618	—
	—	1.6%	—	6.8%	1.7%	.6%	2.2%	—
<i>Spirogyra</i>	—	—	304	102	204	103	268	—
	—	—	1.7%	.5%	.4%	.2%	1.0%	—
<i>Zygnema</i>	—	—	304	—	—	—	—	—
	—	—	1.7%	—	—	—	—	—
Other Filamentous Chlorophyta	1,698	—	1,020	153	—	247	—	—
	2.6%	—	5.5%	.8%	—	.6%	—	—
<i>Closterium</i>	161	—	102	51	—	—	62	—
	.2%	—	1.1%	.3%	—	—	.2%	—
<i>Cosmarium</i>	161	102	—	1,267	306	52	—	—
	.2%	.3%	—	6.5%	.5%	.1%	—	—
<i>Micrasterias</i>	—	51	—	—	—	—	—	—
	—	.2%	—	—	—	—	—	—
<i>Pleurotaenium</i>	—	—	—	—	—	—	62	—
	—	—	—	—	—	—	.2%	—
<i>Sphaeroszoma</i>	—	—	—	—	3,040	52	144	—
	—	—	—	—	5.3%	.1%	.5%	—
<i>Staurastrum</i>	81	203	102	—	—	—	—	—
	.1%	.6%	.6%	—	—	—	—	—
<i>Euglena</i>	890	51	—	204	3,730	2,470	247	—
	1.3%	.2%	—	1.0%	6.5%	5.5%	.9%	—
<i>Phacus</i>	—	—	304	152	1,210	515	62	—
	—	—	1.7%	.8%	2.1%	1.2%	.2%	—
<i>Trachelomonas</i>	890	—	—	—	2,420	247	206	—
	1.3%	—	—	—	4.2%	.6%	.8%	—
Total Algae	66,011	31,953	18,573	19,458	57,778	43,961	27,601	3,816

Table 21. Number of organisms per liter and relative abundance of net plankton at Stuart Station (Site 6)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Chroococcales	—	—	—	—	—	—	—	1.8	—	—	—	—	—
	—	—	—	—	—	—	—	4.3%	—	—	—	—	—
<i>Oscillatoria</i>	69.5	93.0	46.5	11.2	3.8	7.5	1.2	3.7	16.2	13.0	3.1	23.0	45.0
	34.7%	32.9%	9.7%	9.1%	1.8%	7.1%	3.9%	8.9%	21.0%	25.0%	9.8%	14.3%	15.9%
Other Oscilla- toriaceae	23.0	—	—	—	11.2	3.8	8.7	14.2	55.3	19.8	4.1	2.3	6.3
	11.5%	—	—	—	5.5%	3.6%	28.1%	34.0%	71.8%	38.2%	13.0%	1.4%	2.2%
<i>Anabaena</i>	—	—	—	3.8	—	—	1.2	—	—	—	.5	—	—
	—	—	—	3.0%	—	—	3.9%	—	—	—	1.6%	—	—
<i>Chlamydomonas</i>	—	—	3.9	—	3.8	—	—	.6	—	—	—	—	—
	—	—	.8%	—	1.8%	—	—	1.4%	—	—	—	—	—
<i>Pandorina morum</i>	—	—	—	—	7.5	—	—	.6	—	—	—	—	—
	—	—	—	—	3.7%	—	—	1.4%	—	—	—	—	—
<i>Nephrocytium</i>	—	—	—	—	—	—	—	.6	—	—	—	—	—
	—	—	—	—	—	—	—	1.4%	—	—	—	—	—
<i>Ulothrix</i>	—	15.5	31.0	3.8	—	—	—	—	—	—	—	1.3	—
	—	5.4%	6.5%	3.0%	—	—	—	—	—	—	—	.8%	—
<i>Stigeoclonium</i>	—	—	—	—	—	7.7	—	.6	1.2	1.3	.5	—	—
	—	—	—	—	—	7.3%	—	1.4%	1.6%	2.5%	1.6%	—	—
<i>Oedogonium</i>	—	—	23.0	7.5	3.8	—	3.7	3.0	.6	—	—	1.7	1.3
	—	—	4.8%	6.1%	1.8%	—	11.9%	7.2%	.8%	—	—	1.1%	.4%
<i>Cladophora</i>	—	7.7	—	—	—	11.2	—	3.5	2.5	5.1	.5	.6	—
	—	2.7%	—	—	—	10.7%	—	8.4%	3.2%	9.8%	1.6%	.4%	—
<i>Mougeotia</i>	—	—	—	3.8	127.0	3.8	8.7	3.7	—	—	—	—	—
	—	—	—	3.0%	61.7%	3.6%	28.1%	8.9%	—	—	—	—	—
<i>Spirogyra</i>	—	—	3.9	—	7.5	15.0	3.7	1.1	.6	.6	—	.6	—
	—	—	.8%	—	3.7%	14.3%	11.9%	2.6%	.8%	1.2%	—	.4%	—
<i>Zygnema</i>	—	—	—	—	3.8	30.0	—	1.1	—	—	1.0	—	1.3
	—	—	—	—	1.8%	28.6%	—	2.6%	—	—	3.2%	—	.4%
<i>Closterium</i>	—	—	3.9	3.8	37.8	22.5	—	2.5	.6	—	—	—	—
	—	—	.8%	3.0%	18.4%	21.4%	—	6.0%	.8%	—	—	—	—
<i>Cosmarium</i>	—	—	—	—	—	—	1.2	—	—	—	—	—	—
	—	—	—	—	—	—	3.9%	—	—	—	—	—	—
<i>Euglena</i>	—	—	—	—	—	3.8	—	1.2	—	—	—	—	—
	—	—	—	—	—	3.6%	—	2.9%	—	—	—	—	—
<i>Ceratium hirundinella</i>	—	—	—	—	—	—	2.5	.6	—	—	—	—	—
	—	—	—	—	—	—	8.1%	1.4%	—	—	—	—	—
<i>Hydrurus foetidus</i>	108.0	170.0	368.0	90.0	—	—	—	—	—	12.1	21.9	131.0	229.0
	53.9%	59.4%	76.6%	72.8%	—	—	—	—	—	23.3%	69.3%	81.5%	81.0%
<i>Vaucheria</i>	—	—	—	—	—	—	—	3.0	—	—	—	—	—
	—	—	—	—	—	—	—	7.2%	—	—	—	—	—
Total Algae	200.5	286.2	480.6	123.9	206.2	105.3	30.9	41.8	77.0	51.9	31.6	160.5	282.9

Table 22. Number of organisms per liter and relative abundance of nanoplankton at Stuart Station (Site 6)

Algae	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
<i>Cyclotella</i>	—	—	—	—	—	—	—	—	—	347	348	—	—
	—	—	—	—	—	—	—	—	—	.1%	.1%	—	—
<i>Hannaea arcus</i>	—	696	—	348	348	—	—	—	—	695	348	—	—
	—	.7%	—	.1%	.1%	—	—	—	—	.2%	.1%	—	—
<i>Diatoma hiemale</i>	1,390	—	2,085	1,042	—	—	—	—	—	—	—	1,390	—
	.4%	—	.7%	.4%	—	—	—	—	—	—	—	.4%	—
<i>Diatoma vulgare</i>	2,780	348	3,048	4,338	3,480	1,000	3,752	7,645	22,935	30,858	9,730	4,170	2,085
	.8%	.3%	1.0%	1.5%	1.3%	.9%	1.2%	11.5%	8.1%	9.2%	3.4%	1.3%	1.6%
<i>Fragularia</i>	—	1,390	695	—	348	—	—	277	—	—	—	—	—
	—	1.4%	.2%	—	.1%	—	—	.4%	—	—	—	—	—
<i>Meridion</i>	—	—	5,755	—	—	500	—	—	—	—	—	—	—
	—	—	1.9%	—	—	.4%	—	—	—	—	—	—	—
<i>Synedra</i>	20,850	41,700	3,048	7,922	1,044	500	12,092	11,538	30,587	35,445	25,715	23,630	13,205
	6.2%	41.7%	1.0%	2.7%	.4%	.4%	3.9%	17.4%	10.8%	10.6%	9.1%	7.2%	9.9%
<i>Achnanthes</i>	10,286	4,170	11,125	9,312	14,875	9,000	13,482	972	12,510	21,128	16,680	24,325	5,560
	3.1%	4.2%	3.6%	3.2%	5.5%	7.7%	4.3%	1.5%	4.4%	6.3%	5.9%	7.4%	4.2%
<i>Cocconeis</i>	696	—	—	696	12,800	1,200	7,922	389	4,865	2,085	3,057	4,170	1,390
	.2%	—	—	.2%	4.7%	1.0%	2.6%	.6%	1.7%	.6%	1.1%	1.3%	1.0%
<i>Rhoicosphenia</i>	—	—	—	—	348	—	—	—	696	—	—	—	—
	—	—	—	—	.1%	—	—	—	.2%	—	—	—	—
<i>Amphipleura</i>	—	348	—	—	—	—	—	—	—	—	348	—	—
	—	.3%	—	—	—	—	—	—	—	—	.1%	—	—
<i>Gyrosigma</i>	6,115	348	—	—	1,044	—	—	—	—	695	—	695	695
	1.8%	.3%	—	—	.4%	—	—	—	—	.2%	—	.2%	.5%
<i>Navicula cf. capitata</i>	—	—	—	1,042	3,480	4,500	14,456	2,362	9,035	7,923	15,290	14,595	3,475
	—	—	—	.4%	1.3%	3.8%	4.7%	3.6%	3.2%	2.4%	5.4%	4.5%	2.6%
<i>Navicula cf. rhyncoccephala</i>	—	—	—	348	—	2,610	14,177	972	4,445	—	—	—	—
	—	—	—	.1%	—	2.2%	4.6%	1.5%	1.6%	—	—	—	—
<i>Navicula cf. tripunctata</i>	12,510	—	10,008	9,312	12,800	10,332	19,460	4,865	14,177	15,290	12,075	13,900	8,340
	3.7%	—	3.2%	3.2%	4.7%	8.8%	6.3%	7.3%	5.0%	4.6%	4.3%	4.3%	6.3%
Other	155,682	25,020	40,656	24,115	37,555	21,888	42,395	3,752	24,602	49,345	47,538	37,530	12,510
<i>Navicula</i>	46.2%	25.0%	13.1%	8.4%	13.8%	18.8%	13.6%	6.6%	8.7%	14.8%	16.9%	11.3%	9.3%
<i>Pinnularia</i>	—	1,042	—	—	—	—	—	—	—	—	—	—	—
	—	1.1%	—	—	—	—	—	—	—	—	—	—	—
<i>Stauroneis</i>	—	—	—	—	—	250	348	—	—	—	—	—	—
	—	—	—	—	—	.2%	.1%	—	—	—	—	—	—
<i>Gomphonema</i>	31,135	696	131,633	19,460	15,425	8,694	28,495	3,752	34,375	46,148	39,615	33,350	21,545
	9.2%	.7%	42.5%	6.8%	5.7%	7.4%	9.2%	5.6%	12.2%	13.8%	14.1%	10.2%	16.1%
<i>Cymbella</i>	7,505	3,057	60,743	189,040	100,075	23,760	28,772	10,702	61,437	66,720	59,770	115,370	43,090
	2.2%	3.1%	19.6%	65.6%	36.8%	20.3%	9.3%	16.1%	21.7%	20.0%	21.2%	35.2%	32.3%
<i>Epithemia</i>	—	—	—	—	—	—	348	—	—	—	—	—	—
	—	—	—	—	—	—	.1%	—	—	—	—	—	—
<i>Nitzschia acicularis</i>	—	—	—	1,042	45,500	1,697	8,310	3,197	2,362	—	—	—	—
	—	—	—	.4%	16.7%	1.5%	2.7%	4.8%	.8%	—	—	—	—
Other	47,815	20,850	35,723	15,985	21,525	28,620	111,120	14,456	52,820	52,820	47,955	47,955	19,460
<i>Nitzschia</i>	14.2%	20.8%	11.5%	5.5%	8.0%	24.4%	35.8%	21.8%	18.7%	15.8%	17.0%	14.7%	14.6%
<i>Surirella</i>	37,530	—	3,753	—	—	1,200	5,142	696	7,922	4,448	3,057	2,085	2,085
	11.1%	—	1.2%	—	—	1.0%	1.7%	1.0%	2.8%	1.3%	1.1%	.6%	1.6%
Other	—	—	1,668	4,450	348	—	—	—	—	—	—	4,170	—
<i>Pennales</i>	—	—	.5%	1.5%	.1%	—	—	—	—	—	—	1.3%	—
<i>Dinobryon</i>	—	348	—	348	348	250	—	—	—	—	—	—	—
	—	.3%	—	.1%	.1%	.2%	—	—	—	—	—	—	—
<i>Anabaena</i>	2,780	—	—	—	—	—	—	—	—	—	—	—	—
	.8%	—	—	—	—	—	—	—	—	—	—	—	—
<i>Tracholomonas</i>	—	—	—	—	—	—	—	277	—	—	—	—	—
	—	—	—	—	—	—	—	.4%	—	—	—	—	—
Total Algae	337,074	100,913	309,940	288,800	271,343	116,001	310,271	65,852	282,768	333,947	281,526	327,335	133,440

Table 23. Number of organisms per cm<sup>2</sup> and relative abundance of periphyton on glass slides at Stuart Station (Site 6)

Algae	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	2/19 1972	3/11 1972
<i>Cyclotella</i>	—	—	—	—	—	52	—	—	—	—
	—	—	—	—	—	.1%	—	—	—	—
<i>Hannaea arcus</i>	—	51	—	—	—	—	—	—	—	—
	—	.1%	—	—	—	—	—	—	—	—
<i>Diatoma</i>	5,459	705	19,000	204	203	103	3,357	20,593	16,062	1,338
	1.7%	1.7%	9.4%	.4%	.3%	.2%	5.2%	6.8%	7.2%	4.0%
<i>Fragilaria crotonenses</i>	—	—	—	—	—	52	—	—	1,082	—
	—	—	—	—	—	.1%	—	—	.5%	—
<i>Meridion</i>	—	404	204	—	—	—	—	—	—	—
	—	1.0%	.1%	—	—	—	—	—	—	—
<i>Synedra</i>	27,901	825	11,980	—	51	412	5,704	18,945	23,630	1,647
	8.7%	2.0%	6.1%	—	.1%	.8%	8.9%	6.2%	10.6%	4.9%
<i>Achnanthes</i>	6,066	1,928	16,500	29,500	37,290	32,989	5,148	125,615	25,947	4,221
	1.9%	4.7%	8.1%	60.9%	53.1%	61.2%	8.0%	41.3%	11.6%	12.5%
<i>Cocconeis</i>	241	—	102	2,750	7,900	3,851	762	1,853	1,082	—
	.1%	—	.1%	5.7%	11.2%	7.1%	1.2%	.6%	.5%	—
<i>Navicula cf. capitata</i>	—	—	—	—	204	—	824	4,119	1,082	206
	—	—	—	—	.3%	—	1.3%	1.4%	.5%	.6%
<i>Navicula cf. rhyncocephala</i>	—	—	—	204	—	1,133	—	—	—	—
	—	—	—	.2%	—	2.1%	—	—	—	—
<i>Navicula cf. tripunctata</i>	—	—	—	1,320	1,115	1,380	3,501	4,530	2,471	309
	—	—	—	2.7%	1.6%	2.6%	5.5%	1.5%	1.1%	.9%
Other <i>Navicula</i>	42,410	7,122	18,604	7,950	4,304	3,274	11,594	28,006	22,085	3,295
	13.2%	17.5%	9.2%	16.4%	5.9%	6.0%	18.0%	7.8%	9.9%	9.7%
<i>Gomphonema</i>	129,764	13,647	12,680	486	742	1,894	8,442	35,213	46,488	1,493
	40.2%	33.5%	6.3%	1.0%	1.1%	3.5%	13.2%	11.6%	20.9%	4.4%
<i>Cymbella</i>	77,153	8,694	111,200	3,590	1,601	1,071	5,004	28,624	60,697	13,436
	23.9%	21.3%	54.8%	7.4%	2.3%	2.0%	7.8%	9.4%	27.3%	40.0%
<i>Nitzschia acicularis</i>	—	—	—	304	1,218	206	1,235	—	—	—
	—	—	—	.6%	1.7%	.4%	1.9%	—	—	—
Other <i>Nitzschia</i>	21,593	6,924	7,600	1,320	5,274	7,195	17,154	32,372	12,047	3,552
	6.7%	17.0%	3.7%	2.7%	7.5%	13.3%	26.8%	10.6%	5.4%	10.5%
<i>Surtirella</i>	1,213	202	1,518	102	153	154	679	2,059	1,699	257
	.4%	.5%	.7%	.2%	.2%	.3%	1.1%	.7%	.8%	.8%
Other Pennales	—	51	2,550	102	102	52	144	—	—	—
	—	.1%	1.2%	.2%	.2%	.1%	.2%	—	—	—
Chroococcales	2,729	—	—	—	406	—	—	—	—	—
	.8%	—	—	—	.6%	—	—	—	—	—
<i>Oscillatoria</i>	1,213	—	—	406	509	103	350	2,059	1,082	154
	.4%	—	—	.8%	.7%	.2%	.6%	.7%	.5%	.5%
Other <i>Oscillatoriaceae</i>	—	—	—	—	9,188	—	144	—	—	—
	—	—	—	—	13.1%	—	.2%	—	—	—
<i>Ulothrix</i>	972	—	406	102	—	—	—	—	154	—
	.3%	—	.2%	.2%	—	—	—	—	.1%	—
<i>Closterium</i>	—	—	204	102	102	—	62	—	—	—
	—	—	.1%	.2%	.2%	—	.1%	—	—	—
<i>Euglena</i>	241	—	—	—	—	—	—	—	—	—
	.1%	—	—	—	—	—	—	—	—	—
<i>Hydrurus</i>	5,459	202	406	—	—	—	—	—	7,722	3,964
	1.7%	.5%	.2%	—	—	—	—	—	3.5%	11.7%
Total Algae	322,414	40,755	202,954	48,442	70,362	53,921	64,105	303,988	223,330	33,872

Table 24. Number of organisms per liter and relative abundance of net plankton at Bear Canyon (Site 7)

Algae	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971
<i>Chroococcales</i>	— —	— —	— —	3.7 6.6%	— —	— —
<i>Oscillatoria</i>	15.0 3.3%	30.0 14.4%	3.0 3.9%	10.0 17.9%	6.2 20.9%	28.7 25.6%
Other Oscillatoriaceae	4.5 1.0%	22.5 10.8%	— —	8.7 15.5%	1.2 4.1%	35.0 31.2%
<i>Rivularia</i>	15.0 3.3%	— —	— —	— —	— —	— —
<i>Chlamydomonas</i>	— —	25.5 12.2%	— —	2.5 4.5%	— —	— —
<i>Pandorina morum</i>	— —	— —	— —	1.2 2.1%	— —	— —
<i>Scenedesmus</i>	— —	— —	— —	1.2 2.1%	— —	— —
<i>Ulothrix</i>	90.0 19.9%	11.2 5.4%	3.0 3.9%	— —	— —	5.0 4.5%
<i>Cylindrocapsa</i>	— —	— —	10.5 13.7%	— —	— —	— —
<i>Stigeoclonium</i>	— —	— —	— —	— —	— —	1.7 1.5%
<i>Oedogonium</i>	4.5 1.0%	18.0 8.6%	4.5 5.9%	10.0 17.9%	15.5 52.4%	37.5 33.4%
<i>Cladophora</i>	— —	15.0 7.2%	7.5 9.8%	10.0 17.9%	— —	.6 .5%
<i>Mougeotia</i>	4.5 1.0%	7.5 3.6%	— —	2.5 4.5%	— —	— —
<i>Spirogyra</i>	— —	— —	— —	5.0 8.9%	— —	— —
<i>Zygnema</i>	— —	3.8 1.8%	3.0 3.9%	— —	3.7 12.5%	1.2 1.1%
<i>Closterium</i>	4.5 1.0%	67.5 32.4%	42.0 54.9%	1.2 2.1%	.6 2.1%	2.5 2.2%
<i>Pleurotaenium</i>	— —	— —	— —	— —	.6 2.1%	— —
<i>Euglena</i>	— —	— —	3.0 3.9%	— —	.6 2.1%	— —
Other Euglenophyta	— —	— —	— —	— —	1.2 4.1%	— —
<i>Hydrurus foetidus</i>	315.0 69.5%	7.5 3.6%	— —	— —	— —	— —
Total Algae	453.0	208.5	76.5	56.0	29.6	112.2

Table 25. Number of organisms per liter and relative abundance of nannoplankton at Bear Canyon (Site 7)

Algae	8/20 1971	9/15 1971	10/8 1971	11/15 1971
<i>Diatoma vulgare</i>	1,390 .6%	2,085 1.0%	554 .5%	1,390 .5%
<i>Meridion</i>	348 .2%	—	—	2,085 .8%
<i>Synedra</i>	1,042 .5%	4,170 1.9%	3,890 3.5%	12,787 4.8%
<i>Achnanthes</i>	20,125 9.3%	21,127 9.7%	23,907 21.3%	19,460 7.3%
<i>Cocconeis</i>	13,200 6.1%	5,142 2.4%	3,335 3.0%	6,245 2.3%
<i>Rhoicosphenia</i>	696 .3%	—	554 .5%	—
<i>Navicula</i> cf. <i>capitata</i>	—	1,390 .6%	—	348 .1%
<i>Navicula</i> cf. <i>rhyncocephala</i>	5,150 2.4%	4,445 2.0%	2,500 2.2%	6,950 2.6%
<i>Navicula</i> cf. <i>tripunctata</i>	20,475 9.5%	12,510 5.7%	5,837 5.5%	7,500 2.8%
Other <i>Navicula</i>	39,125 18.1%	29,190 13.4%	13,065 11.4%	37,807 14.2%
<i>Stauroneis</i>	696 .3%	—	—	—
<i>Gomphonema</i>	12,075 5.6%	25,020 11.5%	4,725 4.2%	23,630 8.8%
<i>Cymbella</i>	69,250 32.1%	45,452 20.8%	33,637 30.0%	78,535 29.4%
<i>Epithemia</i>	348 .2%	—	—	—
<i>Nitzschia</i> <i>acicularis</i>	1,668 .8%	4,170 1.9%	—	3,475 1.3%
Other <i>Nitzschia</i>	28,250 13.1%	57,267 26.3%	19,460 17.3%	59,770 22.4%
<i>Surirella</i>	1,042 .5%	1,390 .6%	831 .7%	2,711 1.0%
<i>Trachlomonas</i>	696 .3%	4,865 2.2%	—	4,448 1.7%
Total Algae	215,576	218,223	112,295	267,141

Table 26. Frequency, percent cover, and percent composition of the visible benthic flora at 6 localities in Huntington Creek, June 1971-March 1972

	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	2/19 1972	3/11 1972
Lawrence									
Total Frequency	91	100	100	100	100	100	98	95	—
Total Cover	51	81	65.7	89.1	60.6	86.9	73.8	17.7	—
<i>Cladophora</i>									
Frequency	91	77	37	33	20	15	24	5	—
Cover	34	43	4.3	6.6	1.6	4.5	3.6	.13	—
Composition	67	53	6.0	8.0	2.6	5.0	4.8	1	—
<i>Oedogonium</i>									
Frequency	68	100	—	—	—	—	—	—	—
Cover	17	38	—	—	—	—	—	—	—
Composition	33	47	—	—	—	—	—	—	—
<i>Chara</i>									
Frequency	—	—	70	50	82	85	88	90	—
Cover	—	—	37.4	38.3	48.0	63.6	61.0	15.5	—
Composition	—	—	57	43	79.3	73	82.6	87	—
<i>Protoderma</i>									
Frequency	—	—	—	28	12	—	—	—	—
Cover	—	—	—	2.2	1.8	—	—	—	—
Composition	—	—	—	2.0	3.0	—	—	—	—
<i>Potamogeton</i>									
Frequency	—	—	70	57	49	40	41	34	—
Cover	—	—	24	42	9.2	18.8	9.2	2.1	—
Composition	—	—	37	47	15.1	22	12.5	12	—
Highway 10									
Total Frequency	100	81	100	100	100	93	94	73	—
Total Cover	25	57	15.6	18.9	22.7	26.6	29.3	11	—
<i>Cladophora</i>									
Frequency	100	81	97	59	25	48	61	20	—
Cover	25	57	13.4	2.5	1.4	2.5	5.8	.5	—
Composition	100	100	86	13.0	6.0	9.0	19.9	5	—
<i>Chara</i>									
Frequency	—	—	21	49	46	71	51	64	—
Cover	—	—	2.2	16.4	20.5	24.1	22.8	10.5	—
Composition	—	—	14.0	87	90.0	91.0	77.8	95	—
<i>Potamogeton</i> sp.									
Frequency	—	—	—	—	11	—	14	—	—
Cover	—	—	—	—	.8	—	.7	—	—
Composition	—	—	—	—	4.0	—	2.4	—	—
Plant Site									
Total Frequency	—	—	—	—	—	—	—	89	10
Total Cover	—	—	—	—	—	—	—	24	1
<i>Hydrurus</i>									
Frequency	—	—	—	—	—	—	—	89	10
Cover	—	—	—	—	—	—	—	24	1
Composition	—	—	—	—	—	—	—	100	100
Campground									
Total Frequency	75	—	—	77	—	—	—	30	—
Total Cover	25	—	—	6.4	—	—	—	1.5	—
<i>Oscillatoria</i>									
Frequency	—	—	—	77	—	—	—	—	—
Cover	—	—	—	6.4	—	—	—	—	—
Composition	—	—	—	100	—	—	—	—	—

(Table 26 continued on p. 79)

<i>Hydrurus</i>									
Frequency	75	—	—	—	—	—	—	30	—
Cover	25	—	—	—	—	—	—	1.5	—
Composition	100	—	—	—	—	—	—	100	—
Stuart Station									
Total Frequency	100	22	—	—	68	83	74	83	88
Total Cover	30	.55	—	—	6.7	10.6	1.8	14	25
<i>Hydrurus</i>									
Frequency	100	18	—	—	—	—	—	83	88
Cover	30	.45	—	—	—	—	—	14	25
Composition	100	82.0	—	—	—	—	—	100	100
<i>Cladophora</i>									
Frequency	—	4	—	—	61	83	74	—	—
Cover	—	.1	—	—	6.21	10.5	1.8	—	—
Composition	—	18.0	—	—	94.0	99	100	—	—
<i>Oscillatoria</i>									
Frequency	—	—	—	—	18	4.5	—	—	—
Cover	—	—	—	—	.44	.11	—	—	—
Composition	—	—	—	—	6.0	1.0	—	—	—
Bear Canyon									
Total Frequency	—	—	—	—	79	86	88	—	—
Total Cover	—	—	—	—	12.3	7.2	4.4	—	—
<i>Oedogonium</i>									
Frequency	—	—	—	—	79	86	88	—	—
Cover	—	—	—	—	12.3	7.2	3.7	—	—
Composition	—	—	—	—	100	100	84	—	—
<i>Hydrurus</i>									
Frequency	—	—	—	—	—	—	30	—	—
Cover	—	—	—	—	—	—	.7	—	—
Composition	—	—	—	—	—	—	16	—	—

Table 27. Physical and chemical data from Huntington Canyon. Water temperature ( $^{\circ}\text{C}$ ).

Site	4/15 1971	5/13 1971	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	9	10.5	13	15	16	23	13	9	3	-1	0	0	4
Highway 10	nd	nd	nd	12	14	20	13	9	3	-1	0	0	3
Plant Site	5	4	8	10	12	18	13	8	1.5	0	.2	1	3
Campground	5	4	8	9	11	17	13	7	1.5	0	1	1	3
Tie Fork	15	14.5	13	20	22	23	16	13	nd	nd	nd	nd	2
Stuart Station	8.8	8	6	12	15	17	13	7	.5	0	1	1.5	3
Bear Canyon	nd	5	6	11	15	18	14	11	3	nd	nd	nd	nd

nd = no data available

Table 28. Physical and chemical data from Huntington Canyon. Turbidity (JTU).

Site	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	nd	58	10	7	40	5	15	30	80	140	170
Highway 10	nd	nd	nd	5	10	5	10	10	65	65	140
Plant Site	12*	40	0	15	20	13	65	5	15	5	20
Campground	20*	15	0	5	9	13	12	15	0	0	0
Tie Fork	nd	nd	18	35	40	3	nd	nd	nd	nd	75
Stuart Station	6*	0	0	20	22	1	5	15	5	0	5
Bear Canyon	nd	5	5	10	15	1	2	nd	nd	nd	nd

nd = no data available

\*Data recorded during corresponding time periods by Dr. Robert Wingett, Center for Health and Environmental Studies, Brigham Young University.

Table 29. Physical and chemical data from Huntington Canyon. pH.

Site	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	8.85	8.1	8.0	8.1	8.2	8.3	8.1	7.65	7.8	8.35	7.9
Highway 10	nd	nd	nd	7.7	8.3	8.3	8.0	8.0	7.8	8.4	7.9
Plant Site	8.2*	7.6	8.2	8.4	8.4	8.3	8.1	8.2	8.2	8.6	8.1
Campground	8.45	7.6	8.4	8.35	8.3	8.5	8.2	8.35	8.2	8.4	8.1
Tie Fork	8.30	7.8	8.8	8.6	8.8	8.9	nd	nd	nd	nd	7.4
Stuart Station	8.30	7.0	8.4	8.2	8.25	8.3	8.2	8.1	8.1	8.5	7.9
Bear Canyon	8.3*	8.4*	8.4*	8.65	8.25	8.2	8.2	nd	nd	nd	nd

nd = no data available

\*Data recorded during corresponding time periods by Dr. Robert Wingett, Center for Health and Environmental Studies, Brigham Young University.

Table 30. Physical and chemical data from Huntington Canyon. Dissolved oxygen (mg/l).

Site	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	9	5	9	9	10	8	6	3	8	9	11
Highway 10	nd	nd	nd	9	10	8	10	4	6	9	11
Plant Site	10*	9	9*	9*	9	8	9	7	5	9	11
Campground	11	10	9*	10*	9	7	7	9	8	10	11
Tie Fork	8	5	nd	10	14	8	nd	nd	nd	nd	5
Stuart Station	11	9	9*	9*	8	8	8	7	5	9	9
Bear Canyon	11*	7*	9*	8*	8	10	7	nd	nd	nd	nd

nd = no data available

\*Data recorded during corresponding time periods by Dr. Robert Wingett, Center for Health and Environmental Studies, Brigham Young University.

Table 31. Physical and chemical data from Huntington Canyon. Dissolved carbon dioxide (mg/l).

Site	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	2	4	12.8	12	4	2	6	24	16	18	8
Highway 10	nd	nd	nd	12	4	2	4	14	20	6	4
Plant Site	0*	1	4.8	8	2	2	2	6	6	2	2
Campground	1.4	2	6	12	1	2	2	5	6	2	2
Tie Fork	0	0	0	0	0	2	nd	nd	nd	nd	24
Stuart Station	2	3	3.6	4	2	2	2	6	4	2	2
Bear Canyon	nd	0*	nd	0	1	2	2	nd	nd	nd	nd

nd = no data available

\*Data recorded during corresponding time periods by Dr. Robert Wingett, Center for Health and Environmental Studies, Brigham Young University.

Table 32. Physical and chemical data from Huntington Canyon. Phosphate (mg/l).

Site	6/8 1971	6/29 1971	8/20 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	1.43	.10	.24	.16	.72	.30	.15
Highway 10	nd	nd	.31	.06	.20	.32	.15
Plant Site	nd	.15	.07	.08	.18	.22	.11
Campground	4.0	.35	.57	.07	.04	.13	.05
Tie Fork	7.5	nd	nd	nd	nd	nd	.15
Stuart Station	1.31	.25	.04	.02	.04	.18	.03
Bear Canyon	nd	nd	.08	nd	nd	nd	nd

nd = no data available

Table 33. Physical and chemical data from Huntington Canyon. Nitrate nitrogen (mg/l).

Site	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	1.0	.30	1.5	.57	.68	.60	.49	.60	.45	.49	.18
Highway 10	nd	nd	nd	.05	.07	.06	.24	.33	.32	.42	.20
Plant Site	.10*	.40	.03	.03	.08	.01	.22	.30	.24	.34	.14
Campground	.10	.30	.03	.03	.02	.05	.20	.30	.26	.35	.17
Tie Fork	.40	nd	.02	nd	.06	.04	nd	nd	nd	nd	.11
Stuart Station	.40	.20	.10*	.07	.03	.04	.26	.31	.27	.35	.27
Bear Canyon	nd	.10*	.40*	.03	.06	.10	.37	nd	nd	nd	nd

nd = no data available

\*Data recorded during corresponding time periods by Dr. Robert Wingett, Center for Health and Environmental Studies, Brigham Young University.

Table 34. Physical and chemical data from Huntington Canyon. Sulfate (mg/l).

Site	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	nd	1350*	3000	2500	2600	2250	2600	2700	1750	1200	625
Highway 10	nd	nd	nd	nd	1300	1500	1650	1300	1300	350	190
Plant Site	12	8*	17	7	10	8	36	28	20	15	30
Campground	11	3*	5	7	10	10	25	22	18	10	20
Tie Fork	nd	nd	7	nd	22	57	nd	nd	nd	nd	75
Stuart Station	10	6*	8*	6	12	11	20	20	20	11	15
Bear Canyon	nd	2*	nd	4*	5	5	6	nd	nd	nd	nd

nd = no data available

\*Data recorded during corresponding time periods by Dr. Robert Wingett, Center for Health and Environmental Studies, Brigham Young University.

Table 35. Physical and chemical data from Huntington Canyon. Calcium and magnesium hardness (mg/l CaCO<sub>3</sub>).

Site	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence											
Ca Hardness	nd	760	770	660	580	1150	950	1050	650	700	300
Mg Hardness	nd	250	6480	460	870	850	900	950	650	1000	200
Total	nd	1010	7250	1120	1450	1900	1850	2000	1300	1700	500
Highway 10											
Ca Hardness	nd	nd	nd	540	610	1100	750	800	700	300	250
Mg Hardness	nd	nd	nd	160	180	400	550	500	450	300	200
Total	nd	nd	nd	700	820	1500	1300	1300	1150	600	450
Plant Site											
Ca Hardness	115*	120	120	120	100	120	150	140	170	140	140
Mg Hardness	45*	55	60	40	60	60	80	110	40	100	110
Total	160*	175	180	160	160	180	230	250	210	240	250
Campground											
Ca Hardness	120*	120	115	110	110	120	160	140	150	150	140
Mg Hardness	35*	50	45	40	70	60	80	110	60	90	90
Total	155*	170	160	150	180	180	240	250	210	240	230
Tie Fork											
Ca Hardness	nd	55	60	60	60	70	nd	nd	nd	nd	230
Mg Hardness	nd	185	250	260	220	310	nd	nd	nd	nd	170
Total	nd	240	310	320	280	380	nd	nd	nd	nd	400

(Table 35 continued on p. 83)

Stuart Station											
Ca Hardness	100*	135	130	140	130	140	140	140	150	130	110
Mg Hardness	50*	40	45	100	60	70	60	70	50	100	100
Total	150*	175	175	240	190	210	200	210	200	230	210
Bear Canyon											
Ca Hardness	nd	80*	110*	120	120	105	130	nd	nd	nd	nd
Mg Hardness	nd	50*	35*	120	60	55	60	nd	nd	nd	nd
Total	nd	130*	145*	240	180	160	190	nd	nd	nd	nd

nd = no data available

\*Data recorded during corresponding time periods by Dr. Robert Wingett, Center for Health and Environmental Studies, Brigham Young University.

Table 36. Physical and chemical data from Huntington Canyon. Bicarbonate alkalinity (mg/l CaCO<sub>3</sub>).

Site	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	315	330	290	300	330	380	410	300	330	250
Highway 10	nd	nd	280	320	340	360	370	340	270	250
Plant Site	175	170	160	170	200	210	240	200	220	220
Campground	175	160	160	170	200	210	230	220	230	220
Tie Fork	250 <sup>a</sup>	270 <sup>b</sup>	280 <sup>b</sup>	250 <sup>c</sup>	350	nd	nd	nd	nd	380
Stuart Station	165	170	180	190	210	210	220	210	210	200
Bear Canyon	nd	nd	170	130	170	160	nd	nd	nd	nd

nd = no data available

<sup>a</sup>Number includes 75 mg/l of carbonate alkalinity

<sup>b</sup>Number includes 30 mg/l of carbonate alkalinity

<sup>c</sup>Number includes 20 mg/l of carbonate alkalinity

Table 37. Physical and chemical data from Huntington Canyon. Silica (mg/l SiO<sub>3</sub>).

Site	6/8 1971	6/29 1971	7/30 1971	8/20 1971	9/15 1971	10/8 1971	11/15 1971	12/17 1971	1/20 1972	2/19 1972	3/11 1972
Lawrence	7.3	8.75	8.75	9.0	9.3	10.5	13.0	16.0	14.5	17.0	10.0
Highway 10	nd	nd	nd	10.5	14.5	12.5	18.0	18.0	16.0	12.0	9.0
Plant Site	3.9*	3.5	3.4	3.2	4.2	4.35	6.75	7.5	8.3	8.0	7.5
Campground	1.9	4.0*	.31	3.6	3.8	4.35	6.5	4.0	8.3	8.0	7.3
Tie Fork	6.2	nd	1.7	7.5	2.4	5.0	nd	nd	nd	nd	16.5
Stuart Station	4.1	3.5	6.13	6.4	5.6	6.25	6.5	8.5	7.5	8.5	8.0
Bear Canyon	nd	3.5*	7.2*	5.75	5.2	6.65	6.6	nd	nd	nd	nd

nd = no data available

\*Data recorded during corresponding time periods by Dr. Robert Wingett, Center for Health and Environmental Studies, Brigham Young University.

## APPENDIX II

ALGAE COLLECTED FROM HUNTINGTON  
CANYON OCTOBER 1970 - MARCH 1972

## I. Division Chlorophyta

## A. Class Chlorophyceae

## 1. Order Volvocales

## a) Family Chlamydomonadaceae

*Carteria klebsii* (Dang.) Dill  
*Chlamydomonas* sp.

## b) Family Volvocaceae

*Pandorina morum* (Muell.) Bory  
*Volvox tertius* A. Meyer

## 2. Order Tetrasporales

## a) Family Gloeocystaceae

*Gloeocystis* sp.

## 3. Order Chlorococcales

## a) Family Chlorococcaceae

*Characium ambiguum* Hermann  
*C. obtusum* A. Braun

## b) Family Oocystaceae

*Ankistrodesmus falcatus* (Corda) Ralfs  
*Closteriopsis longissima* var. *tropica* West  
and West  
*Nephrocytium lunatum* W. West  
*Oocystis gigas* Archer

## c) Family Dictyosphaeriaceae

*Botryococcus sudeticus* Lemmermann

## d) Family Scenedesmaeae

*Scenedesmus bijuga* (Turp.) Lagerheim  
*S. denticulatus* Lager.  
*S. quadricauda* (Turp.) de Brébisson

## e) Family Hydrodictyaceae

*Pediastrum tetras* (Ehr.) Ralfs

## 4. Order Ulotrichales

## a) Family Ulotrichaceae

*Stichococcus subtilis* (Kutz.) Klercker  
*Ulothrix aequalis* Kutz.  
*U. tenerrima* Kutz.  
*U. tenuissima* Kutz.  
*U. zonata* (Weber & Mohr) Kutz.

## b) Family Microsporaceae

*Microspora willcana* Lagerheim

## c) Family Cyliandrocapsaceae

*Cyliandrocapsa conferta* W. West

## 5. Order Chaetophorales

## a) Family Chaetophoraceae

*Draparnaldia plumosa* (Vauch.) C. A.  
Agardh  
*Protoderma viride* Kutz.  
*Stigeoclonium attenuatum* (Hazen)  
Collins  
*S. stagnatile* (Hazen) Collins

## h) Family Aphanochaetaceae

*Aphanochaete repens* A. Braun

## c) Family Coleochaetaceae

*Coleochaete irregularis* Pringsheim

## 6. Order Oedogoniales

## a) Family Oedogoniaceae

*Oedogonium* spp.

## 7. Order Cladophorales

## a) Family Cladophoraceae

*Cladophora fracta* (Dillw.) Kutz.  
*C. glomerata* (L.) Kutz.  
*Rhizoclonium hieroglyphicum* (C. A. Ag.)  
Kutz.

## 8. Order Zygnematales

## a) Family Zygnemataceae

*Mougeotia capucina* (Bory) C. A.  
Agardh

*M. genuflexa* (Dillw.) C. A. Agardh

*M. parvula* Hassall

*Spirogyra decimina* (Muell.) Kutz.

*S. dubia* Kutz.

*S. porticalis* (Muell.) Cleve

*S.* spp.

*Zygnema insigne* (Hass.) Kutz.

*Z.* spp.

## b) Family Desmidiaceae

*Closterium acerosum* (Schr.) Ehr.

*C. diana* Ehr.

*C. ehrenbergii* Menegh.

*C. lanceolatum* Kg.

*C. moniliferum* Ehr.

*C. rostratum* Ehr.

*C.* spp.

*Cosmarium margariferum* Menegh.

*C. ochthodes* Nord.

*C. ovale* Ralfs

*C. quinarium* Lund

*C. tinctum* Ralfs

*C.* spp.

*Euastrum* sp.

*Micrasterias* sp.

*Pleurotaenium ehrenbergii* Ralfs

*P.* sp.

*Sphaeroszma filiforme* Rabh.

*Staurastrum eustephanum* (Ehr.) Ralfs

*S. gracile* Ralfs

*S. mutica* Breb.

## B. Class Charophyceae

## 1. Order Charales

## a) Family Characeae

*Chara vulgaris* Linnaeus

## II. Division Euglenophyta

## A. Class Euglenophyceae

## 1. Order Englenales

## a) Family Englenaceae

*Euglena acus* Ehrenberg

*E. gracilis* Klebs

*E. minuta* Prescott

*E.* sp.

*Eutreptia* sp.

*Phacus acuminatus* Stokes

*P. pyrsum* (Ehrb.) Stein

*P.* sp.

*Trachelomonas robusta* Swirenko

## III. Division Pyrrophyta

## A. Class Dinophyceae

## 1. Order Peridinales

## a) Family Peridiniaceae

*Peridinium cinctum* (Muell.) Ehrenberg

## b) Family Ceratiaceae

*Ceratum hirundinella* (Muell.) Dujardin

## IV. Division Chrysophyta

## A. Class Xanthophyceae

## 1. Order Heterococcales

## a) Family Characiopsidaceae

*Characiopsis acuta* (A. Braun) Borzi

*C. longipes* (Rabh.) Borzi

## b) Family Chlorotheciaceae

*Ophiocytium* sp.

## 2. Order Tribonematales

## a) Family Tribonemataceae

*Tribonema bombycinum* (C. A. Ag.)

Derbés & Solier

## 3. Order Vaucheriales

## a) Family Vaucheriaceae

*Vaucheria geminata* (Vauch.) De Candolle

- B. Class Chrysophyceae
1. Order Chromulinales
    - a) Family Hydruraceae  
*Hydrurus foetidus* (Vill.) Trev.
  2. Order Ochromonadales
    - a) Family Dinobryaceae  
*Dinobryon cylindricum* Imhof
- C. Class Bacillariophyceae
1. Order Centrales
    - a) Family Coscinodiscaceae  
*Cyclotella meneghiniana* Kutz.
  2. Order Pennales
    - a) Family Fragilariaceae  
*Asterionella formosa* Hassall  
*Diatoma anceps* var. *linearis* M. Perag.  
*D. hiemale* var. *mesodon* (Ehr.) Grunow  
*D. tenue* var. *elongatum* Lyngb.  
*D. vulgare* Bory  
*D. vulgare* var. *breve* Grunow  
*Fragilaria construens* var. *binodus* (Ehr.) Grunow  
*F. construens* var. *venter* (Ehr.) Grunow  
*F. crotonensis* Kitton  
*F. leptostauron* (Ehr.) Hust.  
*F. pinnata* var. *lancettula* (Schum.) Hust.  
*F. virescens* Ralfs  
*Hannaea arcus* (Ehr.) Patrick  
*Hannaea arcus* var. *amphiozys* (Rabh.) Patrick  
*Meridion circulare* var. *constrictum* (Ralfs) v. Heur.  
*Synedra acus* Kutz.  
*S. affinis* Kutz.  
*S. delicatissima* W. Sm.  
*S. pulchella* Ralfs  
*S. pulchella* var. *lanceolata* O'Meara  
*S. radians* Kutz.  
*S. ulna* (Nitz.) Ehr.  
*S. ulna* var. *oxyrhynchus* (Kutz.) v. Heur.  
*S. ulna* var. *subequalis* (Grun.) v. Heur.  
*Tabellaria fenestrata* (Lyngb.) Kutz.
    - b) Family Eunotiaceae  
*Eunotia curvata* (Kutz.) Lagerst
    - c) Family Achnantheaceae  
*Achnanthes deflexa* Reim.  
*A. hauckiana* Grunow  
*A. lanceolata* (Breb.) Grunow  
*A. lanceolata* var. *dubia* Grunow  
*A. lanceolata* var. *havnaldii* (Istv.-Scaarsch.) Cl.  
*A. linearis* fo. *curta* H. L. Sm.  
*A. minutissima* Kutz.  
*Cocconeis disculus* (Schum.) Cleve  
*C. pediculus* Ehr.  
*C. placentula* var. *euglypta* (Ehr.) Cleve  
*C. placentula* var. *lineata* (Ehr.) v. Heur.  
*C. rugosa* Sov.  
*Rhoicosphenia curvata* (Kutz.) Grunow
    - d) Family Naviculaceae  
*Amphipleura pellucida* Kutz.  
*Amphipora alata* (Ehr.) Kutz.  
*Anomooneis vitrea* (Grun.) Reim.  
*Caloneis ventricosa* (Ehr.) Meist.  
*Diploneis pseudovalis* Hust.  
*Gyrosigma acuminatum* (Kutz.) Rabh.  
*G. spenceri* (Quek.) Griff. & Heufr.  
*Mastogloia smithii* Thwaites  
*Navicula bicephala* Hust.  
*N. capitata* Ehr.  
*N. cryptocephala* Kutz.  
*N. cuspidata* var. *major* Meist.  
*N. elginensis* (Greg.) Ralfs  
*N. elginensis* var. *rostrata* (A. mayer) Patrick
- N. exigua* Greg.  
*N. lanceolata* (Ag.) Kutz.  
*N. minima* Grun.  
*N. odiosa* Wallace  
*N. pelliculosa* (Breb.) Hilse  
*N. peregrina* (Ehr.) Kutz.  
*N. pseudoreinhardtii* Patrick  
*N. pupula* Kutz.  
*N. radiosa* Kutz.  
*N. radiosa* var. *tenella* (Breb.) Grunow  
*N. rhyncocephala* Kutz.  
*N. secreta* var. *apiculata* Patrick  
*N. tripunctata* var. *schizonemoides* (v. Heur.) Patrick  
*Neidium affine* var. *longiceps* (Greg.) Cleve  
*N. binode* (Ehr.) Hust.  
*Pinnularia brebissonii* (Kutz.) Rabh.  
*P. viridis* var. *minor* Cleve  
*Pleurosigma delicatulum* W. Sm.  
*Stauroneis anceps* Ehr.  
*S. phoenicenteron* (Nitz.) Ehr.  
*S. phoenicenteron* fo. *gracilis* (Ehr.) Hust.  
*S. smithii* Grunow
- e) Family Gomphonemataceae  
*Gomphonema acuminatum* Ehr.  
*G. constrictum* Ehr.  
*G. gracile* Ehr.  
*G. intricatum* Kutz.  
*G. olivaceum* (Lyngb.) Kutz.
  - f) Family Cymbellaceae  
*Amphora ovalis* Kutz.  
*Cymbella amphi-cephala* Naeg.  
*C. cuspidata* Kutz.  
*C. cymbiformis* Agardh  
*C. gracilis* (Ehr.) Kutz.  
*C. parva* (W. Sm.) Wolle  
*C. ventricosa* Kutz.
  - g) Family Epithemiaceae  
*Denticula elegans* Kutz.  
*Epithemia argus* Kutz.  
*E. turgida* var. *westermanni* Ehr.  
*Rhopalodia gibba* (Ehr.) O. Muell.
  - h) Family Nitzschiaceae  
*Nitzschia acicularis* (Kutz.) W. Sm.  
*N. angularis* var. *affinis* Grun.  
*N. communis* Rabh.  
*N. dissipata* (Kutz.) Grun.  
*N. frustulum* var. *perpusilla* (Rabh.) Grunow  
*N. hungarica* Grun.  
*N. linearis* W. Sm.  
*N. palea* (Kutz.) W. Sm.  
*N. sigmoidea* (Ehr.) W. Sm.  
*N. vermicularis* (Kutz.) Hantz.
  - i) Family Surirellaceae  
*Cymatopleura elliptica* (Breb.) W. Sm.  
*C. solea* (Breb.) W. Sm.  
*Surirella angustata* Kutz.  
*S. baileyi* Lewis  
*S. ovalis* Breb.  
*S. ovata* Kutz.
- V. Division Cyanophyta
- A. Class Myxophyceae
1. Order Chroococcales
    - a) Family Chroococcaceae  
*Chroococcus limneticus* Lemm.  
*C. minutus* (Kutz.) Nag.  
*Gloeocapsa* sp.  
*Gomphosphaeria aponina* Kutz.  
*Merismopodia elegans* A. Br.  
*M. glauca* (Ehr.) Nag.  
*M. tenuissima* Lemm.
  2. Order Chamaesiphonales
    - a) Family Chamaesiphonaceae  
*Chamaesiphon* sp.

## 3. Order Oscillatoriales

## a) Family Oscillatoriaceae

*Lyngbya aerugineo-coerulea* (Kutz.)

Gomont

*L. aestuarii* (Mert.) Leib.*L. major* Meneg.*L. martensiana* Meneg.*L. spp.**Oscillatoria agardhii* Gomont*O. amphibia* Ag.*O. limosa* Ag.*O. tenuis* Ag.*O. spp.**Phormidium* sp.*Schizothrix fragilis* (Kutz.) Gomont*Spirulina major* Kutz.*S. princeps* (West & West) G. S. West

## 4. Order Nostocales

## a) Family Nostocaceae

*Anabaena circinalis* Rabh.*A. spp.**Nostoc paludosum* Kutz.*N. piscinale* Kutz.

## b) Family Scytonemataceae

*Tolypothrix lanata* Wartm.

## c) Family Rivulariaceae

*Calothrix* sp.

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**BREEDING ECOLOGY OF RAPTORS  
IN THE EASTERN GREAT BASIN  
OF UTAH**

by

Dwight G. Smith

and

Joseph R. Murphy



BIOLOGICAL SERIES — VOLUME XVIII, NUMBER 3  
JUNE 1973/ISSN 0068-1024

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# BREEDING ECOLOGY OF RAPTORS IN THE EASTERN GREAT BASIN OF UTAH

by

Dwight G. Smith<sup>1</sup> and Joseph R. Murphy<sup>2</sup>

## ABSTRACT

A comparative study of the breeding ecology of 12 raptor species was conducted in the eastern Great Basin from 1967-1970. The project was designed to determine the composition and densities, habitat selection, territoriality and predatory habits of raptorial birds in a semi-arid environment. All topics were analyzed comparatively, relating the requirements and activities of the 12 raptor species.

Average yearly population densities of all species approximated 0.5 pairs per square mile, but much of the available habitat was not utilized. Predominant raptors were the Ferruginous Hawk and Great Horned Owl. Other important raptors included the Golden Eagle, Red-tailed Hawk and Raven.

The breeding activities of the collective raptor populations occurred over a period of eight months. Great Horned Owls and Golden Eagles were the first raptors to initiate nesting activi-

ties, usually in late January and early February. The raptor breeding season terminated with the fledging of the young Cooper's Hawks and Burrowing Owls in late August.

The fecundity of the raptor populations varied between years. Specific causes of mortality of eggs and young included nest desertion and destruction, predation, apparent egg infertility, and accidents, most of which could be directly attributed to some form of human interference.

The observed home ranges of the raptor species were a function of their body size and breeding status.

The food of the raptors included at least 55 different prey species, but most relied heavily on only one or two species. A correlation between raptor size and mean prey weight was evident. No examples of raptor predation on game or domestic livestock were found.

## INTRODUCTION

Raptorial birds generally occupy the top levels of their food webs and as such exert considerable influence on local mammal and avian prey populations. Shelford (1963) classifies them as major permeant influents and suggests that the raptor populations of the Great Basin desert fulfill roles equivalent to such mammalian predators as the bobcat (*Lynx rufus*), coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), and badger (*Taxidea taxus*). Their declining numbers and economic relationships warrant additional interest, and studies of total raptor populations are needed as a means by which we may elucidate their responses to changing pressures and environmental conditions. Although their large size and predatory habits render them conspicuous, their extensive

territorial requirements present difficulties to raptor ecologists desiring to obtain data on representative populations. Hence, there have been few previous attempts to study collective raptor populations in detail.

The objective of this study is to provide quantitative data on the breeding ecology of central Utah raptors. Aspects of the study which are emphasized include raptor populations and their distribution, yearly productivity, territoriality, and predation. All topics are treated comparatively, relating the requirements and activities of the 12 raptor species. The species studied include four buteonids, the Golden Eagle (*Aquila chrysaetos*), Red-tailed Hawk (*Buteo jamaicensis*), Ferruginous Hawk (*Buteo regalis*), and Swainson's Hawk (*Buteo swain-*

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*sonii*); two falcons, the Prairie Falcon (*Falco mexicanus*), and Sparrow Hawk (*Falco sparverius*); three owls, the Great Horned Owl (*Bubo virginianus*), Short-eared Owl (*Asio*

*flammeus*), and Burrowing Owl (*Speotyto cunicularia*); the Marsh Hawk (*Circus cyaneus*), Cooper's Hawk (*Accipiter cooperii*), and Raven (*Corvus corax*).

## REVIEW OF LITERATURE

Detailed studies on collective raptor populations in North America have been conducted in Michigan and Wyoming (Craighead and Craighead, 1956), the Alaskan tundra (Pitelka, Tomich and Treichel, 1955a, 1955b), and the Tule Lake region of northern California (Dixon and Bond, 1937; Bond, 1939). In other population studies Mathisen and Mathisen (1968) explored the species and seasonal abundance of raptors in Nebraska, and Baumgartner and Baumgartner (1944) examined the food habits and population fluctuations of hawks and owls in Oklahoma. Recently Hickey (1969) has summarized much information on the general status and broad trends of current raptor populations, but his work centers around the Peregrine Falcon (*Falco peregrinus*). Other comparative studies have dealt with the ecology of Great Horned Owls and Red-tailed Hawks. The more informative of these have been conducted in Wisconsin (Orians and Kuhlman, 1956), New York (Hagar, 1957), and Minnesota (LeDuc, 1970). Brown (1966, 1970) has provided much information on African raptor populations, particularly with respect to their niche allocation.

Other associative studies have focused on a particular aspect of raptor ecology, most commonly predation. Specific comparative food habits studies on hawks and owls have been conducted by Fisher (1895), Errington (1932c, 1933), Mendall (1944), and Craighead and Craighead (1956); on hawks by McAtee (1935), Errington and Breckinridge (1938), Hamerstrom and Hamerstrom (1951), and Storer (1966); and on owls by Cahn and Kemp (1930), Wilson (1938), Fitch (1947), Kirkpatrick and Conway (1947), Pearson and Pearson (1947), Marti (1969a), and Earhart and Johnson (1970).

Life history studies of most of the raptors have been conducted in a variety of habitats, and many of them have been summarized in the works of Bent (1937, 1938) and Brown and Amadon (1968). The following are among the more noteworthy of a large amount of published literature on various phases of the nesting ecology of the raptors studied in this report, together with the regions in which they were studied:

*Golden Eagle.* Cameron (1905), McGahan (1967, 1968), Montana; Finley (1906), Dixon (1937), Carnie (1954), California; Arnold (1954), North America; Wellein and Ray (1964), Boeker and Ray (1971), Rocky Mountains; Sandeman (1957), Watson (1957), Brown and Watson (1964), Lockie (1964), Brown (1969), Scotland.

*Great Horned Owl.* Dixon (1914), Fitch (1940), California; Errington (1932b, 1938), Iowa; Swenk (1937), Missouri Valley; Baumgartner (1938, 1939), Iowa and New York; Errington, Hamerstrom and Hamerstrom (1940), north central United States; Houston (1971), Saskatchewan.

*Ferruginous Hawk.* Cameron (1914), Montana; Bowles and Decker (1931), Angell (1968), Washington; Salt (1939), Canada.

*Red-tailed Hawk.* English (1934), Michigan; Fitch, Swenson and Tillotson (1946), California; Austing (1964), North America; Luttich, et al., (1970), Luttich, Keith and Stephenson (1971), Canada; Seidensticker (1970), Montana.

*Scaup's Hawk.* Cameron (1908, 1913), Montana; Bowles and Decker (1934), Washington.

*Prairie Falcon.* Decker and Bowles (1930), Washington; Fowler (1931), California; Bailey and Niedrach (1933), Webster (1944), Ender-son (1964), Colorado; Edwards (1968), Alberta.

*Marsh Hawk.* Breckinridge (1935), Minnesota; Errington and Breckinridge (1936), north-central United States; Hammond and Henry (1949), North Dakota; Hamerstrom (1969), Wisconsin.

*Cooper's Hawk.* McDowell (1941), Schriver (1969), Pennsylvania; Meng (1959), New York and Pennsylvania.

*Sparrow Hawk.* Sherman (1913), Iowa; Roest (1957), Oregon; Enderson (1960), Illinois; Heintzelman (1964), Heintzelman and Nagy (1968), Pennsylvania; Willoughby and Cade (1964), New York.

*Short-eared Owl.* Kitchin (1919), Washington; Snyder and Hope (1938), Toronto; Lockie

(1955), Scotland; Johnson (1956), California; Borrero (1962), Colombia; Short and Drew (1962), Michigan; Munyer (1966), Illinois.

*Burrowing Owl.* Rhoades (1892), Florida; Errington and Bennett (1935), Scott (1940), Iowa; Grant (1965), Minnesota; Coulombe (1971), Thomsen (1971), California.

*Raven.* Oberholser (1918), North America; Harlow (1922), Pennsylvania; Bowles and Decker (1930), Washington; Nelson (1934), Oregon; Cushing (1941), California; Parslow

(1967), Holyoak and Ratcliffe (1968), Great Britain and Ireland; Ratcliffe (1962), England.

Literature pertaining to raptors of the Great Basin includes egg-collecting notes (Wolf, 1928); population studies of wintering eagles (Edwards, 1969); nesting studies of the Golden Eagle, Great Horned Owl, and Ferruginous Hawk (Murphy, et al., 1969); raptor population trends (White, 1969a); and notes on interactions between Red-tailed Hawks and Great Horned Owls (Smith, 1970).

## STUDY AREA

### Location and Topography

This study was conducted in an 80-square-mile section of the eastern edge of the Great Basin Desert in north central Utah. It included parts of Utah and Tooele Counties, in Townships 7 and 8 South, Range 3 West, Salt Lake base and Meridian (Fig. 1). The area chosen is a representative portion of the habitat of this part of the Great Basin. Its coverage is thought to be sufficient to enable the compilation of an accurate record of the raptor species populations.

The topography is characterized by broad, flat, alkaline valleys separated by high ridges and hills. Its major physiographic features, from east to west, include Cedar Valley, the Thorpe and Topliff Hills of the Tintic Range, and Rush Valley. Valley elevations range from 4800 ft in Cedar Valley to 5300 ft in Rush Valley. Maximum elevations were 6190 ft in the Thorpe Hills and 6453 ft in the Topliff Hills.

A major feature of the hills was the numerous sandstone and limestone cliffs and rock outcroppings resulting from the erosion of a series of Paleozoic strata ranging in age from the Lower Cambrian to Upper Pennsylvanian (Bullock, 1959; Bissell, et al., 1959) (Fig. 2). A second striking feature of the hills is the presence of several large quarries, originally mined for clay, calcite, or limestone, but long since abandoned. These quarries are characterized by steep, sheer walls occasionally reaching over 200 feet in height.

### Climate

The general climatic conditions of this portion of the Great Basin have been characterized by Fautin (1946) and Shelford (1963). The mean annual precipitation is 16 inches at the extreme northern edge of the study area and

12 inches over the majority of the rest of the area. Slight local variations occur, with the higher elevations receiving larger amounts (Feltis, 1967). Although the area receives some snowfall, most of the moisture falls from March through May and July through August. Exposure particularly alters the pattern with respect to snowfall accumulation and persistence, and north facing slopes may have from 3 to 12 inches of snow for over a month after southern exposures are bare.

Approximate annual temperatures range from  $-30^{\circ}\text{C}$  to  $65^{\circ}\text{C}$ . Wide seasonal and daily variations occur, amounting to as much as  $30^{\circ}\text{C}$  or more during the summer months. July is the hottest month of the year, averaging  $23^{\circ}\text{C}$ . Sub-zero temperatures can be expected for short periods from December through mid-March.

High winds are a common feature of the early spring months and may result in locally heavy dust storms. These become less severe but may persist throughout all months of the year.

Water flow is ephemeral and no permanent streams, seeps, ponds, or impoundments are present within the study area.

### Vegetation

Two distinct vegetational associations occur, the northern desert shrub and the dwarf conifer community. The desert shrub community is present over lower elevations of most of the valley floors and consists of various shrubs and grasses (Fig. 3). Several of these, becoming locally dominant and forming large, continuous stands, include, in order of their importance, big sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus nauseosus*), shadscale (*Atriplex confertifolia*), greasewood (*Sarcobatus vermiculatus*), winterfat (*Eurotia lanata*),

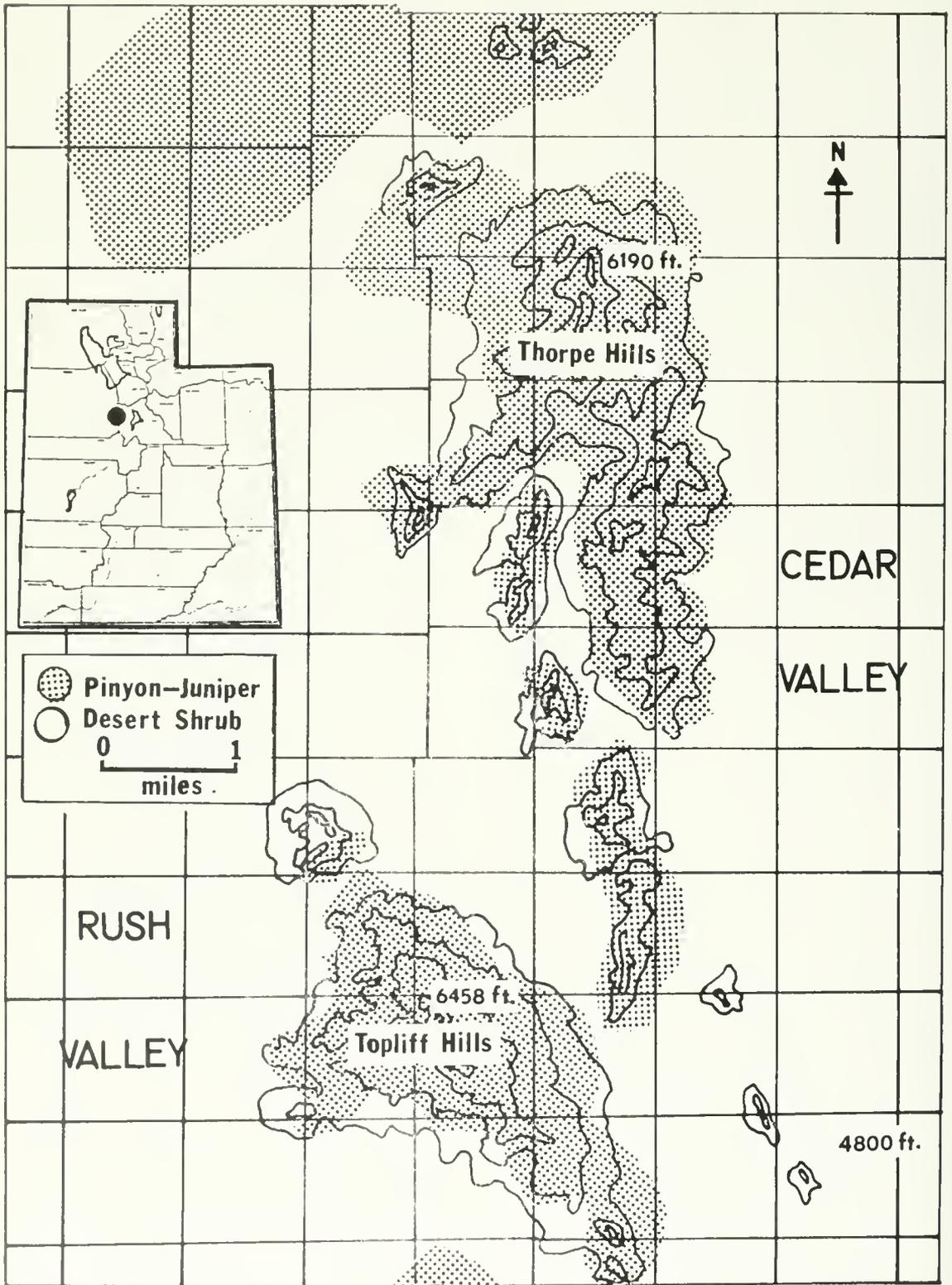


Fig. 1. Location, topography and vegetation of the study area.



Fig. 2. View of a portion of the Thorpe Hills, showing the numerous limestone and sandstone cliff lines and the scattered nature of the Pinyon-Juniper community.

Russian thistle (*Salsola kali*) and horsebrush (*Tetradymia glabrata*). Both Indian ricegrass (*Oryzopsis hymenoides*) and cheat grass (*Bromus tectorum*) are present throughout most of the shrub stages, with the latter apparently increasing its coverage (Christensen and Hutchinson, 1965).

The better drained slopes and hills support the pinyon conifer forest or woodland biome (Kendeigh, 1961). This is characterized by the uniform physiognomy of its principal species, the two most important being Utah juniper (*Juniperus osteosperma*) and pinyon pine (*Pinus monophylla*). The trees average approximately 10–13 ft in height and occur in stands varying in density from 10 to 100 trees per acre (Smith, 1968). Important shrubs of the understory include matchweed (*Gutierrezia sarothrae*) and Ephedra (*Ephedra* sp.). Other components present in lesser amounts include cliffrose (*Cowania mexicana*) and mountain mahogany (*Cercocarpus ledifolius*).

#### Faunal Elements

Fautin (1946) listed a total of 286 animals known to occur in the northern desert shrub community, including 28 mammals, 45 birds (exclusive of the raptors and aquatic species), 10 reptiles and 203 insects. Most of these also occur within the pinyon-juniper community which to date has received no in-depth study

in this area. Hardy (1945) did record 79 bird species of the pinyon conifers and noted that 14 species were summer residents.

The major mammalian herbivores include the mule deer (*Odocoileus hemionus*), black-tailed jackrabbit (*Lepus californicus*), Townsend's ground squirrel (*Spermophilus townsendi*), antelope ground squirrel (*Ammospermophilus leucurus*), desert cottontail (*Sylvilagus auduboni*), and desert wood rat (*Dipodomys* sp.), pocket mouse (*Perognathus* sp.), and several murids and ericetids. Carnivores other than raptors include the mountain lion (*Felis concolor*), coyote (*Canis latrans*), kit fox (*Vulpes macrotis*), bobcat (*Lynx rufus*), and badger (*Taxidea taxus*). Two of the more common summer bird species include the Horned Lark (*Eremophila alpestris*) and Mourning Dove (*Zenaidura macroura*). Common reptile species include the gopher snake (*Pituophis melanoleucus*), striped racer (*Coluber taeniatus*), collared lizard (*Crotaphytus collaris*), and Uinta lizard (*Utastansburiana*).

#### Human Utilization

Two small settlements are present immediately northeast of the study area and portions of the adjacent land are dry-farmed, but the most important human activities include livestock raising and hunting. Most of the valleys and lower elevations are seasonally utilized for sheep

range and are heavily overgrazed. In addition, the direct influence of livestock interests has resulted in the initiation of predator control programs and government trappers periodically remove coyotes, bobcats, and kit foxes.

Recreational hunting activities assume major proportions. Almost all parts of the area are accessible by graded dirt roads, and large numbers of deer hunters in season and rabbit hunters throughout the year utilize the area for sport.



Fig. 3. Sagebrush and bunchgrass community of Cedar Valley.

## METHODS

The study was conducted from December 1966 until August 1970. Most of the field work took place during the four breeding seasons but observations were recorded during every month of the year. Intensive field work began in December of each year and continued through August. During this time at least weekly or bi-weekly visits were made, but often the observation periods were more frequent. Throughout the four breeding seasons the longest interval of time between successive visits was 13 days in April 1970.

Field data cards were designed and printed, and copies of that portion of the study area mapped by the U.S. Geological Survey were Xeroxed. All observations on raptor nests, activities, and locations were recorded on them and supplemented by tape recorded notes.

The major task of the observer during each breeding season involved the location of all

raptor nests. These were found by systematically searching all potential nest sites; that is, all cliff lines, rock outcroppings, and wooded areas were methodically examined. Discovered nests were plotted on an area survey map, then gaps in the distribution were intensively reexamined for missed nests or signs of raptor activity several times during the breeding season. Additional techniques were employed to discover nests; these included observations of behavioral patterns (particularly displays and territorial postures), the mapping of old nests, and the utilization of a fixed wing monoplane for aerial surveys. The latter proved to be of limited use, due primarily to its minimum speed and altitude requirements, but was useful in checking the occupancy of nests of the previous years.

Instances in which apparently nonnesting pairs or individuals were occupying an area necessitated numerous additional and time-con-

suming checks to ensure the accuracy of their status. Apparent transients required similar efforts.

Certain raptor species required proportionally greater efforts than others in locating their nests. This proved to be particularly true of the Great Horned Owl and Short-eared Owl. Their secluded nest sites and nocturnal habits required several early morning and late evening visits in an effort to locate hooting males. Baumgartner (1939) and Errington (1932b) employed this method successfully in other habitats, but the extreme ruggedness of most of the study area terrain allowed only partial success. However, both owl species were observed occasionally during these two time periods, particularly on overcast days or on rainy or snowy days. In contrast, Burrowing Owls were easily located because of their great diurnal activity, more accessible nesting sites, and the habit of one or both of the adults of roosting atop or alongside the burrow. Only two of the diurnal raptors, the Marsh Hawk and Sparrow Hawk, presented problems with respect to the location of their nests. Both species are conspicuous during their daily activities but very secretive relative to the actual location of their nests. These were most easily found by continuous observation of the adult pairs, one of which would eventually return to the nest site. Three of the Marsh Hawk nests were found only after the increased development of the young had rendered their location conspicuous.

The tendency of raptors to reoccupy their nest sites and territories (to be discussed in detail later) greatly facilitated the task of locating nests during the last three years of study.

Data used to compute the raptor activity timetables is based primarily on the more readily accessible nests. In addition, the necessary time period between field observation days promotes a possible time error of two days. The presence of the investigators may have accelerated some

events in the nesting cycle, with the fledging period being particularly vulnerable to change.

Raptor territories and food habits were determined during the nesting seasons of 1969 and 1970. Territories were plotted by observations of pair activities from blinds and by plotting sight locations. The points of maximum distance from the nest site were then connected and the encompassed area determined with a compensating polar planimeter. The determined territory has been described as maximum territory (Odum and Kunezler, 1955) or home range (Craighead and Craighead, 1956). Food habits of all raptors were determined by weekly tabulations of prey items and analyses of pellets gathered from the nest site. Again the more accessible nests were checked most frequently. After the prey had been identified and counted it was removed from the nest. An exception was to leave fresh prey for the young, after marking it for identification. Pellet contents were identified by comparison with specimens of the Brigham Young University Life Sciences Museum collection, following techniques described by Errington (1930, 1932a), Glading, Tillotson and Sellech (1943), and Moon (1949). Dr. V. A. Nelson, entomologist, Southern Connecticut State College, New Haven, Connecticut, assisted in the identification of some insect remains.

All statistical analyses followed programs for the Epic Model 3000 computer except regression, which was determined using Fortran programs. Numerical data within the text is normally presented as mean data, followed by the standard error, sample number, and range. The "t" test, analysis of variance and chi-square tests were used to compare data, and linear regression analysis was used to test the significance of correlated variables. The level of significance is 0.05 unless otherwise noted. All analytical methods are discussed by Goldstein (1964) and Simpson, Roe, and Lewontin (1960).

## RESULTS

### Basic Population Data

The study area supported a total of 354 individuals of 12 raptor species during the four years of study. This included 141 nesting pairs, 20 nonnesting pairs and 32 individuals. The species breakdown was as follows: Golden Eagle, 17 pairs; Great Horned Owl, 31; Ferruginous Hawk, 40; Red-tailed Hawk, 26; Swainson's Hawk, 5; Prairie Falcon, 3; Marsh Hawk,

5; Cooper's Hawk, 1; Sparrow Hawk, 10; Short-eared Owl, 1; Burrowing Owl, 6; Raven, 16.

### Population Composition and Density

Annual species populations are presented in Tables 1-4. Both the total nesting population and the number of nesting species varied from year to year. The collective raptor population consisted of 8 species in 1967 and 1968, 9 in

Table 1. Summary of raptor nesting populations, 1967.

Species	No. of pairs	No. of nesting pairs	No. single birds	No. nesting failures	No. re-nesting attempts	No. successful nesting attempts	No. of nests incomplete histories	No. sq. miles per pair
Golden Eagle	1	3	1	1	0	-	0	20
Great Horned Owl	5	4	1	0	-	-	0	16
Ferruginous Hawk	8	8	2	3	0	-	0	10
Red-tailed Hawk	5	4	0	0	0	-	0	16
Swainson's Hawk	1	1	0	0	-	-	0	80
Prairie Falcon	0	-	1	-	-	-	-	-
Marsh Hawk	0	-	1	-	-	-	-	-
Cooper's Hawk	1	1	0	?	?	-	1	80
Sparrow Hawk	4	3	1	1	0	-	1	20
Short-eared Owl	0	-	2	-	-	-	-	-
Burrowing Owl	0	-	1	-	-	-	-	-
Raven	4	4	0	0	-	-	0	20
Totals	32	28	10	5	0	-	2	-

Table 2. Summary of raptor nesting populations, 1968.

Species	No. of pairs	No. of nesting pairs	No. single birds	No. nesting failures	No. re-nesting attempts	No. successful re-nesting attempts	No. of nests incomplete histories	No. sq. miles per pair
Golden Eagle	4	4	1	2	0	0	0	20
Great Horned Owl	10	9	1	5	0	0	2	8
Ferruginous Hawk	10	9	0	2	0	0	0	8
Red-tailed Hawk	7	7	0	3	2	1	1	11
Swainson's Hawk	1	1	0	0	-	0	0	80
Prairie Falcon	1	1	1	1	0	0	0	80
Marsh Hawk	0	-	1	-	-	-	-	-
Cooper's Hawk	0	-	0	-	-	-	-	-
Sparrow Hawk	3	3	1	1	0	0	0	27
Short-eared Owl	0	-	1	-	-	0	-	-
Burrowing Owl	0	-	0	-	-	-	-	-
Raven	4	4	0	0	-	-	0	20
Totals	40	38	6	14	2	1	3	-

Table 3. Summary of raptor nesting populations, 1969.

Species	No. of pairs	No. of nesting pairs	No. single birds	No. nesting failures	No. re-nesting attempts	No. successful nesting attempts	No. of nests incomplete histories	No. sq. miles per pair
Golden Eagle	5	4	1	2	1	0	0	16
Great Horned Owl	8	8	1	2	0	-	0	10
Ferruginous Hawk	13	12	1	2	0	-	0	6
Red-tailed Hawk	7	6	1	2	1	0	0	11
Swainson's Hawk	2	2	1	2	0	-	0	40
Prairie Falcon	0	-	1	-	-	-	-	-
Marsh Hawk	2	2	0	1	0	-	1	40
Cooper's Hawk	0	-	0	-	-	-	-	-
Sparrow Hawk	2	2	2	1	0	-	-	40
Short-eared Owl	0	-	1	-	-	-	-	-
Burrowing Owl	3	3	0	1	0	-	1	27
Raven	1	1	1	1	0	-	-	20
Totals	46	43	10	14	2	0	2	-

1969, and 11 in 1970. Only 7 of the 12 species nested in all four study years. Of the more sporadic nesters, 3, the Prairie Falcon, Marsh Hawk and Burrowing Owl, nested during two of the four years (not necessarily consecutively) and 2, the Short-eared Owl and Cooper's Hawk, nested in only one of the four years. All, however, were represented by either nonnesting

pairs or individuals during one or more of their nonbreeding years, and are therefore considered to be a minor but normal element of the raptor breeding population of this area.

The minimum and maximum sizes of the total raptor population varied from 74 to 102 individuals and from 32 to 46 pairs. Individuals commonly comprised from 9 to 13 percent of

Table 4. Summary of raptor nesting populations, 1970.

Species	No. of pairs	No. of nesting pairs	No. single birds	No. nesting failures	No. re-nesting attempts	No. successful nesting attempts	No. of nests incomplete histories	No. sq. miles per pair
Golden Eagle	4	3	0	0	-	-	0	20
Great Horned Owl	8	6	19	3	1	1	0	10
Ferruginous Hawk	9	7	2	2	0	-	0	9
Red-tailed Hawk	7	4	0	1	0	0	0	11
Swainson's Hawk	1	1	1	0	-	-	0	80
Prairie Falcon	2	2	0	1	0	-	0	40
Marsh Hawk	3	2	1	1	1	0	1	27
Cooper's Hawk	0	-	1	-	-	-	-	-
Sparrow Hawk	1	1	1	0	-	-	-	80
Short-eared Owl	1	1	0	1	0	-	0	80
Burrowing Owl	3	3	0	1	0	-	0	27
Raven	4	2	0	0	-	-	0	20
Totals	43	32	24	10	2	1	1	-

the total population. Raptor populations increased from 1967 (32 pairs, 10 individuals) to 1969 (46 pairs, 10 individuals) and then declined slightly in 1970 (43 pairs, 6 individuals). The peak number of nesting raptor species did not coincide with the peak raptor populations but rather occurred one year later. The yearly variation in populations was due in part to some shifting of raptor nesting sites onto the study area from previous nesting sites and territories immediately adjacent to the study area. Other possible reasons will be discussed later.

Five species, the Golden Eagle, Great Horned Owl, Ferruginous Hawk, Red-tailed Hawk and Raven comprised over 81 percent of the average yearly raptor populations. Of these, the Ferruginous Hawk was consistently the numerically dominant raptor, averaging approximately 25 percent of the annual breeding population. The next most numerous species were, in order of their abundance, the Great Horned Owl (which approximated over 19 percent), Red-tailed Hawk, Golden Eagle, and Raven. Of the remaining raptors, Sparrow Hawks were almost twice as abundant as Swainson's Hawks, Marsh Hawks, and Burrowing Owls, while the Cooper's Hawk and Short-eared Owl were relatively rare breeding elements. Although a conspicuous permanent resident, the Prairie Falcon rarely achieved breeding status and comprised less than two percent of the average yearly breeding population. The relative percent composition of the large raptors varied only slightly and each species maintained its proportional abundance during the four study years. Thus the population increase from 1967 to 1969 reflected a similar increase in the number of pairs of each, with the notable exception of the Raven population, which remained stable. The limited populations of the smaller raptors prevent clear-cut evaluations. Both the Marsh Hawk and Bur-

rowing Owl populations became established during the last two study years, but the Sparrow Hawk population declined.

Yearly population densities averaged 0.5 pairs per square mile (range 0.4-0.58), based on the 80-square-mile study area. However, approximately one-half of the area was apparently not utilized for any purposes by the nesting raptors. This was particularly true of the lower valley elevations which were situated far from potential nesting sites. If this area were eliminated from the determinations, then the raptor nesting densities would be increased to 1.0 pairs per square mile (range 0.8-1.16).

#### Seasonal Activity Timetables

*Winter Populations.* Central Utah supports a large and varied winter raptor population. Important permanent year-round residents wintering in the area include Golden Eagles, Ravens, Great Horned Owls, and Prairie Falcons. Golden Eagles and Ravens occur singly or in small groups of two to five individuals. Some Golden Eagles may form hunting contacts and share communal roosts with Bald Eagles (*Haliaeetus leucocephalus*). Estimated average yearly winter populations of each were 13 Golden Eagles and 9 Ravens. In contrast, Great Horned Owls and Prairie Falcons were less common. A few Great Horned Owls were flushed in the vicinity of their nesting site of the previous year and a single Prairie Falcon was observed every year, occupying a large winter territory in Cedar Valley. It was occasionally observed hunting among flocks of Horned Larks and Dickcissels (*Spiza americana*).

Large influxes of Bald Eagles and Rough-legged Hawks (*Buteo lagopus*) began arriving in the valleys in late November and December. These conspicuous winter residents rosted com-

munally in canyons and lightly wooded areas near settlements. During the daylight hours they ranged widely to hunt in the valleys, returning to a communal roost shortly before dark (Edwards, 1969). Estimated populations of each in the study area were 30 Bald Eagles and 18 Rough-legged Hawks.

Winter live trapping studies revealed 5 Long-eared Owls (*Asio otus*), and a number of Short-eared Owls. The latter were frequently observed (up to 8 individuals per group) ranging outward from their diurnal communal roosting sites during the late evening hours.

An average of 25 Marsh Hawks, 2 Sharp-shinned Hawks (*Accipiter striatus*), 3 Red-tailed Hawks, 1 Ferruginous Hawk, and 1 Screech Owl (*Otus asio*) were present in the valleys during the winter months. The Marsh Hawk populations indicated a major influx of this species into the area during the winter, but the status of the wintering Red-tailed Hawks and Ferruginous Hawks was uncertain. Two of the Red-tailed Hawks wintered in the vicinity of a previously used Red-tailed Hawk nesting site and may have been permanent residents.

The populations of these winter residents fluctuated and appeared to be related to climatic changes, particularly temperature. Their numbers declined sharply in late January and early February, and they left the area by mid-March, a transition coinciding with the arrival and rapid buildup of the breeding populations.

*Transients.* Known transients, including Red-tailed, Swainson's, and Cooper's Hawks were observed from late February to early May. Large numbers of transient Sparrow Hawks were observed between early April and mid-May, simultaneously with the arrival of the breeding population of Sparrow Hawks. A single Osprey (*Pandion haliaetus*) was observed roosting in a dead cottonwood in Cedar Valley on 29 April in the late evening and presumably roosted overnight. The majority of the transients remained only one or two days in the area, particularly those observed later in the breeding season.

*Activity timetables.* The yearly activity timetables of the raptor populations are presented in Tables 5-8. The breeding activities of the populations occurred over a period of eight months and averaged 202.7 days a year (range 163-228 days). However, the individual species activities occupied only a portion of this period. Although slight yearly variations in the timing and duration of the events of the nesting cycle were evident, the chronological sequence of each raptor species remained essentially un-

changed with respect to the total raptor populations.

Golden Eagles and Great Horned Owls were the first raptors to initiate their nesting activity. Golden Eagles were observed occupying their territories as early as 20 January, and courtship displays were observed from this time onward. Their nests were constructed or rebuilt in February and early March and decorated with greenery. A Great Horned Owl was recorded on its nest site of the previous year on 2 December and pair formation had occurred as early as 10 January in some years. Average egg deposition dates for both species ranged from mid-February to early March, with Golden Eagles generally preceding Great Horned Owls by one or two weeks.

Red-tailed and Ferruginous Hawks were the first of the migratory raptors to arrive in the study area each year. The first Red-tailed Hawks were observed in the vicinity of previous nesting sites during the first week in February and were paired within one or two weeks. At this time pairs would react aggressively when the nest site was approached, screaming and soaring in increasingly higher circles overhead. Only three pairs were observed constructing nests, but the process was a mutual activity, with both members of a pair transporting juniper branches to the nest site. Eggs were usually deposited in late March and early April. The first Ferruginous Hawks were observed from two to five weeks later, usually during the first week in March but as early as 25 February. Eggs were usually deposited in mid-April. As with Red-tailed Hawks, nests were constructed rapidly by both members of a pair until finished, usually within one to three days. Both species were highly secretive during nest construction and if interrupted would frequently stop building activities and begin another nest at a new site. Ferruginous Hawks exhibited a greater tendency to abandon newly constructed nests (12 occurrences) than Red-tailed Hawks (5 occurrences).

Swainson's Hawks were the last of the Buteos to nest, appearing in the valleys in early and mid-April and beginning their nesting between two and three weeks later.

Of the medium and small sized raptors, the Ravens were the first to begin nesting, usually from late February to mid-March. Pairs of Prairie Falcons and Marsh Hawks were observed in late March and early April. The Prairie Falcons were very aggressive at this time both toward humans and other raptors, particularly Great Horned Owls, which if flushed were at-

Table 5. Observed dates of reproductivity of raptors on the Utah study area, 1967.

Species	No. of nests observed	First selection of territory	Earliest laying date	Latest laying date	Average laying date	Earliest hatching date	Latest hatching date	Average hatching date	First brood departure date	Last brood departure date	Average brood departure date	Span of nesting period	Breeding season span
Golden Eagle	3	II 5	III 6	III 18	III 14	IV 15	IV 27	IV 17	VI 12	VII 3	VI 24	II 7	148
Great Horned Owl	4	II 8	III 20	IV 10	IV 1	IV 24	V 12	IV 28	VI 6	VI 17	VI 11	89	131
Ferruginous Hawk <sup>o</sup>	8	III 6	IV 3	IV 15	IV 10	V 9	V 17	V 12	VI 18	VI 27	VI 23	85	115
Red-tailed Hawk	4	II 16	III 26	IV 10	IV 7	V 1	V 14	V 7	VI 15	VI 27	VI 20	93	131
Swainson's Hawk	1	-	IV 17	IV 17	IV 17	V 21	V 21	V 21	VII 2	VII 2	VII 2	76	-
Prairie Falcon	0	-	-	-	-	-	-	-	-	-	-	-	-
Marsh Hawk	0	-	-	-	-	-	-	-	-	-	-	-	-
Cooper's Hawk	1	-	IV 12	V 12	V 12	-	-	-	-	-	-	-	-
Sparrow Hawk	3	IV 10	V 4	V 15	V 9	VI 2	VI 17	VI 6	VII 4	VII 21	VII 8	77	102
Short-eared Owl	0	-	-	-	-	-	-	-	-	-	-	-	-
Burrowing Owl	0	-	-	-	-	-	-	-	-	-	-	-	-
Raven	4	III 15	III 26	IV 8	III 29	V 1	V 15	V 10	VI 3	VI 15	VI 12	81	92

<sup>o</sup>Data from Murphy et al., 1969.

Table 6. Observed dates of reproductivity of raptors on the Utah study area, 1968.

Species	No. of nests observed	First selection of territory	Earliest laying date	Latest laying date	Average laying date	Earliest hatching date	Latest hatching date	Average hatching date	First brood departure date	Last brood departure date	Average brood departure date	Span of nesting period	Breeding season span
Golden Eagle	4	I 20	II 24	III 16	III 10	IV 5	IV 26	IV 22	VI 24	VII 7	VI 29	133	178
Great Horned Owl	9	XII 2 <sup>o</sup>	I 20	II 10	II 4	II 27	III 13	III 2	III 31	IV 27	IV 20	97	146
Ferruginous Hawk <sup>oo</sup>	9	II 25	IV 4	IV 19	IV 8	V 6	V 22	V 10	VI 12	VII 5	VI 25	92	132
Red-tailed Hawk	7	II 6	III 15	III 19	III 17	IV 18	IV 24	IV 20	VI 27	VII 8	V 29	115	152
Swainson's Hawk	1	-	IV 30	IV 30	IV 30	VI 6	VI 6	VI 6	VII 15	VII 15	VII 15	77	-
Prairie Falcon	1	III 19	-	-	-	-	-	-	-	-	-	-	-
Marsh Hawk	0	-	-	-	-	-	-	-	-	-	-	-	-
Cooper's Hawk	0	-	-	-	-	-	-	-	-	-	-	-	-
Sparrow Hawk	3	IV 11	IV 27	V 4	V 1	V 27	VI 4	VI 2	VI 25	VII 4	VII 2	68	84
Short-eared Owl	0	-	-	-	-	-	-	-	-	-	-	-	-
Burrowing Owl	0	-	-	-	-	-	-	-	-	-	-	-	-
Raven	4	II 17	III 20	III 31	III 24	IV 27	IV 5	V 1	V 3	V 11	V 7	52	83

<sup>o</sup>December 2, 1967.

<sup>oo</sup>Data from Murphy et al., 1969.

Table 7. Observed dates of reproductivity of raptors on the Utah study area, 1969

Species	No. of nests observed	First selection of territory	Earliest laying date	Latest laying date	Average laying date	Earliest hatching date	Latest hatching date	Average hatching date	First brood departure date	Last brood departure date	Average brood departure date	Span of nesting period	Breeding Season span
Golden Eagle	4	II 18	II 21	III 18	III 9	IV 3	IV 30	IV 16	VI 5	VII 9	VI 21	138	150
Great Horned Owl	5	I 2	II 21	III 11	II 28	III 25	IV 12	III 30	V 16	VI 1	V 25	100	150
Ferruginous Hawk	12	III 5	III 28	IV 17	IV 4	V 2	V 26	V 11	VI 10	VI 28	VI 20	92	114
Red-tailed Hawk	0	I 20	III 17	IV 5	III 26	IV 28	V 9	V 2	VI 4	VI 15	VI 12	90	146
Swainson's Hawk	2	IV 12	IV 28	V 8	V 5	V 27	VI 11	VI 1	VII 10	VII 10	VII 10	73	89
Prairie Falcon	0	-	-	-	-	-	-	-	-	-	-	-	-
Marsh Hawk	2	III 31	IV 12°	IV 20°	IV 17°	V 7°	V 10°	V 5	VI 11	VI 15	VI 12	67	80
Cooper's Hawk	0	-	-	-	-	-	-	-	-	-	-	-	-
Sparrow Hawk	2	IV 19	V 14	VI 1	V 17	VI 15	VI 30	VI 18	VII 14	VII 28	VII 19	75	100
Short-eared Owl	0	-	-	-	-	-	-	-	-	-	-	-	-
Burrowing Owl	3	IV 17	V 5°	VI 6°	V 18°	VI 7°	VI 17°	VI 10°	VII 6	VII 9	VII 9	62°	82
Raven	4	II 28	III 27	IV 8	IV 2	V 3	V 18	V 12	VI 11	VI 23	VI 17	88	115

°Computed dates from the 1970 data.

°°Computed dates from Bent (1938), Craighead and Craighead (1956).

Table 8. Observed dates of reproductivity of raptors on the Utah study area, 1970.

Species	No. of nests observed	First selection of territory	Earliest laying date	Latest laying date	Average laying date	Earliest hatching date	Latest hatching date	Average hatching date	First brood departure date	Last brood departure date	Average brood departure date	Span of nesting period	Breeding Season span
Golden Eagle	3	II 2	III 6	III 30	III 21	IV 11	V 14	IV 14	VI 7	VI 21	VI 9	107	139
Great Horned Owl	6	II 1	III 9	III 29	III 23	IV 15	V 2	IV 25	V 30	VI 7	VI 5	88	126
Ferruginous Hawk	7	III 10	III 17	III 21	IV 1	IV 22	IV 28	V 12	VI 4	VII 2	VI 25	99	106
Red-tailed Hawk	4	II 6	III 17	IV 7	III 31	IV 17	V 5	V 2	VI 5	VI 13	VI 11	88	126
Swainson's Hawk	1	IV 13	V 13	V 13	V 13	VI 16	VI 16	VI 16	VII 27	VII 27	VII 27	75	83
Prairie Falcon	2	III 28	IV 20	IV 20	IV 20	V 26	V 26	V 26	VII 2	VII 2	VII 2	74	93
Marsh Hawk	2	IV 2	IV 14	IV 19	IV 17	V 18	V 23	V 21	VI 17	VI 26	VI 22	85	73
Cooper's Hawk	0	-	-	-	-	-	-	-	-	-	-	-	-
Sparrow Hawk	1	V 1	V 18	V 18	V 18	VI 17	VI 17	VI 17	VII 15	VII 15	VII 16	58	75
Short-eared Owl	1	III 6	III 28	III 28	III 28	VI 23	VI 23	VI 23	-	-	-	-	-
Burrowing Owl	3	IV 22	IV 30°	V 5°	V 3°	VI 4°	VI 7°	VI 5°	VII 3	VII 10	VII 6	70°	78
Raven	2	II 21	III 19	III 30	III 27	IV 30	V 3	V 1	VI 6	VI 14	VI 9	87	113

°Computed dates from Bent (1938), Craighead and Craighead (1956).

tacked, although no actual contacts were observed. The 1969 egg deposition dates of the Marsh Hawk were computed, using the results from the 1970 data for this species. Individual Short-eared Owls were observed in the vicinity of their nesting territory in the first week in March, and activity dates computed from the data of Bent (1938) and Craighead and Craighead (1956) indicate that egg deposition occurred within three weeks. Sparrow Hawks were observed as early as 10 April, perched on conspicuous locations in the vicinity of their future nesting sites. Pair bonding had occurred by 27 April and egg deposition from two to three weeks later. By late April Burrowing Owls were seen roosting beside the entrance to their nest holes and protested vigorously when investigated. Their activity timetables were computed from the date of fledging on the basis of data given by Bent (1938).

Only egg dates are available for the Cooper's Hawk, but backdating 31 days (average from Craighead and Craighead, 1956) suggests that in this area their territories are selected by mid-April.

The breeding raptor populations were well established by April and May, which were the months of maximum activity. By late May and early June nests of the Great Horned Owl were terminated with the fledging of the young. By the end of June and the first week of July, Red-tailed Hawks, Ferruginous Hawks, Golden Eagles, Ravens, Prairie Falcons, and Marsh Hawks had all completed their nesting activities, and Swainson's Hawks, Burrowing Owls, and Sparrow Hawks had finished their nesting efforts by late July and early August.

The newly fledged young of most species remained within the nesting territory for a period after fledging and were frequently seen in family hunting groups. Defense of the young by adults was particularly strong during this time period but gradually lessened. Within three to five weeks the young had drifted out of the nesting area and into other parts of the valley.

The migratory species began moving out of the area in late August and early September. Their replacement by the first elements of the wintering population was not as sudden as the spring transition, and the interim raptor populations consisted only of permanent residents which were consequently comparatively low in number.

### Nest Site Requirements

*Spatial Distribution.* Figures 4-7 show the yearly distribution of raptor nests (all species)

on the study area and clearly indicate that the nests were unevenly distributed. The majority of sites were present at middle and higher elevations and consistently distributed along the periphery of the central mountains or within the woodland. Only Burrowing Owl, Marsh Hawk, and Ferruginous Hawk (one nest) nest sites were present in the valleys, below the fringes of the Pinyon-Juniper woodland.

*Nest Site.* The nest site selections of the 12 raptor species are summarized in Table 9. The raptors nesting on the study area utilized a wide variety of sites, but some species exhibited a narrower range of selection than others. Actual sites chosen by one or more species included cliffs, quarries, abandoned mining structures, trees, burrows, or the ground.

Almost 35 percent of the nesting sites selected were located in cliffs. The choice of cliff sites by five of the raptor species appears to be related to several factors, including the physiography of the cliff, its vertical height, aspect, position, altitude, and height above the valley floor. Excluding the rock walls of quarries, which are actually artificial structures, the maximum height of cliffs within the study area did not exceed 150 feet, and the great majority averaged less than 50 feet. Two distinct types, sandstone and limestone, are present. Limestone cliffs, because of their distinctive weathering patterns which result in numerous crevices and ledges, provided greater numbers of suitable nesting sites and were heavily utilized by the raptors. The position of the cliff refers to its remoteness. Cliff sites which overlooked the valleys were preferred over similar cliffs located in the interior of the hills. Sites were frequently chosen in the first large cliff (over 20 feet high) above the valley floor. This was particularly evident in locations where several cliff lines were available at increasingly higher elevations in stairstep fashion.

Several abandoned quarries within the study area were utilized for nesting sites by at least six of the raptor species. The amount of use was related to the size and ruggedness of the quarry walls and was apparently independent of the amount of human disturbance. The largest quarries were utilized simultaneously by two or three raptor species every year.

Trees were also a common nesting site (34.6 percent) on the study area. The majority were located in junipers, the predominant trees in the area, but a few were constructed in pinyon, cliffrose, and cottonwood. Nests in junipers and cliffrose were most frequently constructed in the tops of the trees, approximately 11 feet

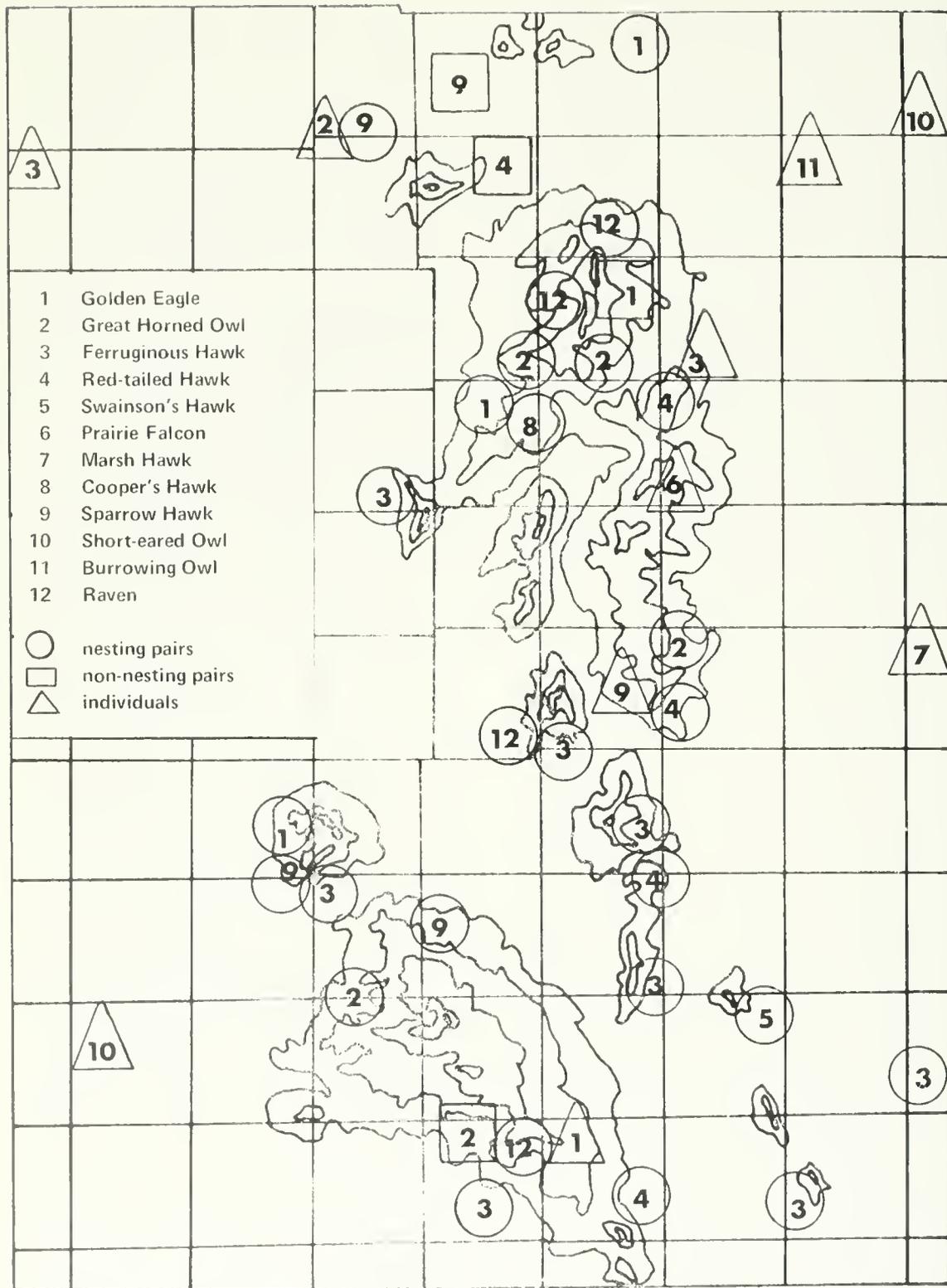


Fig. 1. Distribution of the raptor breeding population in 1967.

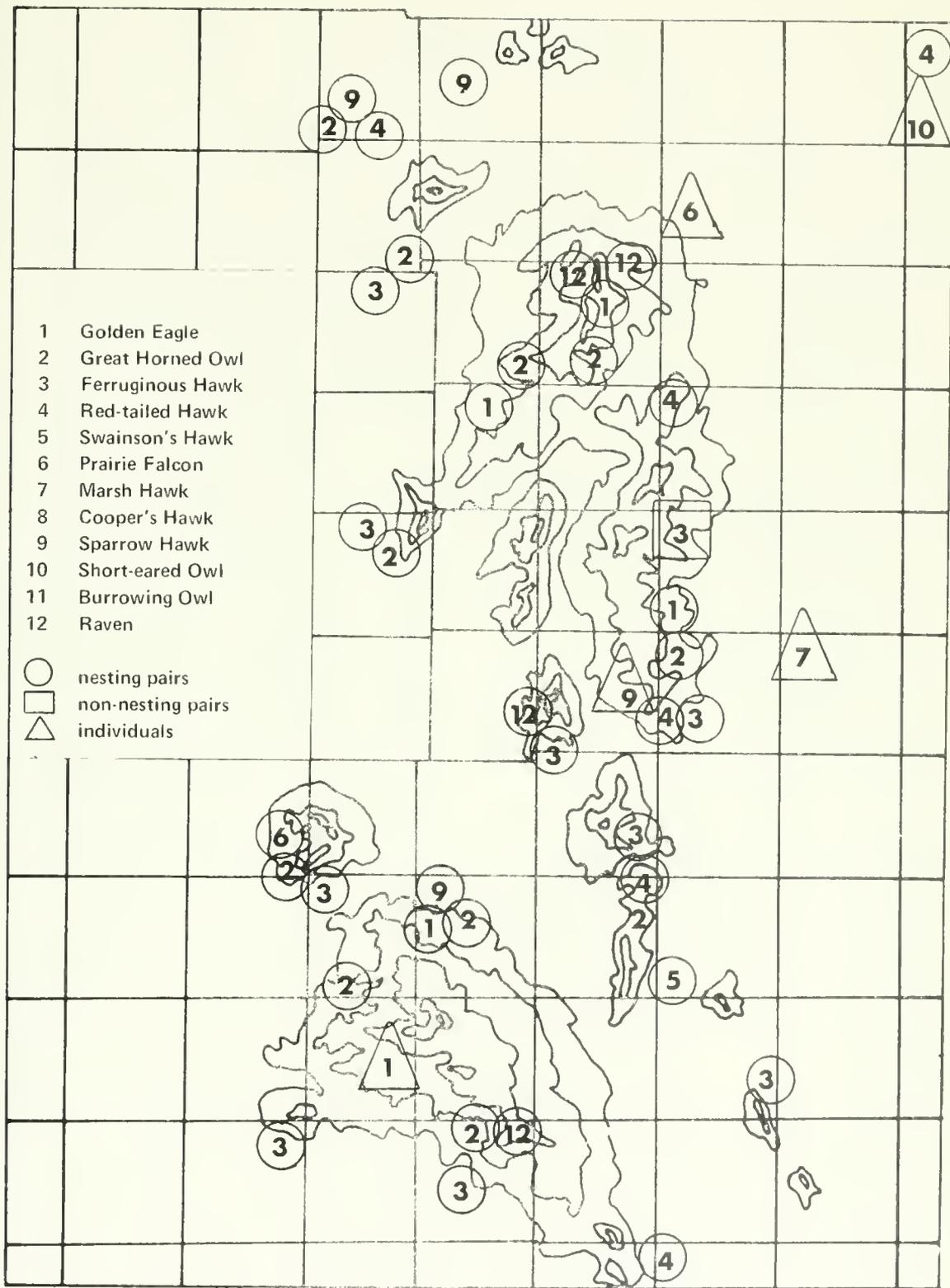


Fig. 5. Distribution of the raptor breeding population in 1965.

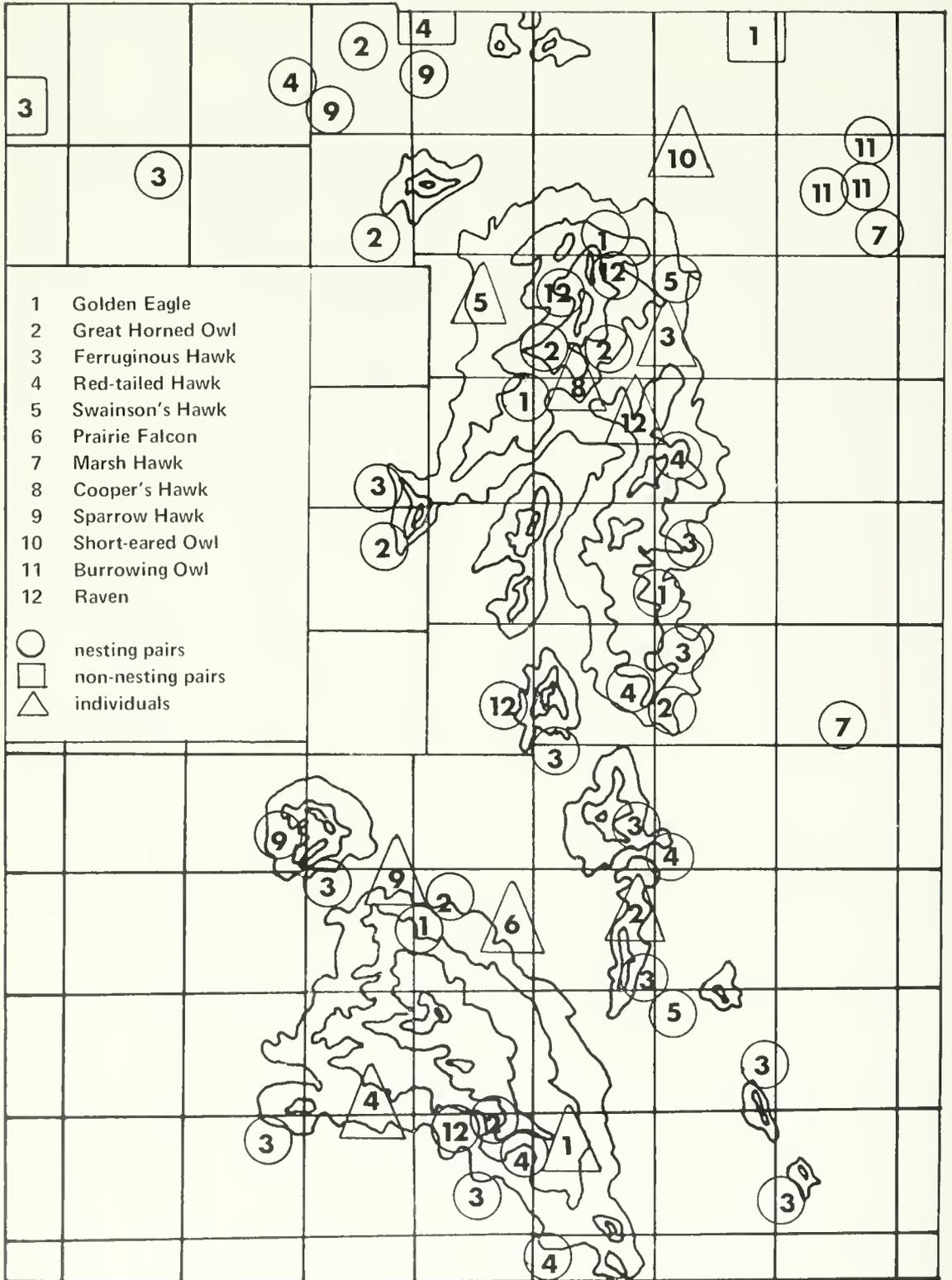


Fig. 6. Distribution of the raptor breeding population in 1969.



Table 9. Summary of nesting site selections of raptors on the study area, 1967-1970.

Species	Quarry Site		Structure Site		Tree Site							
	No.	%	No.	%	Pinyon		Juniper		Cliffrose		Cottonwood	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Golden Eagle	4	2.8	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Great Horned Owl	7	5.0	0	0.0	0	0.0	4	2.8	0	0.0	0	0.0
Ferruginous Hawk	0	0.0	0	0.0	0	0.0	24	17.0	1	0.7	0	0.0
Red-tailed Hawk	2	1.4	0	0.0	3	2.1	7	5.0	1	0.0	1	0.7
Swainson's Hawk	0	0.0	0	0.0	0	0.0	5	3.5	0	0.0	0	0.0
Prairie Falcon	1	0.7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Marsh Hawk	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cooper's Hawk	0	0.0	0	0.0	0	0.0	1	0.7	0	0.0	0	0.0
Sparrow Hawk	5	3.5	2	1.4	0	0.0	2	1.4	0	0.0	0	0.0
Short-eared Owl	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Burrowing Owl	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Raven	1	0.7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Totals	20	14.1	2	1.4	3	2.1	43	30.4	2	0.7	1	0.7

Species	Sagebrush		Ground Site		Greasewood		5-25		Cliff Site		75-150	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Golden Eagle	0	0.0	0	0.0	0	0.0	0	0.0	9	6.4	1	0.7
Great Horned Owl	0	0.0	0	0.0	0	0.0	3	2.1	13	9.2	0	0.0
Ferruginous Hawk	8	5.7	3	2.1	0	0.0	0	0.0	0	0.0	0	0.0
Red-tailed Hawk	0	0.0	0	0.0	0	0.0	2	1.4	5	3.5	1	0.7
Swainson's Hawk	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Prairie Falcon	0	0.0	0	0.0	0	0.0	0	0.0	2	1.4	0	0.0
Marsh Hawk	2	1.4	2	1.4	0	0.0	0	0.0	0	0.0	0	0.0
Cooper's Hawk	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Sparrow Hawk	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Short-eared Owl	1	0.7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Burrowing Owl	0	0.0	1	0.7	5	3.5	0	0.0	0	0.0	0	0.0
Raven	0	0.0	0	0.0	0	0.0	3	2.1	7	5.0	3	2.1
Totals	11	7.8	6	4.2	5	3.5	8	5.6	36	25.5	5	3.5

above ground, which is the average height of the pigmy woodland trees of this area.

The majority of the nests had western exposures (33 percent), but 27 percent faced south and 25 percent east, while only 15 percent faced north. Tree nest exposure, determined by the inclination of the slope, is included in the above (see Table 10). With reference to altitude, 25 percent of the nests were situated between 4800-5200 feet, 63 percent between 5200-5800 feet and 11 percent between 5800-6400

feet. The data of Table 11 indicate that several of the raptor species exhibited a vertical stratification of nesting sites.

Nests of the Golden Eagle were built on cliffs, rock outcroppings, and in quarries. None were constructed in trees, but ground nests and artificial structures were utilized in areas immediately adjacent to the study area. Occupied eyries averaged  $5690 \pm 62.0$  feet (range 5380-6170 feet). No apparent exposure preference was exhibited. All pairs maintained from one to

Table 10. Summary of exposures of occupied nests, 1957-1970.

Species	North		West		South		East	
	No.	%	No.	%	No.	%	No.	%
Golden Eagle	4	2.8	4	2.8	3	2.1	3	2.1
Great Horned Owl	1	0.7	15	10.6	8	5.7	3	2.1
Ferruginous Hawk	3	2.1	10	7.1	15	10.6	8	5.7
Red-tailed Hawk	4	2.8	6	4.3	6	4.3	5	3.5
Swainson's Hawk	0	0.0	0	0.0	1	0.7	4	2.8
Prairie Falcon	1	0.7	2	1.4	0	0.0	0	0.0
Marsh Hawk	0	0.0	0	0.0	0	0.0	4	2.8
Cooper's Hawk	0	0.0	1	0.7	0	0.0	0	0.0
Sparrow Hawk	4	2.8	1	0.7	3	2.1	1	0.7
Short-eared Owl	0	0.0	0	0.0	0	0.0	1	0.7
Burrowing Owl	0	0.0	0	0.0	0	0.0	6	4.3
Raven	4	2.8	8	5.7	2	1.4	0	0.0
Totals	21	14.7	47	33.3	38	26.9	35	24.7

Table 11. Summary of altitudinal distribution of raptor nests, 1967-1970.

Species	4800		5000		5200		5400		5600		5800		6000		6200	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Golden Eagle	0	0.0	0	0.0	1	0.7	4	2.8	6	4.3	0	0.0	3	2.1	0	0.0
Great Horned Owl	0	0.0	0	0.0	5	4.0	9	6.4	10	7.0	1	0.7	0	0.0	2	0.1
Ferruginous Hawk	1	0.7	8	5.7	17	12.1	16	11.3	0	0.0	0	0.0	0	0.0	0	0.0
Red-tailed Hawk	1	0.7	2	0.1	10	7.0	5	4.0	0	0.0	3	2.1	0	0.0	0	0.0
Swainson's Hawk	0	0.0	4	2.8	1	0.7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Prairie Falcon	0	0.0	0	0.0	1	0.7	0	0.0	2	0.1	0	0.0	0	0.0	0	0.0
Marsh Hawk	4	2.8	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Cooper's Hawk	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.7	0	0.0	0	0.0
Sparrow Hawk	0	0.0	0	0.0	6	4.3	0	0.0	3	2.1	0	0.0	0	0.0	0	0.0
Short-eared Owl	1	0.7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Burrowing Owl	6	4.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Raven	0	0.0	0	0.0	0	0.0	3	2.1	1	0.7	1	0.7	7	5.0	2	0.1
Totals	13	9.2	14	8.6	41	29.5	37	26.6	22	14.2	6	4.2	10	7.1	4	0.2

five alternate nests, and one or more of these would also be decorated at the onset of the breeding season.

Great Horned Owls selected cliffs, trees, and quarries for breeding sites. Quarries were a frequently utilized site (almost 26 percent of all Great Horned Owl nests were in quarries), and each year at least one pair nested in the niches, ledges, or cracks of an abandoned quarry. None of the pairs showed any attempt at nest construction but instead occupied old nests of Ravens, Red-tailed Hawks, Ferruginous Hawks, or deposited the eggs directly on the dirt or rock floor of a crevice or ledge. Tree nests were found only in junipers within the study area, but the owls did use old Red-tailed Hawk nests situated in tall cottonwoods in canyons located outside and to the north of the study area. Nests averaged  $5640 \pm 53.7$  feet (range 5340-6320 feet) in altitude. Over 55 percent of the nests faced west and almost 30 percent had southern exposures, while less than 1 percent faced north. Nests were selected in cliffs which ranged from 21 to 65 feet in height, but sheer size of cliff appeared to be less important than seclusion, and crevices were more frequently occupied than ledges.

Ferruginous Hawks were selective in their choice of nesting sites. Nests were constructed in junipers, cliffrose, on low ledges (less than five feet high) or directly on the ground (Fig. 8). The most common nesting site was in a low tree or shrub, either on the periphery of the woodland or in very lightly wooded areas of the foothills. The average altitude of all Ferruginous Hawk nests was  $5290 \pm 25$  feet (range 4990-5500 feet). Low foothills and knolls appeared to offer the best sites and were heavily utilized. In contrast, no nests were located in steep-sided canyons, cliffs, or heavily wooded areas, al-

though such sites were equally available in these same localities.

Red-tailed Hawks exhibited a wide choice of nesting sites somewhat paralleling that of the Great Horned Owl. Their most common nest sites were in junipers, but other localities included cliffs, quarries, pinyons, and cottonwoods (Fig. 9). Nests averaged  $5380 \pm 52.4$  feet, but had a wide altitudinal amplitude (range 4880-5880 feet). Unlike Ferruginous Hawks, Red-tailed Hawks constructed their nests in a variety of habitats. Tree nests were most commonly built on the periphery of the woodland or in lightly wooded areas but a few were also constructed in the center of dense woodlands and in steep-walled canyons. Cliff sites were usually in large rugged cliff lines but again some variation occurred and some nests were constructed on cliffs only 10-15 feet high. Red-tailed Hawks were frequently usurped from their nesting sites by the earlier nesting Great Horned Owls; they then chose secondary, more exposed nesting sites a short distance away.

The choice of nesting sites by the Swainson's Hawks showed considerable overlap with Ferruginous Hawks. Their nests were without exception constructed in low junipers and averaged  $5130 \pm 30.4$  feet in elevation (range 5080-5240 feet). As with Ferruginous Hawks, their most common nesting site was on a low foothill or knoll or at the edge of a juniper woodland.

Nesting sites of the Prairie Falcon averaged  $5590 \pm 88.3$  feet (range 5380-5760 feet). Of the three nests on the study area, two were located in quarries and one in a limestone cliff crevice. One quarry site was also located in a crevice but the second was located in an unused Golden Eagle nest. Heights of the nests above the cliff base ranged from 13-78 feet. In 1970 a pair



Fig. 8. Ferruginous Hawk ground nest in central Cedar Valley. The nest contains two chicks and one un-hatched egg. May, 1968.



Fig. 9. Red-tailed Hawk nest in juniper tree, Skull Valley, Tooele Co., Utah. Two young visible at top of nest. May 1972.

of Prairie Falcons prevented a pair of Great Horned Owls from successfully completing their nesting attempt and then took over the abandoned nest site (Fig. 10).

The four Marsh Hawk nests were situated in Cedar Valley and averaged  $4930 \pm 27.6$  feet in elevation (range 4870–4990 feet). All nests were located in thick sagebrush and rabbitbrush. Although all were ground nests, their location within the extensive sagebrush growth rendered them relatively inaccessible.

The only nesting of the Cooper's Hawk on the study area was in a juniper at an elevation of 6020 feet. The site was located deep within a dense juniper stand atop a ridge between two adjacent peaks, and overlooked Rush Valley. The nest was small and hidden within the middle branches of the tree.

Sparrow Hawks nested in junipers, quarries and abandoned mining structures. Nests averaged  $5460 \pm 49.7$  feet in elevation (range 5350–5670 feet). Quarry sites were actually small crevices in the vertical walls which ranged from 8–32 feet above the quarry floor. The scrape of these nests was most often simply a hollowed out portion of the dirt floor. Both tree nests were situated in small crevices within the tree trunks. Both types of nesting sites were also used



Fig. 10. Cliff nesting site of Prairie Falcons and Great Horned Owls in the western Thorpe Hills.

by Starlings (*Sturnis vulgaris*) nesting in the same localities.

The only Short-eared Owl nest on the study area was located at an elevation of 4890 feet. The nest site was placed at the base of a large clump of sagebrush and was partially sheltered and hidden by its branches. A few twigs had been arranged on the nest floor and down was placed among them; otherwise, no nest construction was attempted.

Nests of the Burrowing Owl averaged 4920 + 1.6 feet in elevation (range 4920–4930 feet). The three nests of the 1969 season and two of the 1970 season were grouped together, forming small colonies which were located in a stand of greasewood, in dry sand and soil (Fig. 11). The remaining nest was located in the bank of a dry reservoir. All were within unused burrows of kit foxes, badgers, or Townsend's ground squirrels.

With few exceptions Raven nests were located in the most remote, inaccessible regions of the study area. Their average elevation was 5950 + 65.5 feet (range 5590–6320 feet). All were well constructed, compact, and set far back into a protective crevice. All had an over-

hanging ledge or rockshelf which prevented direct exposure of the nest (Fig. 12).

*Reoccupation of Nests and Nesting Localities.* Most of the regularly nesting raptor species showed a strong tendency to reoccupy their territories and often their exact nesting sites of the previous year. This was particularly true of crevice-nesting raptors, and it is probable that these partially protected sites are used for an indefinite number of breeding seasons. Table 12 summarizes the reoccupation data. Unfortunately it was not possible to mark individuals, hence it is impossible to determine if the same pairs were present each year. However, many pairs and individuals of pairs exhibited distinctive color or plumage patterns and behavioral characteristics and could be identified on this basis.

Most of the large raptors selected different nest sites within the same territory each year. This was particularly true of the Ferruginous Hawk which selected a different nest site 75 percent of the time, but also remained within the same locality for successive years 77 percent of the time. Similarly, pairs of Golden Eagles, Great Horned Owls, Red-tailed Hawks, and Swainson's Hawks showed strong attachments to

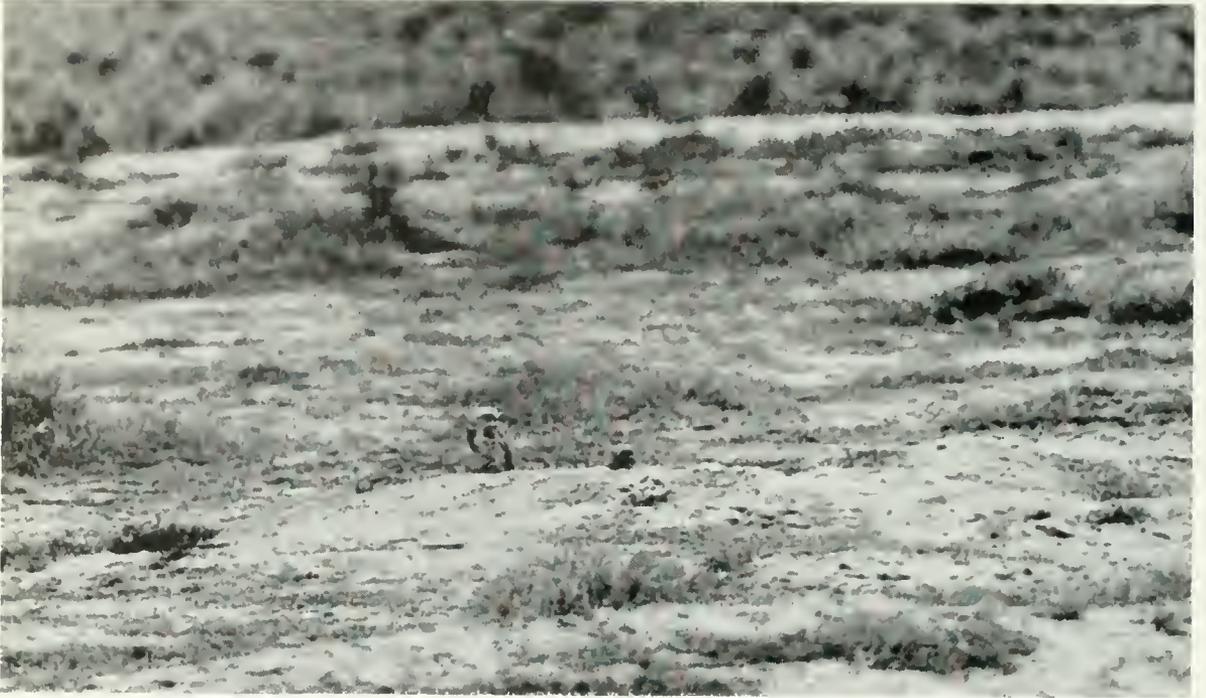


Fig. 11. Burrowing Owl nesting site in northeastern Cedar Valley, July 1970. Both adults are on the mound.



Fig. 12. Raven nest located in well-protected crevice.

a particular area and were often found there even during years in which they did not nest. Long term consecutive occupation of a nest site was more rare. One pair each of Great Horned Owls (nesting in a cliff site) and Ferruginous Hawks (nesting in a tree site) occupied their same respective nest sites for all four years of this study. Another Great Horned Owl pair had occupied their nest site for the fourth consecutive year but were displaced by a Prairie Falcon pair. Several pairs of Golden Eagles, Great Horned Owls, Ferruginous Hawks, and Red-tailed Hawks reoccupied the same nesting site for three consecutive years, and every large raptor occupied at least one nesting site for two consecutive years. Most commonly, those species which nested in a different site selected a new site very near that of the previous year. For example, a pair of Golden Eagles selected three sites in the same quarry for three consecutive years, each but 30 feet from the previous year's site. The same phenomenon was observed in Ferruginous, Red-tailed, and Swainson's Hawks. The amount of shifting appeared to be related to the degree of disturbance as well as the success of the previous year's nest, but pairs would often tolerate considerable disturbance and remain within the same nesting locality.

Of the medium and small raptors, the Raven showed the greatest population stability. The

Table 12. Summary of reoccupation of nesting sites and territories.

Species	No. years occupation of a nest site								No. years territorial occupation°								Total no. of sites
	1		2		3		4		1		2		3		4		
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	
Golden Eagle	5	55.6	2	22.3	2	22.2	0	0.0	0	0.0	0	0.0	2	40.0	3	60.0	9
Great Horned Owl	6	40.0	7	46.7	1	6.7	1	6.7	0	0.0	4	40.0	3	30.0	3	30.0	15
Ferruginous Hawk	18	75.0	2	8.3	3	12.5	1	4.2	1	7.7	2	15.4	4	30.8	6	46.2	24
Red-tailed Hawk	8	57.1	5	35.7	1	7.1	0	0.0	0	0.0	1	14.3	1	14.3	5	71.4	14
Swainson's Hawk	1	33.3	2	68.7	0	0.0	0	0.0	1	50.0	0	0.0	0	0.0	1	50.0	3
Prairie Falcon	3	100.0	0	0.0	0	0.0	0	0.0	1	33.0	2	67.0	0	0.0	0	0.0	3
Marsh Hawk	5	100.0	0	0.0	0	0.0	0	0.0	1	100.0	2	67.0	0	0.0	0	0.0	5
Cooper's Hawk	1	100.0	0	0.0	0	0.0	0	0.0	1	100.0	0	0.0	0	0.0	0	0.0	1
Sparrow Hawk	4	66.7	1	16.7	1	16.7	0	0.0	0	0.0	1	25.0	3	75.0	0	0.0	6
Short-eared Owl	1	100.0	0	0.0	0	0.0	0	0.0	1	100.0	0	0.0	0	0.0	0	0.0	1
Burrowing Owl	6	100.0	0	0.0	0	0.0	0	0.0	2	50.0	2	50.0	0	0.0	0	0.0	6
Raven	2	33.3	1	16.7	2	33.3	1	16.7	0	0.0	0	0.0	0	0.0	4	100.0	6
Totals	60	71.75	20	17.9	10	8.2	3	2.3	8	36.7	14	23.2	13	15.8	22	29.7	93

\*Totals include nesting and non nesting pairs

four pairs of Ravens on the study area occupied their respective territories for four consecutive years and selected but six different nesting sites. Sparrow Hawks also tended to reoccupy the same territories, but their fluctuating populations altered their reoccupation frequencies. None of the Burrowing Owl or Marsh Hawk pairs reoccupied their exact nesting sites of the previous year, but all returned and nested within the same locality. The Prairie Falcons chose three different sites in three different nesting attempts, two of which were located within the same territory.

**Productivity**

*Clutch Size.* The summary of clutch size frequencies from 1967-1970 is presented in Table 13. Golden Eagle clutches on the study area averaged  $2.07 \pm 0.07$  eggs (14 clutches, range 2-3). Differences between the mean clutch size of each of the four study years was not significant. Total fecundity averaged  $6.75 \pm 0.96$  eggs a year.

Great Horned Owl clutches averaged 2.82

$\pm 0.15$  eggs (22 clutches, range 1-4). Clutches of 1968 and 1969 were significantly larger than clutches of 1967 and 1970 ( $t = 2.53; 2.63$ , respectively) but not significantly different from one another ( $t = 1.26$ ). In addition, clutches of 1967-1970 were also not significantly different ( $t = 1.15$ ). Total yearly fecundity averaged  $15.5 \pm 3.3$  eggs.

Clutches of the Ferruginous Hawks averaged  $3.23 \pm 0.12$  eggs (34 clutches, range 2-4). Clutches of 1968 and 1969 were significantly larger than clutches of 1967 and 1970 ( $t = 2.56; 2.75$ , respectively) but not significantly different from one another ( $t = 0.05$ ). Again, clutches of 1967 and 1970 were not significantly different ( $t = 1.35$ ). Total yearly fecundity averaged  $28.3 \pm 5.6$  eggs.

Red-tailed Hawk clutches averaged  $2.89 \pm 0.13$  eggs (19 clutches, range 2-4). Although clutch size showed an increasing trend throughout the four study years, none of the possible differences between yearly clutch sizes was significant. Total yearly productivity averaged  $13.8 \pm 1.43$  eggs a year.

Table 13. Summary of frequency distribution of raptor clutch sizes from 1967-1970.

Species	No. eggs in clutch						
	1	3	3	4	5	6	7
Golden Eagle	0	13	1	0	0	0	0
Great Horned Owl	1	5	13	3	0	0	0
Ferruginous Hawk	0	5	13	16	0	0	0
Red-tailed Hawk	0	4	13	2	0	0	0
Swainson's Hawk	0	4	1	0	0	0	0
Prairie Falcon	0	0	0	0	1	0	0
Marsh Hawk	0	0	1	0	0	0	1
Cooper's Hawk	0	0	1	0	0	0	0
Sparrow Hawk	0	0	0	3	3	1	2
Short-eared Owl	0	0	0	0	0	0	1
Burrowing Owl	?	?	?	?	?	?	?
Raven	0	0	1	3	4	2	4
Totals	1	31	44	27	8	3	9

Clutches of the Swainson's Hawk averaged  $2.2 \pm 0.17$  eggs (5 clutches, range 2-3). There were no significant variations in clutch size between any of the four study years. Total yearly fecundity averaged  $2.75 \pm 0.6$  eggs, rating lowest of the large raptors on the study area.

Comparisons of the average clutch sizes of the large raptors indicate that the mean clutch size of Ferruginous Hawks was significantly larger than the Golden Eagle ( $t=8.23$ ), Great Horned Owl ( $t=2.11$ ), and Swainson's Hawk ( $t=4.76$ ) average clutches but did not differ significantly from average Red-tailed Hawk clutch size ( $t=1.01$ ). Red-tailed Hawk clutches averaged significantly larger than those of Golden Eagle ( $t=5.72$ ) and Swainson's Hawk ( $t=3.2$ ) but did not differ significantly from Ferruginous Hawk or Great Horned Owl ( $t=4.47$  for both) and Swainson's Hawk clutches ( $t=2.63$ ). Golden Eagle and Swainson's Hawk clutches did not differ significantly from one another ( $t=0.678$ ).

Of the smaller raptors, only Sparrow Hawks, Marsh Hawks, and Ravens had sufficient clutch size data for analysis.

Sparrow Hawk clutches averaged  $5.22 \pm 0.38$  eggs (9 clutches, range 4-7). No significant differences between yearly clutch sizes were found. Total yearly productivity averaged  $10.0 \pm 2.18$  eggs.

Clutches of the Marsh Hawk averaged  $5.0 \pm 1.4$  eggs (2 clutches, range 3-7). No comparisons were possible.

Raven clutches on the study area averaged  $5.35 \pm 0.34$  eggs (14 clutches, range 3-7). There were no significant differences between yearly clutch size. Total productivity averaged  $18.8 \pm 1.9$  eggs.

No significant differences were found between the average clutch sizes of the Marsh Hawk, Sparrow Hawk, and Raven but all were significantly larger than the clutches of the large raptors on the study area.

*Hatchability.* In 1967 the overall hatching success of the efforts of all nesting raptors on the study area was  $82.5 \pm 7.6$  percent, the highest of the four study years. In 1968 the overall hatching success was  $77.4 \pm 5.7$  percent, but in contrast the lowest hatching success occurred during the 1969 season ( $75.6 \pm 9.2$  percent). In 1970 the overall hatching success was slightly higher at  $82.0 \pm 4.7$  percent. There were no significant variations in yearly overall hatching success between any of the four study years. The overall hatching success of the five large raptor species when calculated separately showed no significant differences between years,

with the hatching percentages being as follows: 1967,  $84.7 \pm 8.7$  percent; 1968,  $75.9 \pm 7.6$  percent; 1969,  $76.7 \pm 10.24$  percent; 1970,  $84.2 \pm 7.1$  percent.

From 1967-1970 Golden Eagle nesting efforts hatched  $70.8 \pm 14.9$  percent of all eggs for an average of 1.2 young per nest per year. However, the breeding seasons of 1967 and 1970 were highly successful, hatching 100 percent of all eggs produced for an average of 2.0 young per nest; whereas the combined results of 1968 and 1969 revealed a two-year hatching success of less than 42 percent and an average of but 0.88 young per nest.

The average hatching success of Great Horned Owls from 1967-1970 was  $89.4 \pm 3.6$  percent for an average of 2.5 young per nest per year. Great Horned Owl hatching efforts were most successful in 1967 (100 percent hatched, average of 2.0 young per nest) and least successful in 1969 (80 percent hatched) although the efforts of 1969 actually resulted in a greater number of young (2.5) produced per nesting effort.

The average hatching success of Ferruginous Hawks on the study area from 1967-1970 was  $65.2 \pm 5.2$  percent for an average of 2.3 young produced per nest per year. Ferruginous Hawk nesting success was lowest in 1967 (53.3 percent hatched, 1.3 young per nest) but highest in 1969 (81.8 percent hatched, 3.0 young per nest). The hatching success was comparatively low during all four breeding seasons, and a total of 35 eggs produced no young.

Red-tailed Hawk nesting efforts successfully hatched  $76.7 \pm 3.9$  percent of all eggs produced from 1967-1970 for an average of 2.3 young per nest per year. As with Ferruginous Hawks, Red-tailed Hawk hatching success was highest in 1969 (88.9 percent hatched, 2.5 young per nest) but lowest in 1970 (69.2 percent hatched, 2.2 young per nest).

Swainson's Hawks had the highest hatching success of any raptor on the study area, successfully hatching all eggs produced each year. Swainson's Hawks averaged 2.2 young per nest per year but hatched 2.5 young per nest in 1969, their most productive year.

The Prairie Falcon nest for which the initial clutch size was known hatched all five eggs. Hatching success is unknown for the Cooper's Hawks and Burrowing Owls (the latter because of the inaccessibility of the nests). The only Short-eared Owl nest on the study area hatched six young from a clutch of seven eggs (85.7 percent). The two Marsh Hawk nests for which clutch size data are available hatched 70 percent

of the eggs for an average of 3.5 young per nest, but the figures are misleading inasmuch as one nest successfully hatched all seven eggs of the clutch whereas the other nest failed to produce any young.

Sparrow Hawk hatchability is known for 1968-1970. During this time their hatching success averaged  $94.1 \pm 4.9$  percent for an average of 4.7 young per nest. Their hatching success was greatest in 1969 and 1970 (100 percent hatched in both years).

From 1967-1970, Ravens successfully hatched  $70.5 \pm 7.6$  percent of all eggs produced for an average of 3.64 young per nest. Raven hatching success was highest in 1970 (85 percent hatched, 5.0 young per nest) but lowest in 1969, when less than 46 percent of the total eggs produced hatched young for an average of 2.2 young per nest.

Comparisons of hatching success between the different raptor species reveals that Swainson's Hawks had a significantly greater degree of overall success than Ferruginous Hawks ( $t=6.70$ ) and Red-tailed Hawks ( $t=5.85$ ) but did not differ significantly from the other large raptors. Great Horned Owls had the second highest overall hatching success, significantly higher than Ferruginous Hawks ( $t=3.83$ ) but did not vary significantly from that of the other larger raptors.

*Fledging Success.* The overall fledging success of all raptors on the study area was highest in 1970 ( $61.6 \pm 8.5$  percent) and lowest in 1969 ( $53.4 \pm 6.1$  percent), with the 1967 and 1968 breeding seasons showing intermediate success ( $60.2 \pm 7.4$ ;  $59.7 \pm 6.8$  percent, respectively). There were no significant differences in fledging success between any of the study years. Data involving only the large raptor species of the study area revealed a similar overall fledging success, with 1970 again being the most successful breeding season ( $77.8 \pm 10.6$  percent), 1969 the least successful ( $57.7 \pm 7.8$  percent), and 1967 and 1968 again having intermediate degrees of success ( $61.3 \pm 8.9$ ;  $62.9 \pm 9.1$  percent, respectively). Again there were no significant differences in fledging success among any of four study years.

From 1967-1970, Golden Eagle nests on the study area successfully fledged  $55.2 \pm 13.4$  percent of their original clutches for an average of 1.0 young fledged per nest. Fledging rates were highest in 1967 and 1970, when combined data indicate a survival rate of 75.0 percent and 1.33 young fledged per nest, and lowest in 1968 and 1969, which had a combined fledging average of 35.4 percent and 0.75 young per nest.

The overall fledging success of Great Horned Owls from 1967-1970 was  $75.6 \pm 7.2$  percent for an average of 2.0 young fledged per nest. The yearly fledging range varied from 100 percent (2.0 young per nest) in 1967 to a low of 70 percent in both the 1968 and 1969 breeding seasons (1.75 young per nest; 2.33 young per nest, respectively). Great Horned Owls successfully fledged the highest percentage of young each year among the large raptors on the study area, but Ferruginous Hawks fledged a similar overall average of 2.0 young per nest.

Ferruginous Hawks on the study area successfully fledged an overall average of  $56.2 \pm 5.3$  percent for an average of 2.0 young per nest per year. Ferruginous Hawks were most successful in 1969 and fledged an average of 2.67 young per nest during this season, the highest number fledged per nest by any of the large raptors during any study year. In contrast, their relative fledging success during the other three study years was but 50.6 percent for an average of 1.63 young fledged per nest for each of the three years.

From 1967-1970 the average fledging success of Red-tailed Hawks was  $58.9 \pm 4.6$  percent for an average of 1.74 young fledged per nest. As with the Ferruginous Hawks, Red-tailed Hawks had their greatest fledging success in 1969 (72.2 percent) and also produced the greatest number of young per nest (2.17 fledged per nest) during this breeding season.

Swainson's Hawks had the second highest fledging success on the study area, averaging  $72.5 \pm 13.4$  percent during the four study years. Although their average clutch size was highest in 1969, they fledged but 1.0 young per nest this year, the lowest of the four study years.

Of the medium and small raptors, Prairie Falcons in 1970 fledged but 20 percent of their clutch of five eggs while Short-eared Owls fledged none of six young.

Burrowing Owls fledged an average of 10 young per year in 1969 and 1970, for an average of 3.33 young per nest per year.

From 1968-1970 the average fledging success of Sparrow Hawks on the study area was  $59.1 \pm 8.8$  percent for an average of 2.83 young fledged per nest. Sparrow Hawk fledging success was highest in 1970 (80 percent, 4.0 young per nest) but low in 1968 and 1969; the combined data for these two years indicates a fledging success of 48.7 percent for an average of 2.6 young fledged per nest per year.

The overall fledging success of Ravens on the study area was  $47.4 \pm 3.3$  percent for an average of 2.57 young per nest. Raven fledging

success was consistently low, but was higher in 1967 (57.1 percent, 3.0 young per nest) than during the remaining study years.

*Mortality.* The hatching and fledging percentages presented in Tables 14-17 are based on the total number of eggs produced. The mortality percentages of each of these stages can therefore be determined by subtracting the represented figures from 100 percent. Specific causes of the loss of eggs or young were often difficult or impossible to determine, but important causes included nest desertion or destruction, human interference, predation and apparent egg infertility (see Table 18).

Nest desertion was observed in every raptor species except the Raven and Cooper's Hawk, with 24.1 percent of the established nests eventually being deserted before the fledging of the young. The majority were deserted before eggs

had been deposited, and all species showed an increasing tendency to tolerate disturbance after the young had hatched. Human interference, including the presence of the investigators, was the probable cause of the greatest number of desertions, but many raptor pairs tolerated a considerable amount of disturbance and yet retained their nests (see Smith and Wilson [1971] for a discussion of individual and species differences in toleration of disturbance).

Red-tailed Hawks and Great Horned Owls exhibited a tendency to desert their nests (33.3 and 25.9 percent respectively). Both select very similar nesting sites and often utilize the same site in alternate years. In 1968 and again in 1969 a Great Horned Owl flushed from its nest was attacked by a pair of Red-tailed Hawks nesting in close proximity. In both cases the Red-tailed Hawk nests (both containing full

Table 14. Summary of productivity of raptor nesting populations, 1967.

Species	No. complete clutches	Average clutch size	Range of clutch size	Total no. of eggs produced	No. young hatched	Percent young hatched	No. young fledged	Percent young fledged
Golden Eagle	3	2.0	-	6	4	66.7	2	33.3
Great Horned Owl	4	2.0	1-3	8	8	100.0	8	100.0
Ferruginous Hawk	6	2.5	2-4	15	8	53.3	7	46.7
Red-tailed Hawk	4	2.5	2-3	10	7	70.0	6	60.0
Swainson's Hawk	1	2.0	-	2	2	100.0	1	50.0
Prairie Falcon	0	-	-	-	-	-	-	-
Marsh Hawk	9	-	-	-	-	-	-	-
Cooper's Hawk	1	3.0	-	?	?	?	?	?
Sparrow Hawk	2	4.5	4-5	9	?	?	?	?
Short-eared Owl	0	-	-	-	-	-	-	-
Burrowing Owl	0	-	-	-	-	-	-	-
Raven	4	5.2	4-7	21	15	71.4	12	57.1
Totals	34	-	-	71	44	-	36	-

Table 15. Summary of productivity of raptor nesting populations, 1968.

Species	No. complete clutches	Average clutch size	Range of clutch size	Total no. of eggs produced	No. young hatched	Percent young hatched	No. young fledged	Percent young fledged
Golden Eagle	4	2.0	-	8	4	50.8	3	37.5
Great Horned Owl	8	3.0	2-4	24	21	87.5	15	62.5
Ferruginous Hawk	9	3.7	3-4	33	21	63.6	19	57.6
Red-tailed Hawk	5	2.8	2-3	14	11	78.6	8	57.1
Swainson's Hawk	1	2.0	-	2	2	100.0	2	100.0
Prairie Falcon	1	?	?	?	0	-	-	-
Marsh Hawk	0	-	-	-	-	-	-	-
Cooper's Hawk	0	-	-	-	-	-	-	-
Sparrow Hawk	3	5.7	4-7	17	14	82.4	9	52.9
Short-eared Owl	0	-	-	-	-	-	-	-
Burrowing Owl	0	-	-	-	-	-	-	-
Raven	1	5.0	3-6	20	16	80.0	10	50.0
Totals	35	-	-	118	89	-	66	-

Table 16. Summary of productivity of raptor nesting populations, 1969.

Species	No. complete clutches	Average clutch size	Range of clutch size	Total no. of eggs produced	No. young hatched	Percent young hatched	No. young fledged	Percent young fledged
Golden Eagle	4	2.2	2-3	9	3	33.3	3	33.3
Great Horned Owl	6	3.3	3-4	20	16	80.0	14	70.0
Ferruginous Hawk	12	3.7	3-4	44	36	81.8	32	81.8
Red-tailed Hawk	6	3.0	2-4	18	16	88.9	13	72.2
Swainson's Hawk	2	2.5	2-3	5	5	100.0	2	40.0
Prairie Falcon	0	-	-	-	-	-	-	-
Marsh Hawk	2	?	?	?	?	?	5	?
Cooper's Hawk	0	-	-	-	-	-	-	-
Sparrow Hawk	2	4.5	4-5	9	9	100.0	4	44.4
Short-eared Owl	0	-	-	-	-	-	-	-
Burrowing Owl	3	?	?	?	?	?	8	?
Raven	4	5.5	4-7	22	10	45.5	9	40.9
Totals	41	-	-	127	95	-	90	-

Table 17. Summary of productivity of raptor nesting populations, 1970.

Species	No. complete clutches	Average clutch size	Range of clutch size	Total no. of eggs produced	No. young hatched	Percent young hatched	No. young fledged	Percent young fledged
Golden Eagle	3	2.0	-	6	6	100.0	6	100.0
Great Horned Owl	4	2.5	2-3	10	9	90.0	7	70.0
Ferruginous Hawk	7	3.0	2-4	21	13	61.9	10	47.6
Red-tailed Hawk	4	3.3	3-4	13	9	69.2	6	46.2
Swainson's Hawk	1	2.0	-	2	2	100.0	2	100.0
Prairie Falcon	1	5.0	-	5	3	60.0	1	20.0
Marsh Hawk	2	5.0	3-7	10	7	70.0	5	50.0
Cooper's Hawk	0	-	-	-	-	-	-	-
Sparrow Hawk	1	5.0	-	5	5	100.0	4	80.0
Short-eared Owl	1	7.0	-	7	6	85.7	0	0.0
Burrowing Owl	3	?	?	?	?	?	12	?
Raven	2	6.0	5-7	12	10	85.0	5	41.7
Totals	29	-	-	91	-	-	58	-

clutches) were subsequently abandoned as was the Great Horned Owl nest of 1968 (Smith, 1970). Their most commonly chosen sites, i.e., quarries, are in highly vulnerable situations which invite human presence and interference. Twice in 1968 Red-tailed Hawks built nests in quarry sites which were almost daily subject to human disturbances. In both cases the nests were subsequently abandoned before eggs were deposited. In 1970 a Great Horned Owl occupied its quarry nest of the former three seasons. Later interaction with a Prairie Falcon apparently caused it to abandon this crevice site before egg deposition took place. This Great Horned Owl pair successfully re-nested only 42 feet from their original site which was then occupied (unsuccessfully) by the Prairie Falcon pair. Nest desertion frequently led to re-nesting attempts by Red-tailed Hawks, particularly if

nests had been deserted before egg deposition occurred. None, however, were successful during the four-year study.

Golden Eagles also frequently deserted their nests, with 25.9 percent of all nesting attempts terminated by desertion. As with Great Horned Owls and Red-tailed Hawks, the most frequent cause of nest desertion was some form of human interference. Two pairs each deserted their nests in two of the three years in which they attempted to nest. Egg collecting and photography activities were observed around these nests before their desertion. A re-nesting attempt occurred in 1969 but was unsuccessful.

Ferruginous Hawks deserted nests 22.2 percent of the time. Several of the pairs would tolerate no activity around the nest, particularly during the time period immediately after egg deposition had been completed; these birds de-

Table 18. Summary of causes of mortality, 1967-1970.

Species	Total no. eggs produced	Successful nests <sup>a</sup>			Unsuccessful nests					
		Egg losses		Juvenile losses All causes	Nest destruction			Nest destruction		
		Infertile	Other		Egg not laid	Eggs laid	Young	Eggs not laid	Eggs laid	Young
Golden Eagles	27	2( 2)	1( 1)	1( 1)	1	3( 7)	0	0	0	1( 2)
Great Horned Owl	62	2( 2)	2( 3)	4( 4)	5	1( 3)	1( 3)	1	0	1( 3)
Ferruginous Hawk	113	8( 9)	5( 6)	5( 6)	2	6(18)	0	0	1( 2)	1( 4)
Red-tailed Hawk	55	0	5( 7)	4( 4)	4	2( 5)	1( 3)	0	0	1( 3)
Swainson's Hawk	11	0	1( 1)	0	0	0	1( 3)	0	0	0
Prairie Falcon	5	1( 1)	1( 1)	1( 1)	2	0	0	0	0	0
Marsh Hawk	?	?	?	1( 2)	0	1( 3)	0	0	0	0
Cooper's Hawk	3	?	?	?	?	?	?	?	?	?
Sparrow Hawk	40	0	0	3( 5)	1	1( 3)	0	0	0	1( 5)
Short-eared Owl	7	1( 1)	0	0	0	0	1( 6)	0	0	0
Burrowing Owl	?	?	?	?	2	?	?	?	?	?
Raven	75	4( 5)	7(18)	11(16)	0	0	0	0	0	0
Totals	398	18(20)	22(37)	30(39)	17	14(39)	4(15)	1	1( 2)	5( 17)

<sup>a</sup>Numbers in columns refer to number of nests; number in parenthesis following refer to number of eggs or young.

sorted their sites immediately after the nesting tree had been climbed or ground site checked. However, none of the nests were abandoned after the adults had hatched young.

In 1969 one Swainson's Hawk nest with three young aged 1.5 weeks was deserted. Only one of the pair was seen in the nest vicinity. Three days later several pieces of the remains of a Swainson's Hawk were found beneath the roost of a pair of Golden Eagles which maintained a territory in the same area. Evidently this predation caused the termination of the Swainson's Hawk's nesting activities.

Prairie Falcons abandoned two of three nesting sites because of human activities. In addition, Marsh Hawks, Sparrow Hawks, Short-eared Owls, and Burrowing Owls also deserted one or more of their nests because of human presence or interference. Marsh Hawks deserted a nest containing three eggs which, when checked, were infertile. Prairie Falcons abandoned one nest due to aggression conflicts with Great Horned Owls (previously discussed) and deserted another nest located in a quarry which was frequently visited by hunters and campers. Sparrow Hawks abandoned two nests because of similar activities. Apparently our investigations were the cause of the nest desertion by Burrowing Owls and the Short-eared Owl.

Nest destruction occurred in 4.9 percent of the 141 initiated nests. Causes of nest destruction included human interference and accidents. Human interference in this case refers to the destruction of the young and/or adults. An exposed quarry site was occupied in 1968 by a pair of Great Horned Owls. Despite disturbances they persisted in their attention to the nest and succeeded in hatching three young, but both the nest and young were subsequently destroyed. In 1969 the same site was occupied

by a Red-tailed Hawk pair which also succeeded in hatching three young. Again the nest was destroyed before the young fledged. Another Great Horned Owl nest occupied in 1969 was destroyed before egg deposition. The body of one of the adults was found beneath the nesting tree, minus its feet and several tail feathers. Two Ferruginous Hawk nests were similarly destroyed. One containing two eggs was located alongside a well-traveled road. The female was later found shot, the eggs broken and the nest destroyed (Weston and Ellis, 1968). The second nest was located in a favorite rabbit hunting locale and produced four young. Shortly before the young would have fledged, the nest was found destroyed, with three shotgun shells lying beneath the nesting tree. One Sparrow Hawk nest was also destroyed. This nest was located among the ruins of an abandoned mining structure and had been deliberately exposed.

An accident destroyed a Golden Eagle nest in 1967, the only observed instance of the natural destruction of a raptor nest. The nest had been positioned in a loose shale quarry wall which collapsed, killing both young (Murphy et al., 1969).

Based on the successful nests (i.e., those which fledged at least one young) 6.5 percent of all eggs produced by all raptors species were apparently infertile and another 11.4 percent were lost before hatching. Eggs which did not hatch after a suitable time period were judged infertile; however, additional eggs may have been infertile but were destroyed prior to our checking them. Ferruginous Hawks had the highest apparent percentage of infertile eggs (10.1 percent) of any raptor species. Seven Ferruginous Hawk nests contained one infertile egg each and one contained two. Most commonly, one of a clutch of three or four eggs

was infertile. Both Golden Eagles and Great Horned Owls also produced infertile eggs. In 1968 a Golden Eagle pair produced a clutch of two eggs. One egg disappeared early during the incubation period, but the adult continued to incubate the remaining egg. After 49 days the egg had not hatched and was subsequently abandoned. Raven nests also appeared to produce a high number of infertile eggs on the study area, with 6.7 percent of their total eggs judged to be infertile.

Reasons for other egg losses are mostly unknown, but the eggs usually disappeared during incubation. However, one case is interesting. In 1968 a Red-tailed Hawk pair produced a clutch of two eggs. During the incubation period one member of the pair was found destroyed (presumably shot). One egg disappeared but the remaining adult remated with a new individual and successfully incubated and then fledged a young from the remaining egg.

Losses of young are also combined because of lack of knowledge of specific causes. Juvenile mortality occurred most commonly in Raven nests, but Golden Eagle, Great Horned Owl, Ferruginous Hawk, and Red-tailed Hawk juveniles also occasionally disappeared.

Little information was obtained on post-fledging mortality, although this is the period during which the majority of deaths among first-year birds occurs (Hickey, 1949; Lack, 1954; Sprunt, 1963). In previous studies on raptor mortality in this area, Ellis, Smith, and Murphy (1969) recorded a high percentage of juveniles among birds which had been illegally shot by hunters and suggested that juveniles are particularly vulnerable to this form of destruction.

### Territoriality

The definition and concept of a territory has been much discussed in the literature (Noble, 1939; Nice, 1941, 1943; Odum and Kuenzler, 1955). Within the study area, however, the minimal amount of intraspecific home range overlap coupled with the very few instances of observed territorial defense suggests that the most applicable concept is the "maximum home range" category as described by Odum and Kuenzler (1955). Using this method, the extreme positions and movements of raptors are plotted and connected and the area contained within is the derived home range. The home ranges plotted in 1969 and 1970 were determined from a minimum of 25 observations per pair.

*Home Range Establishment and Defense.* Home range establishment dates of all raptor

species from 1967-1970 have been previously presented in Tables 5-8. At the beginning of the raptor breeding season, the permanent residents selected their future nesting sites and confined their activities within a restricted area. During this period Golden Eagles were often observed in such conspicuous activities as soaring, courtship display, and occupying a prominent perch. Great Horned Owls were frequently active in the early evening hours making short flights from one perch to another. Both individuals and pairs were observed hooting from the cover of one perch, then making a short flight to a new perch and hooting again. No intraspecific or interspecific actions were observed during this period, although on a few occasions a Golden Eagle of one nesting pair flew within sight of the nesting locale of a neighboring pair, maintaining a good distance from the actual nest site. Indeed, the pairs at times seemed to be keeping watch on their neighbor's nest while establishing their own territorial rights, much in the manner described by Dixon (1937). No Golden Eagle and Great Horned Owl interactions occurred, although pairs nested in close proximity in 1968, 1969, and 1970. There is little or no overlap in their respective activity patterns and they do not usually come in contact with one another. Unlike other large raptors, Golden Eagles did not attack flushed Great Horned Owls even when owls were flushed within 50 feet of active Golden Eagle nests.

Returning migratory pairs rapidly occupied their territories and assumed territorial establishment activities. Ferruginous, Red-tailed, and Swainson's Hawks were highly aggressive at this time. In several locales Ferruginous Hawk pairs nested in close proximity. Their morning and evening soaring flights frequently provoked interaction, and at times members of three pairs would be observed soaring but short distances from one another. Usually the act of soaring kept the pairs distant, but occasionally one would apparently venture too close and provoke a response. One or both members of a pair would posture and chase one or both members of another pair simultaneously, although no actual contact was ever observed. In one example of interspecific contact, a Ferruginous Hawk pair attacked a Great Horned Owl which had landed some 30 feet from its cliff nest. The Hawks dove at it in turn several times, each time coming to within 3-9 feet of its head but avoiding contact. The owl in turn met each attack by raising its wings in defense posture and vigorously clapping its beak. The hawks persisted until the owl flew into a nearby cliff crevice, whereupon the hawks resumed their

soaring. In this case the Ferruginous Hawks had arrived in the area and occupied their territory of the previous year in the morning and were actively defending it in the late afternoon of the same day.

Red-tailed Hawk pairs defended their territories against Great Horned Owls, Ferruginous Hawks, and Golden Eagles but no intraspecific conflicts were observed. Red-tailed Hawks always attacked flushed Great Horned Owls and on at least three occasions struck from above with open talons, although never visibly injuring them. The owls made no attempt to defend themselves during such attacks but instead flew to the nearest cover. On one occasion a Red-tailed Hawk pair attacked and drove a Golden Eagle out of their territory. The eagle was persistently attacked from above when approximately 1 1/5 miles from the Red-tailed Hawk nesting site and rapidly flew out of the area, followed for a distance by the red-tails. Red-tailed Hawks also threatened Ravens, but only if close to the nest site. The Ravens maintained a cautious distance from soaring Red-tailed Hawks and usually only a swoop in their direction sufficed to chase them away.

Encounters between Swainson's Hawks and Ferruginous Hawks often occurred and are discussed by Murphy, et. al., (1969).

Prairie Falcons quickly and aggressively reacted to the presence of any raptors within their nesting vicinity during this period. However, Ravens were tolerated surprisingly close to the nesting vicinity, and in 1970 a pair of Ravens nested within 75 feet of an active Prairie Falcon eyrie. Both sites, however, were out of sight of one another and hidden within recesses in cliffs.

Very little information was obtained on aggression and territorial reactions of the medium- and small-sized raptors during this period. Generally their nests were widely spaced and showed no overlap, with the exception of the Burrowing Owls. A Sparrow Hawk pair was observed attacking a Red-tailed Hawk flying about 50 feet above its nest site, but reacted passively to the presence of Ravens and Golden Eagles. Burrowing Owls vigorously protested disturbances from investigators but allowed Marsh Hawks to fly within their home ranges. Marsh Hawks were similarly tolerant of the Burrowing Owls and on two occasions nested within the home range of Short-eared Owls.

As the breeding season progressed, the raptors generally became less aggressive toward one another and fewer aggression contacts were observed. At times much tolerance was shown

toward other raptor species flying over the nest site, while on other occasions they would be attacked and driven away. Definite vertical territory limits appear to be present and were easily observed during the reactions of a pair to the presence of investigators. On several occasions a second and sometimes a third pair were observed soaring above a nesting pair which were themselves attacking the investigators. At these times the intruding pairs remained unchallenged as long as they maintained their higher altitudes. However, in one such instance a Ferruginous Hawk pair from a nearby nest flew over a Red-tailed Hawk nest at low altitude; the intruders were immediately attacked by the nesting pair, which successfully drove them away after one grappled with one of the Ferruginous Hawks.

*Home Range Coverage.* The home ranges determined during the breeding seasons of 1969 and 1970 are plotted in Fig. 13-21. Generally the specific size and shape of the raptor home ranges appeared to be a function of their size and breeding status (i.e., nesting pair, nonnesting pair, or individual), the topography of the surrounding locale, and apparently the breeding population densities. Home ranges of nesting raptor pairs were usually larger than home ranges of nonnesting pairs and both maintained larger home ranges than individuals of the same species. Almost all of the raptors nesting in the foothills had home ranges extending far into the desert but only short distances into the interior of the hills. Their nests, therefore, were usually located at the edge of the home range.

Average home ranges of all raptors except Swainson's Hawks, Sparrow Hawks, and Burrowing Owls were larger in 1970, correlating with the overall decreased raptor population densities. None, however, were significantly larger than the average home ranges of 1969. Additional home range information of the raptor species is presented as follows (only home ranges which were entirely within the study area limits are included in the following data).

The home ranges of nesting Golden Eagle pairs averaged  $9.05 \pm 1.1$  sq miles in 1969 (3 pairs, range 6.6 — 11.8 sq miles) and  $8.98 \pm 0.6$  sq miles in 1970 (3 pairs, range 7.91 — 10.3 sq miles). Maximum diameters of the home ranges averaged  $4.09 \pm 0.4$  miles in 1969 (range 3.08 — 4.99 miles) and  $3.85 \pm 0.4$  miles in 1970 (range 3.25 — 4.8 miles). Golden Eagles possessed the largest home ranges of any raptor nesting within the study area and appeared to be little affected by topographic barriers. They also appear to consistently utilize a sizeable

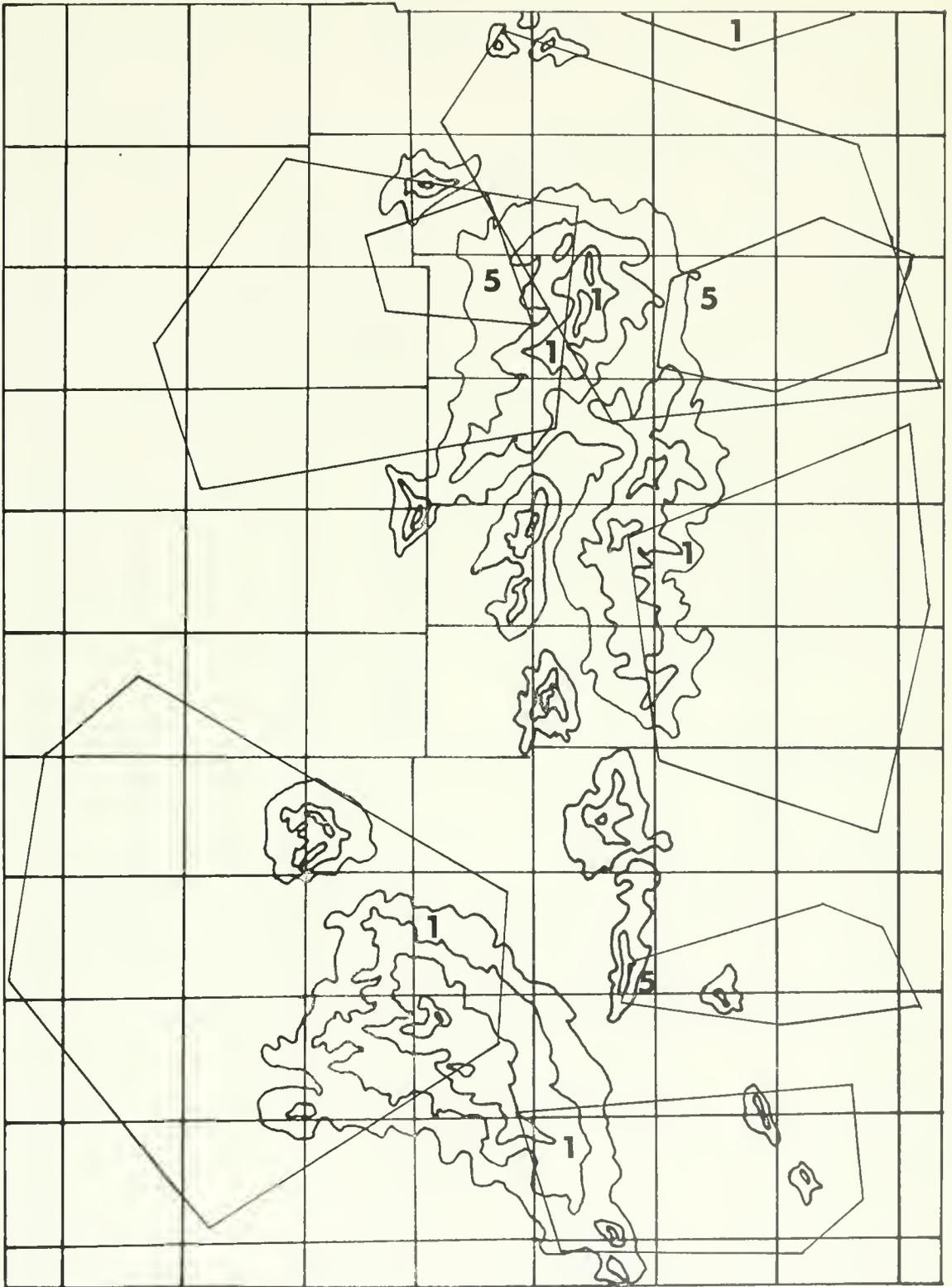


Fig. 13. Home ranges of Golden Eagles (1) and Swainson's Hawks (5) in 1969.

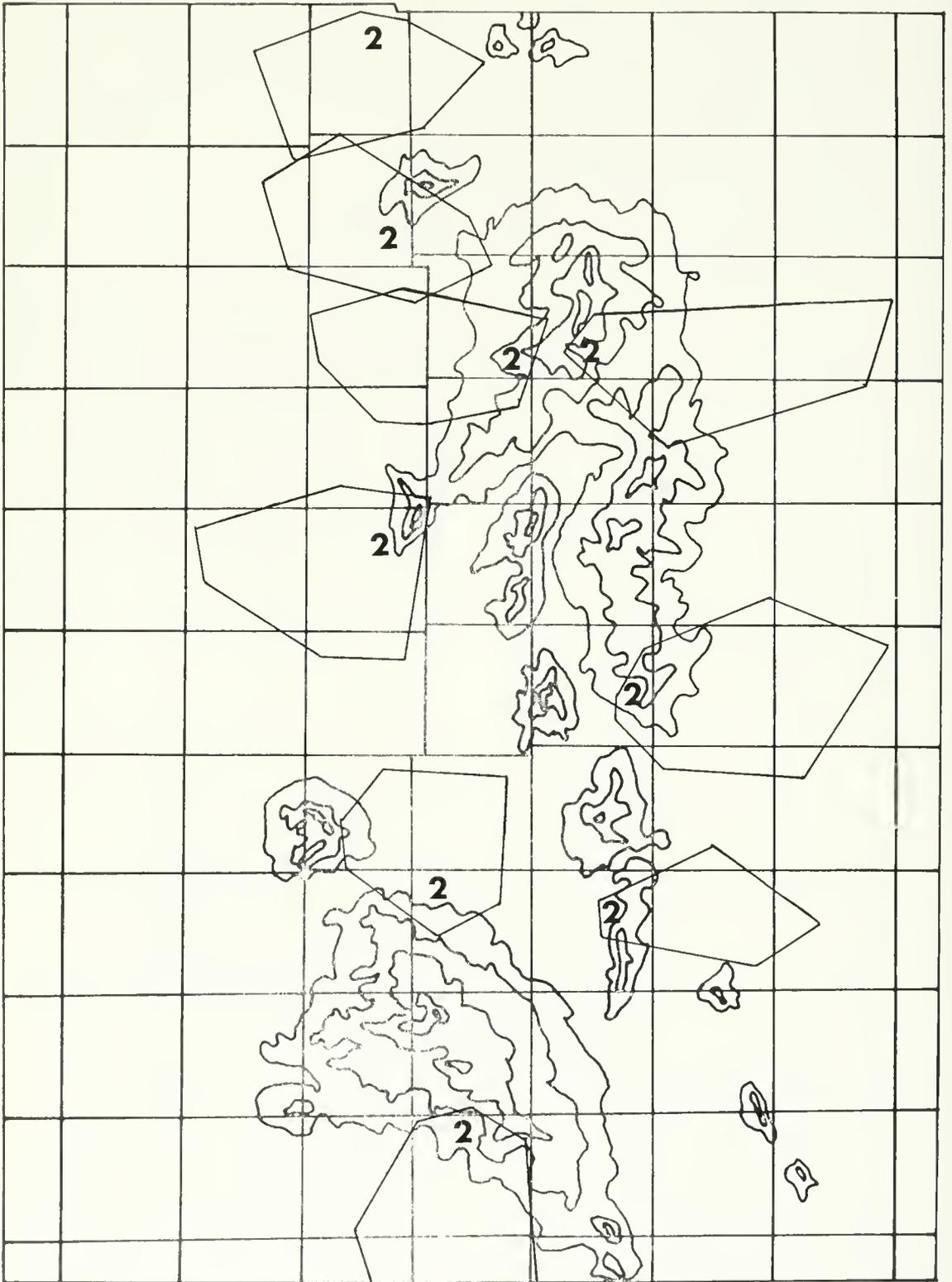


Fig. 14 Home ranges of Great Horned Owls (2) in 1969.

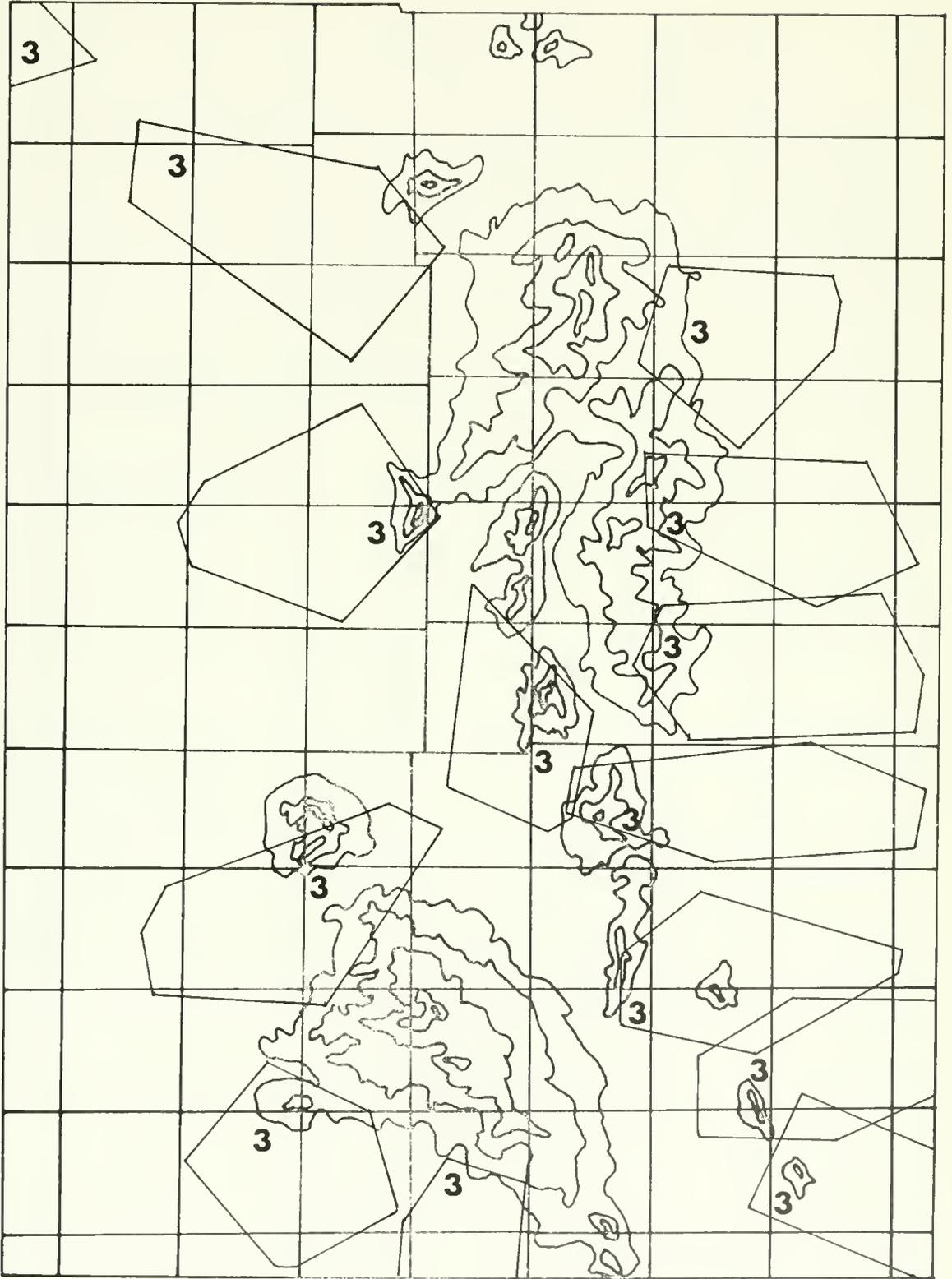


Fig. 15. Home ranges of Ferruginous Hawks (3) in 1969.

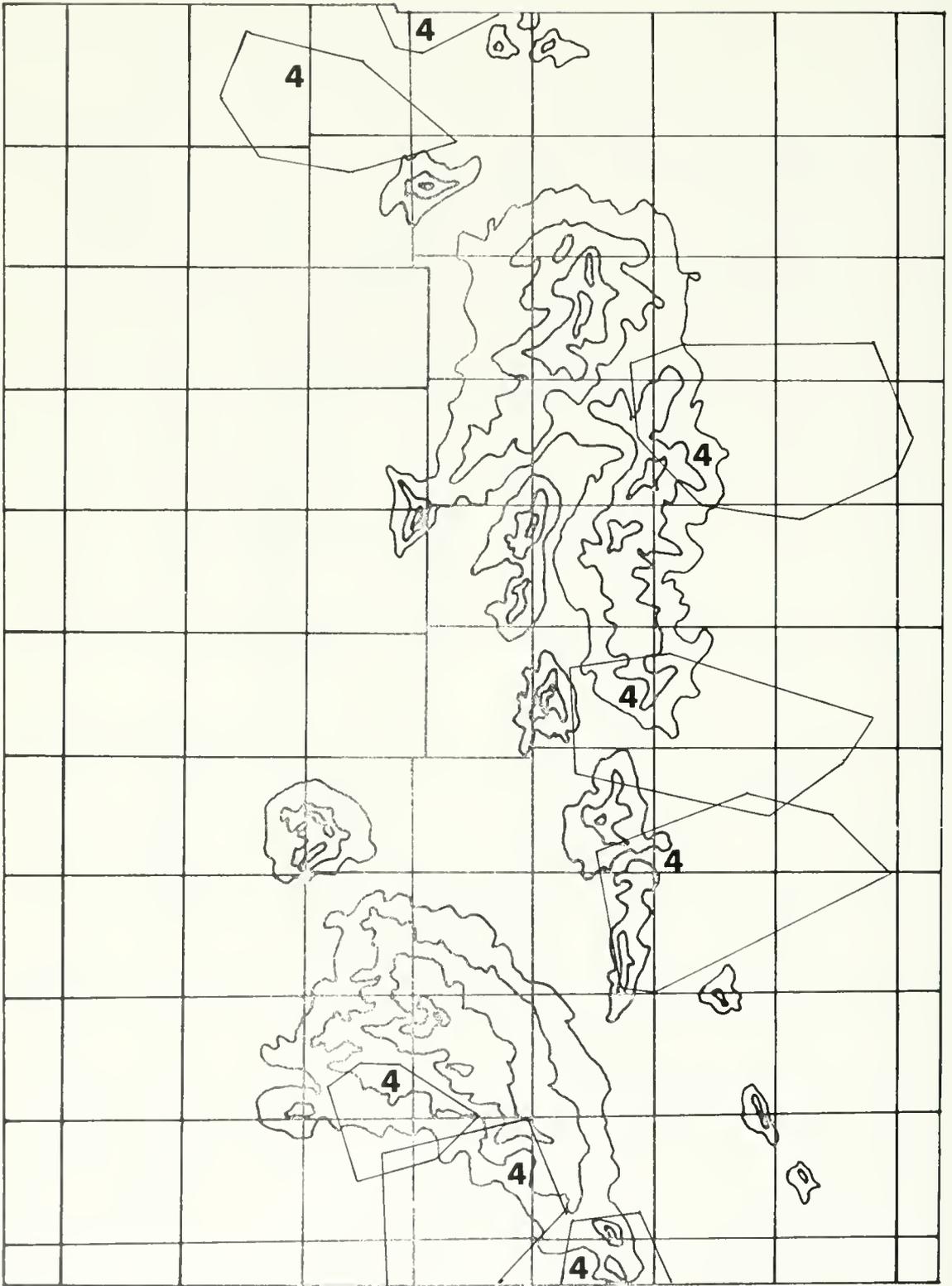


Fig. 16. Home ranges of Red-tailed Hawks (4) in 1969.

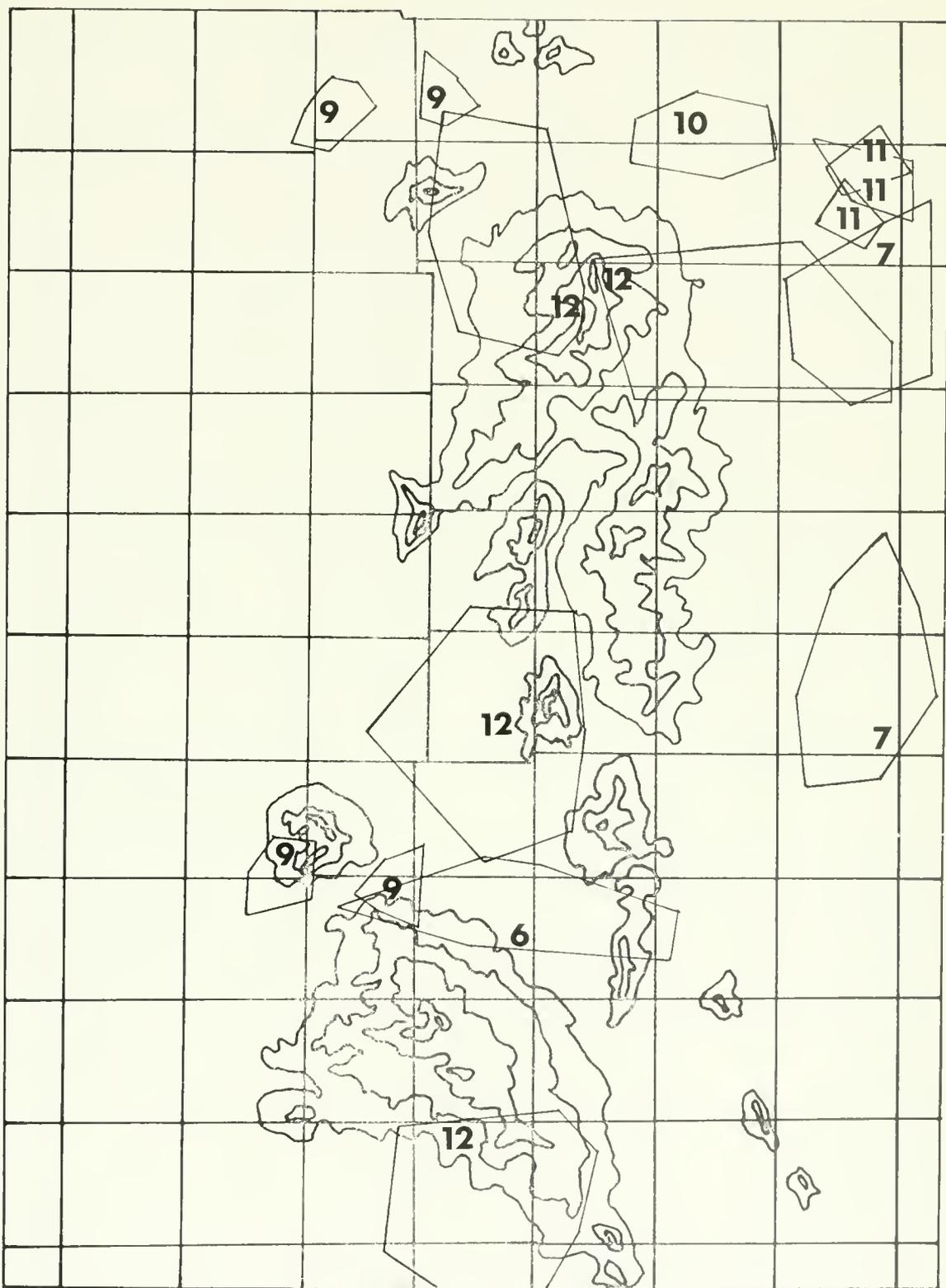


Fig. 17. Home ranges of Prairie Falcons (6), Marsh Hawks (7), Sparrow Hawks (9), Short-eared Owls (10), Burrowing Owls (11) and Ravens (12) in 1969.

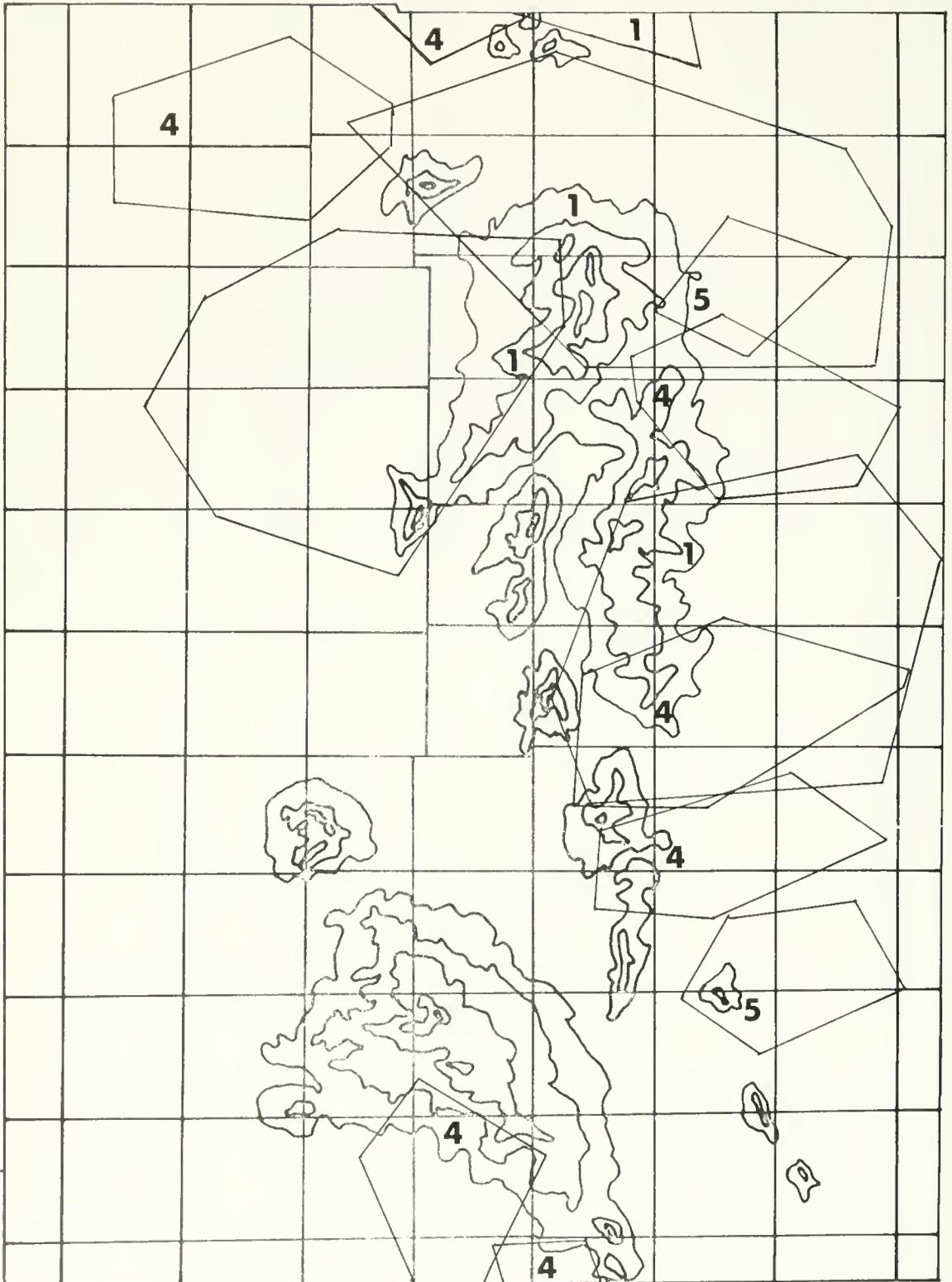


Fig. 18. Home ranges of Golden Eagles (1), Red-tailed Hawks (4) and Swainson's Hawks (5) in 1970.

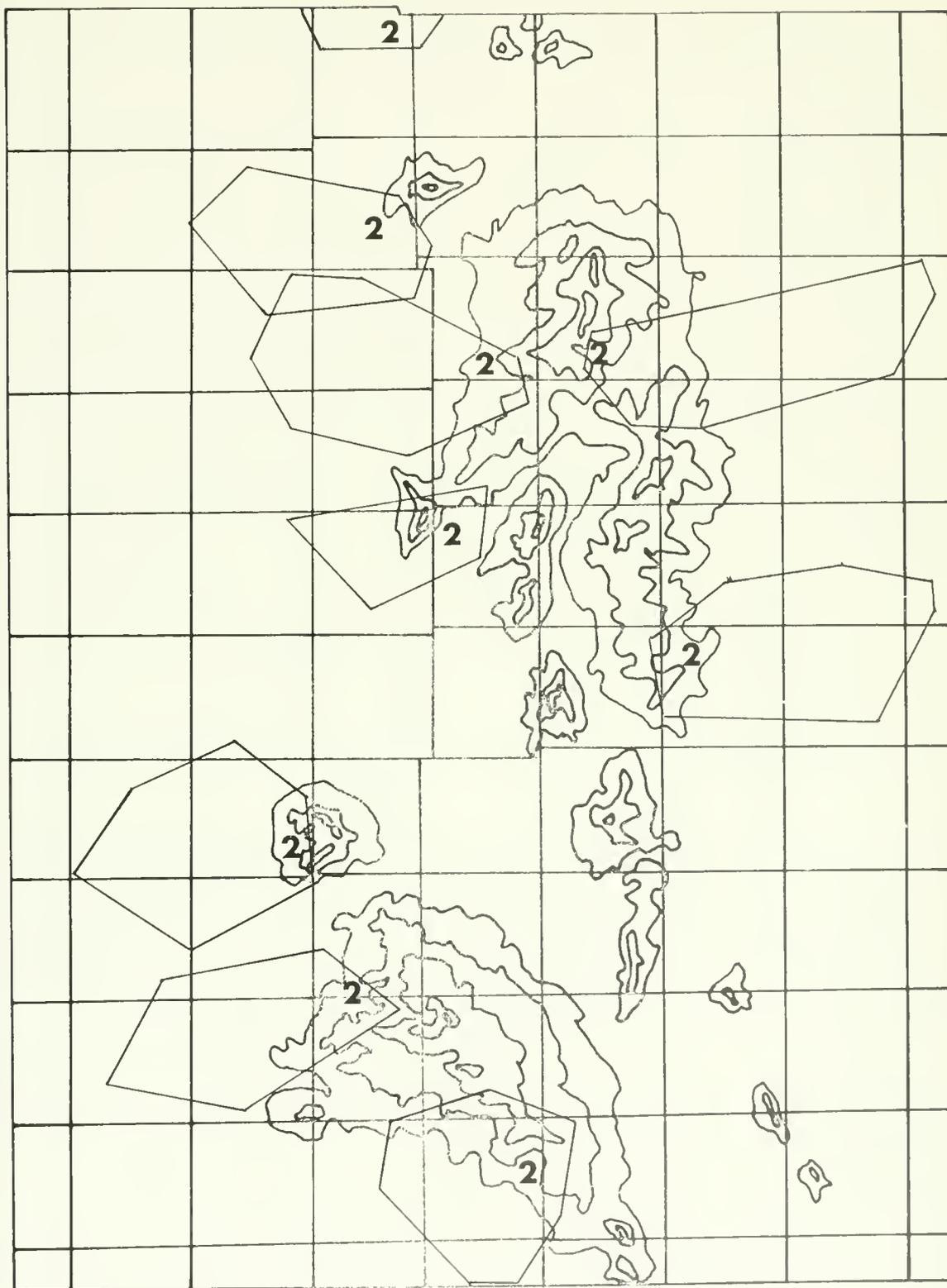


Fig. 19. Home ranges of Great Horned Owls (2) in 1970.

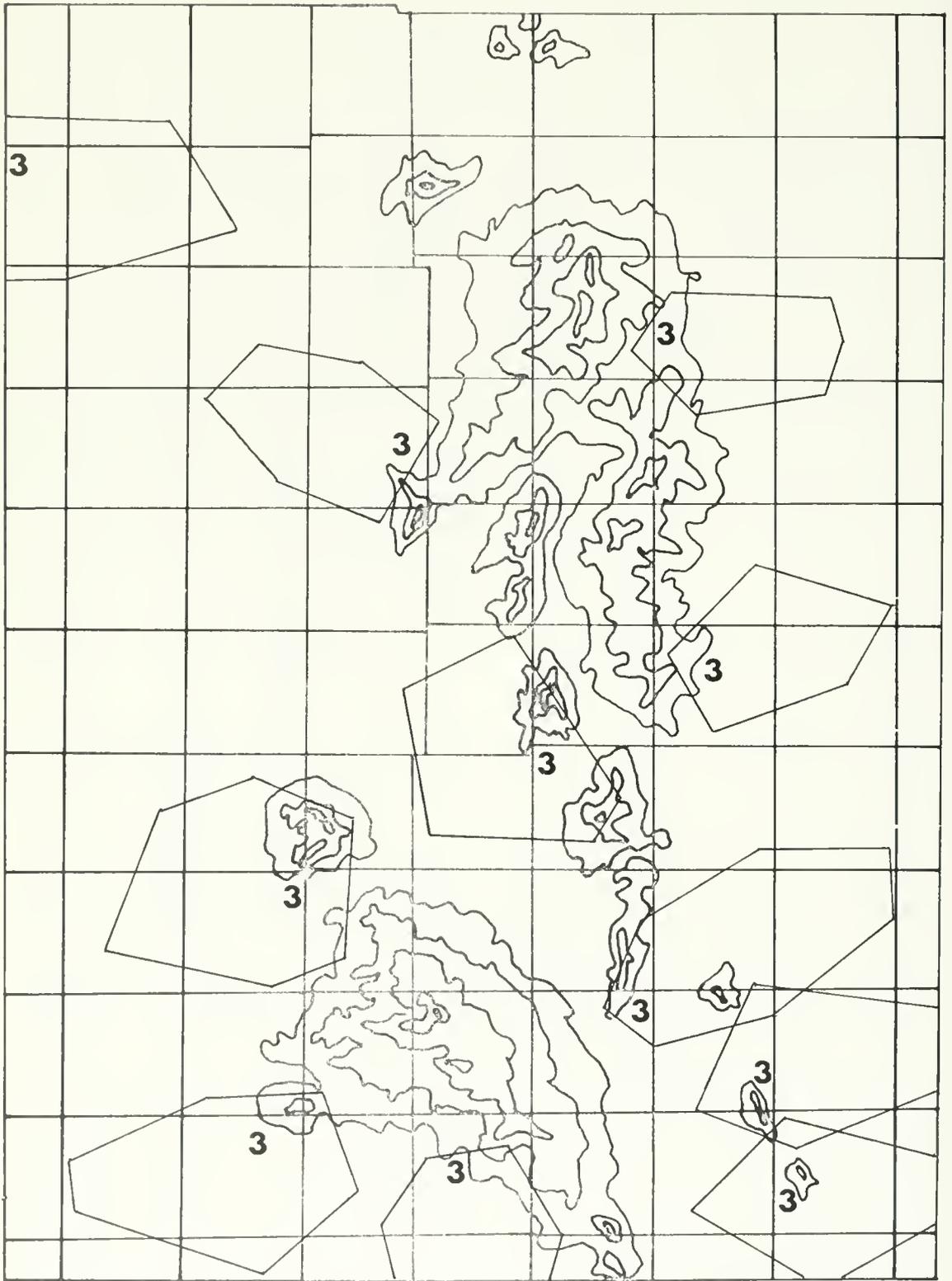


Fig. 20 Home ranges of Ferruginous Hawks (3) in 1970.

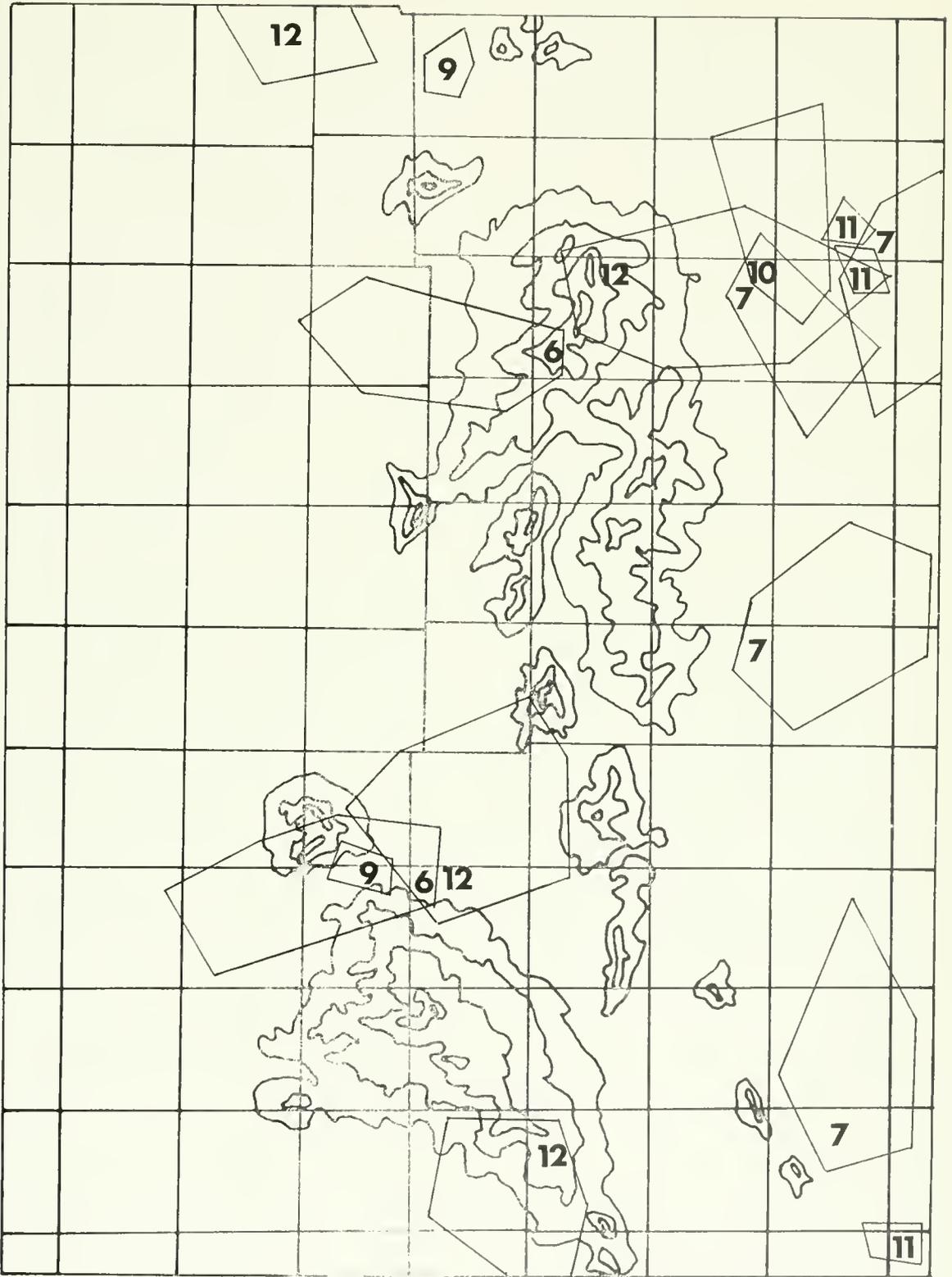


Fig. 21. Home ranges of Prairie Falcons (6), Marsh Hawks (7), Sparrow Hawks (9), Short-eared Owls (10), Burrowing Owls (11) and Ravens (12) in 1970.

portion of their home range, in contrast to many of the smaller raptor species on the study area. In 1969 an individual Golden Eagle occupying a home range in the southeast portion of the study area maintained a home range of 2.48 sq miles with a maximum diameter of 2.33 miles, although it was far removed from the home ranges of the nesting Golden Eagle pairs.

Home ranges of Great Horned Owl pairs averaged  $1.88 \pm 0.1$  sq miles in 1969 and  $2.16 \pm 0.2$  sq miles in 1970 (7 pairs in 1969 and 1970 each, range 1.62 – 2.22 sq miles and 1.36 – 2.7 sq miles, respectively). Maximum diameters of home ranges in 1969 averaged  $1.87 \pm 0.1$  miles (range 1.3 – 2.53 miles) and  $2.1 \pm 0.3$  miles in 1970 (range 1.89 – 2.8 miles). Great Horned Owls ranged widely into the deserts from their nesting sites in the foothills and maintained large home ranges. Their home ranges appeared to be restricted by the topography of the nesting locale, and pairs from two nests only 0.46 miles apart but on opposite sides of the Thorpe Hills showed no home range overlap although both nesting sites were active during all four breeding seasons. Instead, the pairs hunted in opposite valleys and were never observed near the tops of the intervening ridges. In other areas, however, slight overlaps in adjacent home ranges were observed between three pairs in 1969 and two pairs in 1970. In 1970 two nonnesting Great Horned Owl pairs maintained home ranges of  $1.64 \pm 0.2$  sq miles, significantly smaller than the average home ranges of the five nesting pairs ( $t = 3.2$ ). The observed home range of an individual on the study area in 1969 was about 1.04 sq miles with the maximum diameter of 1.72 miles, relatively smaller than the home ranges maintained by either nesting pairs or nonnesting pairs.

The home ranges of Ferruginous Hawk pairs averaged  $2.04 \pm 0.2$  sq miles in 1969 (9 pairs, range 1.36 – 3.02 sq miles) and  $2.52 \pm 0.2$  sq miles in 1970 (5 pairs, range 1.76 – 3.10 sq miles). Maximum diameters averaged  $2.086 \pm 0.1$  miles (range 1.51 – 2.61 miles) in 1969 and  $2.02 \pm 0.1$  miles in 1970 (range 1.75 – 2.6 miles). As with Great Horned Owls their shapes and boundaries were in large part determined by topography, and all observed home ranges extended widely into the valleys but only short distances into the hills in which the nesting site was located. Five adjacent home ranges overlapped in 1969 and three in 1970, although in no case was the degree of overlap extensive. In 1970 a nonnesting pair possessed

a home range of 1.76 sq miles, the smallest home range of any Ferruginous Hawk pair of that year and significantly smaller than the average home ranges of the 1970 nesting pairs ( $t = 3.03$ , at the 0.001 level of probability). Home ranges of individuals on the study area in 1969 and 1970 averaged  $1.51 \pm 0.07$  sq miles (3 individuals, range 1.36 – 1.66 sq miles) and were significantly smaller ( $t = 3.7$ ) than the home ranges of 1969 and 1970 pairs.

In 1969 the home ranges of four Red-tailed Hawk pairs averaged  $2.19 \pm 0.2$  sq miles (range 1.48 – 2.78) and had average maximum diameters of  $2.21 \pm 0.13$  miles (range 1.79 – 2.48 miles). In 1970 the home ranges of four Red-tailed Hawk pairs averaged  $2.805 \pm 0.3$  sq miles (range 2.16 – 3.74 sq miles) and had average maximum diameters of  $2.25 \pm 0.09$  miles (range 2.07 – 2.52 miles). Home ranges of Red-tailed Hawks were larger than the home ranges of other *Buteo* and Great Horned Owl pairs but smaller than Golden Eagle home ranges. In 1969 home range overlaps occurred between four adjacent Red-tailed Hawk pairs and in 1970 between two adjacent pairs. As with other large raptors, the home ranges of Red-tailed Hawks ranged widely into the deserts but very little into the hills. The average home ranges of two nonnesting pairs in 1970 were  $2.59 \pm 0.3$  sq miles, significantly less than the average home ranges of nesting pairs ( $t = 3.95$ ). The home range of an individual present on the study area in 1969 was 0.92 sq miles, also significantly smaller ( $t = 5.4$ ) than the average home ranges of the 1969 Red-tailed Hawk pairs.

Swainson's Hawk pairs possessed the smallest home ranges of any of the large raptors on the study area and averaged  $1.83 \pm 0.23$  sq miles in 1969 (2 pairs, range 1.6 – 2.06 sq miles) and 1.18 sq miles in 1970 (1 pair). The average maximum diameter of the 1969 home ranges was 2.09 miles  $\pm$  0.1 miles (range 1.94 – 2.23 miles) and that of the 1970 home ranges 1.51 miles. As Swainson's Hawks were few and widely spaced, no overlap of home ranges occurred. Individuals (one each year) were present in both 1969 and 1970 and maintained average home ranges of but  $0.87 \pm 0.03$  sq miles, significantly smaller ( $t = 3.51$ ) than the average home ranges of the pairs.

The home ranges of two Prairie Falcon pairs in 1970 averaged  $2.35 \pm 0.12$  sq miles (range 2.18 – 2.52 sq miles) with average maximum diameters of  $2.09 \pm 0.05$  miles (range 2.01 – 2.17 miles). Prairie Falcons maintained the largest home range of any of the medium-

and small-sized raptors but they were also larger than the average home ranges of the Swainson's Hawks nesting in 1970. Craighead and Craighead (1956) found similar large Prairie Falcon home ranges near Moose, Wyoming. Possible reasons for the maintenance of such large territories by a medium-sized raptor are presented by Schoener (1968). In 1969 an individual Prairie Falcon maintained a narrow home range of 1.64 sq miles with a maximum diameter of 2.59 miles.

The home ranges of two Marsh Hawk pairs in 1969 averaged  $1.62 \pm 0.3$  sq miles (range 1.58 — 1.66 sq miles) and had average maximum diameters of  $1.83 \pm 0.09$  miles (range 1.7 — 1.95 miles). In 1970 the home ranges of three pairs averaged  $1.74 \pm 0.15$  sq miles (range 1.38 — 2.02 sq miles) and had maximum home range diameters averaging  $1.97 \pm 0.13$  miles (range 1.58 — 2.62 miles). Marsh Hawk home ranges were entirely within the Cedar Valley area east of the Thorpe and Topliff Hills.

Sparrow Hawk home ranges averaged  $0.31 \pm 0.08$  sq miles in 1969 (4 pairs, range 0.18 — 0.56 sq miles) and 0.26 sq miles in 1970. Maximum diameters of the ranges averaged  $0.743 \pm 0.003$  miles (range 0.63 — 0.81 miles) in 1969 and 0.62 miles in 1970. None of the widely spaced Sparrow Hawk nests overlapped. In 1970 an individual maintained a home range of 0.16 sq miles with a maximum diameter of 0.58 miles.

In 1969 the average home ranges of three Burrowing Owl pairs was  $0.36 \pm 0.11$  sq miles (range 0.16 — 0.62 sq miles). In 1970 the average home range of three Burrowing Owl pairs was  $0.28 \pm 0.04$  sq miles (range 0.20 — 0.36 sq miles). The average maximum diameters of the 1969 home ranges was  $0.71 \pm 0.09$  miles (range 0.53 — 0.91 miles) and of the 1970 home ranges was  $0.593 \pm 0.05$  miles (range 0.51—0.72 miles). All Burrowing Owl home ranges were located east of the Thorpe and Topliff Hills and confined to the valley floor, primarily within the greasewood communities. The home ranges of the three adjacent pairs of 1969 and two adjacent pairs of 1970 overlapped considerably.

The only Short-eared Owl pair on the study area occupied in 1970 a home range of 1.48 sq miles, with a maximum diameter of 1.76 miles. In 1969 an individual Short-eared Owl had occupied the same territory but had maintained a home range of only 0.66 sq miles with a maximum diameter of 1.21 miles. In both cases the home range extended over the valley floor and did not enter the foothills or hills.

In 1969 two Raven pairs possessed home ranges averaging  $2.31 \pm 0.32$  sq miles (range 1.86 — 2.76 sq miles) with average maximum diameters of  $2.22 \pm 0.15$  miles (range 2.07 — 2.53 miles). In 1970 two Raven pairs maintained home ranges of  $2.74 \pm 0.17$  sq miles (range 2.5 — 2.98 sq miles) with average maximum diameters of  $2.12 \pm 0.26$  miles (range 1.76 — 2.48 miles). Raven pairs maintained larger home ranges than all of the other raptor species except Red-tailed Hawks and Golden Eagles. They also appeared to be little influenced by topography and possessed widely ranging territories.

*Intraspecific and Interspecific Associations.* Nesting and home range associations between raptor species are examined as follows through (1) an analysis of observed hostile interactions between species, (2) the degree of overlap of intra- and interspecific home ranges, and (3) measurements of distances to nearest neighbors of all raptor species.

A catalog of observed hostile interactions is presented in Table 19. All forms of interactions, including stooping, pursuits, fights, and displays are combined. Most of the observed interactions concerned territorial disputes or nest defense or displacement activities caused by the presence of the investigator; this has been previously discussed in other sections of this paper. The two most aggressive species appear to be the Ferruginous and Red-tailed Hawk, and one is tempted to suggest that their aggressiveness directly results in their high nesting populations and positions of dominance. Undoubtedly their high populations and competition for similar nesting sites produce some conflicts both within the species populations and between these and other raptor species with similar habitat requirements, such as Swainson's Hawks. The similar habitat requirements of Red-tailed Hawks and Great Horned Owls almost certainly produces the same degrees of hostile interactions. Unfortunately, many of the observed interactions were prompted by disturbance caused by the investigators. This is particularly true of the previously discussed attacks on Great Horned Owls by Red-tailed Hawks, Ferruginous Hawks, and Prairie Falcons, and it is probable that this nocturnal species has little or no contact with these hawks in its normal activity patterns, although both Cameron (1914) and Weigand (1967) observed Ferruginous Hawks attacking Great Horned Owls.

Few interactions of any kind were observed between any of the medium- and small-sized raptors. Their small populations and wide dis-

Table 19. Catalog of interspecific and intraspecific interactions observed on the study area from 1967-1970.

Species Attacking	Golden Eagle	Great Horned Owl	Ferruginous Hawk	Red-tailed Hawk	Swainson's Hawk	Prairie Falcon	Marsh Hawk	Cooper's Hawk	Sparrow Hawk	Short-eared Owl	Burrowing Owl	Raven
Golden Eagle	0	0	1	3	0	1	0	0	0	0	0	0
Great Horned Owl	0	0	4	12	0	4	0	0	0	0	0	2
Ferruginous Hawk	0	0	5	6	4	0	0	0	0	0	0	0
Red-tailed Hawk	0	0	6	2	0	0	0	0	2	0	0	0
Swainson's Hawk	2	0	12	0	0	0	0	0	0	0	0	0
Prairie Falcon	0	0	0	0	0	0	0	0	0	0	0	0
Marsh Hawk	0	0	0	0	0	1	0	0	0	0	0	0
Cooper's Hawk	0	0	0	0	0	0	0	0	0	0	0	0
Sparrow Hawk	2	0	0	0	0	0	0	0	0	0	0	0
Short-eared Owl	1	0	0	0	0	0	0	0	0	0	0	0
Burrowing Owl	0	0	0	0	0	0	0	0	0	0	0	0
Raven	3	0	0	3	0	1	0	0	1	0	0	2
Totals	8	0	28	26	4	7	0	0	3	0	0	4

persal account for at least part of this lack (particularly intraspecific contacts), but their differing habitat requirements also prevent much interspecific contact with the large raptor species. However, this is not true of the Prairie Falcon, which ranks third in aggressiveness on the basis of observed aggression contacts. In this case, however, Prairie Falcons are a raptor with habitat requirements similar to those of the larger species.

Information on intraspecific and interspecific overlap of home ranges is useful in estimating the degree of association of the various raptor species and is determined from the pooled data of the home range determinations of 1969 and 1970. The large Golden Eagle home ranges overlapped to some extent with every nesting raptor species. Golden Eagle home ranges overlapped with almost one-half of the nesting Great Horned Owl pairs in amounts ranging from 6-100 percent overlap; with 45 percent of the Ferruginous Hawk home ranges in amounts varying from 6-100 percent; with one-third of the Red-tailed Hawk home ranges in amounts varying from 5-90 percent; with 25 percent of the Swainson's Hawks in amounts varying from 18-65 percent and with most of the small- and medium-sized raptors in amounts varying from slight (as with the Burrowing Owls) to considerable. Great Horned Owl home ranges showed very similar overlaps with the majority of the raptors but did not overlap with home ranges of the Short-eared Owl and Burrowing Owl, supporting Errington's supposition (1938) that they will tolerate no other owls within their home range.

Overlap between adjacent Great Horned Owl

pairs was present in 32 percent of the population but in very slight (2-5 percent) amounts. Ferruginous Hawk home ranges also overlapped with the majority of the raptor species in amounts varying from approximately 2-100 percent. In 1969 and again in 1970, three close nesting Ferruginous Hawk pairs in the extreme southeast portion of the study area overlapped approximately 5-10 percent of their adjacent boundaries, but in very slight amounts. The majority of the medium- and small-sized raptors had home ranges overlapped by the large raptors as discussed previously. No intraspecific overlap between adjacent ranges of Sparrow Hawks, Marsh Hawks or Ravens occurred, but most were widely spaced. Marsh Hawk home ranges did overlap with Short-eared Owl home ranges (approximately 24 percent), Burrowing Owl home ranges (6-85 percent), and Raven home ranges (35 percent), but did not overlap with Sparrow Hawk or Prairie Falcon home ranges. With one exception all Burrowing Owl home ranges overlapped, both with adjacent pairs and extensively within all members of the small colony.

The distances to nearest neighbors should indicate to some extent the degree of tolerance displayed between adjacent pairs of the same species and that existing between different raptor species. In the following, results from all four study years are pooled. Golden Eagle nests were spaced an average of  $2.18 \pm 0.23$  miles apart (14 nests, range 1.28 - 3.6 miles). The nearest nests were separated by the high ridges of the intervening Thorpe Hills and the pairs tended to hunt in opposite valleys. Distances between Golden Eagle and Great Horned

Owl nests averaged only  $0.695 \pm 0.18$  miles (range 0.05 — 1.52 miles), but distances between Golden Eagles and the large *Buteo* hawks on the study area averaged  $1.54 \pm 0.22$  miles to Ferruginous Hawk nests (range 0.55 — 2.51 miles);  $1.52 \pm 0.13$  miles to Red-tailed Hawk nest sites (range 0.83 — 2.65 miles); and  $2.32 \pm 0.994$  miles (range 0.73 — 3.91 miles) to Swainson's Hawk nesting sites. Despite their very similar nesting requirements, distances between Golden Eagle and Raven nests averaged  $1.37 \pm 0.21$  miles (range 0.06 — 3.0 miles). Distances between adjacent Great Horned Owl pairs averaged  $1.19 \pm 0.21$  miles (range 0.64 — 3.5 miles). The maximum distances were observed between nests across areas which lacked suitable nesting cliffs and had very little cover. Great Horned Owl nests were often in relatively close proximity to nests of most of the diurnal Buteos, averaging  $0.766 \pm 0.16$  miles to Ferruginous Hawk nest sites (range 0.21 — 1.7 miles);  $0.886 \pm 0.17$  miles to Red-tailed Hawk nests (range 0.004 — 1.48 miles); and  $0.677 \pm 0.09$  miles to Raven nests. As with the Golden Eagle nests, Great Horned Owls nested far from Swainson's Hawk nesting sites, averaging  $2.2 \pm 0.16$  miles distant (range 1.85 — 2.69 miles).

Distances between adjacent Ferruginous Hawk nests averaged  $1.55 \pm 0.1$  miles (range 0.81 — 3.39 miles). Ferruginous Hawks averaged  $0.826 \pm 0.13$  miles (range 0.39—2.06 miles) from Red-tailed Hawk nest sites and  $0.788 \pm 0.13$  miles (range 0.29—1.06 miles) from Swainson's Hawk nests. In contrast, distances to nests of the Raven averaged  $1.3 \pm 0.22$  miles (range 0.46 — 2.44 miles). Distances between adjacent Red-tailed Hawk nests averaged  $2.05 \pm 0.18$  miles (range 1.27 — 4.2 miles) and were the most widely spaced of the large raptors except for those of the Swainson's Hawk and Raven nesting sites, averaging  $1.17 \pm 0.07$  miles to the former (range 0.95 — 1.35 miles) and  $1.08 \pm 0.12$  miles to the latter (range 0.55 — 1.84 miles).

Measurements of distances between the medium- and small-sized raptors proved to be unrealistic because of their small populations and wide range of habitat requirements. The majority were very distant from any of the large raptor nesting sites, but exceptions were noted. Prairie Falcon pairs nested within 0.013 miles (within the same cliffline) of an active Great Horned Owl nest, and Ravens in 1968 nested but 0.28 miles from a Golden Eagle nest, with all nests successfully fledging at least one young.

Adjacent Marsh Hawk nests averaged  $2.39 \pm 0.57$  miles apart (range 1.12 — 3.65 miles). Most of the Marsh Hawk, Burrowing Owl, and Short-eared Owl nesting sites were in close proximity (i.e., less than one-half mile apart); this is undoubtedly a result of their similar habitat requirements. Nests of the Burrowing Owl colony averaged but  $0.042 \pm 0.01$  miles apart (range 0.015 — 0.08 miles) and were the most closely spaced of any intraspecific nests on the study area.

In summary, intraspecific nests maintained minimum average distances apart, with the noted exception of the Burrowing Owl; but interspecific nesting site distances varied greatly, primarily because of apparent tolerance differences among species and the influence of activity patterns which will be discussed later, all of which combined to reveal the habitat as a mosaic of distinct home ranges centering around the nesting sites.

#### Hunting Activity Patterns and Habitat

The hunting activity periods of the raptors are presented in Fig. 22 and 23. These were derived from observations of birds from blinds and from notes on the specific activity of raptors when sighted. The area contained within the lines represents the relative degree of activity, and the thin lines which may or may not be present represent additional but limited activity. Although it is a well-known fact that raptors will hunt at any time if hungry or when in need of prey for their young, they do exhibit definite hunting periods. The activity patterns of all of the diurnal raptors fall into a pattern of separate morning and afternoon or early evening hunting periods, and all showed a lull or midafternoon period of inactivity. Among the large raptors, Ferruginous Hawks were the first to initiate hunting activities in the day, and their most intensive hunting periods occurred from first light, 0545 hrs to sunrise (approximately 0600 hrs) and between 1745 hrs and 2045 hrs in the late afternoon and evening until shortly after sunset. Ferruginous Hawks typically hunted over mixed sagebrush-grassland areas but were also observed hunting in the sagebrush-*Tetradymia* areas near the nests. Both Red-tailed Hawks and Golden Eagles initiated their hunting activities in the mid-morning at approximately 0830 hrs and both species terminated their morning hunt near 1200 hrs. Golden Eagles ranged over a wide area and have been observed hunting in a variety of habitats, but Red-tailed Hawks most frequently hunted in sagebrush stands. Although

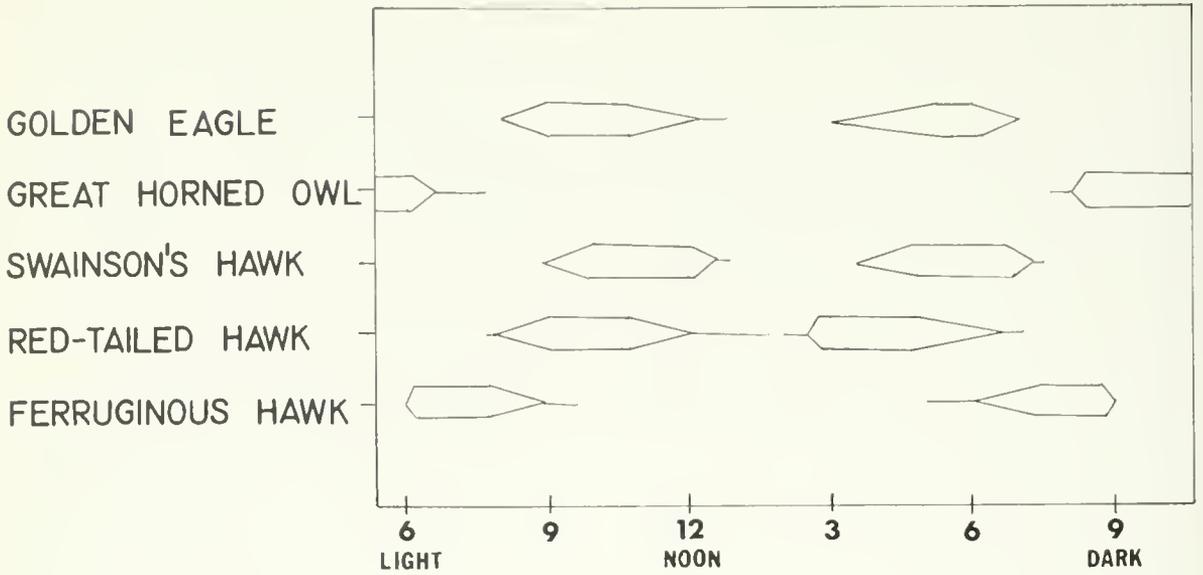


Fig. 22. Hunting activity patterns of the large raptors on the study area.

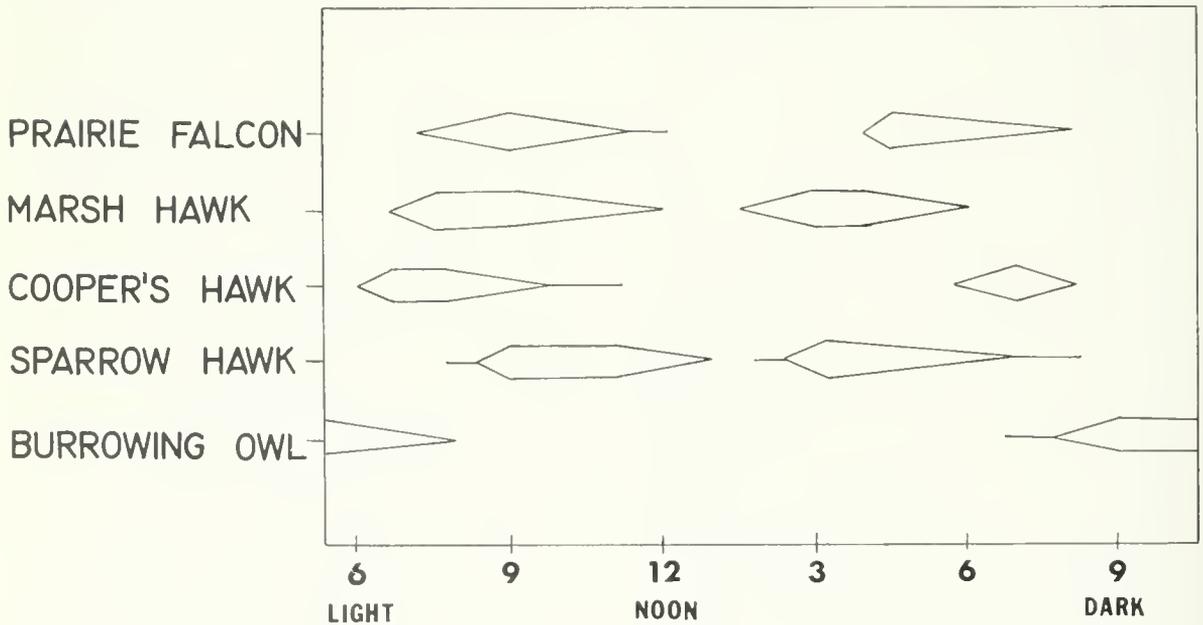


Fig. 23. Hunting activity patterns of medium- and small-sized raptors.

Red-tailed Hawks also ranged widely, one pair hunted over a small sagebrush stand less than 0.03 miles from their nesting site. Both species had similar intensive hunting periods, from approximately 1445 to 1830 hrs, but Red-tailed Hawks tended to hunt throughout a greater portion of the day than any other large raptor species. The morning hunting periods of the Swainson's Hawk began well after that of the Ferruginous Hawk had terminated, and their afternoon hunting periods were completed before Ferruginous Hawks began to hunt.

Swainson's Hawks also tended to hunt in the immediate nesting vicinity in habitats similar to those in which Ferruginous Hawks predominantly hunted.

All of the small raptors nesting on the study area initiated their hunting periods very early in the morning and generally before sunrise. Marsh Hawks were particularly active at this time but continued until well into the morning hours. Sparrow Hawks were the last of the small raptors to begin hunting, initiating their morning hunt at approximately 0745 hrs. Spar-

row Hawks probably hunted during more hours of the day than any other raptors on the study area, although still exhibiting peak late morning (1045-1200 hrs) and late afternoon periods. They hunted over a wide variety of habitats including pinyon-juniper, winterfat, and mixed grassland areas. Prairie Falcons exhibited similar hunting habitat preferences. On the other hand, both Marsh Hawks and Ravens apparently preferred to hunt over sagebrush or mixed grassland-rabbitbrush stands.

All of the nocturnal raptors on the study area showed some tendency to hunt during daylight hours. Great Horned Owls and Short-eared Owls began hunting periods in the late evening hours after sunset but before darkness. Both showed essentially two periods of intensive hunting, one beginning at approximately 2030-2045 hrs and continuing until 2400 hrs, and the other beginning in the early morning hours from 0430 to shortly after first light. On two occasions Great Horned Owls were observed in the late afternoon from approximately 1645 hrs until darkness. In both instances the day was overcast and snowy. Similar observations of diurnal hunting by Great Horned Owls have been noted by Fitch (1940) and Vaughn (1954). Burrowing Owls are very alert and ac-

tive during the daylight hours, and their peak activity periods are from approximately 0430 to 0645 hrs and from 1740 to 2330 hrs. They were also observed hunting, although infrequently, as late as 0850 hrs in the morning, and may occasionally hunt at any time of the day.

### Predation

The prey of 9 species of raptors was examined in 1969, and of 11 in 1970. A total of 2111 prey individuals of 55 prey species were identified and tabulated (Tables 20-39). The prey of the collective raptor population included 75.2 percent mammals (1588 prey individuals of 17 mammal species), 8.5 percent reptiles (27 individuals of 7 species) and 15 percent invertebrates (316 individuals of 8 families). Minor but not significant variations in prey species and frequency occurred between the two years.

Golden Eagles utilized a total of only ten prey species, including five mammal and five avian species. Mammals were much more frequently preyed upon (96.5 percent of the total prey) and comprised the bulk of the prey biomass (99.4 percent), whereas birds comprised 0.6 percent of the prey biomass and averaged only 3.3 percent of the individuals taken. Lago-

Table 20. Food habits of Golden Eagles in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Lepus californicus</i>	155	74.5	356,500	88.6
<i>Sylvilagus sp.</i>	43	20.8	43,000	10.7
<i>Ammospermophilus leucurus</i>	3	1.4	435	0.1
<i>Perognathus formosus</i>	1	0.5	19	Tr.°
<i>Zenaidura macroura</i>	1	0.5	153	Tr.
<i>Chondestes grammacus</i>	1	0.5	30	Tr.
<i>Buteo swainsoni</i>	2	1.0	988	0.5
<i>Asio flammeus</i>	1	0.5	340	Tr.
Totals	207	99.7	401,465	99.9

\*Present in trace amounts only

Table 21. Food habits of Golden Eagles in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Lepus californicus</i>	68	57.1	156,400	80.5
<i>Sylvilagus sp.</i>	35	29.4	35,000	18.0
<i>Ammospermophilus leucurus</i>	9	7.6	1,305	0.7
<i>Mustela frenata</i>	2	1.7	356	0.2
<i>Zenaidura macroura</i>	1	0.8	153	0.1
<i>Otocoris alpestris</i>	3	2.5	56	Tr.°
<i>Buteo swainsoni</i>	1	0.8	988	0.5
Totals	119	99.9	194,258	100.0

\*Present in trace amounts only

Table 22. Food habits of Great Horned Owls in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Lepus californicus</i>	165	58.9	379,500	91.4
<i>Sylvilagus auduboni</i>	32	11.4	32,000	7.7
<i>Neotoma lepida</i>	6	2.1	1,302	0.3
<i>Perognathus parvus</i>	2	0.7	30	Tr.*
<i>Dipodomys microps</i>	8	2.9	520	0.1
<i>Dipodomys ordii</i>	11	3.9	748	0.2
<i>Microtus sp.</i>	5	1.8	190	Tr.
<i>Peromyscus maniculatus</i>	7	2.5	119	Tr.
<i>Cyanocephalus cyanocephalus</i>	3	1.1	50	Tr.
<i>Zenaidura macroura</i>	5	1.8	765	0.2
<i>Phalaenoptilus nuttallii</i>	1	0.4	62	Tr.
Scorpionida	35	12.5	30	Tr.
Totals	280	100.0	415,316	100.0

\*Present in trace amounts only

Table 23. Food habits of Great Horned Owls in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Lepus californicus</i>	83	49.1	190,900	89.6
<i>Sylvilagus sp.</i>	19	11.2	19,900	8.9
<i>Neotoma lepida</i>	1	0.6	217	0.1
<i>Dipodomys ordii</i>	24	14.2	1,632	0.8
<i>Dipodomys microps</i>	3	1.8	195	0.1
<i>Peromyscus maniculatus</i>	12	7.1	204	0.1
<i>Microdipodops megacephalus</i>	2	1.2	48	Tr.
<i>Onychomys leucogaster</i>	3	1.8	114	Tr.
<i>Zenaidura macroura</i>	4	2.4	612	0.3
<i>Otocoris alpestris</i>	1	0.6	28	Tr.
<i>Pica pica</i>	1	0.6	173	Tr.
Scorpionida	16	9.5	14	Tr.
Totals	169	100.1	214,037	99.9

\*Present in trace amounts only

morphs were the predominate food item of Golden Eagles on the study area and constituted over 95 percent of the prey in 1969 and 80 percent of the prey in 1970, contributing 98.9 percent of the prey biomass each year. The next most important food item was the Antelope Ground Squirrel, which averaged 4.5 percent of the food items and 0.4 percent of the volumetric diet for the two years. Four of the total of ten prey species taken by Golden Eagles during the two years were birds, but none contributed significantly to the diet. Two of the bird species were raptors (Short-eared Owl and Swainson's Hawk) and are examples of the Golden Eagle's ability to prey on other avian predators. Dixon (1937), Arnold (1954), Carnie (1954), McGahan (1968), and others have reported similar examples of Golden Eagle predation on other raptors.

Great Horned Owls on the study area utilized a total of 16 prey species, including 10 mammal, 5 bird, and 1 invertebrate species. Mammals constituted 85.6 percent of the prey individuals and 99.7 percent of the total prey biomass, while birds comprised 3.5 percent of the prey items but only 0.3 percent of the prey biomass. Invertebrates accounted for 11 percent of the prey individuals but contributed minor amounts of prey biomass. Lagomorphs were the most frequently taken prey item, averaging 65.3 percent of the total prey individuals recorded; they contributed 98.9 percent of the total prey biomass during 1969 and 1970. Two species of Kangaroo Rats were the next most frequently recorded prey, averaging over 11 percent of the total prey items but contributing only 0.6 percent of the total prey biomass. Although contributing only minor amounts to the

Table 24. Food habits of Ferruginous Hawks in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Lepus californicus</i>	105	57.7	241,500	95.0
<i>Sylvilagus sp.</i>	6	3.3	6,000	2.4
<i>Amospermophilus leucurus</i>	18	9.9	2,610	1.0
<i>Spermophilus townsendi</i>	2	1.1	382	0.2
<i>Perognathus parvus</i>	1	0.5	15	Tr.
<i>Dipodomys ordii</i>	25	13.7	1,700	0.6
<i>Dipodomys microps</i>	2	1.1	130	Tr.
<i>Onychomys leucogaster</i>	1	0.5	38	Tr.
<i>Peromyscus maniculatus</i>	4	2.2	68	Tr.
<i>Otocoris alpestris</i>	9	4.9	252	0.1
<i>Calamospiza melanocorys</i>	3	1.6	150	Tr.
<i>Zenaidura macroura</i>	1	0.5	153	Tr.
<i>Poocetes gramineus</i>	2	1.1	100	Tr.
<i>Pituophis melanoleucus</i>	2	1.1	744	0.3
<i>Cnemidophorus tigris</i>	1	0.5	24	Tr.
Totals	182	99.7	253,866	99.6

\*Present in trace amounts only

Table 25. Food habits of Ferruginous Hawks in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Lepus californicus</i>	97	56.4	223,100	93.0
<i>Sylvilagus sp.</i>	13	7.6	13,000	5.4
<i>Amospermophilus leucurus</i>	8	4.7	1,160	0.5
<i>Perognathus parvus</i>	3	1.7	45	Tr.
<i>Dipodomys ordii</i>	17	9.9	1,156	0.5
<i>Dipodomys microps</i>	6	3.5	390	0.2
<i>Peromyscus maniculatus</i>	9	5.2	153	Tr.
<i>Otocoris alpestris</i>	14	8.1	392	0.2
<i>Poocetes gramineus</i>	1	0.6	30	Tr.
<i>Oreoseptes montanus</i>	1	0.6	33	Tr.
<i>Pituophis melanoleucus</i>	3	1.7	372	0.2
Totals	172	100.0	239,831	100.0

\*Present in trace amounts only

Table 26. Food habits of Red-tailed Hawks in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Lepus californicus</i>	111	58.4	255,300	92.5
<i>Sylvilagus sp.</i>	17	8.9	17,000	6.2
<i>Spermophilus townsendi</i>	4	2.1	764	0.3
<i>Eutamias minimus</i>	2	1.0	146	Tr.
<i>Peromyscus maniculatus</i>	13	6.8	221	Tr.
<i>Microtus sp.</i>	22	11.6	836	0.3
<i>Otocoris alpestris</i>	6	3.2	168	Tr.
<i>Sialia currucoides</i>	1	0.5	45	Tr.
<i>Cyanocephalus cyanocephalus</i>	7	3.7	350	Tr.
<i>Sturnis vulgaris</i>	3	1.6	252	Tr.
<i>Pituophis melanoleucus</i>	1	0.5	372	0.1
<i>Masticophis taeniatus</i>	3	1.6	507	0.2
Totals	190	99.9	275,961	99.6

\*Present in trace amounts only

total biomass of Great Horned Owl prey, at least one species of scorpion was taken quite frequently during all four study years (see Murphy, et al., 1969). Although scorpions were not taken by all Great Horned Owl pairs, they showed up consistently and almost exclusively in the nest site pellets of a pair nesting in the west Thorpe Hills area, serving to indicate the possibilities of error when analyzing food habits of raptor pairs. Interestingly, the female of this pair had an irregular left eye and it is tempting to speculate that there was a possible connection. Errington, Hamerstrom, and Hamerstrom (1940) suggested that predation on arthropods is most characteristic of recently fledged owls, but as previously noted, the scorpions were found every year that this female was present. One Black-billed Magpie

was taken by a pair of Great Horned Owls nesting in pinyon-juniper. Magpies were common around the towns and cultivated areas of the northeast portion of Cedar Valley and frequently nested in cottonwoods and elms in those areas. They did not nest within the study area, probably because of a combination of unsuitable habitat and possible predation.

Ferruginous Hawks within the study area utilized a total of 17 prey species, including 9 mammal, 6 avian, and 2 reptile species. Mammals comprised 89.5 percent of the prey individuals and 99.4 percent of the total prey biomass. In contrast, birds comprised only 8.7 percent of the total prey items and 0.2 percent of the total prey biomass, while reptiles included 1.7 percent of the total prey individuals and 0.3 percent of the total prey biomass. Lago-

Table 27. Food habits of Red-tailed Hawks in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Lepus californicus</i>	71	50.7	163,300	90.0
<i>Sylvilagus sp.</i>	15	10.7	15,000	8.2
<i>Spermophilus townsendi</i>	1	0.7	191	0.1
<i>Ammospermophilus leucurus</i>	9	6.4	1,304	0.7
<i>Peromyscus maniculatus</i>	26	18.6	442	0.2
<i>Microtus sp.</i>	1	0.7	38	Tr.
<i>Thomomys bottae</i>	2	1.6	340	0.2
<i>Otocoris alpestris</i>	3	2.1	84	Tr.
<i>Tyrannus verticalis</i>	1	0.7	36	Tr.
<i>Sturnis vulgaris</i>	9	6.4	756	0.4
<i>Pituophis melanoleucus</i>	1	0.7	372	0.2
<i>Crotaphytus collaris</i>	1	0.7	30	Tr.
Totals	140	100.0	181,893	100.0

<sup>o</sup>Present in trace amounts only

Table 28. Food habits of Swainson's Hawks in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Lepus californicus</i>	42	51.2	96,600	95.0
<i>Sylvilagus sp.</i>	4	4.9	4,000	3.9
<i>Peromyscus maniculatus</i>	7	8.5	119	0.1
<i>Microtus sp.</i>	3	3.7	114	0.1
<i>Spermophilus townsendi</i>	1	1.2	191	0.2
<i>Calamospiza melanocorys</i>	3	3.7	99	0.1
<i>Lanius ludovicianus</i>	1	1.2	52	0.1
<i>Oreoscoptes montanus</i>	1	1.2	45	Tr.
<i>Sayornis saya</i>	2	2.4	56	0.1
<i>Zonotrichia leucophrys</i>	1	1.2	30	Tr.
<i>Pituophis melanoleucus</i>	1	1.2	372	0.4
Locustidae	15	18.3	95	Tr.
Carabidae	1	1.2	0.23	Tr.
Totals	82	99.9	101,688	100.0

<sup>o</sup>Present in trace amounts only

Table 29. Food habits of Swainson's Hawks in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Lepus californicus</i>	15	19.0	34,500	78.2
<i>Sylvilagus auduboni</i>	9	11.4	9,000	20.4
<i>Peromyscus maniculatus</i>	2	2.5	34	0.1
<i>Microtus sp.</i>	1	1.3	38	0.1
<i>Otocoris alpestris</i>	11	13.9	308	0.7
Unident. Passerines	8	10.1	240	0.5
Locustidae	17	21.5	11	Tr.
Carabidae	5	6.3	1	Tr.
Tenebrionidae	2	2.5	1	Tr.
Gryllidae	9	11.4	4	Tr.
Totals	79	99.9	44,137	100.0

\*Present in trace amounts only

Table 30. Food habits of Prairie Falcons in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Ammospermophilus leucurus</i>	5	19.2	725.0	20.6
<i>Peromyscus maniculatus</i>	1	3.8	17.0	0.5
<i>Lepus californicus</i> (juv.)	2	7.7	2,300.0	65.2
<i>Otocoris alpestris</i>	7	26.9	196.0	5.6
<i>Oberholseria chlorura</i>	1	3.8	30.0	0.9
<i>Poocetes gramineus</i>	1	3.8	27.0	0.7
<i>Sturnis vulgaris</i>	3	11.5	84.0	2.4
<i>Sturnella neglecta</i>	1	3.8	145.0	4.1
Locustidae	5	19.2	3.2	Tr.
Totals	26	99.7	3,527.2	100.0

\*Present in trace amounts only

Table 31. Food habits of Marsh Hawks in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Lepus californicus</i> (juv.)	12	31.6	1,200.0	50.1
<i>Spermophilus townsendi</i>	5	13.2	755.0	31.5
<i>Peromyscus maniculatus</i>	7	18.4	119.0	5.0
<i>Reithrodontomys Megalotis</i>	2	5.3	24.0	1.0
<i>Otocoris alpestris</i>	4	10.5	112.0	4.7
<i>Zenaidura macroura</i>	1	2.6	153.0	6.4
<i>Poocetes gramineus</i>	1	2.6	30.0	1.0
Carabidae	6	15.8	1.4	1.3
Totals	38	100.0	2,394.4	101.0

\*Present in trace amounts only

morphs again were the most frequent prey item, averaging 62.5 percent of the total prey and contributing 97.4 percent of the prey biomass in each of the two years. The next most frequently taken prey items were, in order of their average yearly frequency: Ord's kangaroo rat, constituting 11.8 percent of the total prey but only 0.5 percent of the prey biomass; the antelope ground squirrel, which averaged 7.3

percent of the total prey individuals and 0.25 percent of the prey biomass; and the Horned Lark, which averaged 6.5 percent of the total prey and 0.15 percent of the prey biomass. The two kangaroo rat species and pocket mouse reflect essentially crepuscular hunting activity patterns of the Ferruginous Hawk as discussed earlier. Ferruginous Hawks also infrequently preyed on gopher snakes.

Mammals were also the major prey of Red-tailed Hawks, comprising 89.1 percent of the prey individuals and 99.4 percent of the total prey biomass, while birds constituted 9.1 percent and 0.2 percent, and reptiles accounted for 1.8 percent and 0.3 percent of the total prey items and total prey biomass, respectively. The major items of importance were again the lagomorphs, which accounted for 64.4 percent of the prey items and 98.5 percent of the total prey biomass. In addition, Red-tailed Hawks preyed

on 6 other mammal species, 5 avian, and 3 reptile species. Other mammal species of importance included the deer mouse, which comprised 12.7 percent of its total diet; meadow mice, comprising 6.2 percent; and the antelope ground squirrel, which constituted 3.2 percent. Starlings and Pinyon Jays were the most frequently taken avian prey species. Starlings were first recorded in Utah in 1949 in and around urban areas (Behle, 1954). Since that time they have spread widely throughout the state and

Table 32. Food habits of Marsh Hawks in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Lepus californicus</i>	5	13.5	5,000.0	86.9
<i>Peromyscus maniculatus</i>	15	40.5	255.0	4.4
<i>Spermophilus townsendi</i>	1	2.7	191.0	3.3
<i>Otocoris alpestris</i>	7	18.9	196.0	3.4
<i>Poocetes gramineus</i>	3	8.1	81.0	1.4
Demestidae	5	13.5	1.2	Tr.
<i>Crotaphytus collaris</i>	1	2.7	30.0	0.5
Totals	37	99.9	5,754.2	99.9

<sup>o</sup>Present in trace amounts only

Table 33. Food habits of Sparrow Hawks in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Microtus sp.</i>	5	6.5	190.0	17.6
<i>Peromyscus maniculatus</i>	18	23.4	306.0	28.3
<i>Otocoris alpestris</i>	6	7.8	168.0	15.6
<i>Sialia currucoides</i>	2	2.6	90.0	8.3
<i>Passer domesticus</i>	2	2.6	50.0	4.6
<i>Sturnis vulgaris</i>	3	3.9	252.0	23.3
<i>Uta stansburiana</i>	1	1.3	4.0	0.4
Araneae	2	2.6	0.8	Tr.
Locustidae	29	37.6	18.3	1.7
Curculionidae	7	9.1	0.7	Tr.
Uniden. Coleoptera	2	2.6	0.6	Tr.
Totals	77	100.0	1,080.4	99.8

<sup>o</sup>Present in trace amounts only

Table 34. Food habits of Sparrow Hawks in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Peromyscus maniculatus</i>	7	21.2	119.0	30.4
<i>Passer domesticus</i>	3	9.1	75.0	19.2
<i>Sturnis vulgaris</i>	2	6.1	168.0	42.9
<i>Uta stansburiana</i>	3	9.1	12.0	3.1
<i>Phrynosoma platyrhinos</i>	1	3.0	9.0	2.3
Locustidae	13	39.4	8.2	2.1
Curculionidae	4	12.1	0.4	Tr.
Totals	33	100.0	391.6	100.0

<sup>o</sup>Present in trace amounts only

Table 35. Food habits of Short-eared Owls in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Dipodomys ordii</i>	7	20.0	476	37.4
<i>Reithrodontomys megalotis</i>	2	5.7	24	1.9
<i>Peromyscus maniculatus</i>	19	54.3	323	25.9
<i>Perognathus parvus</i>	3	8.6	45	3.5
Unidentified passerine	1	2.9	30	2.4
<i>Sturnis vulgaris</i>	1	2.9	84	6.6
<i>Sturnella neglecta</i>	2	5.7	290	22.6
Totals	35	100.1	1,272	100.3

Table 36. Food habits of Burrowing Owls in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Dipodomys ordii</i>	11	12.4	748.0	73.1
<i>Perognathus formosus</i>	1	1.1	19.0	1.9
<i>Microtus sp.</i>	2	2.2	76.0	7.4
<i>Phalaenoptilus nuttali</i>	1	1.1	62.0	6.0
<i>Otocoris alpestris</i>	3	3.3	84.0	8.2
<i>Uta stansburiana</i>	1	1.1	4.0	0.3
Locustidae	29	32.6	18.3	1.9
Scarabidae	19	21.3	5.7	0.6
Silphidae	11	12.4	3.3	0.3
Carabidae	7	7.9	1.6	0.2
Tenebrionidae	2	2.2	1.1	0.1
Aranae	2	2.2	0.8	Tr.
Totals	89	99.8	1,023.8	100.0

<sup>o</sup>Present in trace amounts only

Table 37. Food habits of Burrowing Owls in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Dipodomys ordii</i>	4	5.5	272.0	61.9
<i>Peromyscus maniculatus</i>	2	2.7	34.0	7.7
<i>Reithrodontomys megalotis</i>	1	1.4	12.0	2.7
<i>Otocoris alpestris</i>	2	2.7	56.0	12.7
<i>Passer domesticus</i>	1	1.4	25.0	5.7
<i>Uta stansburiana</i>	3	4.2	12.0	2.7
Locustidae	34	46.6	21.4	4.9
Silphidae	13	17.8	3.9	0.9
Carabidae	8	11.0	1.8	0.4
Scarabidae	5	6.8	1.5	0.3
Totals	73	100.1	439.6	99.9

are perhaps the most common nesting species on the study area in such areas as quarries and abandoned mining structures, where they are occasionally preyed on by raptors. Red-tailed Hawks also infrequently preyed on snakes, the two species recorded from this study being the gopher snake and striped racer.

Swainson's Hawks on the study area utilized a total of 15 prey species including 5 mammal,

5 avian, 1 reptile, and 4 invertebrate species. The relative composition of the Swainson's Hawk diet is as follows: mammals, 51.9 percent of the total prey individuals and 99.1 percent of the total prey biomass; birds, 16.9 and 0.8 percent; reptiles, 0.6 and 0.2 percent; invertebrates, 30.6 and less than 0.1 percent. Swainson's Hawks were the only large raptors studied in which the average frequency of lagomorph prey was less

than half of the total diet. Lagomorphs thus constituted 56.1 percent of the diet in 1969 but only 30.4 percent in 1970. However, in both years the lagomorphs, by virtue of their large body size, comprised almost 99 percent of the total prey biomass. The second most numerous prey items were Locustid insects which comprised an average 19.9 percent of the yearly diet, although contributing comparatively small amounts of the total biomass. Other insects taken included carabids, tenebrionids, and gryllids. Deer mice were taken infrequently, as were meadow mice. Horned Larks were the most frequently taken avian species and constituted almost 7 percent of the total prey taken.

Information on the food habits of the Prairie Falcon was obtained only during the 1970 breeding season. Prairie Falcon prey consisted of nine species, including three mammal, five avian and one insect species. Birds were the most frequently taken prey and comprised 49.8 percent of the prey individuals but only 4.1 percent of the total prey biomass. Mammals comprised 30.7 percent of the prey individuals

and contributed a prey biomass of 86.3 percent, while invertebrates accounted for 19.2 percent of the prey individuals but for little or no biomass. The two most frequently taken prey species were the Horned Lark (26.9 percent of the total prey individuals) and antelope ground squirrel (19.2 percent), but juvenile black-tailed jackrabbits comprised over 65 percent of the prey biomass, even though taken only one-sixth as often.

The food of Marsh Hawks included 10 prey species, of which there were 4 mammals, 3 birds, 1 reptile, and 2 invertebrate species. Marsh Hawks preyed most frequently on mammals (62.5 percent of the prey items) which also contributed the bulk of the prey biomass (91.9 percent). Of the other major prey groups, birds were taken 21.4 percent of the time and comprised 8.5 percent of the prey biomass, reptiles 14.7 and 0.7 percent and invertebrates 1.4 and 0.3 percent, respectively. The most important prey of the Marsh Hawks included black-tailed jackrabbits and the deer mouse. The majority of rabbits taken were immatures,

Table 38. Food habits of Ravens in 1969.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Lepus californicus</i> (juv)	19	31.1	19,000.0	95.6
<i>Peromyscus maniculatus</i>	12	19.7	204.0	1.0
<i>Microtus</i> sp.	3	4.9	114.0	0.6
<i>Neotoma lepida</i>	1	1.6	217.0	1.1
<i>Spizella passerina</i>	1	1.6	38.0	0.2
<i>Passer domesticus</i>	3	4.9	75.0	0.4
<i>Oreoscoptes montanus</i>	1	1.6	45.0	0.2
<i>Masticophis taeniatus</i>	1	1.6	169.0	0.9
Dermeestidae	9	14.8	0.9	Tr.
Silphidae	6	9.8	1.8	Tr.
Cureulionidae	2	3.3	0.2	Tr.
Unident. Coleoptera	3	4.9	0.9	Tr.
Totals	61	99.8	19,864.8	100.0

<sup>o</sup>Present in trace amounts only

Table 39. Food habits of Ravens in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass <sup>o</sup>
<i>Sylvilagus</i> sp.	6	16.7	6,000.0	90.7
<i>Peromyscus maniculatus</i>	13	36.1	221.0	3.3
<i>Otocoris alpestris</i>	4	11.1	112.0	1.7
<i>Sturnis vulgaris</i>	1	2.8	84.0	1.3
<i>Masticophis taeniatus</i>	1	2.8	169.0	2.6
<i>Sceloporus grasciosus</i>	2	5.6	26.0	0.4
Unident. Coleoptera	9	25.0	2.7	Tr.
Totals	36	100.1	6,614.7	100.0

<sup>o</sup>Present in trace amounts only

juveniles, or carrion but they comprised 22.6 percent of the total prey biomass. Deer mice were taken more frequently, yet, by contrast, Townsend's ground squirrels comprised only 8 percent of the prey items but 17.4 percent of the total prey biomass. Horned Larks and Mourning Doves were also taken occasionally.

Sparrow Hawks on the study area utilized a total of 12 species, which included 2 mammal, 4 birds, 2 reptiles, and 4 invertebrates. The relative composition of the prey frequency and biomass of the major prey groups of the Sparrow Hawk is as follows: mammals, 25.6 percent and 38.2 percent; birds, 16.1 and 57.0 percent; reptiles, 6.7 and 2.9 percent; and invertebrates, 51.7 and 1.9 percent. Locustids were the most important invertebrate prey species, averaging 35.5 percent of the yearly diet. The more important vertebrate prey species included the deer mouse, which comprised 22.3 percent of the total prey items and 29.5 percent of the total prey biomass, and Starlings, which contributed the bulk of the prey biomass (33.3 percent), although taken infrequently. Of the avian prey species, English Sparrows, Starlings, and Western Bluebirds reflect the habitat selection of Sparrow Hawks, being the most common nesting birds in and around the abandoned mines, quarries, and mining structures. The occurrence of Western Bluebirds as prey is interesting, because the disappearance of a bluebird and the subsequent failure of its nesting efforts coincided with the appearance of this species in the prey of a Sparrow Hawk pair. The bluebirds had selected a nesting site within the wooden walls of a mining cabin only 80 feet from the Sparrow Hawk nest and were incubating a clutch of five eggs when checked the day before the disappearance. Two days later the remains of a bluebird were found among the prey items in the Sparrow Hawk pair's nest. Powers (1966) cites possible examples of Sparrow Hawk predation on bluebirds in Montana, and Drinkwater (1953) recorded a case of Sparrow Hawks capturing young bluebirds by nest robbing.

Information on Short-eared Owl food habits was obtained only in 1970 and is derived from the analysis of 19 pellets gathered from the unsuccessful nest site. Pellet analysis yielded a total of 7 prey species and 35 individuals, but only mammals and birds were present. Mammals contributed 88.6 percent of the prey individuals and 68.2 percent of the prey biomass, while birds comprised 11.5 percent and 31.8 percent, respectively. The two most important prey species were Ord's kangaroo rat and the deer mouse. Deer mice were taken almost three

times as often as any other prey species and contributed 26.4 percent of the total prey biomass. Ord's kangaroo rat was the next most frequently taken prey and comprised 37.4 percent of the prey biomass. Western Meadowlarks contributed 22.8 percent of the total prey biomass.

Burrowing Owl prey included a total of 15 species of which there were 5 mammal, 3 avian, 1 reptile, and 6 invertebrate species. Burrowing Owls preyed most frequently on invertebrates, which comprised 80.4 percent of the prey individuals but only 4.8 percent of the total prey biomass, the lowest of all the major animal groups except the reptiles. Mammals contributed 80.4 percent of the total prey biomass and almost 13 percent of the prey individuals taken, while birds comprised 4.3 percent of the prey items and 16.3 percent of the prey biomass. Locustids were taken more frequently than any other species, averaging 39.6 percent of the prey individuals but only 3.4 percent of the total prey biomass. In contrast, Ord's kangaroo rat comprised only 9 percent of the yearly prey items but contributed 67.5 percent of the total prey biomass. Burrowing Owls lined the entrance of their burrows with chewed up prey remains and manure, a fact also recorded by Stoner (1932, 1933), Bent (1938), and Scott (1940).

Ravens on the study area utilized a total of 16 prey species which included 5 mammal, 5 avian, 2 reptile, and 4 invertebrate species. The majority of their food habits were determined from castings and prey remains at the nest, and there is the possibility that some of the prey brought to the nestlings may have been carrion. Mammals comprised 55.1 percent of the prey individuals and 96.2 percent of the total prey biomass. Birds comprised 11 percent of the prey individuals but only 1.9 percent of the total prey biomass, as did reptiles. Invertebrates, entirely insects in this case, accounted for 28.9 percent of the prey individuals but contributed only minor amounts to the total prey biomass. Lagomorphs constituted the principal prey and averaged 23.9 percent of the yearly prey individuals and 93.2 percent of the total prey biomass. Although birds were taken infrequently, Horned Larks and English Sparrows were the most common avian prey species. Dermestids and unidentified beetles were the most frequently taken invertebrates. In 1970 the deer mouse was the most commonly recorded prey species, but no black-tailed jackrabbits were found—in contrast to 1969. Almost two-thirds of the jackrabbits were immatures or juveniles, and there is the possibility that some were taken as carrion.

## DISCUSSION AND CONCLUSIONS

## Populations

The average yearly raptor population supported by this area of the Great Basin is apparently low. Craighead and Craighead (1956) recorded yearly populations of 140 raptors (9 species, 64 pairs, 12 individuals) during a two-year study of a 36-square-mile Michigan woodlot habitat, and a population of 91 raptors (10 species, 45 pairs, 1 individual) in a 12-square-mile study area near Moose, Wyoming, representing average densities of 1.8 and 3.8 raptor pairs per square mile in Michigan and Wyoming, respectively. These are almost four and ten times the average densities of raptor pairs recorded from this study. Additional comparisons are available from studies of particular species.

Golden Eagles nesting on the study area average 20 square miles per pair. Comparatively, Dixon (1937) recorded densities of approximately 36 square miles per pair in Southern California, and Arnold (1954) found similar pair densities in Colorado. In other studies Lockie (1964) found Golden Eagle densities of one pair per 27.1 square miles in the Scottish Highlands and McGahan (1968) reported one pair per 66.3 square miles in Montana. Watson (1957) found relatively high breeding densities of one pair per 9 square miles in another Scottish study, but in a later study covering a wider portion of the same area Brown and Watson (1964) found Golden Eagle pair densities ranging from approximately 20 to 34 square miles per pair.

Great Horned Owl densities averaged one pair per 10 square miles in central Utah. Studies in other habitats have reported much higher densities. Baumgartner (1939) estimated populations of one pair per 0.5 square miles of riparian habitat near Lawrence, Kansas, and one pair to 3 or 4 square miles near Ithaca, New York. Fitch (1947) estimated a very high population density of one pair per 0.25 square miles in California chaparral. In other studies Errington, Hamerstrom, and Hamerstrom (1940) found one pair per 2 square miles near Prairie du Sac, Wisconsin; Orians and Kuhlman (1956) recorded average densities of one pair per 5 square miles, also in Wisconsin; and Hager (1957) reported Great Horned Owl densities of one pair per 4.4 square miles in central New York. Craighead and Craighead (1956) found average densities of one pair per 5.8 square miles in Michigan and one pair per 3 square miles of study area in northern Wyoming.

Densities of Ferruginous Hawks on the study area averaged one pair per 8 square miles. Data on population studies from other areas are lacking.

Red-tailed Hawks averaged approximately one pair per 13 square miles on the study area. Comparisons with other areas indicates these densities to be exceptionally low. Fitch, Swenson, and Tillotson (1946) reported densities of one pair per 0.5 square miles in Madera County, California, and Orians and Kuhlman (1956) found densities of one pair per 2.2 and 2.8 square miles in Wisconsin. In other studies Hager (1957) reported densities of one pair per 2.2 square miles in central New York; LeDue (1970) found one pair per 1.62 square miles in southeast Minnesota; and Luttich, Keith, and Stephenson (1971) reported one pair per 2.7 square miles near Rochester, Alberta. Craighead and Craighead (1956), however, recorded a similar low density of one pair per 12.9 square miles in Michigan but found high densities of one pair per 1 square mile in Wyoming.

Comparable information on the population densities of the majority of the rest of the raptors nesting on the study area is lacking, but Craighead and Craighead (1956) found greater densities of Swainson's Hawks, Prairie Falcons, Marsh Hawks, Short-eared Owls, and Ravens than were present in the central Utah area.

The relatively low raptor population densities encountered in this study may be due to a number of factors. As previously noted, approximately one-half of the area (i.e., much of the intervening valley floors) is not used by any of the breeding raptors for any purpose. If these areas are eliminated, then the relative raptor population densities become more equitable with those of other geographic areas. In addition, the raptor population studies presented in the literature are often representative only of a specific or confined area, which was chosen because of its high concentration of raptors (see Craighead and Craighead 1956, p. 5; Orians and Kuhlman 1956, p. 382), thus artificially eliminating the bare or dead areas. Hence, the raptor data may or may not be representative of the entire area to which they are referred.

The Utah area regularly supports from 9 to 11 raptor species, fully as many as was found by Craighead and Craighead (1956) in both Michigan and Wyoming. In addition, a broad overlap of raptor species occurred between these areas, with five of the Utah study area species

also present in Michigan and seven in Wyoming. The majority of the raptors on the study area show a wide geographic range and exhibit considerable adaptability to various habitats. That this is not a major cause of the observed density variations is also shown by the much higher densities of the same species in many areas of their range as already noted, with the single exception of the Golden Eagle. However, lack of suitable cover and habitat has apparently limited the populations of the smaller raptors, particularly the Sparrow Hawk and Cooper's Hawk. The latter species, although known to nest occasionally in the pinyon-juniper community (Wolf, 1928; Bee and Hutchings, 1942), is probably outside of its optimum habitat. It would appear however, that the relatively low populations of most of the raptors in the study area cannot be attributed to habitat factors alone.

The lower productivity of this Great Basin Desert biome should limit the raptor populations to some extent, even though mammalian predator control programs have resulted in higher populations of lagomorphs and rodents, the chief food source of the raptors. Additional evidence supporting this possibility is derived from the observed fluctuations of raptor populations in response to lagomorph population fluctuations, a subject which will be discussed in detail later. Two important raptor species on the study area, the Golden Eagle and Ferruginous Hawk, were not part of the raptor population composition of the areas studied by Craighead and Craighead (1956). Their size, home range requirements, and apparent intolerance of other raptor species almost certainly influenced the density of small raptors, particularly in view of the previously noted Golden Eagle predation on Short-eared Owls and Swainson's Hawks. Ferruginous Hawks apparently have restricted habitat requirements and did not nest in the riparian cottonwood communities in canyons to the north and east of the study area. Here nesting Red-tailed Hawks maintained densities on the order of one pair per 0.5 - 2.0 sq miles, approximately similar to those densities reported from other parts of their range, and further indicative of the possible effects of the large and aggressive Golden Eagles and Ferruginous Hawks.

*Population Fluctuations.* Variations in yearly raptor populations were evident during the four-year study. Raptor populations were highest in 1969, averaging 37.8 percent above the 1967 raptor population levels, while 1968 and 1970 populations were intermediate. In addition,

a high proportion of pairs of the 1969 population attempted to nest (93.4 percent), compared to 87.5 percent of the 1967 population, 95.0 percent of the 1968 population, and 74.4 percent of the 1970 raptor population. These population variations were due primarily to yearly fluctuations of several of the large raptor species, specifically the Great Horned Owl, Red-tailed Hawk, Ferruginous Hawk, and Swainson's Hawk and were apparently independent of the relatively stable populations of the medium- and small-sized raptors.

The tendency of pairs to reoccupy nesting sites and territories has the effect of stabilizing the raptor population. This tendency is apparently prevalent in almost all raptor species. Craighead and Craighead (1956) reported that almost 75 percent of the raptor pairs in the Michigan and Wyoming study areas reoccupied their same nesting vicinity. Elsewhere, Luttich, Keith, and Stephenson (1971) reported that only 12.4 percent of their Red-tailed Hawk pairs built a new nest during the four-year study near Rochester, Alberta, and both Hagar (1957) and Orians and Kuhlman (1956) observed numerous instances of Great Horned Owls and Red-tailed Hawks reoccupying their nesting sites or territories of the previous year. Cade (1960), and more recently, White (1969b) have expressed the opinion that a traditional or "genetic" linkage may be responsible for the almost continuous occupancy of certain cliffs or locales by Peregrine Falcons (*Falco peregrinus*) in Alaska, and Herbert and Herbert (1965) have suggested the same of falcons in the New York City region. Conceivably, such a tradition may apply to other raptor species equally as well, and nesting locales may be re-used continuously for long periods of time. Nest decay and disintegration in this area of the Great Basin is remarkably slow, and nesting sites which were photographed in 1941-1944 by Robert G. Bee (Unpubl. notes, BYU Life Sciences Museum) were still present and in some cases in use by the same species in 1967-1970, suggesting a similar trend towards long term occupancy of a particular site.

### Nest Site

*Comparisons with Other Geographic Areas.* The 12 raptor species nesting on the study area show a wide variation in nesting selection throughout their geographic range. In this portion of the Great Basin the majority of Golden Eagle nests are located in cliffs (100 percent in the study area) but Murphy, et al., (1969) recorded a few built on artificial structures or

directly on the ground, and Bee and Hutchings (1942) reported Golden Eagles nesting in junipers and Douglas fir. In southern California, Dixon (1937) found Golden Eagles nesting almost exclusively in cliffs, oaks, or eucalyptus trees. Carnie (1954) also found Golden Eagles nesting in both cliffs and trees in the coastal ranges of California. Elsewhere, Wellein and Ray (1964) reported that in Colorado, New Mexico, and Wyoming 87 percent of their Golden Eagle nests were in cliffs, 11 percent in trees, and 1.3 percent were on the ground. In Saskatchewan, Whitfield et al. (1969) noted that all Golden Eagle nests were constructed in cliffs. In Scotland, Watson (1957) found 70 percent of the Golden Eagles nesting in cliffs and 30 percent in trees, but Gordon (1955) indicates that the majority of nests in the central Highlands are in trees, and in cliffs in the Hebrides.

In this area 59.3 percent of the Great Horned Owl nests were in cliffs, 25.9 percent in quarries, and 14.8 percent in junipers, but in the eastern portion of their range most nest in trees. Orians and Kuhlman (1956), LeDue (1970), and others have recorded all Great Horned Owls nesting in trees. In studies from the western portion of the range, Dixon (1914) found Great Horned Owls in California utilizing cliff sites and Fitch (1947) reported a ground site in Madera County, California. In Utah, Sugden (1929) reported a Great Horned Owl nesting in the ruins of Indian cliff dwellings, and Bee and Hutchings (1942) found nests in junipers, cottonwoods, quarries, and directly on the ground.

On the study area, Ferruginous Hawks nested in trees, primarily junipers, (69.4 percent) and on the ground. Cameron (1914) in Montana and Bowles (1931) in Washington have described ground nests of the Ferruginous Hawk and Jacot (1934) found a bulky nest in a 34-foot cedar. Bent (1937) reported Ferruginous Hawks nesting in swamp oaks in North Dakota. In Canada, Godfrey (1966) describes nesting sites in trees, ledges, river cutbanks, and on hillsides. Angell (1968) observed a Ferruginous Hawk nest built on a slight cliff ledge in Franklin County, Washington. In central Utah, Bee and Hutchings (1942) found Ferruginous Hawks nesting predominately in junipers but noted that they also nest in tall trees and cliff ledges.

The nesting site selections of Red-tailed Hawks show wide variations throughout their range. On the study area 54.5 percent of their nests were constructed in trees, 36.4 percent in cliffs, and 9.1 percent in quarries. In other parts

of the state, Wolf (1928) reported them nesting in trees and cliffs and Hardy (1939) describes a Red-tailed Hawk nest constructed on a pinnacle in the Book Cliffs of central Utah. Elsewhere throughout most of their range, they most commonly nest in trees. In California, Fitch, Swenson, and Tillotson (1946) recorded all 18 pairs of their Red-tailed Hawks nesting in trees, as did Orians and Kuhlman (1956) in Wisconsin; Hagar (1957) in central New York; Freemeyer (1966) in Lyon County, Kansas; Tyler and Sactveit (1969) in South Dakota and Iowa; and LeDue (1970) in southeast Minnesota. However, they will evidently nest in any available site, and Dixon and Bond (1937) found eight pairs nesting in the Petroglyph Cliff area in northeastern California.

All Swainson's Hawk nests on the study area were constructed in low junipers in the foothills. Wolf (1928) and Bee and Hutchings (1942) also found this to be the same site preference for their Swainson's Hawk nests. In Montana, Cameron (1913) found Swainson's Hawks nesting in a variety of low trees, but primarily in ash and cottonwoods.

Two of the three Prairie Falcon nests on the study area were located in quarries and the third was located in a limestone cliff crevice. Cliff nesting appears to be the rule for this species throughout its range, and no exceptions seem to have been recorded. Burrowing Owls similarly show few deviations from the typical burrow nest site. Both Marsh Hawks and Short-eared Owls are more commonly found nesting around water. Bent (1937) describes a number of nests located in marshes and swamps in Massachusetts, North Dakota, and New Jersey. Bent also notes that J. W. Sugden wrote him of a Marsh Hawk nest site in a dry wheat field at least four miles from water in Salt Lake County, Utah.

All of the Sparrow Hawks on the study area nested in holes and crevices of structures, quarries, or junipers. Hole nesting is apparently mandatory for this species and the majority of sites reported in the literature are of this type, although the cavity may take the form of a nesting box (Heintzelman, 1964).

Ravens on the study area nested in high remote cliffs, but Bee and Hutchings (1942) also found their nests in mining structures and trees. Elsewhere, Ravens have shown equal if not greater adaptability. In Washington, Bowles and Decker (1930) found Ravens nesting in cliff potholes, abandoned houses, on telephone poles and oil derricks, and among the beams of a railroad trestle. Bent (1946) recorded 13

of 17 nests in cliffs or ledges, and the remaining 4 in conifers varying from 45-85 feet. In the north they nest in cliffs or ledges, often in close proximity to Peregrine Falcons and Rough-legged Hawks (Fay and Cade, 1959; Cade, 1960). In England they commonly nest in high cliffs or in both deciduous and conifer trees (Holyoak and Ratcliffe, 1968).

*Differentiation among Species' Nest Sites.* The review of the literature presented above suggests that these raptor species show a wide range of nesting site selection throughout the various portions of their geographic range. Yet in areas where they nest together, such as here in central Utah, both similarities and subtle differences may be present. The similarities observed are, of course, to some degree a function of the uniformity of the habitat. For the larger raptor species, and many of the smaller raptors also, the foothills and hills lying between large expanses of surrounding desert provide the most attractive of the potential nesting sites, offering at once a combination of remoteness, inaccessibility, and surveillance of possible approaches. All of the raptors except the Marsh Hawks and Burrowing Owls nested most often in junipers or cliffs, which simply represent the predominant form of available nesting sites. Some species, however, selected a narrower range of nesting sites than did others.

Both Ferruginous Hawks and Swainson's Hawks apparently required a restricted form of nesting habitat. Both nested exclusively on the low foothills surrounding the perimeters of the valleys and in low junipers which were either isolated or situated on the fringes of the pinyon-juniper woodland. Ferruginous Hawks particularly seemed to prefer isolated knolls and tended to nest at higher elevations than Swainson's Hawks. Three such knolls present in the southeastern corner of the study area were each continuously occupied by a breeding pair of Ferruginous Hawks during the four study years. Observations of nesting sites in adjacent locales reinforce this conclusion.

In contrast, Great Horned Owls and Red-tailed Hawks showed a much wider selection of nesting sites. Both commonly nested in cliffs, quarries, or trees but these sites tended to be more remote than those of the Swainson's Hawk and Ferruginous Hawk. Both appeared to prefer nesting sites in long cliff lines or within canyons over the more exposed tree sites, in contrast to the Ferruginous Hawks and Swainson's Hawks, neither of which nested in canyons or on high cliffs. However, tree sites were occasionally used, and Great Horned Owls

sometimes nested in abandoned Ferruginous Hawk juniper nests, such exposed sites utilized only if they were removed from active Ferruginous Hawk nests and territories. Although Great Horned Owls did on occasion nest in relatively close proximity to active Ferruginous Hawk nests (average distance of  $0.766 \pm 0.16$  miles, minimum of 0.21 miles), these close nests were always within cliff crevices and relatively unexposed. Neither Great Horned Owls nor Red-tailed Hawks nested in thick pinyon-juniper woodlands, preferring instead to nest in semi-isolated junipers or within 50-70 feet of the edge of the woodland. On the other hand, some differences between the two species were apparent. Great Horned Owls tended to nest at slightly higher elevations than Red-tailed Hawks and preferred to nest within crevices or caves, whereas Red-tailed Hawks usually nested on cliff ledges.

Golden Eagle nesting sites overlapped considerably with those of Prairie Falcons and Ravens and, to a lesser extent, with Great Horned Owls. Both Golden Eagles and Prairie Falcons always chose cliff or quarry nesting sites, which may reflect their need for high cliffs; a pair of Falcons nesting in 1970 utilized a Golden Eagle quarry nest which had been constructed the previous year.

Of the remaining raptors, the Cooper's Hawk showed virtually no overlap in its choice of nesting sites. No other raptor nested within thick pinyon-juniper woodlands and at such high elevations. In contrast, Short-eared Owls and Marsh Hawks both exhibited similar choices in nesting sites with both nesting in rabbitbrush-sagebrush stands on the desert floor. Burrowing Owls similarly nested on the valley floor, but achieved a measure of isolation owing to their utilization of burrows for nests.

Sparrow Hawk nesting sites overlapped with none of the medium- and small-sized raptor species on the study area. Sparrow Hawks most commonly nested in and around human structures. They did not nest directly on the valley floors except at higher elevations and in juniper cover.

Statistical comparisons of the average nesting elevations of the raptor species reinforce the above statements. Analysis of variance tests indicate that the average nesting elevations of the five large raptor species differed significantly ( $p < 0.01$ , "F" = 19.1). Paired "t" tests reveal that all possible differences are significant except between the Great Horned Owls and Golden Eagles. However, although these two species show much overlap in nest site eleva-

tion, it has already been shown that they prefer different sites.

Similar analysis of variance tests of the five medium- and small-sized raptor species for which sufficient comparative data is available also show significant differences in their average nesting elevations but only at  $p < 0.05$  levels ("F" = 12.2). Most of the lesser variation is attributable to the essentially similar nesting site elevations of Marsh Hawks, Short-eared Owls, and Burrowing Owls as discussed previously; and paired "t" tests between those species most likely to be competitive revealed significant differences in nesting elevations between all medium- and small-sized raptors, with the three exceptions noted. The other three species, i.e., Prairie Falcon, Cooper's Hawk and Raven, nested in sites similar to those of the large raptor species (cliffs and/or at high altitudes). Comparisons between these and the cliff-nesting Red-tailed Hawks, Great Horned Owls, and Golden Eagles reveal that there was no significant difference in average nesting elevation between Prairie Falcons and Golden Eagles, but Ravens and Cooper's Hawks nested at significantly higher elevation than Golden Eagles, Great Horned Owls, and Red-tailed Hawks.

*Populations and Breeding Habitat Requirements.* Although Ferruginous Hawks were the predominant raptor species on the study area, their abundance was confined to certain localities which can be readily described topographically and, to an extent, by the physiognomy of the surrounding vegetation. In areas where the optimum conditions were absent, their numbers dwindled rapidly and they were replaced by the Red-tailed Hawk. Red-tailed Hawks in turn were apparently incapable of displacing Ferruginous Hawks from the foothill regions, although they were present in immediately adjacent locales if a suitably different nest site (i.e., a cliff or steep-sided canyon) was available. This situation is strikingly evident in areas where the two species nest in close proximity (<1.0 miles apart).

Woodbury and Cottam (1962) have described the various ecological habitats of Utah, and it might be useful to examine the presence and relative populations of the raptor species within those habitats occurring in the study area and surrounding localities. The applicable habitat types of Woodbury and Cottam include the following: pinyon conifers, present over all of the higher, better drained portions of the study area and adjacent locales; desert scrub, present over the lower elevations of Cedar and Rush valleys; canyonheads, present in the higher

mountain ranges immediately north and south of the study area; and cultivated valleys, not one of Woodbury and Cottam's original habitat types, but nevertheless present over a large portion of Cedar Valley northeast of the study area.

Six of the raptor species nested within the pinyon-juniper habitat, but all spent some if not most of their hunting activity periods in the adjacent desert areas. Of these the Cooper's Hawk appears to belong most exclusively within the woodland, nesting in relatively dense stands and hunting primarily in the lightly wooded areas or over small hill-top meadows. In contrast, both the Swainson's Hawk and Ferruginous Hawk are the least exclusive members, nesting on its fringes, or as in the case of the Ferruginous Hawk, in the transitional area between pinyon conifers and desert scrub. Ferruginous Hawks constructed almost one-third of their nests within the desert scrub community, well beyond the limits of the woodland, and they achieve their maximum populations in such localities.

Raptors associated with the desert scrub community in the study area include Marsh Hawks, Short-eared Owls, and Burrowing Owls. These species all nested on the valley floors at essentially the same altitude and appeared to be restricted to this community. However, all other raptors except the Cooper's Hawk hunted within this community.

The predominant raptors nesting in canyons included Great Horned Owls and Red-tailed Hawks (Fig. 24). Canyons apparently precluded Ferruginous Hawks and Swainson's Hawks in some way, as neither attempted to nest within this habitat type, either on the study area or in adjacent locales. Large canyons to the northeast supported dense populations of nesting Red-tailed Hawks, with nesting pairs averaging 0.5 linear miles apart in years of maximum populations.

The cultivated land northeast of the study area also differed in raptor species composition and relative populations. Here Sparrow Hawks and Magpies were the most common raptorial forms, with both utilizing the windrows of cottonwoods for nesting sites. Red-tailed Hawks and Great Horned Owls infrequently nested here also; such nests were usually disrupted or destroyed by humans before completion of the cycle.

### Productivity

*Clutch Size Comparisons.* Comparisons with other populations indicate slight variations in average clutch size of most of the study area



Fig. 24. Great Horned Owl nest in West Canyon, March 1969. The nest was constructed the previous year by Red-tailed Hawks.

raptors, but the majority are insignificant. Consequently, a few comparisons should suffice.

Yearly Golden Eagle clutches on the study area averaged  $2.07 \pm 0.07$  eggs. In a series of studies in California Dixon (1937) reported average clutches of 2.0 eggs, Hanna (1930) found an average clutch size of 1.7 eggs, and Slevin (1929) found an average clutch size of 1.95 eggs for 21 clutches. In Scotland Gordon (1927) reported an average clutch size of 1.91 eggs per clutch for 82 clutches. Jollie (1943) found 1.8 eggs per clutch for five clutches in Colorado, and more recently McGahan (1968) recorded an average clutch size of 2.1 eggs for 20 nests in Montana.

Great Horned Owl clutches on the study area averaged  $2.82 \pm 0.15$  eggs. Surprisingly, only a few studies are available for comparison. Craighead and Craighead (1956) reported average clutch sizes of 1.9 eggs in Michigan and 2.2 eggs in Wyoming. Wolluter (1969) reported an average clutch size of 1.9 eggs for nine nests near Lawrence, Kansas, and Tyler and Sactveit (1969) reported average clutches of 2.0 eggs for three nests in South Dakota and Iowa. In-

terestingly, all are significantly lower than the average Great Horned Owl clutches of this area ( $t = 5.43$  for the Kansas comparison,  $t = 5.54$  for the South Dakota and Iowa comparison, and  $t = 4.49$  for the Wyoming area comparison).

Insufficient comparative data is available on the average clutch size for Ferruginous Hawks.

Red-tailed Hawk clutches on the study area averaged  $2.89 \pm 0.13$  eggs. In Michigan, Craighead and Craighead (1956) recorded average clutches of 2.0 eggs, but in Wyoming an average of 2.3 eggs per clutch was found. Elsewhere, Freemeyer (1966) found an average clutch size of 1.9 eggs for 21 nests in Kansas; LeDuc (1970) found an average of 2.3 eggs per clutch for three nests in Minnesota; and Luttich, Keith, and Stephenson (1971) reported an overall average of  $2.0 \pm 0.1$  eggs per clutch in Saskatchewan. Paired "t" tests indicate that the average clutch sizes recorded from this study are significantly larger than the overall average clutches of each of the other areas noted above.

Swainson's Hawk clutches on the study area averaged  $2.2 \pm 0.17$  eggs. In the only other

informative study available Cameron (1913) found an average clutch size of  $2.6 \pm 0.67$  eggs in Montana, significantly higher than those from this area.

The single Prairie Falcon clutch contained 5.0 eggs. Craighead and Craighead (1956) reported average Prairie Falcon clutches of 5.0 eggs in Wyoming, but Enderson (1964) found an average clutch size of 4.5 eggs for 55 nests from the intermountain area.

Marsh Hawk clutches on the study area averaged  $5.0 \pm 1.4$  eggs. Elsewhere, Hammond and Henry (1949) in a three-year study in North Dakota found a range of  $4.87 \pm 0.806$  to  $5.25 \pm 0.774$  eggs per clutch for 60 clutches, while Craighead and Craighead (1956) found average clutches of 4.35 eggs per clutch in Michigan, and Sealey (1967) reported an average clutch size of 4.18 eggs for 21 nests in Alberta and Saskatchewan.

The single Short-eared Owl clutch contained 7 eggs. In other areas Goelitz (1918) reported an average clutch size of 7.3 eggs for four nests in Saskatchewan, but Kitchin (1919) found an average clutch size of only 3.5 eggs for seven nests in western Washington. At the northern edge of the range, Pitelka, Tomich, and Treichel (1955a, 1955b) reported an average clutch size of 6.8 eggs for 22 clutches.

Sparrow Hawk clutches in the study area averaged  $5.22 \pm 0.38$  eggs. In Michigan and Wyoming their average clutch sizes were 4.4 eggs (Craighead and Craighead, 1956). Roest (1957) indicates an average clutch size of 5.1 eggs in Oregon, and Heintzelman and Nagy (1968) found an average clutch size of 4.23 eggs for 13 nests in Pennsylvania. In experimental propagation studies, Willoughby and Cade (1964) reported an average clutch size of 3.66 eggs for 12 clutches.

Raven clutches on the study area averaged  $5.36 \pm 0.34$  eggs. Comparatively, Craighead and Craighead (1956) found mean clutch sizes of three nesting pairs in Wyoming to average 5.7 eggs. In England, Ratcliffe (1962) reported an average clutch size of 4.6 eggs for 139 nests.

*Hatching Success.* From 1967-1970, 14 nesting efforts of Golden Eagles produced 1.2 young per nest for an overall hatching success of  $70.8 \pm 14.9$  percent. Comparatively, Wellem and Ray (1964) reported 1.59 young hatched per nest for 23 nests in the southern Rockies, and McGahan (1968) found an average of 1.59 young per nest hatched in Montana. In central Saskatchewan, Whitfield et al., (1969) found an average of 1.8 young per nest from six nests.

Great Horned Owls on the study area hatched an average of 2.5 young per nest per year. Elsewhere, Craighead and Craighead (1956) reported a two-year average of 1.42 young per nest in Michigan and 2.0 young per nest hatched in Wyoming. Orians and Kuhlman (1956) reported an average of 1.4 young per nest in Wisconsin while Hagar (1957) found average broods of 1.9 young per nest during his two-year study in central New York. More recently, Marti (in Adolphson and Jonkel, 1969) reported an average of 2.4 young per nest for 13 nests in Colorado; Dunstan (in Adolphson and Jonkel, 1969) found 1.9 young in 11 nests in South Dakota; and Adolphson and Jonkel reported 1.96 young per nest for 21 nests, also in South Dakota.

Ferruginous Hawk nests on the study area averaged  $65.2 \pm 5.2$  percent hatching success for an average of 2.3 young per nest. In the only comparative study Adolphson and Jonkel (1969) reported 2.66 young fledged from three nests, but the hatching success is not given.

Red-tailed Hawks on the study area hatched  $76.7 \pm 3.9$  percent of all eggs produced for an average of 2.3 young per nest per year. Elsewhere, Craighead and Craighead (1956) found an average of 1.3 young hatched per nest in Michigan and 2.1 young hatched per nest in Wyoming. Hagar (1957) reported an average brood size of 1.9 young per nest in New York and Luttich, Keith and Stephenson (1971) found an overall hatching rate of 1.9 young per nest of 75 nests in Alberta.

Swainson's Hawks on the study area averaged 2.2 young hatched per nest per year. Comparatively, Craighead and Craighead (1956) reported an average of 1.25 young hatched from four clutches in Wyoming.

The Prairie Falcon nest on the study area hatched 3 of 5 eggs. Elsewhere, Craighead and Craighead (1956) found all five eggs of a nest in Wyoming hatched, but more recently Enderson (1964) found only 1.9 young hatched per nest studied.

The two Marsh Hawk nests hatched an average 3.5 young per nest. Comparatively, Hammond and Henry (1949) reported an average hatching rate of 4.07 young per nest for 60 nests in North Dakota, Craighead and Craighead (1956) found a very low hatching rate of 1.4 young per nest for 13 nests in Michigan, and Sealey (1967) found an average of 1.55 young hatched per nest for 11 nests in Alberta and Saskatchewan.

From 1968-1970 Sparrow Hawks on the study area hatched an average of 4.7 young per nest.

In other areas, Craighead and Craighead (1956) found an average of 2.5 young hatched per nest in Michigan and 4.3 young hatched in Wyoming. In another study, Heintzelman and Nagy (1968) reported 3.29 young hatched per nest for 13 nests in central Pennsylvania.

Ravens produced an average of 3.64 young per nest on the study area. In their study, Craighead and Craighead (1956) reported an average of 5.0 young hatched per nest for three nests in Wyoming.

*Fledging Rates.* During the four-year study, Golden Eagle nests fledged an average of 1.0 young per nest. Elsewhere, Wellein and Ray (1964) recorded an average of 1.32 birds fledged per nest from 23 nests in the southern Rockies, and McGahan (1968) found an average of 1.37 young fledged per nest from 45 successful nestings in Montana. In a series of studies in Scotland, Watson (1957) found an average of 0.8 young fledged per nest over a twelve-year study period, Sandeman (1957) recorded 1.4 young fledged from 19 successful nests, and Brown and Watson (1964) reported 1.3 young per nest from 19 successful nests. Recently, Dunstan (in Adolphson and Jonkel, 1969) found an average of 1.67 young fledged per nest from 21 nests in South Dakota.

From 1967-1970 Great Horned Owl nests fledged an average of 2.0 young per nest for 27 nesting efforts. Comparatively, Craighead and Craighead (1956) found an average of 0.55 young fledged per nest in Michigan and 2.0 fledged per nest in Wyoming; Orians and Kuhlman (1956) reported an average of 1.87 young fledged per nest in Wisconsin; and Hagar (1957) recorded an average of 1.7 young fledged in New York. Recently, Wollhuter (1969) found an average of 1.5 young fledged per nest in Kansas.

Ferruginous Hawks fledging rates averaged 2.0 young per nest. In comparison, Dunstan (in Adolphson and Jonkel, 1969) reported an average of 2.66 young fledged per nest for three nests in South Dakota.

Red-tailed Hawks fledged an average of 1.74 young per nest on the study area. Comparatively, this is higher than Craighead and Craighead (1956); Fitch, Swenson, and Tillotson (1946); LeDuc (1970); and Luttich, Keith and Stephenson (1971); but this is lower than the overall average of 1.9 young fledged per nest reported by Orians and Kuhlman (1956) and Hagar (1957). Ellis in Florida and Dunstan in South Dakota (in Adolphson and Jonkel, 1969) found an average of 1.2 young and 2.5 young fledged per nest, respectively, for each of the

two areas, with the latter data obtained from 20 nests. Jonkel (in Adolphson and Jonkel, 1969) reported an average of 0.52 young fledged per nest for 31 nests, also in South Dakota.

Swainson's Hawks on the study area fledged an average of 1.4 young per nest. Craighead and Craighead (1956) found only 0.4 young fledged per nest for five nests in Wyoming. Recently, Adolphson (1969) found an average of 2.0 young fledged per nest in South Dakota.

The Prairie Falcon nest fledged only one of three young. In Colorado, Enderson (1964) recorded an average of 1.2 young fledged per pair and Scaley (1967) reported an average of 2.5 young fledged per nest in southern Alberta.

The four Marsh Hawk nests of 1969-1970 fledged an average of 2.5 young per nest. Elsewhere, Hammond and Henry (1949) reported an average of 2.1 young per nest fledged in North Dakota, and Craighead and Craighead (1956) found a very low fledging rate of 0.17 young per nest in Michigan for 13 nests.

From 1968-1970 Sparrow Hawks on the study area fledged an average of 2.83 young per nest. Comparatively, Craighead and Craighead (1956) found an average fledged rate of 3.4 young per nest in Michigan and 3.8 young per nest in Wyoming.

The six nests of the Burrowing Owl on the study area fledged an average of 3.33 young per nest. In comparison, Grant (1965) estimated a rate of 3.83 young fledged per nest in Minnesota.

Ravens fledged only 2.57 young per nest on the study area. Craighead and Craighead (1956) found an average of 3.3 young fledged per nest in Wyoming.

*Synopsis of Mortality and Population Trends.* As is evident from the comparison of the relative hatching success and mortality data with other studies, no significant differences exist and most of the variations existing are within the ranges reported from this study. The same holds true also for the majority of the causes of mortality, with nest desertion, egg infertility, and human interference being the principal causes of the observed mortality of eggs and young. There was no evidence of any mortality of young or eggs attributable to mammalian predation, even though ground nests of Ferruginous Hawks, Red-tailed Hawks, and Golden Eagles (the latter outside the study area but within the same habitat type) were directly accessible, and several carnivores, including coyotes, bobcats, kit foxes and mountain lions were present in the study area. Angell (1968) reported a Ferru-

ginous Hawk pair successfully defending their brood against an intruding coyote, which suggests that these raptors are little troubled by such mammals. Avian predation could be an important factor, but it was actually only observed in the two cases of Golden Eagle predation on other raptors, as previously mentioned.

### Territoriality

*Comparisons with Other Areas.* Comparative information on home range size is available from a few published sources.

Golden Eagles on the study area maintained average home ranges of 9.02 sq miles. This is almost equivalent to the 9.0 sq miles of territory reported by Watson (1957) for five pairs in Scotland; however, Brown and Watson (1964) found average Golden Eagle home ranges varying from 20 to 34 sq miles.

Great Horned Owls on the study area maintained average home ranges of 2.02 sq miles. Comparatively, Miller (1930) observed that Great Horned Owls maintained an irregular shaped territory, with the largest diameter of no more than one-half mile, while Baumgartner (1938) found Great Horned Owl territories to have a diameter of 0.5 miles. Craighead and Craighead (1956) found four pairs near Moose, Wyoming, to have an average home range of  $0.82 \pm 0.15$  sq miles, or roughly half that of the owls in central Utah.

Red-tailed Hawk home ranges on the study area averaged 2.5 sq miles. Fitch, Swenson, and Tillotson (1946) reported that 6 Red-tailed Hawk territories in California chaparral ranged from only 0.125 — 0.313 sq miles, but it is possible that peripheral areas were not included in their determinations. Craighead and Craighead (1956) reported somewhat larger home ranges of six pairs in Michigan, which averaged  $1.45 \pm 0.21$  sq miles. In Wyoming, they found eight pairs having average home ranges of  $0.731 \pm 0.11$  sq miles.

There is no apparent comparative data for the home ranges of Ferruginous Hawks and Short-eared Owls.

Swainson's Hawk home ranges on the study area averaged 1.51 sq miles per pair. Craighead and Craighead (1956) reported an average of  $0.95 \pm 0.55$  for five pairs.

Prairie Falcons on the study area averaged 2.35 sq miles in home range size. This is much smaller than the 9.96 sq miles Craighead and Craighead (1956) reported for a pair in Wyoming.

Marsh Hawks on the study area maintained average home ranges of .68 sq miles. In Michigan,

Craighead and Craighead (1956) reported the home ranges of 11 Marsh Hawk pairs as  $0.974 \pm 0.17$  sq miles.

Burrowing Owls on the study area averaged 0.32 sq miles in their home range coverages. Grant (1965) reported territorial sizes of 0.025 and 0.019 sq miles for two pairs in Minnesota and suggested that pairs in colonies maintained home ranges of 0.016 to 0.028 sq miles.

Sparrow Hawk home ranges of the study area averaged 0.29 sq miles. Comparatively, Craighead and Craighead (1956) reported average home ranges of  $0.504 \pm 0.15$  sq miles for five pairs in Michigan and  $0.78 \pm 0.14$  sq miles for 11 pairs in Wyoming.

Ravens on the study area possessed average home ranges of 2.53 sq miles. Comparative data from Moose, Wyoming, indicates that average home ranges of three Raven pairs were  $3.62 \pm 0.4$  sq miles (Craighead and Craighead, 1956).

*Home Range Characteristics.* Characteristically, the home ranges of raptors on the study area extended well out into the desert, which serves as their principal hunting area. Some of the study area, however, was unused; that is, it contained no portions of any raptor home ranges. Such unused areas were typically far from any potential nesting sites and apparently undesirable in terms of food resources. Undoubtedly, raptors which have to travel less to provide sufficient food for their young are more efficient in their reproductive efforts, and it is probable that these peripheral areas are seldom, if ever, utilized.

The rugged topography of the study area played an important role in preventing more frequent intraspecific contacts and actually allowed two raptor populations to exist, one on each side of the centrally located hills.

Intraspecific and interspecific home range overlaps and distances between active nests appeared to be a function of several factors, including tolerance and population densities, specific nesting site selection, and activity patterns. Intraspecific home ranges only slightly overlapped, if at all (except in the Burrowing Owl case), and never overlapped in the vicinity of the nest site. Interspecific home range overlap was more common. Thus, home ranges of Golden Eagles, Great Horned Owls, Ferruginous Hawks, Swainson's Hawks, and Ravens all overlapped to some extent in amounts previously noted. Within this large raptor group, however, home range overlaps between members of the same genus, e.g., *Buteo*, were less extensive than between relatively unrelated raptors. Hence both Golden Eagle and Raven home ranges

showed virtually 100 per cent overlap with some pairs of Ferruginous Hawks and Red-tailed Hawks, and in one year with Swainson's Hawks also. However, the actual nest site of each of these diurnal raptors was relatively far removed from nest sites of other species, and their flight patterns indicated a form of altitudinal territoriality which permitted movement to their more commonly utilized hunting areas.

Home range overlaps between Great Horned Owls and other raptors were common and often extensive. In addition, their average distances to nearest interspecific neighbors were the lowest of any of the large raptors on the study area. That this is a reflection of their activity patterns is indicated by the aggressiveness with which other raptors react to their presence when flushed. Obviously then, Great Horned Owls are able to take advantage of a large portion of the total habitat available compared to the diurnal Buteos because of the direct absence of interspecific territorial competition, although their populations are smaller than those of the Ferruginous Hawk.

Most of the smaller raptors on the study area nested within the home ranges of one or more of the larger raptors and occasionally, as previously noted, were preyed upon by them. Home ranges of these smaller raptors seldom overlapped between two species of comparable size, e.g., the Sparrow Hawk and Burrowing Owl, but much variation occurred in other cases. Burrowing Owls displayed the greatest interspecific tolerances, but their differing activity patterns contributed to the allowance of their observed home range overlaps with Marsh Hawks. Similarly, the close nesting and high degree of overlap between Marsh Hawk and Short-eared Owl home ranges can also be attributed to differing activity patterns which prevented direct confrontation between the two species. Marsh Hawk pairs were generally tolerant of intraspecific and interspecific home range overlaps. Raven pairs, however, tolerated little intraspecific home range overlap even though their large home ranges overlapped considerably with other species.

*Relationship of Species' Home Range Sizes.* With few exceptions there is an evident relationship between raptor weight and territorial size, with the Sparrow Hawks maintaining the smallest and Golden Eagles the largest observed home ranges. Schoener (1968) has shown a strong relationship between territorial size and body weight for a number of herbivorous and predatory bird species. The determination of a similar regression of body weight to territorial

size in the raptors results in a positive slope of  $0.0022 \pm 0.0004$ , significantly larger than zero ( $t = 9.36$ ) at the 0.001 level (Fig. 25). This suggests that their larger body weights require higher energy budgets, which in turn necessitate larger home ranges to provide adequate food supply. The slightly smaller home ranges of the Ferruginous Hawks and Swainson's Hawks (compared to those raptors of similar size, such as the Great Horned Owl and Red-tailed Hawk) may reflect their nesting site preferences which place them nearer to their prey source in the valleys. On the other hand, the relatively large home ranges of the Prairie Falcons do not appear to be explicable, except perhaps in terms of the wide-ranging food procurement of this raptor.

*Relationship between Home Range Sizes and Raptor Population Densities.* Home ranges of the Great Horned Owl, Red-tailed Hawk, and Swainson's Hawk on the study area are, on the whole, much larger than those recorded in studies from other regions, suggesting that these desert-nesting raptors range more widely for food. The increased home range sizes may also reflect the nature of the habitat, which provides nesting sites in the hills and foothills and thereby promotes the location of nests on the perimeter of the home range. Another aspect of the relatively larger territories may relate to the low population densities of these central Utah raptor populations. The 1970 home ranges of Great Horned Owls, Ferruginous Hawks, Red-tailed Hawks, Marsh Hawks and Ravens were larger than the comparable home ranges of the denser 1939 populations of these species, but the

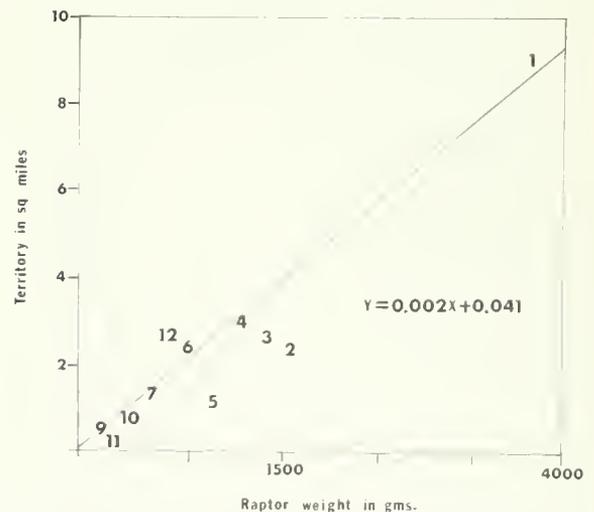


Fig. 25. Relationship between raptor weight and territorial size. Numbers refer to raptor species as previously noted.

differences are not statistically significant and the correlation cannot be made until additional data are accumulated. Other studies have shown such a relationship between territory size and population density, with territories becoming larger as population densities decrease (Craighead and Craighead, 1956; Krebs, 1970; Southern, 1970). However, the already large home ranges on the study area suggest that any additional increase in size over those recorded might be negated by the reduced efficiency of food procurement, although we have no way of demonstrating this at present.

*Functions of the Home Ranges.* The classic concept of the function of territorial behavior suggests that it is a method of population regulation in birds and other vertebrates (Howard, 1920; Wynne-Edwards, 1955, 1962). All raptors residing on the study area maintained definite home ranges and largely confined their activities within them. Pairs reoccupying their territories of the previous breeding season maintained similar home ranges from year to year (within the noted size changes previously discussed) if the same nest site was reoccupied, but modified their boundaries somewhat if a new nest site was chosen, with the new territorial shape conforming to the pattern of radiation away from the new nesting site. In a few cases, the new home ranges differed greatly in shape and specific boundaries compared with the previous breeding season, perhaps due to the replacement of one or both members of a pair. Southern (1970) found that Tawny Owl territories changed very little from year to year, even with changes in nesting sites. This may reflect the differences between the nonmigratory Tawny Owls, which maintain year-round territories, versus the migratory species nesting on the Utah study area, which each year must return and reclaim their territories.

Thus, although all raptors on the study area were in a sense territorial, it is questionable as to whether territoriality limited or regulated their populations. Brown (1969) has suggested types of territorial behavior which acting as a function of population densities would not be limiting at low densities (i.e., all raptors would be able to breed), but they would tend to be limiting at high population levels because some pairs would be excluded from breeding. Unfortunately, none of his categories exactly fits the territorial behavior of the raptor population within the present study area which, as we have already shown, depends primarily on the relative food supply as a breeding stimulus.

Territoriality certainly regulated the individual species populations and probably also the combined *Buteo* species populations in regions of the study area with dense raptor populations, but of course it would not be operative in the regions of low population density. In addition, evidence of old nests was present in many regions of the study area which remained unused by the raptors during this study. This tends to preclude the possibility that territory was a major limiting factor in regulating breeding populations, except locally, and suggests instead that the raptor population of this area may be undergoing a long-term overall decline caused by an as yet unidentified factor or factors.

### Predation

*Comparisons with Other Areas.* Raptors are considerably opportunistic in their predatory habits and take a variety of prey throughout different parts of their range. For this reason, and because literature on food habits of the various species of raptors is plentiful, comparisons will be limited only to the major food items.

All of the large raptors in this area relied heavily, indeed almost completely, on the lagomorphs for their chief food source. Although the frequency of lagomorphs to total prey items in the diet varied somewhat between the five large raptor species, their relative contribution to the total prey biomass was consistently above 90 percent for each species, with the remaining prey species contributing only minor amounts to the total prey biomass and commonly to the total prey frequency.

Elsewhere, the studies of Gloyd (1925), McAtee (1935), Woodgerd (1952), Arnold (1954), Carnie (1954), McGahan (1968), Whitfield et al. (1969), and Packard et al. (1969) have shown a similar predominance of lagomorphs (*Lepus* and *Sylvilagus* sp.) ranging from 28 to 96 percent in Golden Eagle diets. Other important prey items from these studies included ground squirrels (principally *Spermophilus*), which constituted over 26 percent of the prey taken by California Golden Eagles in Carnie's (1954) study, and a variety of avian species which generally constituted less than 15 percent of the total prey items. Murie (1944) reported an Alaskan population which fed primarily on ground squirrels (*Citellus undulatus*). A number of European studies have reported higher avian prey frequencies (Hagan, 1952; Lockie and Stephen 1959; Uttendorfer, 1939); Watson, 1957; Brown and Watson, 1964), and the latter reported that Red Grouse and Ptarmigan (*Lagopus* sp.) comprised 60 percent of the total num-

ber of prey items of a Scottish Golden Eagle population.

Errington (1932c), Errington, Hamerstrom and Hamerstrom (1940), Alcorn (1942), Baumgartner and Baumgartner (1944), Fitch (1947), Orians and Kuhlman (1956), Crawford (1968), Seidensticker (1968), and Marti (1969a) also found lagomorphs to be the principal volumetric contribution to the Great Horned Owl diets within their respective study areas, but found most other prey species more important in terms of frequency. Thus, Fitch (1940) found woodrats (*Neotoma fuscipes*) and Jerusalem Crickets (*Stenapelmatius*) being taken most commonly; Brodie and Maser (1967), Crawford (1968), Seidensticker (1970), and Marti (1969a) found murids taken most frequently; and Baumgartner and Baumgartner (1944) reported cotton rats (*Sigmodon hispidus*) as the most frequently taken prey item on their study area. In other areas lagomorphs were absent or negligible constituents of Great Horned Owl diets. Burns (1952) reported a Florida Great Horned Owl family preying primarily on American coots (*Fulica americana*), and Bond (1940) found harvest mice (*Reithrodontomys megalotis*) to be the principal constituent of the diet of a Nevada population.

Red-tailed Hawk diets similarly show wide variations throughout their range, and lagomorphs are often unimportant constituents. Fisher (1895) and McAtee (1935) found murids to be the principal food item of their food habits studies, and Errington (1932c) and Errington and Breckinridge (1938) reported almost equal numbers of mice and ground squirrels. Later studies have also revealed the importance of ground squirrels, which comprised the majority of prey items of studies in Wyoming (Craighead and Craighead, 1956), California (Fitch, Swenson, and Tillotson, 1946), and Canada (Meslow and Keith, 1966). Recently, Luttich et al. (1970) have shown the Richardson's ground squirrel (*Spermophilus richardsonii*) to be the most important constituent of the total prey biomass of Alberta Red-tailed Hawk populations. In contrast to the heavy utilization of mammals noted from the above studies, Orians and Kuhlman (1956) found their Wisconsin population preying consistently upon birds, of which pheasants (*Phasianus colchimus*) were the most important item. However, Hardy (1939) found the most important prey of a Red-tailed Hawk nest in central Utah to consist of lagomorphs and blow-

In Montana, Cameron (1914) found Ferruginous Hawks to be feeding primarily on

prairie dogs (*Cynomys* sp.) and meadow mice, but Fisher (1895) and Angell (1968) reported that lagomorphs comprised the greater proportion of prey items from their studies, followed by ground squirrels. Both Cameron (1914) and Angell (1968) noted that birds were taken most frequently during the first weeks after the young had hatched, an observation in agreement with the present study.

Food habits of Swainson's Hawks apparently vary greatly. Cameron (1913), Munro (1929), Fisher (1895), and White (1966) have all reported large numbers of insects taken by this species, but their principal volumetric prey items are apparently ground squirrels (Craighead and Craighead, 1956). In Utah, Stanford (1929) reported a pair feeding on field mice and crickets.

Prairie Falcons on the Utah study area preyed most frequently upon Horned Larks and ground squirrels, but juvenile lagomorphs contributed much of their total prey biomass. Elsewhere, the studies of Fowler (1931), McAtee (1935), Bond (1939), Enderson (1964), and Edwards (1968) reported similar prey preferences, with the exception of the lagomorphs. In other studies, Tyler (1923) reported the virtually complete utilization of birds by a California population, while Craighead and Craighead (1956) found both meadow mice and ground squirrels to be taken twice as often as avian prey.

Marsh Hawks on the study area preyed primarily upon deer mice, although birds were also taken and juvenile lagomorphs were important constituents of the total prey biomass. McAtee (1935) found birds, particularly Song Sparrows (*Melospiza* sp.), to be the most frequent species in the stomachs he examined, followed by meadow mice and lagomorphs. Breckinridge (1935) and Errington and Breckinridge (1936) also reported a predominance of avian prey but found that ground squirrels and cottontails comprised the larger portion of the total prey biomass. In contrast, Craighead and Craighead (1956) reported meadow mice occurring most frequently in Michigan, followed by birds, with rabbits and ground squirrels each comprising relatively minor amounts of the total prey biomass.

Short-eared Owls on the study area utilized primarily white-footed deer mice, followed by kangaroo rats. Elsewhere, Short-eared Owls seem to exhibit a distinct preference for small mammals, particularly deer mice and meadow mice, and Errington (1932c), Snyder and Hope (1938), Fischer (1947), Kirkpatrick and Con-

way (1947), Johnston (1956), Short and Drew (1962), and Mmyer (1966) all recorded high incidences of these two prey species. In addition, all of the above studies also recorded large numbers of birds taken as prey.

Sparrow Hawks on the study area took a wide variety of prey, but invertebrates were their main dietary item, particularly grasshoppers; deer mice were next in importance. Heintzelman (1964) has summarized much of the information on North American Sparrow Hawk predation and indicates that murid rodents and grasshoppers are the most common components of the Sparrow Hawk diet.

Invertebrates, particularly grasshoppers, comprised the majority of the prey taken by Burrowing Owls on the study area. Scott (1940) reported Burrowing Owl populations in Iowa to be preying primarily on locustids and scarabids and noted that vertebrates were rarely taken, in agreement with the findings of Bourdo and Hesterberg (1950) in Michigan. Grant (1965) and Marti (1969a), however, while noting a similar heavy utilization of invertebrates, also found that murids formed a conspicuous portion of the total prey biomass.

Surprisingly, lagomorphs were an important element of the Raven diet in central Utah, but an unknown percentage was undoubtedly carrion. Deer mice were next in importance and were the most frequently taken prey species. Nelson (1934) also found a heavy utilization of lagomorphs (51 percent of the total prey taken), followed by invertebrates, chiefly insects.

*Prey Species Taken Versus Availability.* Many of these central Utah raptors show similarities in their food habits, particularly when compared within their relative size classes. Raptors have been shown to respond to temporarily superabundant foods, but are also considerably opportunistic and will apparently take whatever is available and most easily and efficiently caught. Comparisons between the total number of available prey species (potentials derived from Fautin, 1946) reveal that the collective raptor population utilized much of its potential prey base. Thus 60.7 percent (17 of the 28 species listed by Fautin) of the mammal species, 51.1 percent (23 of a potential 45) of the birds, 70 percent of the reptiles (7 of 10 species), and 11.9 percent of the available invertebrate families (8 of 67 plus families) were utilized by one or another raptor species.

However, the food habits studies were designated primarily to ascertain major predation trends and, although sufficient, are not exhaustive. Hence, these raptors almost certainly will

take more prey species than revealed by this study, although this would occur only rarely. Instead, only a few species were heavily utilized and these tended to be the most common animals on the study area.

Lagomorphs, primarily the black-tailed jackrabbit, were the most heavily utilized vertebrate prey species and were recorded as prey more frequently than any other vertebrate species. As such, and in some form, they were the major prey of 7 of the 11 species of raptors studied, including the 5 large raptor species. Only the smaller raptors excluded this species from their diet. Black-tailed jackrabbits were also the single most abundant and conspicuous medium-sized mammal on the study area. All of the raptors showed great efficiency in procuring the young of this species, and as many as nine immature jackrabbits were recorded in a Golden Eagle nest at one time.

Other mammals of particular importance as prey included the antelope ground squirrel, two kangaroo rat species, and the deer mouse. Antelope ground squirrels were a common food item of the large raptors and most of the medium-sized raptors, but failed to appear in the diets of the smaller raptors. They were the most frequent mammalian prey of the Prairie Falcon. Kangaroo rats were a very common minor permanent influent and were significant elements of the diets of all of the owl species nesting on the study area and also the crepuscular Ferruginous Hawk. Both Ord's kangaroo rat and the chisel-toothed kangaroo rat were taken by Great Horned Owls and Ferruginous Hawks, but only the former was taken by Burrowing Owls and Short-eared Owls, whose home ranges were restricted to the valley floor. Deer mice were distributed in all the study area habitats and were frequently taken by four raptors, including the Red-tailed Hawk, and less frequently by most of the other raptor species.

Horned Larks were the most prevalent avian species on the study area and were the only bird species of major importance as prey. They were recorded among the prey of 10 raptor species, being excluded only from the Short-eared Owl's diet.

Locustids were the only invertebrates taken in large numbers and were included in the diet of four raptor species. They were of particular importance to both Burrowing Owls and Sparrow Hawks. Interestingly, Fautin (1946) found Orthopterans much less common than at least eight other major insect orders, which suggests that these represent a lower limit of efficient prey size available to the raptors on the study

area (although not necessarily representing the smallest prey which might be taken).

*Relationship between Raptors and Their Prey.* In examining the food habits of raptors, the frequency percentage of prey items can be considered to reflect the prey species which the raptors are expending time and energy to obtain, whereas the biomass percentages essentially reveal what prey species sustain the raptors. Logically, raptors will be most efficient if they can expend their energies on the largest prey species which they are able to safely capture and kill, thereby achieving a maximization of the ratio between the food biomass necessary for their daily energy budget and their energy-expending hunting time. An analysis of the raptor-prey size relationships on the study area reveals this to be the case (Fig. 26), and a gradual increase in mean prey weight was found to correspond with an increase in average raptor species weight. The regression of the two variables results in a positive slope of  $0.601 \pm 0.221$ , significantly larger than zero at the 0.001 level ( $t = 4.92$ ). There were no significant variations in mean prey weight between raptors of approximately the same weight. This is evident in comparisons of mean prey weights of the *Buteo* hawks and Great Horned Owl and points up the fact that these species must be directly competing for the same food.

In summary, the predatory habits of these raptors reflect prey availability and a size dif-

ferential selection correlating with the raptor's body weight. Although apparently no available prey species was too small to serve potentially as a food source, several of the largest mammals were not utilized, including the mule deer, badger, coyote and kit fox. These species are apparently larger than the maximum prey weight which can safely and efficiently be obtained and are thus safe from avian predation, although infrequent accounts of Golden Eagles attacking or killing mule deer (Craighead and Craighead, 1956), bighorn sheep lambs (Kennedy, 1948), pronghorn antelope (Lehti, 1947), and white-tailed deer (Willard, 1916) have been recorded.

With one exception, no examples of raptor predation on game or domestic species were found during this study, despite the fact that the valleys served for sheep range and lambing during the spring months. McGahan (1968) also reported a conspicuous lack of predation on domestic sheep and lambs in Montana. Ravens on the study area, however, sometimes lined their nests with sheep wool, probably taken from carrion.

### The Ferruginous Hawk

Ferruginous Hawks were the predominant raptors on the study area and also the dominant Buteos. In this respect, they appear to displace the Red-tailed Hawk and Swainson's Hawk and limit the respective populations of these species within the study area habitats. Allen (1874) also recorded Ferruginous Hawks as the most numerous raptor in Montana with the exception of the Sparrow Hawk, and recently Grayson (in Adolphson and Jonkel, 1969) reported that Ferruginous Hawks were displacing Red-tailed Hawks and occupying their former nesting territories in the Texas panhandle. The same possibility exists in the Utah area also, as evidenced by the fact that Behle (1944) reported Swainson's Hawks to be the most common hawks of the central Utah valleys.

Yet the Ferruginous Hawk's dominance and indeed its presence is highly limited by its narrow breeding habitat requirements, as previously discussed. In favorable areas it consistently produces significantly larger clutches than any of the other large raptors on the study area and also succeeds in fledging more young per nest. In these areas it is apparently limited only by its minimum interspecific (nearest neighbor) nesting site distances. But it tends to be entirely absent from unfavorable habitats, which stands in marked contrast to the relatively versatile Great Horned Owl, Red-tailed Hawk, Raven, and even Golden Eagle, which may on

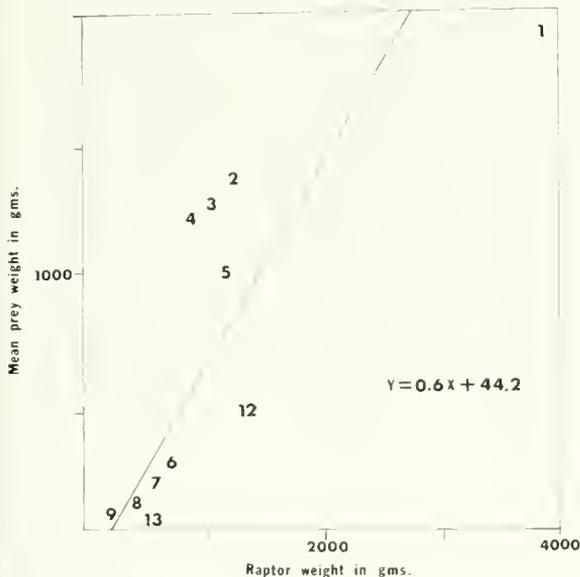


Fig. 26. Relationship between raptor weight and mean weight of prey species taken. Numbers refer to raptor species and follow standard text numbers. The number 13 refers to the Long-eared Owl, included in this correlation analysis.

occasion display a surprisingly wide choice of nesting sites. Its absence from less favorable areas is conspicuous and can be predicted on the basis of the vegetational and topographic features of the habitat. Thus, neither steep-sided canyons nor the interiors of pinyon-juniper woodlands were utilized. Neither of these habitats support the high lagomorph populations which constitute the chief prey of the Ferruginous Hawks. Consequently, these habitats may have been avoided because they would necessitate longer flight times to and from the more favorable sagebrush and grassland hunting areas, and additional time would have to be spent in food procurement. Instead, the Ferruginous Hawk pairs choose to nest within very short distances of their food supply, thereby lessening the problem of procuring adequate food for their large broods.

This suggests that Ferruginous Hawks are dominant in numbers because they find suitable habitats within the limits of the study area which allow a maximization of their productivity. Undoubtedly, their status as the largest of the North American Buteos is also contributory.

### The Long-eared Owl

The status of the Long-eared Owl in this area of the Great Basin is uncertain. Although Henshaw (1875) and Bee and Hutchings (1942) recorded this species nesting in pinyon-juniper, only one nest was found in this habitat type during the present study. It was located in an old Ferruginous Hawk nest constructed in the top of a juniper and within a dense pinyon-juniper stand in southwestern Rush Valley (Fig. 27). The nest was approximately 2.5 ft x 3.0 ft and almost flat. On 3 May it contained three newly hatched young and three eggs and on 26 May five nearly full grown young were present and subsequently banded.

Fifteen pellets and several prey remains were removed from the nest and analyzed. The results are presented in Table 40. Mammals comprised 90.4 percent of the total prey taken and

93.3 percent of the total prey biomass. The two principal species were, in order of their importance, Ord's kangaroo rat and the deer mouse. The mean prey weight taken by this species was 40.8 gms, or only 4.5 gms higher than the mean prey weight taken by the closely related species, the Short-eared Owl. This is, however, three and four times larger than the mean prey weight taken by Sparrow Hawks and Burrowing Owls on the study area, although a wide overlap within the variety of prey taken by these four raptors is evident.

The absence of Long-eared Owl nests on the study area invites comment, as does their apparent scarcity in the pinyon-juniper community. As previously discussed, Long-eared Owls comprised a sizeable portion of the wintering owl populations and were trapped almost three times as often as Great Horned Owls. Yet they were virtually absent from the same area during the breeding season. Although both Long-eared Owls and Great Horned Owls prey on some similar species, their prey selection differential is great; hence, their rare breeding status cannot be attributed to severe competition with the larger owl. However, the combination of breeding habitat requirements and potential predation offers another possibility. Long-eared Owls do not construct their own nests but rather utilize abandoned nests of a wide variety of avian and mammal species, and in other parts of their range, squirrel nests and Cooper's Hawk nests are frequently utilized (Bent, 1938; Armstrong, 1958; Reynolds, 1970). In addition, these nests are normally placed in dense conifer stands (Randle and Austing, 1952). In the pinyon-juniper habitat, however, the only nests available are those of the Ferruginous Hawk, Red-tailed Hawk, and Swainson's Hawk. All of these are constructed in the tops of junipers and are directly exposed to potential predators from above. Furthermore, probably all of the large raptors which nest in this area are capable of killing Long-eared Owls, and in other areas Golden Eagles (McGahan, 1968), Great Horned Owls (Errington, Hamerstrom, and Hamer-

Table 10. Food habits of Long-eared Owls in 1970.

Species	No. Indv.	% Indv.	Approx. Biomass	% Biomass
<i>Dipodomys ordii</i>	10	45.5	680	75.7
<i>Peromyscus maniculatus</i>	7	31.8	119	13.3
<i>Microtus sp.</i>	2	9.1	24	2.7
<i>Perognathus parvus</i>	1	4.5	15	1.6
Unident. Passerine	2	9.1	60	6.7
Totals	22	100.0	898	100.0



Fig. 27. Juniper tree nest containing a brood of five young Long-eared Owls in Rush Valley, 30 May, 1969.

strom, 1940), and Red-tailed Hawks (Collins, 1962) have been recorded as preying upon this species. B. F. Harrison (personal communication) cites a specific example wherein a Long-eared Owl was flushed from a similar juniper nest (in this same area) containing eight well-developed eggs. When rechecked about two hours later, both eggs and adults had disappeared. The rapidity of their disappearance and the absence of remains of either the eggs or adults suggests that the predator was probably a hawk or Raven.

The above considerations suggest that Long-eared Owls require well-concealed nesting sites in dense cover or thickets, all of which are lacking in the pinyon-juniper community. Hence, their breeding success is rendered uncertain because of the high levels of exposure of the only available nesting sites.

#### Effect of the Investigator

The effect of the investigations and the presence of the investigators are difficult to evaluate except where such presence clearly led directly to the destruction of the raptor's nests, eggs or

young, or resulted in adult mortality. The effect of the investigators on raptor nesting activities was often deleterious. Despite the fact that nest visits were kept short, particularly in cold weather, adverse effects occurred. Most commonly these effects took the form of nest abandonment, with loss of eggs and young occurring less frequently. There is some indication, however, that the birds adjusted somewhat to the investigators after the first breeding season, and several of the pairs which had abandoned their nests in 1967 tolerated similar nest visits during the subsequent breeding seasons and nested successfully. However, some—particularly two Golden Eagle pairs—never became tolerant of human presence and activities.

The aggressiveness of the adults toward the investigators varied greatly, both among species and among pairs of a species and even within the members of a pair. Generally Golden Eagles and Swainson's Hawks rapidly departed and did not reappear during nest visits, but Ferruginous Hawks and Red-tailed Hawks always pressed attacks if young were in the nest, although terminating them before actual contact was made. Great Horned Owls were probably

the most dangerous raptors in the study area. Several females made determined attacks, and three made actual contact, two knocking one of the authors out of the nesting tree, and the third lacerating the scalp and forehead of a colleague (Bruce Arnell, personal communication). Of the medium-sized and small-sized raptors, Prairie Falcons were the most aggressive and Ravens and Sparrow Hawks the most vocal. None, however, made serious threats or determined attacks against the investigators.

### SUMMARY

A study of the breeding ecology of raptorial birds was conducted in central Utah from 1967 to 1970. The objectives of the study were to provide four years of quantitative data on the breeding raptor populations and their distribution, their habitat utilization, yearly productivity and success, territoriality, and predation.

The study area supported a total of 354 individuals of 12 raptor species during the four study years. The yearly raptor population varied from 8 to 11 raptor species and from 32 to 46 pairs. Individuals commonly comprised from 9 to 13 percent of the yearly raptor population, and a varying percentage of pairs did not attempt to nest. Ferruginous Hawks were the predominant raptor species and comprised some 19 percent of the total yearly raptor population. Other important raptors included the Golden Eagle, Red-tailed Hawk, and Raven.

Yearly population densities averaged 0.5 pairs per square mile, much lower than raptor populations found in Michigan and Wyoming (Craighead and Craighead, 1956). However, much of the area was not utilized, and if such areas were eliminated from the calculations, the raptor population densities would be increased.

The breeding activities of the collective raptor population occurred over a period of eight months. Raptor species exhibited a definite breeding sequence relative to one another, and each species initiated its nesting activities at slightly different time periods, although some overlap occurred between early and late nesters of different species. Great Horned Owls and Golden Eagles were the first raptors to initiate nesting activities, usually in late January or early February. Red-tailed Hawks were the first of the migratory raptors to return and begin nesting and were closely followed by Ferruginous Hawks. Swainson's Hawks were the last of the large raptors to begin nesting, usually in late May or June, and at approximately the same

In summary, the activities of the investigation did apparently provoke the nesting raptor species to some extent and apparently resulted in mortality in extreme cases. The effect of this mortality on the total population and population trends is unknown, but it is certainly not as drastic as the sum total of untoward human activities directed against the nesting raptors, which must contribute to the overall low raptor density of this area. Only additional evidence will permit definite conclusions, however.

time Cooper's Hawks and Burrowing Owls initiated their nesting activities.

The raptors exhibited a wide range of nest site selection within the limits imposed by the study area habitat. The large raptors nested primarily in cliffs (including quarries) or junipers; but many of the medium- and small-sized raptor species, such as the Marsh Hawk, Short-eared Owl, and Burrowing Owl were ground nesters. Observations indicated that several of the raptor species exhibited a vertical stratification of nesting sites. Territories and, less commonly, nesting sites were usually reoccupied by a pair of the same species.

The fecundity of the collective raptor population varied between years. Specific causes of mortality of eggs and young included nest desertion and destruction, predation, apparent egg infertility, and accidents. Human interference was the probable cause of most of the observed nest desertion and destruction. Approximately 6.5 percent of all eggs produced were apparently infertile, of which the majority were from Ferruginous Hawk nests.

The observed home ranges of the raptor species were a function of their relative size and breeding status. Thus, nesting pairs maintained larger home ranges than nonnesting pairs, which in turn held larger home ranges than individuals. The sizes and shapes of the home ranges conformed generally to the topography of the nesting locale and usually ranged widely into the surrounding desert. Distances between nearest neighbors of closely related species of similar weight were greater than between relatively unrelated species. An exception occurs between species with differing activity patterns, such as the nocturnal owls and the diurnal hawks. Overlapping of home ranges was seldom substantial between pairs of the same species, but it was somewhat more frequent between pairs of different species.

Each of the raptor species maintained definite hunting activity periods. The obvious differential occurred between the diurnal hawks, eagles and ravens, and the nocturnal owls; but at least one species, the Ferruginous Hawk, exhibited a crepuscular hunting activity timetable.

The food of the raptors on the study area included at least 55 different prey species, but most relied heavily on only 1 or 2 species. The principal prey of the majority of the large raptors was the black-tailed jackrabbit, which also figured prominently in the diets of some of the medium-sized raptors. Other prey species of importance to one or more raptor species included

the antelope ground squirrel, two kangaroo rat species, the white-footed deer mouse, and the Horned Lark. The smaller raptors also took large numbers of invertebrates, principally orthopterans. Generally the raptors preyed heavily upon the most abundant potential prey species, and a correlation of predator-prey size was found, indicating that the various raptor species preyed most heavily upon the largest prey species which they could most efficiently capture and kill. No examples of raptor predation on game or domestic livestock were found during the study period.

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#### APPENDIX—WEIGHTS OF PREY SPECIES USED IN THE BIOMASS CALCULATIONS.

Species	Approx. wt. in gms.	Source
MAMMALS		
<i>Lepus californicus</i>	2300	Haskell and Reynolds (1947)
<i>Sylvilagus sp.</i>	1000	Seidensticker (1968)
<i>Spermophilus townsendi</i>	191	Cornish and Mrosovsky (1965)
<i>Ammospermophilus leucurus</i>	145	This study
<i>Eutamias minimus</i>	78	This study
<i>Thomomys bottae</i>	170	This study
<i>Perognathus parvus</i>	15	This study
<i>Perognathus formosus</i>	19	This study
<i>Dipodomys microps</i>	65	This study
<i>Dipodomys ordii</i>	68	Desha (1967)
<i>Microdipodops megacephalus</i>	24	This study
<i>Onychomys leucogaster</i>	38	Marti (Unpubl IBP data)
<i>Reithrodentomys megalotis</i>	12	Marti (Unpubl IBP data)
<i>Peromyscus maniculatus</i>	17	Bee (1947)
<i>Neotoma lepida</i>	217	Marti (Unpubl IBP data)
<i>Microtus sp.</i>	38	Bee (1947)
<i>Mustela frenata</i>	178	Marti (Unpubl IBP data)
BIRDS		
<i>Buteo swainsoni</i>	988	Craighead and Craighead (1956)

<i>Zenaidura macroura</i>	153	Hutt and Ball (1938)
<i>Asio flammeus</i>	340	Craighead and Craighead (1956)
<i>Chordeiles minor</i>	75	This study
<i>Phalaenoptilus nuttallii</i>	62	This study
<i>Tyrannus verticellus</i>	36	This study
<i>Sayornis saya</i>	28	This study
<i>Otocoris alpestris</i>	28	Behle (1943)
<i>Pica pica</i>	173	Seidenstiecker (1968)
<i>Cyanocephalus cyanocephalus</i>	108	Poole (1938)
<i>Oreoscoptes montanus</i>	45	This study
<i>Sialia currucoides</i>	45	Marti (Unpubl IBP data)
<i>Larius ludovicianus</i>	52	Esten (1931)
<i>Passer domesticus</i>	25	Poole (1938)
<i>Oberholseria chlorura</i>	30	This study
<i>Calamospiza melanocorys</i>	33	Marti (Unpubl IBP data)
<i>Poecetes gramineus</i>	27	Poole (1938)
<i>Spizella breweri</i>	30	This study
<i>Zonotrichia leucophrys</i>	30	Baldwin and Kendeigh (1938)
<i>Sturnis vulgaris</i>	84	Poole (1938)
<i>Sturnella neglecta</i>	145	Poole (1938)
REPTILES		
<i>Crotaphytus collaris</i>	30	This study
<i>Uta stansburiana</i>	4	This study
<i>Sceloporus graciosus</i>	13	This study
<i>Phrynosoma platyrhinus</i>	9	This study
<i>Cnemidophorus tigris</i>	24	This study
<i>Masticophis taeniatus</i>	169	This study
<i>Pituophis melanoleucus</i>	372	This study
INVERTEBRATES		
<i>Carabidae</i>	0.23	Marti (Unpubl IBP data)
<i>Scarabidae</i>	0.3	Marti (Unpubl IBP data)
<i>Silphidae</i>	0.3	Marti (Unpubl IBP data)
<i>Curculionidae</i>	0.1	Marti (Unpubl IBP data)
<i>Tenebrionidae</i>	0.55	Marti (Unpubl IBP data)
<i>Locustidae</i>	0.63	This study
<i>Aranæ</i>	0.4	Marti (Unpubl IBP data)
<i>Scorpionidae</i>	1.45	This study

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EFFECTS OF A NUCLEAR  
DETONATION ON ARTHROPODS  
AT THE NEVADA TEST SITE

by

Dorald M. Allred



BIOLOGICAL SERIES — VOLUME XVIII, NUMBER 4  
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# EFFECTS OF A NUCLEAR DETONATION ON ARTHROPODS AT THE NEVADA TEST SITE<sup>1</sup>

by

Dorald M. Allred<sup>2</sup>

## INTRODUCTION

Allred, Beck, and Jorgensen (1963b, 1964) and Jorgensen, Allred, and Beck (1963) discussed the effects of the nuclear detonation "Sedan" on vegetation and rodents at the Nevada Test Site. My report discusses the effects of that same detonation on arthropods.

Project Sedan, a phase of the Plowshare program for peaceful uses of nuclear energy, was detonated underground at a depth of 194m on

July 6, 1962. The thermonuclear device of 100 short kilotons created a crater 98m deep and 390m in diameter (Fig. 1). Intense radioactive fallout was generally confined within an area of 6.5km by 9.7km. Ecological studies, which utilized the techniques described by Allred, Beck, and Jorgensen (1963) for trapping ground-dwelling arthropods, were made before and after the detonation.

## METHODS

Can pit-traps were placed at intervals between 305m (1000 ft) and 2743m (9000 ft) from ground zero (GZ = the center of the nuclear detonation) as shown by the circles on Fig. 2. One year after the detonation, pit cans were also arranged in three grids as shown on Fig. 2. Each grid consisted of four transects 3m apart, each transect with five cans 6m apart.

Cans along the main transect, which was 2438m long, were open for the capture of animals from June 17 through July 5, 1962 (pre-test). Arthropods were removed from the cans at two-day intervals prior to the detonation. Beginning on August 25 after the detonation, which was as soon as safety conditions allowed entry into the area, the cans were opened and left until September 23, 1962 (posttest). During this latter time, collections were also made at two-day intervals, except for three periods when strong winds created sufficient movement of radioactive dust to create a safety hazard. During this period, entry into the area was not allowed, and collection intervals of five to seven days were used. A year later, from 20 to 30 June, and 15 to 25 August 1963, cans were opened and visited at two-day intervals.

Pit cans on the three grids which were established in 1963 were also open from 20 to

30 June and 15 to 25 August 1963, and visited every second day.

Jorgensen, Allred, and Beck (1963:51) designated two pretest and three posttest zones (Fig. 2). On the basis of their analysis of vegetation before the detonation and subsequent effects of the blast (Ibid:54), I designated nine sectors for analysis of the arthropod populations (Fig. 2). The major vegetative types according to sectors are shown in Table 1.

For purposes of comparative populations between the 2438m transect and the grids, I grouped those sectors of similar vegetative types and damage with the specific area of the grid. The grid closest to GZ (10t) is compared to the section of the transect within sectors 1 to 3, the second grid (10u) with sectors 4 to 6, and the grid farthest from GZ (10w) with sectors 7 to 9.

In order to extrapolate population indices from other areas of similar vegetative types of the test site to those expected in the nine sectors of the Sedan experiment, relative population factors were determined for four major types which correspond to the zones and vegetative analysis as designated by Jorgensen, Allred, and Beck (1963:51, 54), and the nine sectors as used in my report (Table 2). These are

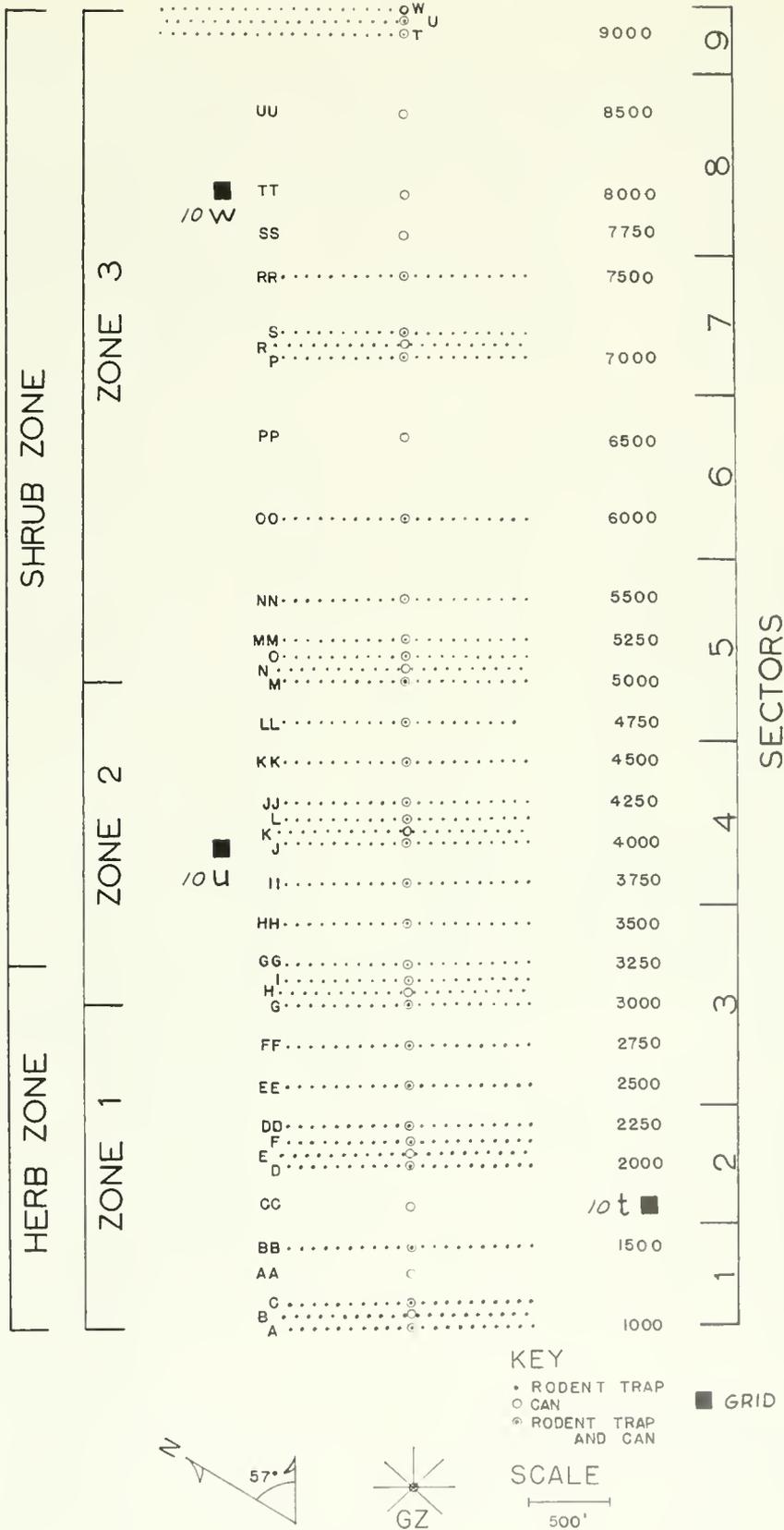
<sup>1</sup>BYU-AEC Report COO-786-60

<sup>2</sup>Center for Health and Environmental Studies, Brigham Young Univ., Provo, Utah 84602



Fig. 1. Crater of project Sedan. Note vehicle and people at lower left corner.

(Jorgensen et al. Zones)



(Allred Analysis)

Fig. 2. Trap placement before and after detonation of Sedan. Zones of Jorgensen et al. (1963) are shown for comparison with sectors used herein.

TABLE 1. Principal vegetative types and conditions in nine sectors before and after the detonation of Sedan.

Sector	Feet from GZ	Pretest	Posttest
1	0-1500	<i>Salsola</i> -Grass	Covered with soil
2	1500-2500	<i>Salsola</i> -Grass- <i>Hymenoclea</i>	Covered with soil
3	2500-3500	<i>Hymenoclea</i> - <i>Grayia</i> -Grass	ditto
4	3500-4500	<i>Coleogyne</i> - <i>Grayia</i> -Grass	Vegetation destroyed; partly covered with soil
5	4500-5500	<i>Coleogyne</i> - <i>Grayia</i>	Vegetation damaged; layer of dust
6	5500-6500	<i>Coleogyne</i> - <i>Grayia</i>	No change; layer of dust
7	6500-7500	<i>Coleogyne</i> - <i>Grayia</i>	No change; layer of dust
8	7500-8500	<i>Coleogyne</i> - <i>Grayia</i> - <i>Lycium</i>	No change; layer of dust
9	8500-9500	<i>Coleogyne</i> - <i>Grayia</i>	No change; layer of dust

TABLE 2. Relative abundance factors\* of arthropods in four vegetative types at the Nevada Test Site, 1959-1963.

Group and species	Sa	Plant Community**					
		Gr Ly (dis)	Co Gr Ly (dis)	Co Gr Ly (undis)			
Tenebrionid Beetles							
<i>Araeoshizus sulcicollis</i>	1	48	56	46			
<i>Centrioptera muricata</i>	1	39	25	5			
<i>Conibiosoma elongatum</i>	1	39	25	7			
<i>Edrotes orbus</i>	3	8	5	1			
<i>Eleodes armata</i>	1	7	6	5			
<i>E. grandicollis</i>	1.4	8	4	1			
<i>E. hispilabris</i>	12	34	17	1			
<i>E. longipilosa</i>	0	0	0	1			
<i>E. nigrina</i>	0	0	0	0			
<i>Eupsophylus castaneus</i>	0	2	1	4			
<i>Euschides luctatus</i>	0	1.3	1.3	1			
<i>Eusattus agnatus</i>	1	2.6	0	0			
<i>Metoponium convexicolle</i>	1	2.5	1.3	2			
<i>Pelecyphorus pantex</i>	1	3	1.6	3			
<i>P. semilacvis</i>	0	1.5	1	2			
<i>Triorophus laevis</i>	1	32	18	5			
<i>Trogloderus costatus</i>	4	18	9	1			
Ants							
<i>Aphaenogaster megommatus</i>	0	2	1	2			
<i>Crematogaster coarctata</i>	1	1	1	1			
<i>Iridomyrmex pruinosum</i>	1	2	7	9			
<i>Myrmecocystus mexicanus</i>	1	9	8	12			
<i>M. mimicus</i>	1	2	2	2			
<i>Pheidole bicarinata</i>	1	2	1	1			
<i>Pogonomyrmex californicus</i>	1	1.5	1	1			
<i>P. rugosus</i>	1	121	86	129			
<i>Veromessor lariversi</i>	7	4	3	1			
<i>V. smithi</i>	0	0	1	2			
Orthopterans							
<i>Arenicaga erratica</i>	0	1	2	3			
<i>Ceuthophilus fossor</i>	1	1.5	1	1			
<i>C. lamellipes</i>	1	1	1	2			
<i>Litaneutria minor</i>	1	1.5	4	6			
<i>Stenopelmatus fuscus</i>	1	5	4	5			

Table 2 (Continued)

Scorpions				
<i>Hadrurus spadix</i>	1	3	3	4
<i>Vaejovis becki</i>	1	2	2	2
<i>V. boreus</i>	0	.5	.3	.5
<i>V. confusus</i>	1	3	2	3
Solpugids				
<i>Branchia potens</i>	0	.5	2	3
<i>Eremobates scopulatus</i>	1	1.5	1	1.5
<i>Eremorhax pulcher</i>	1	1	.5	.5
<i>Hemerotrecha californica</i>	0	3	3	5
<i>H. proxima</i>	0	2	1	2
<i>H. serrata</i>	1	1	1	1
Spiders				
<i>Calilena restricta</i>	0	3	2	3
<i>Gnaphosa hirsutipes</i>	1	4	6	9
<i>Haplodrassus eunis</i>	1	5	9	14
<i>Herpyllus hesperolus</i>	1	3	5	7
<i>Loxosceles unicolor</i>	0	0	0	0
<i>Megamyrmecion naturalis-</i> <i>ticum</i>	0	0	1	2
<i>Neoanagraphis chamberlini</i>	1	1.5	2	2.5
<i>Orthonops gertschi</i>	0	1	1	1.5
<i>Physocyclus tanneri</i>	0	0	0	0
<i>Psilochorus utahensis</i>	1	1	1	1
<i>Syspira eclecticia</i>	0	.5	1	1

\*All numbers are related to the factor of "1" which represents the least abundant. "0" indicates not found. Factors are not comparable between species.

\*\*Sa = *Salsola*; Gr Ly (dis) = *Grayia-Lycium* disturbed, Co Gr Ly (dis) = *Coleogyne-Grayia-Lycium* disturbed; Co Gr Ly (undis) = *Coleogyne-Grayia-Lycium* undisturbed

(1) *Salsola*, (2) disturbed *Grayia-Lycium*, (3) disturbed *Coleogyne-Grayia-Lycium*, and (4) undisturbed *Coleogyne-Grayia-Lycium* (Table 2).

Similar factors were determined for the seasonal occurrence and abundance of each species of arthropod in other areas of the test site not affected by the Sedan experiment so as to determine the expected species and their populations during the different sampling periods in the environs of project Sedan (Table 3). Factors of adjustment were used to standardize sectors and grids, as well as other areas and seasonal collecting at the test site, to the number of stations and collections. Five equations were used as follows.

For pretest and posttest populations of each sector and vegetative type,

$$PN_A = N_C \times T_S$$

where

$PN_A$  = number of animals collected adjusted to the number of collecting attempts,

$N_C$  = actual number of specimens collected, and

$T_S$  = adjustment factor of the number of traps in a given sector or vegetative type, as

determined by the greatest number of traps used in any of the vegetative areas or sectors, divided by the number of traps in the specific sector or vegetative type considered.

Seasonal adjustment factors were determined by  $S_F = \frac{P_H}{P_L}$

where

$S_F$  = the seasonal adjustment factor,

$P_H$  = the greatest population collected in one of the four months, June through September, over the whole test site, and

$P_L$  = the lowest population as above.

The base factor for determining the expected population of a given species for a specific vegetative type and month was calculated as

$$B_F = \frac{PN_A}{SJu_F + SJy_F}$$

where

$B_F$  = the base factor,

$PN_A$  = as explained above,

$SJu_F$  = the seasonal adjustment factor for June, and

$SJy_F$  = the seasonal adjustment factor for July.

The posttest expected population was determined by

$$P_X = B_F \times S_F$$

where

$P_X$  = the expected population for a given period,

$B_F$  = the base factor as explained above, and

$S_F$  = the seasonal adjustment factor for the

period considered.

If the period considered was more than one month, then the equation should read:

$$P_X = B_F \times (S_{1F} + S_{2F})$$

where

$S_{1F}$  = the first seasonal adjustment factor, and

$S_{2F}$  = the second seasonal adjustment factor, and so on.

TABLE 3. Relative abundance factors\* of arthropods related to above-ground activity during four months at the Nevada Test Site, 1959-1963.

Group and species	Month			
	June	July	Aug.	Sept.
<b>Tenebrionid Beetles</b>				
<i>Araconshizus sulcicollis</i>	1.6	1	2.2	3
<i>Centrioptera muricata</i>	37	22	4	1
<i>Conibiosoma elongatum</i>	1	2	1	1
<i>Edrotes orbis</i>	1	2	10	9
<i>Eleodes armata</i>	1	1.2	3.2	8.8
<i>E. grandicollis</i>	1	2	7	8.5
<i>E. hispilabris</i>	3	1	1.4	1.4
<i>E. longipilosa</i>	0	1	1	0
<i>E. nigrina</i>	0	0	3	0
<i>Eupsophylus castaneus</i>	18	1	0	0
<i>Euschides luctatus</i>	0	0	0	3
<i>Eusattus agnatus</i>	0	0	2	0
<i>Metoponium convexicolle</i>	1.5	1	1	1.5
<i>Pelecyporus pantex</i>	0	1	76	30
<i>P. semilaevis</i>	0	1	20	10
<i>Triorophus laevis</i>	17	7	2.4	1
<i>Troglderus costatus</i>	1.4	1	3.6	1.2
<b>Ants</b>				
<i>Aphaenogaster megommatus</i>	1	122	133	0
<i>Crematogaster coarctata</i>	8	17	21	1
<i>Iridomyrmex pruinosum</i>	27	14	3	1
<i>Myrmecocystus mexicanus</i>	1	1	2	2
<i>M. mimicus</i>	1	2	2	1
<i>Pheidole bicarinata</i>	6	7	3	1
<i>Pogonomyrmex californicus</i>	3	5	3	1
<i>P. rugosus</i>	1.5	1	2	1.5
<i>Veromessor lariversi</i>	6	10	1	0
<i>V. smithi</i>	1	0	0	0
<b>Orthopteraus</b>				
<i>Arenivaga erratica</i>	15	1	3	0
<i>Ceuthophilus fossor</i>	79	34	1	2
<i>C. lamellipes</i>	0	1	5	6
<i>Litaneutria minor</i>	3	4	3	1
<i>Stenopelmatus fuscus</i>	4	7	5	1
<b>Scorpions</b>				
<i>Hadrurus spadix</i>	1	2	1	1
<i>Vaejovis becki</i>	2	2	2	1
<i>V. boreus</i>	1	2	2	2
<i>V. confusus</i>	3	2	2	1
<b>Solpugids</b>				
<i>Branchia potens</i>	7	11	0	1

Table 3 (Continued)

<i>Eremobates scopulatus</i>	2	1	0	0
<i>Eremorhax pulcher</i>	1	1	0	0
<i>Hemerotrecha californica</i>	65	20	2	1
<i>H. proxima</i>	0	0	0	0
<i>H. serrata</i>	1	5	6	2
Spiders				
<i>Calilena restricta</i>	3	4	1	1
<i>Gnaphosa hirsutipes</i>	14	11	1	7
<i>Haplodrassus eunis</i>	1	0	1	2
<i>Herpyllus hesperolus</i>	2	1	0	4
<i>Loxosceles unicolor</i>	5	9	7	1
<i>Megamyrmecion naturalisticum</i>	3	3	2	1
<i>Neoanagraphis chamberlini</i>	1	1	1	2
<i>Orthonops gertschi</i>	7	6	0	1
<i>Physocyclus tanneri</i>	0	0	1	0
<i>Psilochorus utahensis</i>	5	5	4	1
<i>Syspira eclecticica</i>	5	6	4	1

\*All numbers are related to the factor of "1" which represents the least abundant. "0" indicates not found. Factors are not comparable between species

RESULTS

Beetles

*Araeoschizus sulcicollis*. Beetles of this species were present in all sectors except number 8 before the detonation, and most densely concentrated in sectors 5, 6, 7, and 2, respectively (Table 4). One and two months after the detonation, populations were 86 percent below the expected normal, and somewhat evenly distributed between all sectors except number 8, where none were found. In June 1963, populations were 62 percent below the expected normal and occurred in only four sectors, including number 8, but none were closer to GZ than 1067m. In August 1963, populations were 93

percent below the expected normal and were found only in sector 8.

Ecologically, significant differences in population occurred from the expected normal in all sectors except numbers 1 and 2. The pretest population in sector 2 was considerably higher than the norm, whereas the posttest population was not significantly different. In sectors 3 to 9, pretest and posttest populations were significantly lower than the expected norm.

*Centrioptera muricata*. Beetles of this species were present in only four sectors before the detonation and were most densely concentrated in sectors 7 and 8 (Table 5). One and two months

TABLE 4. Effects of a nuclear detonation on populations of beetles of the species *Araeoschizus sulcicollis*.

Sector	Pre-test	No. specimens					
		Aug.-Sept. 1962		Posttest		Aug. 1963	
		Actual	Expected	Actual	Expected	Actual	Expected
1	3	°	°	0	2	0	3
2	11	°	°	0	7	0	9
3	4	1	8	0	2	0	3
4	1	4	2	5	1	0	1
5	28	5	56	6	17	0	24
6	18	4	36	0	11	0	15
7	14	4	28	7	8	0	12
8	0	0	0	2	0	5	0
9	7	2	14	0	4	0	6
Total	86	20	144	20	52	5	73

\*Collection attempts not made

TABLE 5. Effects of a nuclear detonation on populations of beetles of the species *Centrioptera muricata*.

Sector	Pre-test	No. specimens					
		Posttest					
		Aug.-Sept. 1962		June 1963		Aug. 1963	
		Actual	Expected	Actual	Expected	Actual	Expected
3	1	0	0	0	1	0	0
6	4	0	0	0	3	0	0
7	9	2	1	0	6	0	1
8	9	0	1	0	6	0	1
Total	23	2	2	0	16	0	2

after the detonation, populations were not reduced from the expected. None were found in sectors 3 and 6 immediately after the detonation, and in 1963 none were found in any sector.

Ecologically, pretest populations were not significantly different from the expected norm in any sector except numbers 3 and 4, where they were lower. Similarly, posttest populations were also significantly lower than the norm in these two sectors, whereas in other sectors populations were as expected.

*Conibiosoma elongatum*. One specimen was taken in sector 9 before the detonation; none were taken after. Elsewhere on the test site beetles of this species were relatively abundant in *Coleogyne* and *Grayia-Lycium*, but not in *Salsola*. Seasonally they were common from June to September.

*Edrotes orbus*. Animals of this species were present only in sector 6 before the detonation. One and two months after the detonation they were densely concentrated in sectors 3, 4, and 5, whereas none were found in sector 6. Post-test populations occurred in six of the sectors. One and two months after the detonation, the population actually increased over the expected by 64 percent. In June 1963 the population showed an increase of 300 percent, whereas in

August 1963 a decrease of 100 percent from the expected occurred.

Ecologically, pretest populations were not significantly different from the expected norm, except in sector 3 where they were lower. Post-test populations were significantly higher than expected in sectors 3, 4, and 5.

*Eleodes armata*. Beetles of this species were present in all sectors except numbers 1 and 8 prior to the detonation (Table 6). Greatest concentrations were in sectors 7, 6, and 5, respectively. One and two months after the detonation they were not found in sectors 2, 3, and 6, but were still most densely concentrated in sectors 5, 6, and 7. Populations immediately after the detonation were diminished by 74 percent. In June 1963, beetles were found only in three sectors, and their populations were 66 percent higher than expected. In August 1963, the population had diminished from the expected norm by 80 percent.

Ecologically, these beetles were significantly more abundant in sectors 5, 6, and 7 before the detonation than was expected.

*Eleodes grandicollis*. Beetles were found only in sectors 1 and 4 before the detonation. One and two months after the detonation beetles were present in sectors 3, 4, 5, and 7, but not

TABLE 6. Effects of a nuclear detonation on populations of beetles of the species *Eleodes armata*.

Sector	Pre-test	No. specimens					
		Posttest					
		Aug.-Sept. 1962		June 1963		Aug. 1963	
		Actual	Expected	Actual	Expected	Actual	Expected
2	4	0	0	1	0	0	1
3	4	0	2	0	0	0	1
4	2	1	1	2	0	0	0
5	12	4	7	0	1	0	2
6	14	0	8	0	1	0	2
7	19	2	10	2	1	2	3
9	7	2	4	0	0	0	1
Total	62	9	32	5	3	2	10

\*Collection attempts not made

in sector 1 as previously found. A decrease of 30 percent from the expected population occurred. In June 1963, no beetles were found, and in August 1963, the population was 75 percent lower than the expected norm.

Ecologically, pretest populations were not significantly different from the expected in any sector, except number 3. Likewise, the posttest population in sector 3 was the only one that differed significantly from the expected norm.

*Eleodes hispilabris*. Beetles of this species were found only in sectors 1 to 5 before the detonation, and only in sectors 1, 2, 3, 6, and 7 after detonation. In no sector were they densely concentrated. One and two months after the detonation the population had diminished from the expected norm by 34 percent. In June 1963, the population was the same as expected, and in August 1963, it had increased over the norm by 50 percent.

Ecologically, pretest populations in sectors 1 to 4 were significantly higher than expected, and posttest populations in sectors 2, 3, 4, and 6 were significantly lower than the norm.

*Eleodes longipilosa*. One specimen was taken in sector 3 after the detonation in June 1963. In other areas of the test site, these beetles were taken in similar vegetative types in May, July, and August, but only in small numbers.

*Eleodes nigrina*. Two specimens were taken in sectors 3 and 4 in August and September 1962, immediately after the detonation, but none at any other time. In other areas of the test site these beetles were taken only in the Pinyon-Juniper community, mainly in August. Their occurrence in the disturbed *Grayia-Lycium* and *Coleogyne* near the Sedan crater was unexpected.

*Eupsophylus castaneus*. Eight beetles of this species were taken in sectors 3, 4, and 5 after the detonation in June 1963. None were taken at other times. In other areas of the test site these beetles were most common in vegetative types other than those near the Sedan crater and, seasonally, were most abundant in May and June.

*Euschides luctatus*. Two specimens were taken in sector 4 immediately after the detonation in August and September 1962. None were found at other times. In other areas of the test site these beetles were relatively common in vegetative types similar to those which surround the Sedan crater, but they were essentially absent between May and September.

*Eusattus agnatus*. Thirteen beetles of this species were taken in sectors 1 to 4 in August 1963; none were taken at other times. In other areas of the test site these beetles were most abundant in the same vegetative types that surround the Sedan crater, but they were absent from June to September.

*Metoponium convexicolle*. Four specimens were found in sectors 3, 5, 6, and 9 after the detonation in June 1963. None were found at other times. In other areas of the test site these beetles were most abundant in the same vegetative types as in the Sedan environs, but their populations were at a minimum in August, with an increase in September.

*Pelecyphorus pantex*. None were found prior to the detonation or in June 1963. Immediately after the detonation in August and September 1962, 46 specimens were found in sectors 3 to 7. In August 1963, 130 beetles were found in all sectors except number 1. In other areas of the test site these beetles were relatively abundant in the same vegetative types as occur around the Sedan crater. Seasonally in other areas, they were most abundant in August and September and essentially absent at other times. This explains their absence in June and July before the detonation, as well as in June 1963.

*Pelecyphorus semilaevis*. Beetles of this species were not found in the Sedan area prior to the detonation. After the detonation in August and September 1962, three specimens were found in sectors 4, 5, and 7. None were found in June 1963, but in August 1963, 16 beetles were found in sectors 1 to 7 and in 9. In other areas of the test site these beetles were common in the same vegetative types that surround the Sedan crater. Seasonally, however, they occurred almost exclusively in August and September. This explains their absence in June and July in the Sedan area.

*Triorophus laevis*. Before the detonation these beetles were present in every sector except numbers 7 and 8 (Table 7). They were most densely concentrated in sector 6. One and two months after the detonation they were found only in sectors 3, 4, 5, and 7, and most densely concentrated in sectors 3 and 4. At that time the population was 1000 percent greater than the expected norm. In June 1963, these beetles were found only in sectors 5 to 8, and their population was 29 percent less than the expected norm. In August 1963, beetles were not found in any sector.

Ecologically, pretest populations were signif-

TABLE 7. Effects of a nuclear detonation on populations of beetles of the species *Triorophus lacvis*.

Sector	Pre-test	No. specimens					
		Aug.-Sept. 1962		Posttest		Aug. 1963	
		Actual	Expected	Actual	Expected	Actual	Expected
1	1	0	0	0	1	0	0
2	4	0	0	0	3	0	0
3	1	20	0	0	1	0	0
4	2	15	0	0	1	0	0
5	1	5	0	5	1	0	0
6	11	0	2	4	8	0	1
7	0	4	0	4	0	0	0
8	0	0	0	2	0	0	0
9	9	0	1	0	6	0	1
Total	29	44	3	15	21	0	2

\*Collection attempts not made.

icantly lower in sectors 3 and 4 and higher in sector 6 than was expected. After the detonation, the only significant difference was a decrease in the population below that expected in sector 3.

*Trogloclerus costatus*. Beetles of this species were present only in sectors 1 and 2 before the detonation. One and two months after the detonation they were found only in sectors 3, 4, and 5. In that period their populations were only 23 percent less than the expected norm. In June 1963, the populations were 100 percent above the norm and, in August 1963, 307 percent above the expected.

Ecologically, these beetles had a lower pretest population in sectors 3 and 4 than expected, but after the detonation their populations in sectors 1 to 4 were significantly higher.

*Changes within Sectors*. Some significant differences occurred between the population trends in different sectors during the posttest recovery time. Populations generally and consistently were less than the expected normal but for few exceptions. In August 1963, the population in sector 2 was 13 percent above the expected, whereas in sector 8 it was 400 percent higher. At other posttest times in these two sectors the populations were considerably less than the expected normal. However, sectors 3 and 4 had posttest population increases during each sampling date except one, June 1963, when the population was only 7 percent less than expected. At other times the population was from 125 percent to 291 percent above the expected normal. As indicated by analysis of the vegetation, sector 3 was in the fringe area where the plants were destroyed and/or covered by a shallow layer of soil throw-out. Sector

4 was typified by a removal of most of the vegetation by flying debris, with a small amount of throw-out deposition. Pretest populations in sectors 1 and 2 were moderate and in sectors 5 and 9 generally were high. Except for sector 8, pretest populations of sectors 3 and 4 were lowest of all sectors. The hypothesis is presented that the unexpected increase in posttest populations in sectors 3 and 4 may have been due to physical transport by the force of the detonation of beetles from sectors 1 and 2 to sectors 3 and 4. Furthermore, as a result of reverse air movement immediately after the detonation, some beetles may have been carried back towards sectors 3 and 4 from the more outlying sectors where populations were highest. Because of the tough protective exoskeleton and nature of these beetles, one may assume that they were able to withstand the shock and buffeting. This hypothesis is supported by a change of species distribution in the sectors. In sector 3 in August and September 1963, four species were present that were not taken in this sector before the detonation. Two of these were present before the test in sectors 1 and 2, one was present in sector 4, and the other was not found prior to the test. In sector 4, six species were found posttest that were apparently not there pretest. Two of these were present in adjacent sectors before the detonation, but the other four were not found prior to the detonation.

Complete or nearly complete elimination of the population occurred in five of the sectors at some period after detonation. A reduction of 100 percent occurred in August and September 1962 in sectors 2 and 8, and June and August 1963 in sector 9. Ninety-four percent reduction was noted in sector 6 in August

and September 1962, and 96 percent in sector 5 in August 1963.

Total populations of all species of tenebrionid beetles were 58 percent lower than the expected normal in August and September 1962, 61 percent lower in June 1963, and 58 percent lower in August 1963.

Beetles of eight species were found both before and after the detonation. Six other species were found after the test that apparently were not present before (Table 8). Seasonally and ecologically, four of these should have been present before the detonation, whereas the other two were not expected. However, five of the species were expected to be present after the test, but one species found after was unexpected. Heretofore *Eleodes nigrina* was found only in the Pinyon-Juniper community, and its occurrence in the *Grayia-Lycium* and *Coleogyne* communities was unforeseen.

Species stabilization in the sectors was greatly upset during the postshot periods of August and September 1962 and June 1963 (Table 9). By August 1963, the numbers of kinds of species had become somewhat stabilized, but in lower numbers than during the predetonation time.

*Conibiosoma elongatum* was taken before the detonation in sector 9 but not after in any sector. This species was taken from June to September in similar vegetative types in other areas of the test site; so its disappearance was unexpected.

*Grid vs. Transect Extrapolation.* Results between the main transect stations and the grids could not be correlated relative to the numbers of beetles captured. On the basis of adjustment to the number of can traps used in each grid and the respective sectors of the main transect, considerable differences were noted. In June 1963, the transect cans caught 190 percent and 55 percent more beetles, respectively, than did the grid cans in regions 1 and 3. At the same time in region 2, the transect cans caught 9 percent less than did the grid cans.

In August 1963, the grid cans consistently caught more beetles than did the transect cans—20 percent, 57 percent, and 37 percent more in regions 1, 2, and 3, respectively.

In July and August 1963, when the grids and transect were utilized simultaneously, beetles of 19 species were collected. Six of these were found only in those cans arranged as a grid, whereas 13 were captured in cans on the

TABLE 8. Species of tenebrionid beetles found after but not prior to a nuclear detonation.

Species	Sector where found	Date	Presence Expected
<i>Eleodes nigrina</i>	4	Aug.-Sept. 1962	no
<i>Eupsophylus eastaneus</i>	3,4,5	June 1963	yes
<i>Euschides luctatus</i>	4	Aug.-Sept. 1962	yes
<i>Metoponium convexicolle</i>	3,5,6,9	June 1963	yes
<i>Pelecyporus pantex</i>	2 to 9	Aug.-Sept. 1962	yes
		Aug. 1963	
<i>Pelecyporus semilaevis</i>	1 to 7,9	Aug.-Sept. 1962	yes
		Aug. 1963	

TABLE 9. Number of species of tenebrionid beetles found in specific sectors pretest and posttest Sedan.

Sector	Pretest	Posttest		
		Aug.-Sept. 1962	June 1963	Aug. 1963
1	5	0	3	3
2	5	0	2	4
3	5	6	4	3
4	5	10	5	3
5	4	7	6	3
6	5	2	3	3
7	3	8	3	3
8	1	0	2	2
9	3	3	1	2

\*Collection attempts not made.

main transect and on the grid. None were taken on the transect that were not also taken on the grids.

*Crater Occupants.* Minimal populations of beetles of five species were found in the bottom of the Sedan crater in July and August 1963, one year after the detonation. These were *Centrioptera muricata*, *Chilometopon abnorme*, *Coelocnemus sulcata*, *Eleodes armata*, and *Eleodes hispilabris*. Three of these were previously taken in the environs of the Sedan crater. *Coelocnemus sulcata* was not reported from the test site heretofore, whereas *C. abnorme* was reported previously from other areas of the site. *Centrioptera muricata* was taken before the test on transect F in sector 2, approximately 488m from the lip of the resulting crater. *Eleodes armata* was taken before the detonation within 488m of the crater and *E. hispilabris* within 183m of the crater.

### Ants

*Aphaenogaster megommatus.* Ants of this species were not found prior to or immediately after the test, but a single specimen was taken in June 1963 in sector 7. The usual habitat of this species is not the vegetative types that occur in the environs of the Sedan crater but is commonly the *Larrea-Franseria* community. Seasonally these ants were most active above ground in July and August, and only one specimen was taken elsewhere on the test site in June.

*Crematogaster coarctata.* Two ants of this species were taken in sectors 3 and 9 prior to the test, and only one was taken on the grid in sector 2 in August 1963. This species was not commonly found elsewhere at the test site in the vegetative types peculiar to the Sedan crater environs, although seasonally it was abundant from June to August in other areas.

*Iridomyrmex pruinosum.* Animals of this species were present in small numbers in sectors 1, 2, 5, 8, and 9 prior to the test. After the test in June 1963, three specimens were found in sector 7. Elsewhere on the test site this species was common in the same vegetative types as those which surround the Sedan crater. Seasonally it was most common in June and July, but rapidly diminished in above-ground activity in August.

*Myrmecocystus mexicanus.* Ants of this species were present in sectors 4 to 9 prior to the detonation (Table 10). One and two months after the detonation none were found in any sector except 4 and 9. In June 1963, ants were found in sectors 5 to 7. In sector 6, 175 percent more ants were found than expected. In August 1963, ants were found in sectors 3, 7, and 8; none were expected in sector 3. In other sectors, except 7, fewer animals were found than expected. An increase of 175 percent occurred in sector 7. Considering all sectors at the period of one and two months after the detonation, populations were 94 percent less than expected; in June 1963, 42 percent more; and in August 1963, 55 percent less.

Ecologically, pretest and posttest populations were significantly lower than expected in all sectors except numbers 1 and 2.

*Myrmecocystus mimicus.* Ants were present in sectors 2, 5, 7, 8, and 9 before the detonation (Table 11). One and two months after the test, specimens were found only in sector 9. In June 1963, ants were present in sectors 5, 7, and 8, and in sectors 5 and 7 in August 1963. In sector 8 in June 1963 twice as many ants were present as expected, and in August 1963 in sector 5, 4½ times more ants were present than expected. One and two months after the detonation, populations in all sectors had diminished from the expected by 84 percent. In

TABLE 10. Effects of a nuclear detonation on populations of ants of the species *Myrmecocystus mexicanus*.

Sector	Pre-test	No. specimens					
		Aug.-Sept. 1962		Posttest		Aug. 1963	
		Actual	Expected	Actual	Expected	Actual	Expected
3	0	0	0	0	0	1	0
4	2	1	4	0	2	0	2
5	9	0	17	4	5	0	9
6	7	0	12	11	4	0	7
7	5	0	8	2	3	11	4
8	2	0	2	0	1	2	2
9	7	2	12	0	4	0	7
Total	32	3	55	17	19	14	31

TABLE 11. Effects of a nuclear detonation on populations of ants of the species *Myrmecocystus mimicus*.

Sector	Pre-test	No. specimens					
		Aug.-Sept. 1962		June 1963		Aug. 1963	
		Actual	Expected	Actual	Expected	Actual	Expected
2	1	0	0	0	3	0	1
5	4	0	4	1	1	9	2
7	18	0	16	2	5	4	11
8	5	0	5	2	1	0	3
9	7	5	6	0	2	0	4
Total	35	5	31	5	12	13	21

\*Collection attempts not made.

June 1963 the population was 58 percent lower, and in August 1963, 38 percent lower than expected.

Ecologically, pretest and posttest populations were not significantly different from the expected norm, except in sector 7, where the population before the test was higher than expected.

*Pheidole bicarinata*. Before the detonation, ants were found in all sectors except number 9 (Table 12). None were found one and two months later. In June 1963, ants were found only in sectors 4 and 5 and none were found in any sector in August 1963. A 100 percent reduction from the expected occurred one and two months after the detonation, whereas the populations in June 1963 were 75 percent lower, and in August, 100 percent lower than expected.

Ecologically, the only significant deviation from the expected norm was in sector 2 before the detonation, when populations were higher than expected.

*Pogonomyrmex californicus*. Ants of this species were found in every sector except number 9 before the detonation (Table 13). One and

two months after the detonation they were found in sectors 4, 5, 6, and 9. In June 1963, they were found in all sectors except numbers 7 and 8, but in August 1963, only in sectors 1 to 5. One and two months after the detonation the population was only 23 percent less than expected, in June 1963 it was 46 percent less, and in August 1963 it had diminished by 76 percent.

Ecologically, populations in most sectors before the test were significantly different from the expected norm. In sectors 1, 2, and 9 they were lower than expected, whereas in sectors 3 and 5 they were higher. After the detonation, populations in all sectors except 5 and 6 were lower than the expected norm, whereas in sector 5 the population was higher. No significant change from the expected occurred in sector 6.

*Pogonomyrmex rugosus*. Only one specimen of this species was found before the detonation in sector 9. One and two months after the detonation, two specimens were found in sector 9. None were found in June and August 1963. In other areas of the test site ants of this species

 TABLE 12. Effects of a nuclear detonation on populations of ants of the species *Pheidole bicarinata*.

Sector	Pre-test	No. specimens					
		Aug.-Sept. 1962		June 1963		Aug. 1963	
		Actual	Expected	Actual	Expected	Actual	Expected
1	1	0	0	0	1	0	0
2	7	0	0	0	3	0	1
3	2	0	1	0	1	0	0
4	1	0	0	1	1	0	0
5	5	0	1	2	2	0	1
6	4	0	1	0	2	0	1
7	2	0	1	0	1	0	0
8	2	0	1	0	1	0	0
Total	24	0	5	3	12	0	3

\*Collection attempts not made.

TABLE 13. Effects of a nuclear detonation on populations of ants of the species *Pogonomyrmex californicus*.

Sector	Pre-test	No. specimens					
		Aug.-Sept. 1962		June 1963		Aug. 1963	
		Actual	Expected	Actual	Expected	Actual	Expected
1	4	0	0	1	3	3	3
2	3	0	0	3	1	1	1
3	40	0	22	5	13	3	17
4	14	6	9	1	5	1	7
5	28	25	18	6	10	4	14
6	7	14	4	4	3	0	3
7	5	0	4	0	3	0	3
8	5	0	4	0	3	0	3
9	0	2	0	2	0	0	0
Total	106	47	61	22	41	12	51

\*Collection attempts not made.

were most abundant in the *Coleogyne* and *Grayia-Lycium* communities, where seasonally their above-ground activity was greatest from June to September.

*Veromessor lariversi*. Seven ants of this species were found in sector 5 before the detonation. None were found after the tests except on the grid in sector 2, where two specimens were taken in June 1963. In other areas of the test site, ants of this species were inhabitants principally of Pinyon-Juniper areas and were most active in June and July.

*Veromessor smithi*. Five ants of this species were found only in June 1963 after the detonation in sectors 5 and 6, and on the grid of sector 8. In other sections of the test site these ants were taken infrequently in few numbers only in the *Coleogyne* community in June.

*Changes within Sectors*. In August and September, 1962, populations in all sectors were consistently less than the expected normal, except in sector 6 where they were the same as

expected. In June 1963, all populations were less than the expected normal, except in sector 6 where they were 200 percent higher. All populations in August 1963 were less than the expected norm.

Pretest populations were lowest in sectors 1 and 2 and highest in sectors 3 and 5.

No significant changes in species composition occurred in the sectors by August and September immediately after the test. However, in sector 9 one species was found after the detonation that was not taken prior to the test. Most changes were noted in June 1963, when three species were found in sectors 5, 6, and 7 that had not been found there previously. Similarly, two species were found in August 1963, in sectors 2 and 3. Eight species were found before the detonation, only four in August and September immediately after the detonation, seven in June 1963, and only four in August 1963 (Table 14). One species, *Veromessor lariversi*, taken in sector 5 before the detonation, was never taken subsequently, and

TABLE 14. Number of species of ants found in specific sectors pretest and posttest Sedan.

Sector	Pretest	Posttest		
		Aug.-Sept. 1962	June 1963	Aug. 1963
1	3	0	1	1
2	4	0	1	2
3	3	0	1	2
4	3	2	2	1
5	6	1	5	2
6	3	1	2	0
7	4	0	4	2
8	5	0	1	1
9	5	4	1	0

\*Collection attempts not made.

two species, *Aphaenogaster megommatus* and *Veromessor smithi* in sectors 5 and 7, taken in June 1963, were not found at any other time.

Complete or nearly complete elimination of the population occurred in eight of the sectors at some period after the detonation. A reduction of 100 percent occurred in August and September 1962 in sectors 1, 2, 3, 7, and 8, and in August 1963 in sectors 6 and 9. Ninety percent reduction was noted in sector 4 in August 1963. In June 1963, populations in general were not reduced as drastically as at other times. In fact, in sector 6 in June 1963, a 200 percent increase in population occurred when compared to the expected norm. Similarly, the population in sector 6 in August and September 1962 was the same as anticipated.

Total populations of all species of ants were 64 percent lower in August and September 1962 than the expected normal, only 30 percent lower in June 1963, but 69 percent lower in August 1963.

*Grid vs. Transect Extrapolation.* One specimen of *Myrmecocystus mexicanus* was taken on the grid in sector 8 in June 1963 and one on the grid in sector 4 in August 1963, although beetles of this species were not taken on the main transect in that sector. Similarly, other species taken on the grids but not on the corresponding transect in 1963 are *Crematogaster coarctata* and *M. mimicus* in sector 2 in August, *Pheidole bicarinata* in sector 2 in June, and *Veromessor smithi* in sector 8 in June. None were found on the transect that were not also taken on the corresponding grid.

### Orthopterans

The few specimens of this group collected in June and August 1963 have not as yet been identified to species. Consequently, effects of the detonation on these insects are discussed only for the immediate posttest period of August and September 1962.

*Arenivaga erratica.* Roaches of this species were found in all sectors except 5, 8, and 9 before the detonation. After the test, the specimens which were found only in sectors 3, 4, 5, and 9 represented a 450 percent increase above the number expected. In other areas of the test site roaches of this species were abundant in the same vegetative types as those which occur in the environs of the Sedan crater. Seasonally, however, populations of these roaches were at low levels during August and September.

*Ceuthophilus fossor.* Crickets of this species were found in sectors 1 to 7 (except 6) before

the detonation. After the test they were found only in sector 9 in small numbers. In other areas of the test site these insects were most common in the same vegetative types that occur around the Sedan crater. Seasonally they were most abundant from March through July, and in few numbers in August and September. This seasonal variation likely accounts for the few numbers found immediately after the detonation in the Sedan area.

*Ceuthophilus lamellipes.* These crickets were found in all sectors except numbers 2 and 7 before the detonation. Afterward, they were found in all sectors except number 6. Their numbers after the test were diminished by 97 percent from the expected normal. In other areas of the test site these crickets were most abundant in the same vegetative types that occur in the environs of the Sedan crater. Seasonally they were most abundant from August to November. Consequently, such few numbers after the detonation seem significant.

*Litaneutria minor.* Three praying mantids were found only in sectors 1, 5, and 6 before the detonation; none were found after. In other parts of the test site these insects were most abundant in *Coleogyne*, which also occurs in the area of the Sedan crater. Seasonally they were relatively abundant during August and September. Their apparent absence after the test likely was due to normal low populations in this particular area.

*Stenopelmatus fuscus.* Before the detonation, Jerusalem crickets were found only in sectors 1 to 5. After the test they were taken in sectors 3 to 9, except 7 and 8. In all sectors except 3 and 5 the numbers found were greater than expected. Considering all sectors, populations increased by 36 percent over the expected. In other areas of the test site these crickets were most abundant in *Grayia-Lycium* and Pinyon-Juniper areas. Their populations were low in other vegetative types. Seasonally they were most abundant from May to August and in October. Consequently, their high populations in the environs of the Sedan crater in August and September were expected.

*Changes within Sectors.* In August and September 1962, populations in all sectors except number 7 were considerably less than the expected normal. In sector 7 an increase in numbers occurred. Considering all species and all sectors, a 93 percent reduction in population occurred after the detonation.

Before the detonation, species distribution was about equal between all sectors except num-

bers 8 and 9, which had only one species present. After the detonation, numbers of species were concentrated in sectors 3, 4, 5, and 9. Three of the four species in sector 9 after the test were found no closer than sectors 5 and 7 prior to the test.

### Scorpions

*Hadrurus spadix.* Scorpions of this species were found in few numbers and only in sectors 1, 4, and 5 before the detonation. In August and September 1962 (after the test) they were found in greater numbers than expected and only in sectors 3 and 5. In June and August 1963, they were found in few numbers in sector 7. In no sector did the numbers deviate significantly from the expected, either before or after the detonation. In other areas of the test site these scorpions were most abundant in the *Artemisia* and Mixed plant associations, types which were not common in the environs of the Sedan crater. Seasonally over the test site these animals were active from April to October, predominantly in July.

*Vaejovis beeki.* Before the detonation these scorpions were found in sectors 3 to 9, except 4. After the test in August and September 1962, the scorpions were found only in sectors 3, 4, 5, and 7. In June 1963, they were found only in sector 7, and in August 1963, only in sector 8. In no sector did the numbers found deviate significantly from the expected, either before or after the detonation. In other areas of the test site these scorpions were abundant in the same vegetative types that occur in the environs of the Sedan crater. Seasonally they were collected from March to September, predominantly from June to August.

*Vaejovis boreus.* Scorpions of this species were not found in the Sedan area prior to the detonation. In August and September 1962 they were found in sectors 3, 4, and 5, but none were found in June or August 1963. The numbers present in the sectors did not deviate significantly from the expected, either before or after the detonation. In other areas of the test site these scorpions were not abundant in the *Grayia-Lycium* community and were not found at all in the *Coleogyne* and *Salsola* communities. Seasonally they were taken from June to September, and predominantly from July to September.

*Vaejovis confusus.* Before the detonation these scorpions were found in all sectors except numbers 6 and 8. In August and September 1962 they were found in sectors 3, 4, 5, and 7. In that latter period, populations had in-

creased by 438 percent above the expected. In June 1963, scorpions were found in sectors 2 to 7 (except number 6), and in August 1963 only in sectors 1, 2, 5, and 9. Significant differences from the expected occurred in sectors 1 and 2 before the detonation and in sectors 3, 4, 5, and 7 after the detonation, when more scorpions were found than expected. In other areas of the test site, scorpions of this species were moderately abundant in the similar vegetative types that occur in the environs of the Sedan crater. Seasonally, specimens were taken from March to November, predominantly from June to August.

*Changes within Sectors.* Significant differences occurred in populations in sectors 6, 8, and 9 in August and September 1962, when numbers were reduced by 100 percent. Similar reductions occurred in sectors 1, 6, 8, and 9 in June 1963 and in sectors 3, 4, 6, and 7 in August 1963. Significant changes occurred in sectors 3, 4, 5, and 7 in August and September 1962, with increases of 575 percent, 950 percent, 350 percent, and 125 percent, respectively. Only one significant increase occurred in June 1963—sector 7 with 166 percent. No increases were noted in August 1963. Considering all sectors, populations in August and September 1962 increased 160 percent but decreased by 50 percent and 72 percent in June and August 1963, respectively, from the expected normal.

Species composition in the sectors before the test varied from one to three. In August and September 1962, sectors 3 and 5 contained all four species, but in June and August 1963, no sector contained more than one species, except sector 7, which had three in June.

*Crater Occupants.* One specimen of *Hadrurus spadix* was found in the bottom of the crater in July 1963.

*Grid vs. Transect Extrapolation.* Scorpions of *Hadrurus spadix* were found on the grids in sector 2 in August, sector 4 in June and August, and sector 8 in June, but not on the corresponding parts of the main transect. Those belonging to *Vaejovis beeki* were found on the grids in sectors 2 and 4 in August, but not on the transect. Scorpions of *V. confusus* were taken on the grids in sector 8 in June and sectors 4 and 8 in August, but not on the corresponding transect.

### Solpugids

*Branchia potens.* These solpugids were found in few numbers and only in sector 8 before the detonation. None were found after.

In other areas of the test site, these organisms were found in the *Coleogyne* and *Grayia-Lycium* communities in relative abundance from June to September, predominantly in June and July. Their seasonal limitations likely explain their absence in August and September, but not their absence in June 1963.

*Eremobates scopulatus*. These specimens were found only in sector 1 before the test; none were found after. In other areas of the test site these animals were present in the similar vegetative types that occur in the area of the Sedan crater, found predominantly in May, but also present in June and July. This seasonal limitation likely explains their absence in June and August after the test.

*Eremorhax pulcher*. This solpugid was found only in sector 4 prior to the detonation; none were found after except on the grid in sector 2. In other areas of the test site this new species, described by Muma (1963), was taken in few numbers in the *Grayia-Lycium* and *Salsola* communities in June and July.

*Hemerotrecha californica*. Solpugids of this species were found before the detonation in sectors 2, 3, 5, 6, and 7. None were found after the test. In other parts of the test site these animals were most abundant in the *Coleogyne* and *Grayia-Lycium* communities, but none were found in *Salsola*. Seasonally they were taken from April to September, predominantly in June. Their absence in the sectors in June 1963 was unexpected.

*Hemerotrecha proxima*. This species described as new by Muma (1963) was represented by specimens found in sector 8 after the test, but only in August and September, 1962. In other areas of the test site the few specimens of this species that were taken were predominantly in the *Grayia-Lycium* community in October. Their occurrence in sector 8 was expected, but not so early in the season.

*Hemerotrecha serrata*. A single specimen was found in sector 2 before the test, but none after. In other areas of the test site these solpugids were commonly found in the same vegetative types that occur in the environs of the Sedan crater. Seasonally they were found from June to September, predominantly in July and August.

*Changes within Sectors*. The almost complete absence of solpugids in any of the sectors after the detonation is indicative of the tremendous influence of the detonation on solpugids, although seasonal differences must be

considered as somewhat influential also on their occurrence.

*Crater Occupants*. Specimens of two species taken from the crater in August 1963 were not found on the main transect, but one of the species was taken on the grids in sectors 2 and 4. One specimen each of *Eremobates zinni* and *Therobates cameronensis* was found in the crater in August 1963. In other areas of the test site *E. zinni* was the most abundant in the *Grayia-Lycium* community and was also found in *Salsola*; none was taken in *Coleogyne*. Seasonally this species was found only in July and August. *Therobates cameronensis* was found in moderate abundance in *Coleogyne* and *Grayia-Lycium* but not in *Salsola*. It occurred from May to July.

*Grid vs. Transect Extrapolation*. Only one species of solpugids was taken on the grids but not on the main transect—*Eremobates zinni*, taken in sectors 2 and 4 in August 1963. A specimen of *Eremorhax pulcher* was taken from the grid in sector 2 in August 1963, but not on the corresponding parts of the transect.

## Spiders

*Calilena restricta*. A single specimen was taken in sector 6 before the test. None were taken after. In other areas of the test site these spiders were only moderately abundant in the *Grayia-Lycium* community. They were active from February to December, predominantly from June to November.

*Gnaphosa hirsutipes*. Only three spiders of this species were taken before the test, all in sector 7. None were taken after. In other areas of the test site these spiders were relatively abundant in the same vegetative types that occur in the environs of the Sedan crater. They were active from February to November, predominantly in June and July.

*Haplodrassus eunis*. Three specimens of this spider were taken in sectors 2 and 3 before the detonation. None were found after. In other areas of the test site these spiders were common in undisturbed vegetation of the types that occur in the environs of the Sedan crater. They were active all months of the year, but in predominant numbers only in the nonsummer months of October to April.

*Herpyllus hesperolus*. A single spider of this species was taken in sector 8 before the test, and one specimen was taken after the detonation in sector 7 and in August 1963. One specimen was taken on the grid in sector 2

in June 1963. In other areas of the test site these spiders were relatively abundant in undisturbed vegetation of the types which occur in the area of the Sedan crater. Seasonally they were active the year around, but predominantly in April. Few were taken from June to August.

*Loxosceles unicolor*. Spiders of this species were not found prior to the detonation. After the test, a single specimen was found in sector 8 in June, and two in sectors 2 and 7 in August 1963. These spiders were not found in other areas of the test site in the same vegetative types that occur near the Sedan crater. They were found predominantly in the Mixed type of vegetation from April to September, predominantly in July and August.

*Megamyrmecon naturalisticum*. Spiders of this species were found before the test in sectors 2 and 7. None were found after. In other areas of the test site these spiders were most common in the *Coleogyne* community from April to September, predominantly in June and July.

*Neoanagraphis chamberlini*. Spiders of this species were taken before the test in all sectors except number 9. The only ones found after the test were taken in sectors 2, 6, and 8 in June, and in sector 4 in August 1963. In other areas of the test site these spiders were common in the *Coleogyne*, *Grayia-Lycium*, and *Salsola* communities. They were active from February to October, predominantly from June to October.

*Orthonops gertschi*. These spiders were found before the test in sectors 5, 7, and 9. None were found after. In other areas of the test site spiders of this species were not abundant in the vegetative types common to the Sedan

area. They were active from March to September, predominantly from April to July.

*Physocyclus tanneri*. Only one specimen of this species was taken before the test, in sector 6. None were found after. In other areas of the test site these spiders were not abundant and were found only in August.

*Psilochorus utahensis*. Spiders of this species were the most abundant ones represented in the Sedan area. They were found before the test in all sectors, predominantly in sectors 6 and 7 (Table 15). One and two months after the detonation they were not found at all. In June 1963, they were found in all sectors except numbers 1 and 2, and in August 1963, they were found on the grids in sectors 2 and 8. Considering all sectors, their 100 percent reduction in numbers from the expected norm in August and September 1962 and in August 1963 is significant. Likewise, in June 1963 their populations were reduced by 50 percent. In other areas of the test site these spiders were predominant in the same vegetative types that occur around the Sedan crater. Seasonally they were active all year, predominantly from June to August. Ecologically, before the test, in all sectors populations of this spider were higher than expected. After the detonation, populations were not generally different from the expected.

*Syspira eclecticica*. Spiders of this species were found before the test only in sectors 8 and 9. None were found after. In other areas of the test site, these spiders were not common in the same vegetative types that occur around the Sedan crater. They were active from April to November, predominantly from May to August.

*Changes within Sectors*. Significant differences from the expected occurred in August and

TABLE 15. Effects of a nuclear detonation on populations of spiders of the species *Psilochorus utahensis*.

Sector	Pre-test	No. specimens					
		Aug.-Sept. 1962		Posttest		Aug. 1963	
		Actual	Expected	June 1963 Actual	Expected	Actual	Expected
1	8	°	°	0	4	0	2
2	4	°	°	0	2	0	1
3	7	0	3	1	4	0	2
4	8	0	3	0	4	0	2
5	7	0	3	4	4	0	2
6	21	0	9	4	10	0	7
7	19	0	8	5	9	0	6
8	7	0	3	7	4	0	2
9	7	0	3	2	4	0	2
Total	90	0	32	23	36	0	26

\* Collection attempts not made

September 1962 in sectors 6 and 7, where a 100 percent reduction in population occurred. In June 1963, reductions of 100 percent occurred in sectors 1 and 4, whereas in sectors 5, 6, and 8 populations were much higher than expected. In August 1963, 100 percent reductions from the expected occurred in all sectors except 2 and 7, where the actual numbers were equal to the expected. Considering all sectors, populations in August and September 1962 decreased by 100 percent, increased 33 percent in June 1963, then decreased by 80 percent in August 1963 from the expected normal.

Species composition in the sectors before the test varied from 2 to 5. In June 1963, sectors 3, 5, 7, and 9 each contained only one

species, whereas sectors 6 and 8 each contained two. In August 1963, sector 7 contained two species.

*Grid vs. Transect Extrapolation.* Spiders of *Hicrpyllus hesperolus* were not found on the main transect in sector 2 in June, but were found on the corresponding grid. Those of *Loxosceles unicolor* were not found on the transect in sector 2 in August, but were found on the grid. Spiders of *Neoanagraphis chamberlini* were not found on the transect in sectors 2, 4, and 8 in June and August, but were found on the grids. *Psilochorus utahensis* was not found on the transect in sectors 2 and 8 in August and sector 4 in June, but was found on the corresponding grids.

SUMMARY

Fifty-three arthropod species were studied in an area affected by an underground nuclear detonation. These were represented by 10 species of ants, 17 beetles, 5 orthopterans, 4 scorpions, 6 solpugids, and 11 spiders (Table 16). Relative populations were determined prior to the detonation and at three periods after the detonation—(1) one and two months after (August and September 1962), (2) 11 months after (June 1963), and (3) 13 months after (August 1963). One and two months after the detonation, the number of species was reduced from the expected by 48 percent, by 52 percent after 11 months, and by 66 percent after 13 months. Greatest reduction of specimens occurred with spiders, followed by ants and beetles. Fewest changes occurred in the number of scorpions.

Populations of each group changed significantly in each period. Reductions from 30 percent to 100 percent occurred in all groups in all periods after the detonation except for the scorpions one and two months after, when an increase of 160 percent was noted. After 11 months spiders had increased 33 percent (Table 17).

Within specific sectors, populations did not vary significantly from the expected except in a few instances. In August and September 1962, immediately after the detonation, populations of arthropods in sectors 3, 4, and 5 were much higher than expected. This represented the area from approximately 65m to 140m from ground zero. The increase may have been due primarily to the physical transport and initial survival of those arthropods living closer

TABLE 16. Effects of a nuclear detonation on species occurrence of arthropods in the disturbed area.

Category	No. Species						Total
	Ants	Beetles	Orthoptera	Scorpions	Solpugids	Spiders	
Total no. involved	10	17	5	4	6	11	53
Pretest							
Expected	10	14	5	4	5	10	48
Present	8	9	5	3	4	10	39
Posttest Aug.-Sept. 1962							
Expected	9	16	5	4	3	11	48
Present	4	12	4	4	1	0	25
Posttest June 1963							
Expected	10	11	4	4	5	10	44
Present	7	8	•	3	0	3	21
Posttest Aug. 1963							
Expected	9	15	5	4	2	9	44
Present	3	8	•	2	0	2	15

\*Data not available.

to ground zero than 65m. Similarly, slight increases were noted in sectors 7 and 9, but these likely were not significant. In June 1963 in sector 5 and in August 1963 in sector 3, slight

increases in populations were noted. These may have been due to seasonal differences correlated with vegetative type, and are also not considered significant.

TABLE 17. Population trends of arthropods affected by a nuclear detonation.

Group	Percent change from expected normal		
	Aug.-Sept. 1962	June 1963	Aug. 1963
Ants	- 64	- 30	- 69
Beetles	- 58	- 61	- 58
Orthoptera	- 93	•	•
Scorpions	+160	- 50	- 72
Solpugids	- 90	-100	-100
Spiders	-100	+ 33	- 80

\*Data not available

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