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"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

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CONTENTS

ERRATUM

McGriff, Darlene and John Modin. 1983. *Thelohania contejeani* parasitism of the crayfish, *Pacifastacus leniusculus,* in California. Calif. Fish Game, 69(3): 178–183.

Page 182. Second sentence of second paragraph should read:
"However, O'Keeffee and Reynolds (in press), using microscopic examination, found that up to about 4.0% of *Austropotamobius pallipes* infected with *Thelohania* in Ireland eluded detection by macroscopic examination."

Calif. Fish and Game 70(2): 68–77 1984

VARIATION IN TROPHIC STATE INDICATORS IN TWO NORTHERN CALIFORNIA RESERVOIRS [1]

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Monitoring of certain limnological parameters has been conducted in Paradise and Magalia Reservoirs since 1974 to determine if enlargement of Paradise Reservoir or increased development in the watershed would lead to a deterioration of water quality. Increased levels of nitrogen and phosphorus compounds and phytoplankton in 1976 suggested enrichment was occurring. However, from 1976–1980, these parameters returned to their 1974 levels. This reversal can best be explained by an increased flushing rate due to abnormally high rainfall.

INTRODUCTION

Paradise and Magalia are two water supply reservoirs in the foothills of the Sierra Nevada at 780 m and 680 m elevation, respectively (Figure 1). These reservoirs, owned by the Paradise Irrigation District, are the primary source of domestic water for the city of Paradise. Magalia and Paradise Dams impound flow in Little Butte Creek (Figure 1). Magalia Dam, constructed in 1917, is located 4 km downstream from Paradise Dam and is a 30 m high hydraulic-fill structure. Paradise Dam, constructed in 1954 and enlarged in 1976 is a 52 m high rolled, earth-fill structure. Annual discharge from Magalia Dam has ranged from 3,430,377 m^3 to 27,090,236 m^3 in the last 10 years. Development of large tracts of mountainous land in the Little Butte Creek watershed above the reservoirs and the concomitant problem of waste disposal have been a cause for concern to the Butte County Health Department and the Paradise Irrigation District. In 1971–73, the California Department of Water Resources (DWR) conducted an investigation of surface and groundwater in the watershed and identified certain limnological parameters which needed regular monitoring: concentration of nitrogen and phosphorus compounds in the surface and bottom waters and volume of phytoplankton in the two reservoirs during March–May. Since this would encompass spring turnover, nutrients and phytoplankton populations would be at their highest levels.

These parameters have been measured biennially since 1974. In addition dissolved oxygen, temperature and conductivity were recorded. During this period Paradise Dam was raised approximately 8 m, increasing reservoir capacity from 7.9×10^6 m^3 to 14.2×10^6 m^3. The purpose of this study was to monitor changes in these limnological parameters which could result from the reservoir enlargement as well as the continued increase in the human population in the watershed. If significant change occurred, Paradise Irrigation District would be able to initiate corrective measures to prevent further deterioration.

[1] Accepted for publication November 1982.

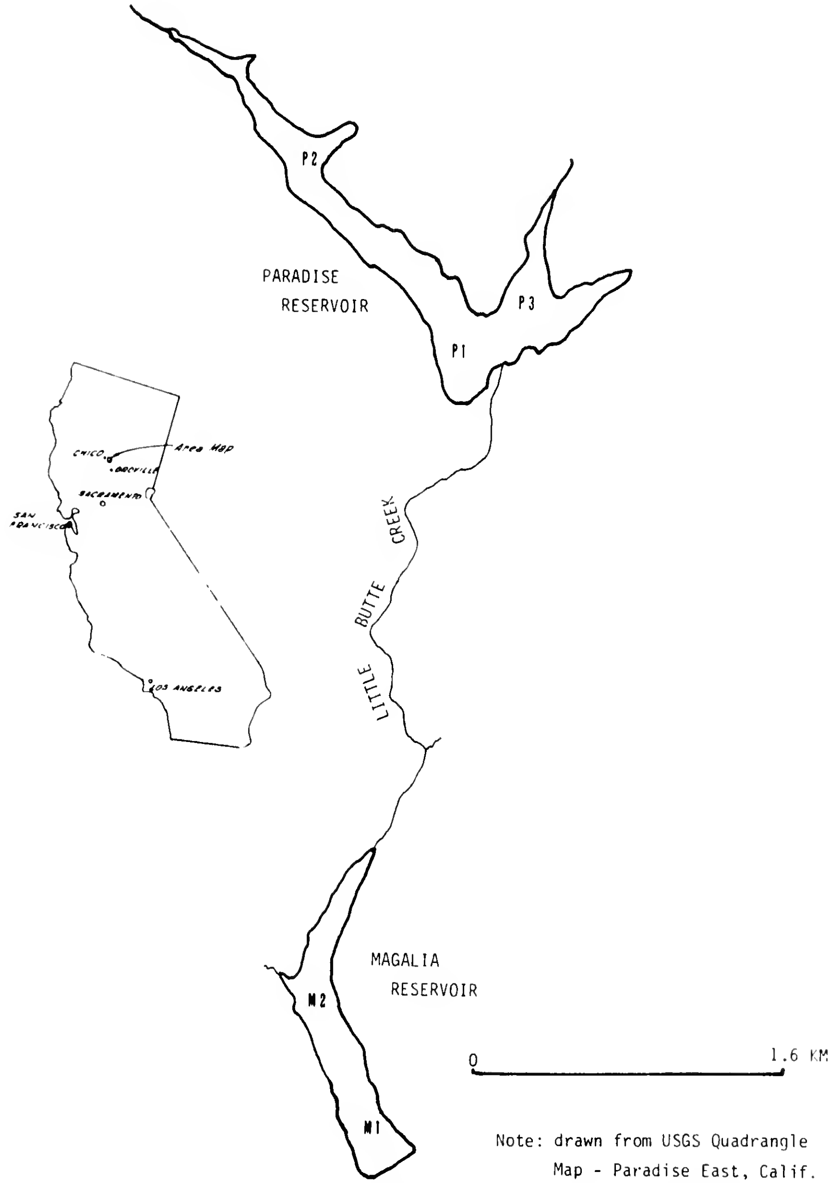


FIGURE 1. Location of Paradise and Magalia Reservoirs in northern California and location of sampling stations.

METHODS

Water samples were collected from the top and bottom metre of the water column at three stations in Paradise and two stations in Magalia Reservoir (Figure 1). These were frozen until analysis could be done. Organic nitrogen was determined by the total Kjeldahl method followed by nesslerization (APHA

1975). The nessler method is sensitive to 20 μg/l ammonia nitrogen. Nitrate nitrogen was determined by the Brucine method (APHA 1975), which is recommended for concentrations from 0.1–1 mg NO_3—N/l. Total nitrogen was obtained by adding the organic nitrogen results and the nitrate-nitrogen results. Data for 1972 was taken from the DWR reservoir study.

Total phosphorus was determined by a persulfate digestion followed by the ascorbic acid method (APHA 1975), which is sensitive to concentrations as low as 10 μg P/l.

Phytoplankton were collected at one station in each reservoir with a Wisconsin net pulled vertically through the water column (1974, 1978, 1980) or with a Van Dorn water sampler at 5 m intervals (1972, 1976). Samples were preserved until they could be counted. Organisms/l were converted to volume of cells/ml by measuring linear dimensions and using appropriate formulas.

Dissolved oxygen, temperature and electrical conductivity were measured at one station in each reservoir at 1 m intervals throughout the water column with a Hydrolab IIB meter.

All sampling was done every 2 weeks during the spring. Station locations corresponded as closely as possible to those used by DWR in their 1971–73 study.

RESULTS

Total Nitrogen and Phosphorus

Total nitrogen was always less than 0.5 mg/l-N but generally showed an increase from 1972 to 1976 and then generally decreased from 1976 to 1980 (Figure 2). No trend was discernible between surface and bottom waters or between the two reservoirs, although the overflow from Paradise runs into Magalia.

Total phosphorus concentrations were similarly quite low (Figure 3), with levels increasing to their highest in 1976 (0.1–0.35 mg/l-P) and then decreasing to less than 0.05 mg/l-P by 1980.

For all years investigated, total nitrogen and phosphorus tended to be depleted in surface waters and stayed the same or increased slightly in deepest waters in both reservoirs.

Volume of Phytoplankton

The variation in volume of phytoplankton paralleled the variation in nutrient concentration (Figure 4). Phytoplankton volume was lowest in 1974 and 1980 and highest in 1976.

Phytoplankton composition varied over the eight years of study. In 1972 the dominants were flagellates, but the DWR study did not identify them further. In 1974, the phytoplankton of both reservoirs was dominated by *Asterionella formosa* with *Dinobryon sertularia* occasionally being numerous. *D. sertularia* was most abundant in both reservoirs in 1976, reaching 143 x 10^6 μ^3/ml in Paradise, and 69 x 10^6 μ^3/ml in Magalia. In 1978 this phytoplankter often constituted 99% of the population, but the volumes were reduced from 1976. In 1980, *D. sertularia* again was predominant, constituting over 50% of the volume. The maximum volumes were similar to what they were in 1974.

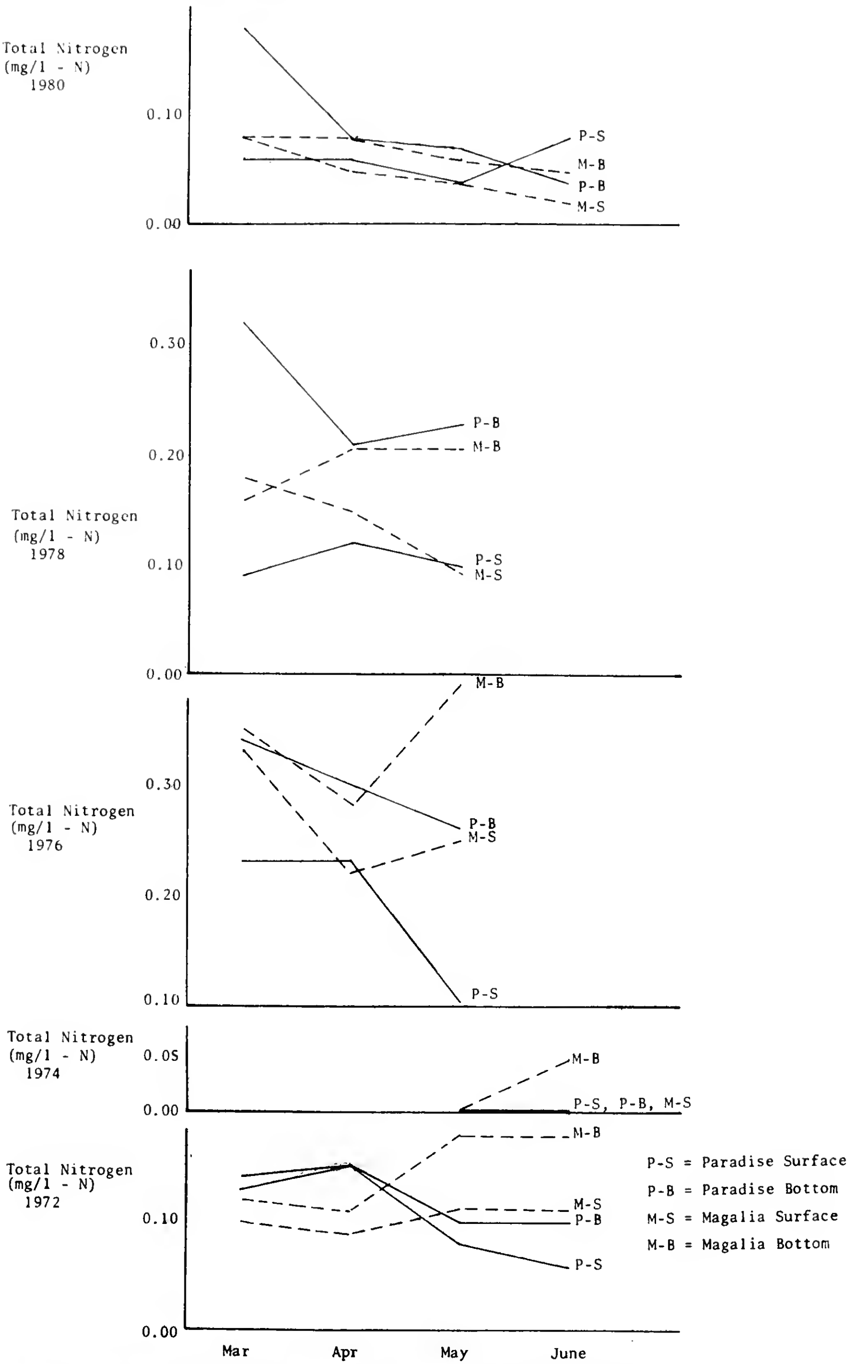


FIGURE 2. Variation in total nitrogen during the spring in surface and bottom water samples from Paradise and Magalia Reservoirs, 1972–1980.

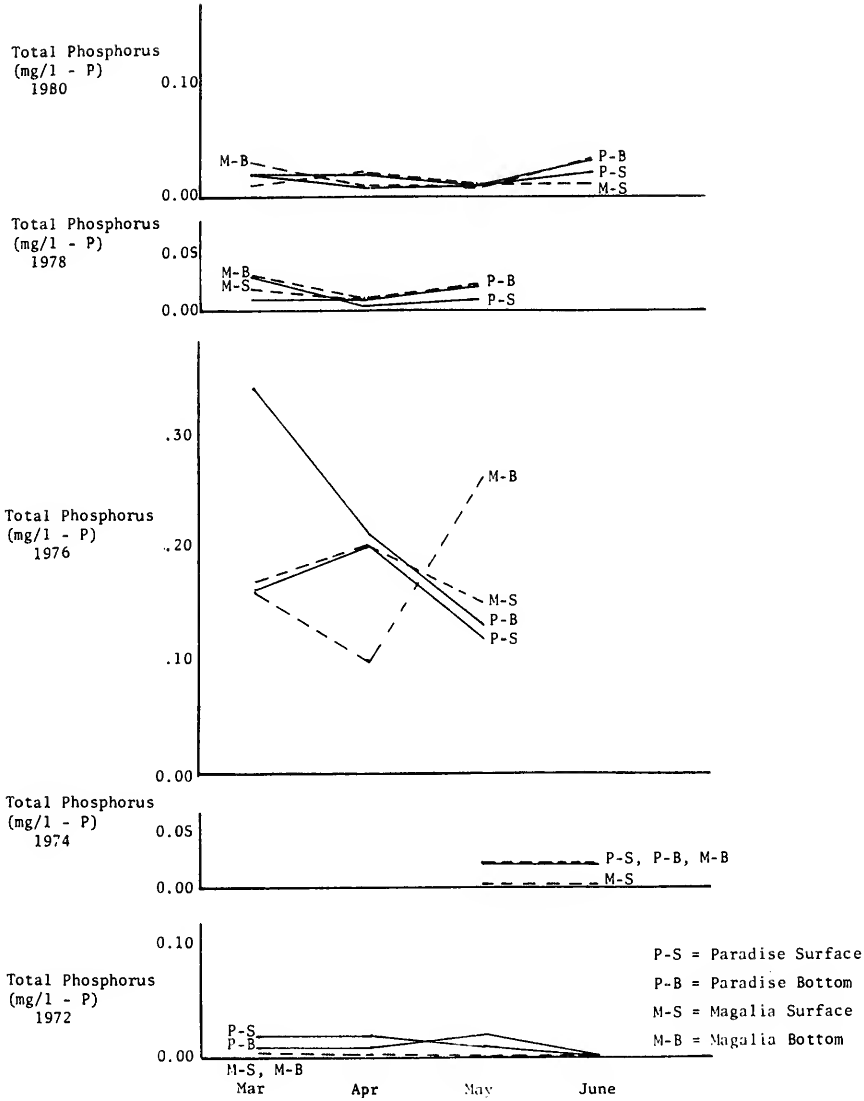


FIGURE 3. Variation in total phosphorus during the spring in surface and bottom water samples from Paradise and Magalia Reservoirs, 1972–80.

Blue-green algae was totally missing from the phytoplankton in 1978 and 1980, but had been present in small quantities previously.

Physical Parameters

Variation in temperature, oxygen and conductivity were documented for 1972 and 1978 (Figure 5), and were representative of the entire period of study.

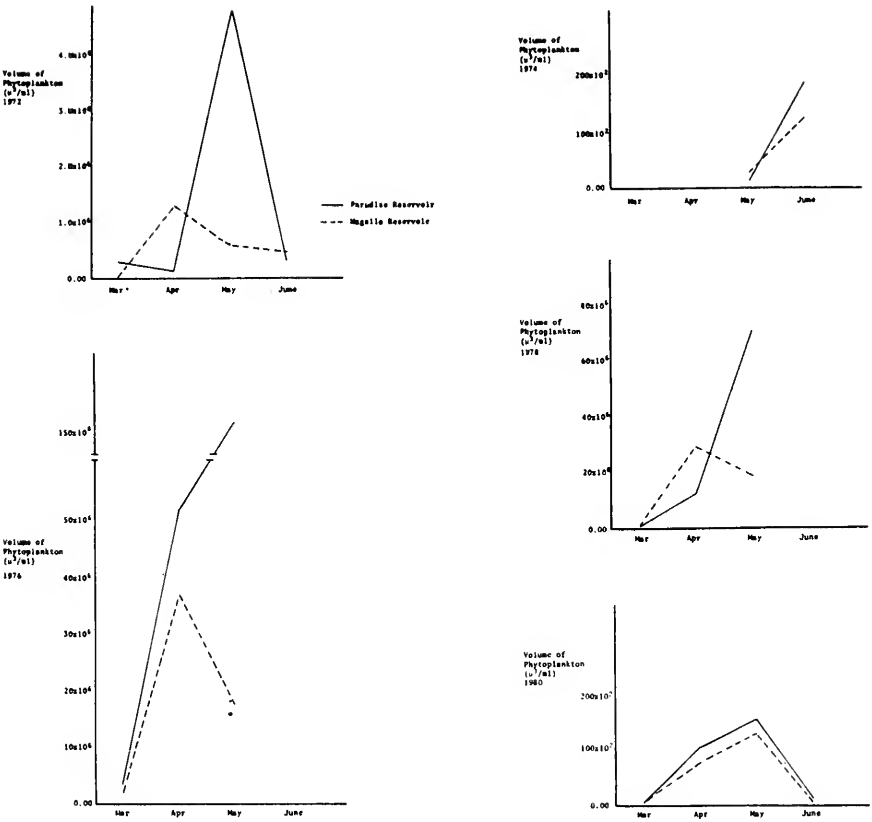


FIGURE 4. Variation in the volume of phytoplankton in Paradise and Magalia Reservoirs during the spring (1972–80).

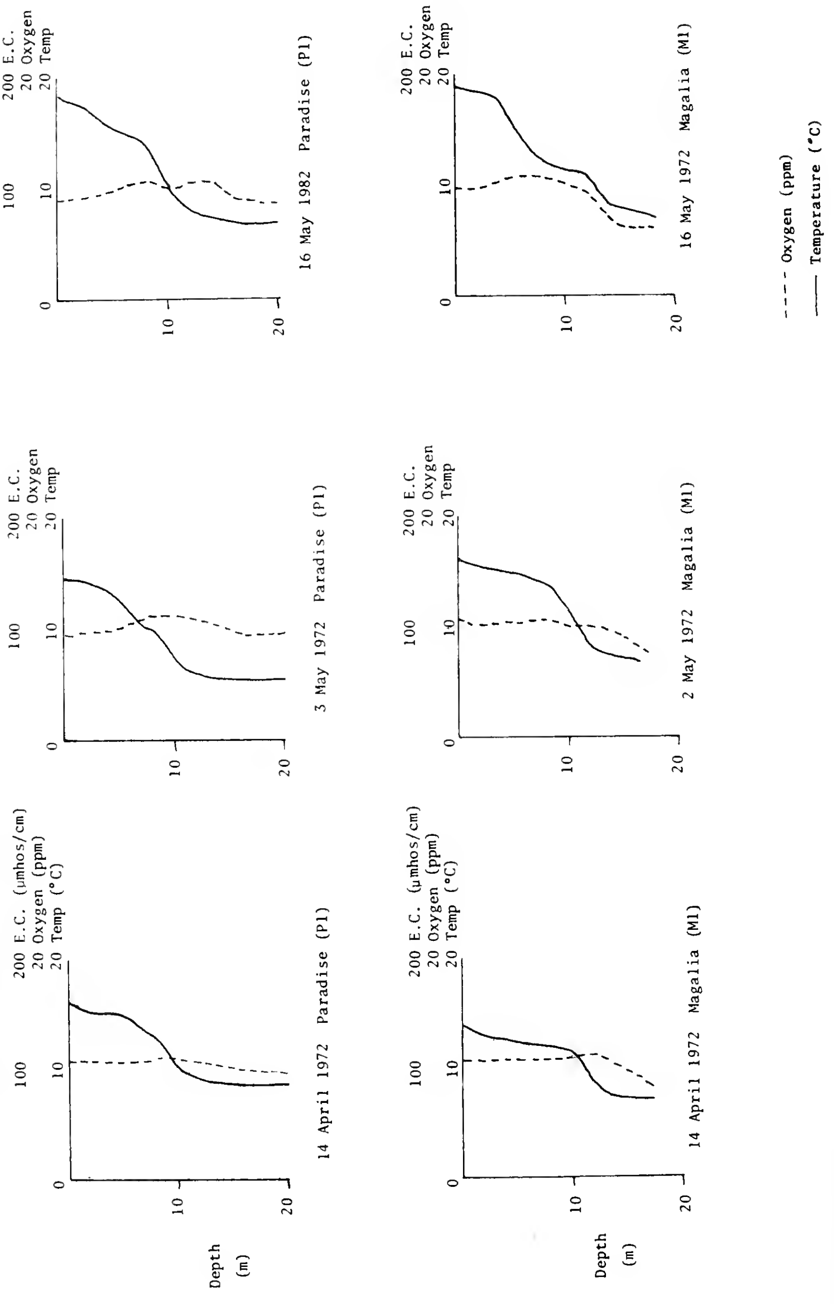
Both reservoirs were generally isothermal during most of the spring, but became thermally stratified in May or June. This persisted until August or September.

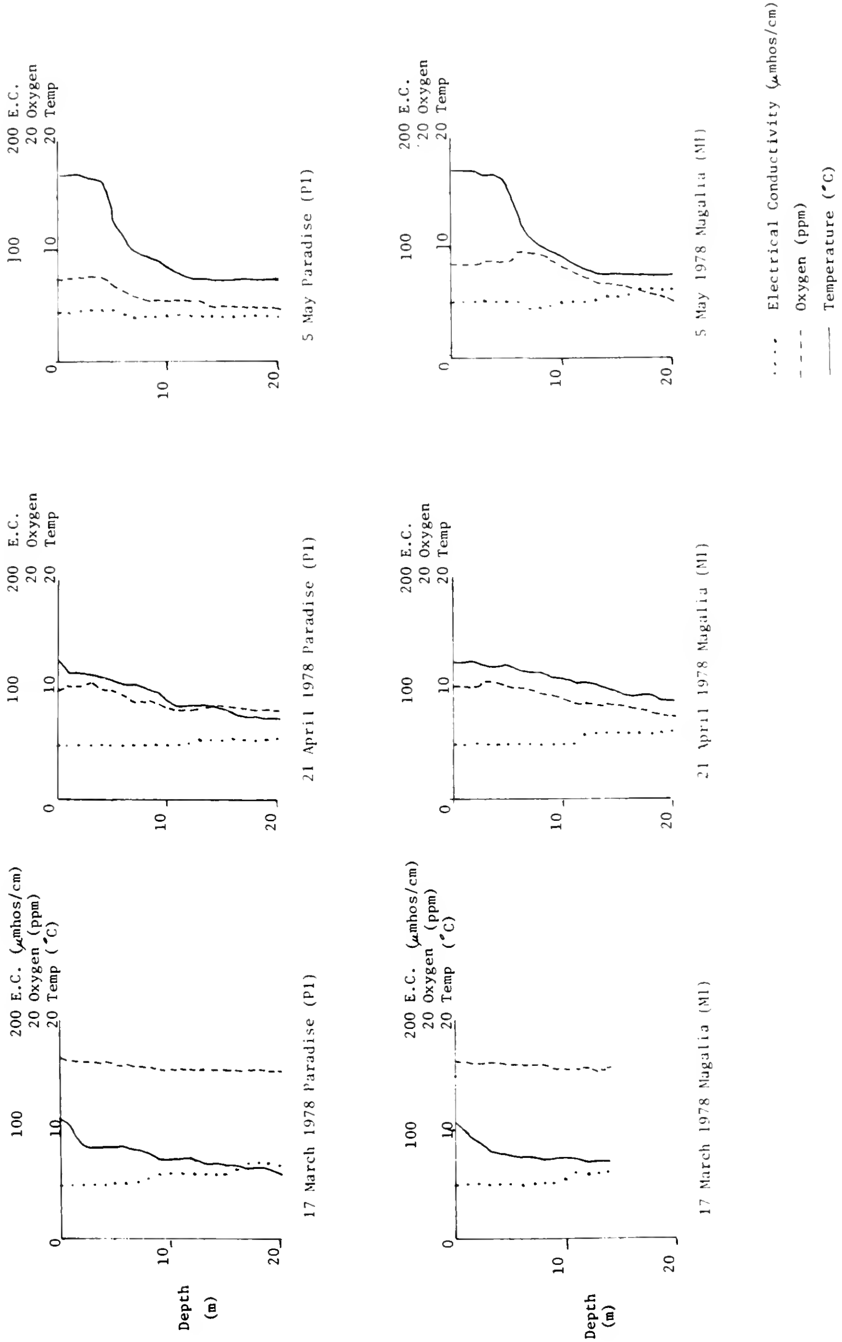
Paradise Reservoir has a multiple outlet system with releases at the bottom, 6.5 m, and 15 m above the bottom. Average water column temperatures are generally higher in Paradise Reservoir because colder water is released through the bottom outlet and flows into Magalia Reservoir.

Oxygen levels were generally at saturation throughout the water column, but during the two study years when summer conditions were examined (1972 and 1974), levels dropped to less than 50% saturation. Occasionally levels dropped to < 1 mg/l near the bottom in mid-summer.

Electrical conductivity was consistently low throughout the study period: 50–70 μmhos/cm. It increased slightly during the summer.

FIGURE 5. Variation in electrical conductivity, oxygen and temperature in Paradise and Magalia Reservoirs during spring, 1972 and 1978.




17 March 1978 Paradise (P1)
21 April 1978 Paradise (P1)
5 May 1978 Paradise (P1)
17 March 1978 Magalia (M1)
21 April 1978 Magalia (M1)
5 May 1978 Magalia (M1)
200 E.C. (µmhos/cm)
20 Oxygen (ppm)
20 Temp (°C)
Depth (m)
Electrical Conductivity (µmhos/cm)
Oxygen (ppm)
Temperature (°C)

DISCUSSION

It has often been observed that newly formed reservoirs begin in an enriched or highly productive state resulting from the decomposition and subsequent nutrient release of recently flooded land (Visser 1970, Mitchell 1973). However, this may be offset by increased flushing or shortened retention time. Taylor (1971), in a study of six TVA reservoirs, found reservoirs with a longer retention time tended to be more productive, possibly because nutrients were changed to more available forms. Nicola and Borgeson (1970) observed that a high rate of flushing retarded nutrient accumulation. This is particularly critical to productivity in reservoirs with outlet structures that draw water from the hypolimnion, as is the case in Magalia Reservoir.

In Paradise and Magalia Reservoirs, the increased flushing during a period of high-rainfall years appears to have reversed any trend toward eutrophication. Rainfall data was collected at Paradise Reservoir by DWR. 1972 and 1976 were relatively dry years (annual total < 76.2 cm) compared to 1974, 1978 and 1980 (annual total > 127 cm) (Figure 6). The increase in the level of trophic state indicators, nutrient concentration and phytoplankton volume observed in 1976 was reversed in 1978. By 1980 the reservoirs were approaching their 1974 trophic condition (total nitrogen < 0.10 mg/l-N, total phosphorus < 0.05 mg/l-P, phytoplankton < 2.0 x $10^4 \mu^3$/ml).

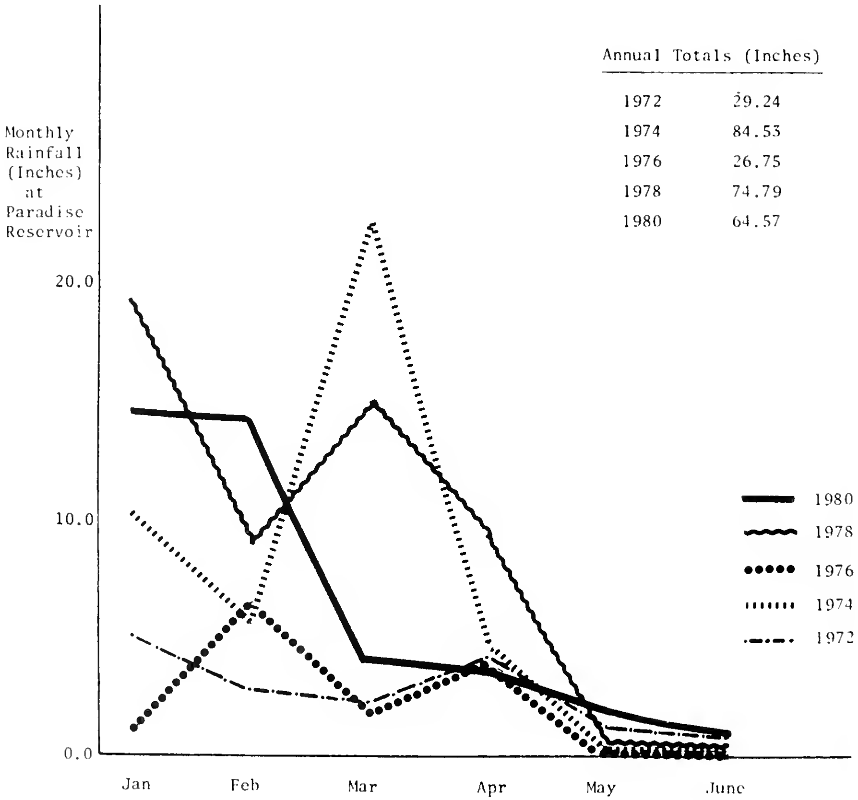


FIGURE 6. DWR Precipitation Record at Paradise Dam for selected years.

Long term precipitation data show that the mean value of precipitation falling on the watershed is approximately 117.8 cm/yr. During the eight years of study there has been considerable variation in total annual rainfall (67.9 cm—215.3 cm). Rain in this mediterranean climate occurs almost exclusively from October –April. The monthly averages for this watershed are listed in Table 1 (Paradise Irrigation District records for 56 years).

TABLE 1. Average Monthly Rainfall In The Little Butte Creek Watershed (Paradise Irrigation District—56 years of record converted to cm)

Month	*Average rainfall (cm)*
Jul	0.18
Aug	0.40
Sep	1.47
Oct	6.98
Nov	15.34
Dec	21.67
Jan	24.56
Feb	20.47
Mar	16.71
Apr	10.26
May	3.91
Jun	1.65

In these lakes, the amount of rain in the winter months determines the lake limnological characteristics during the spring months. Abnormally high rainfall in one month has the effect of bringing in nutrients, which sets the scene for a large phytoplankton population in spring. If heavy rains occur two months in a row, the effect is to flush nutrients out of the reservoirs and low concentrations of nutrients support low phytoplankton populations. This can best be seen in the 1976 and 1980 results.

In 1976, over 15.2 cm of rain fell in February. The amounts of total nitrogen and phosphorus were high both in surface and bottom waters (Figures 2 and 3). Peak phytoplankton populations occurred in April and May (Figure 4).

In 1980, 37.1 cm of rain fell in January followed by 36.3 cm in February. Surface nutrient levels were very low and the spring phytoplankton volume was 3–4 orders of magnitude smaller.

In nutrient-poor lakes such as these, and in climates where rainfall varies so radically, care must be taken in applying general limnologic and trophic state indicator concepts. It is imperative that study of trophic change be long term. An important note for future water use planning is that during dry years, when water demand will be highest, water quality will be lowest.

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Calif. Fish and Game 70(2): 78–88 1984

COMPARATIVE CONDITION OF BLACK-TAILED DEER, *ODOCOILEUS HEMIONUS COLUMBIANUS,* IN TWO HERDS IN TRINITY COUNTY, CALIFORNIA [1]

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Measures of condition, health, and reproductive status were compared in black-tailed deer from the Weaverville and Hayfork herds in Trinity County, California, in winter 1979–80. Weaverville deer showed significantly lower bled and eviscerated carcass weights, significantly lower reproductive synchrony, apparently lower reproductive rates, and apparently higher frequency and abundance of parasites. No differences in kidney fat, femur marrow fat, mean date of conception, and fetal weight gain were detected between herds. The data suggest Weaverville deer are in poorer condition than Hayfork deer.

INTRODUCTION

Black-tailed deer, *Odocoileus hemionus columbianus,* is an important wildlife resource in Trinity County (Figure 1). The Weaverville herd, of which 80 to 90% is migratory (U.S. Fish and Wildlife Service 1975), occupies about 362,500 ha. Summer and transitional range used by the Weaverville herd occupies about 90% of the total area, and winter range about 10% (Burton, unpublished). Vegetation consists of coniferous forest, predominantly Douglas-Fir, *Pseudotsuga menziesii,* and ponderosa pine, *Pinus ponderosa.* Digger pines, *P. sabiniana,* occur at lower elevations on drier sites. Interspersed within the coniferous forest are patches of hardwoods such as California black oak, *Quercus kelloggii;* Oregon white oak, *Q. garryana;* interior live oak, *Q. wislizenii;* and madrone, *Arbutus menziesii,* as well as shrub species such as wedgeleaf ceanothus, *Ceanothus cuneatus;* lemon ceanothus, *C. lemonii;* deerbrush, *C. integerrimus;* manzanita, *Arctostaphylos spp.*; silk-tassel, *Garrya fremontii;* and mountain mahogany, *Cercocarpus betuloides.* The Hayfork herd is also migratory (Figure 1). It occupies about 270,000 ha, of which about 84% is summer and transitional range and 16% is winter range (Dunaway 1966). The vegetation on the seasonal ranges used by the Hayfork herd is similar to that on Weaverville deer ranges, with the addition of chamise, *Adenostoma fasciculatum,* as a winter range shrub.

[1] This research was supported by the Pacific Southwest Region and Shasta-Trinity National Forest, USDA Forest Service, and the Trinity River Basin Fish and Wildlife Task Force. Work was done while senior author was with the Department of Agronomy and Range Science, University of California, Davis. Accepted for publication December 1982.

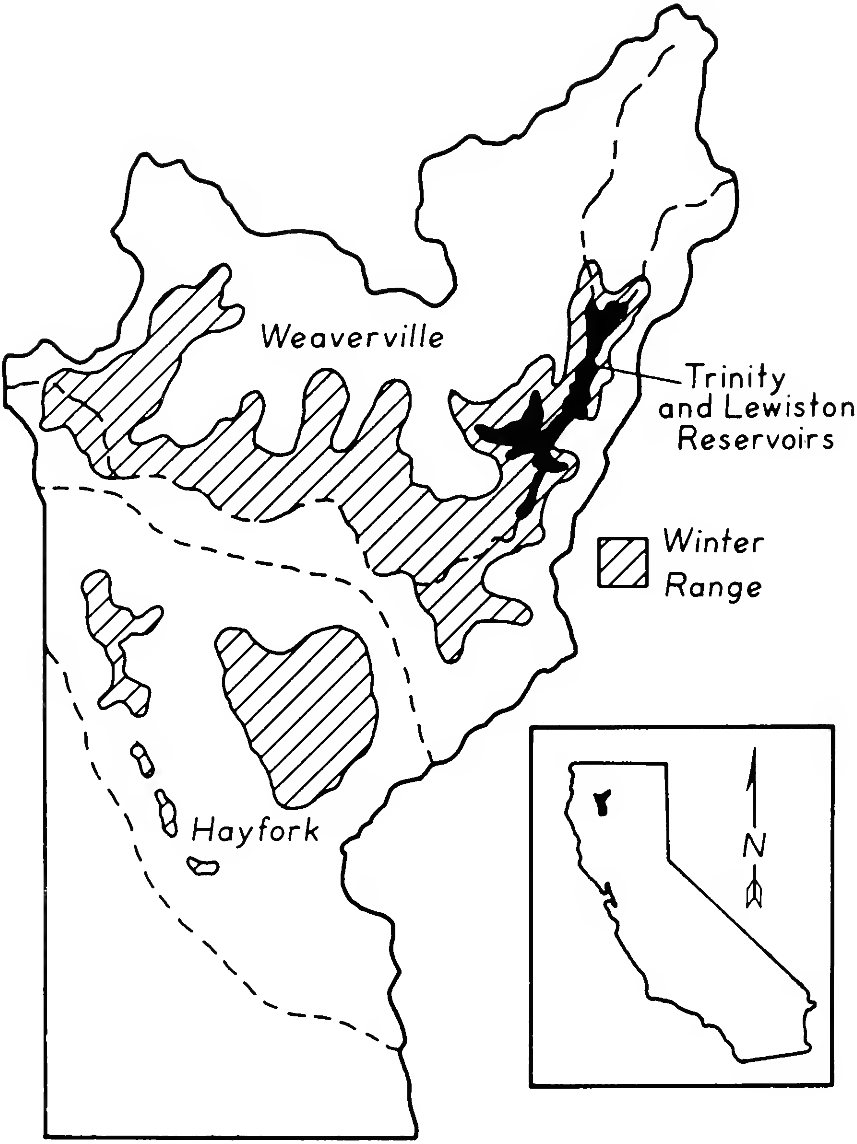

FIGURE 1. Weaverville and Hayfork deer herds in Trinity County, California.

Between 1960 and 1963, about 6,980 ha in Trinity County were inundated by the filling of Trinity (Clair Engle) and Lewiston Reservoirs. Much of this area was deer winter range used by the Weaverville herd. The result was a decline of between 4,000 and 6,000 deer (U.S. Fish and Wildlife Service 1975, Kie *et al.* 1982). As part of an ongoing study, aspects of deer population dynamics (Kie *et al.* 1982), potential for mitigating deer habitat loss (Kie *et al.* 1980), and deer response to habitat improvement programs (Kie and Menke 1980) have been previously reported. The purpose of this research was to compare measures of condition, health, and reproductive status between the Weaverville deer herd and the Hayfork deer herd. Only the former was directly affected by reservoir construction.

METHODS

To assess condition, health, and reproductive status of deer, a systematic collection program was undertaken during winter 1979–80. Ten Weaverville deer and 9 Hayfork deer were collected between 16 December 1979 and 5 February 1980, and 11 Weaverville deer and 10 Hayfork deer were collected between 21 March 1980 and 22 April 1980. Deer, mostly adult does, were shot with a rifle from a vehicle. Date, time, location, habitat type and browse species present were recorded. Each day when the collection was finished, all deer were processed. Bled carcass weight (BCW) was measured first. An examination for external parasites was made before the body cavity was opened. Eviscerated carcass weight (ECW) was measured after the internal organs had been removed, but with the head and hide still attached.

Both kidneys were removed and weighed with and without their capsule of connective tissue and the attached fat. From these weights, the kidney fat index (KFI) was calculated (Anderson and Medin 1965, after Riney 1955). One femur was removed and later processed for femur marrow fat (FMF) by the oven-dry method (Neiland 1970). Adrenal glands were fixed in 10% formalin, trimmed of excess connective tissue, and weighed to determine paired adrenal gland weight (ADRWT).

Presence and abundance of internal parasites were noted. Levels of both external and internal parasites were recorded as negative, light, medium, or heavy (Salwasser and Jessup, unpublished).

The number of fetuses, and the weight and hind foot length (HFL) of each, were recorded. Fetal sex was recorded when it could be determined on a morphological basis. The following regression of age against HFL, developed for mule deer in the central Sierra Nevada (Salwasser and Holl 1979), was used to determine the age of each fetus:

$$\text{Estimated age in days} = 68 + 0.59\ (\text{HFL in mm})$$

Ovaries were fixed in 10% formalin, and sectioned with a razor blade. Corpora lutea of pregnancy were counted (Cheatum 1949*a*).

A 1-pint rumen sample was removed and frozen. Results of rumen analyses are reported elsewhere (Kie *et al.* In Press). A primary incisor was removed and sent to Matson's Microtechnique (Milltown, Montana) for age determination based on cementum annuli. (Trade names and commercial enterprises or products are mentioned for information only. No endorsement by the U.S. Department of Agriculture is implied.)

Deer were classified as fawns between 0 and 11 months of age, or as adults 12 months and older. Adults were further classified as yearlings (12–23 months) or mature deer (24 months and older).

To determine sources of variation, values for BCW, ECW, KFI, FMF, and ADRWT from 33 does were subjected to an analysis of covariance, using the BMDP statistical program P2V (Dixon 1977). The analysis considered the main factor effects of herd (two levels) and collection period (two levels), the effects of herd X period interactions, and the effects of a covariate (age in years). This procedure required the assumption of a linear relationship between the covariate and each dependent variable. To satisfy this assumption, $\log_{10}$ BCW, $\log_{10}$ ECW, and $\log_{10}$ age were used in the analysis of covariance of BCW and ECW. Arcsin transformations were used with KFI and FMF values to ensure uniform residual variances and additivity of treatment effects (Gilbert 1973).

RESULTS AND DISCUSSION

Age

The age distributions of collected deer were similar between the Weaverville and Hayfork herds (Figure 2). The difference between herds in the relative proportion of deer less than 2.5 years old reflects sampling selectivity and is not believed to represent actual age distributions. In the older age classes, deer 2.5 years old were most common in the Weaverville collection, and deer 3.5 years old were most common among the Hayfork sample. However, sample sizes were too small to infer age structure in the populations at large.

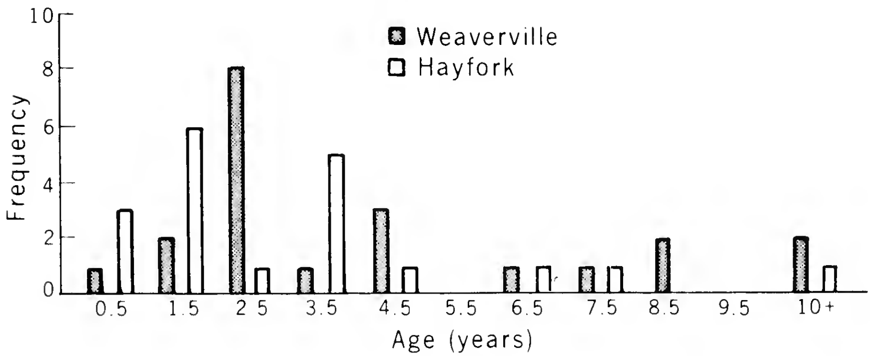

FIGURE 2. Age distribution of deer collected from the Weaverville and Hayfork herds.

Body Weight

Both BCW and ECW (Table 1) were significantly higher ($p < 0.05$ and $p < 0.10$, respectively) among Hayfork deer than among Weaverville deer. BCW and ECW did not differ between collection periods. Mature Weaverville deer appeared to lose body weight between collection periods; mature Hayfork deer did not (Table 1); however, this trend was not statistically significant (no herd × period interaction in BCW and ECW). As expected, BCW and ECW increased significantly ($p < 0.01$) as deer became older.

Dressed weight of white-tailed deer, *C. virginianus,* is a sensitive indicator of physical condition (Park and Day 1942). Deer on a high nutritional plane are heavier than those on a low nutritional plane (Leopold *et al.* 1951, Severinghaus 1955, Robinette *et al.* 1973). The significantly lower BCW and ECW values for Weaverville deer in this current study are thought to reflect poorer range conditions and a chronically lower nutritional plane than those of Hayfork deer.

TABLE 1. Mean Weight and Fat Values of Adult Does, Early Winter and Late Winter Collections (Sample Size in Parentheses).

	Weaverville		*Hayfork*	
Weight or fat value	*Early*	*Late*	*Early*	*Late*
Bled carcass weight (BCW) (kg)				
Yearlings	26.8 (1)	29.0 (1)	37.4 (2)	37.0 (2)
Mature deer	40.4 (8)	38.0 (9)	40.1 (4)	43.5 (6)
Eviscerated carcass weight (ECW) (kg)				
Yearlings	20.0 (1)	21.3 (1)	27.4 (2)	26.1 (2)
Mature deer	29.3 (8)	27.0 (9)	29.3 (4)	30.0 (6)
Kidney fat index (KFI) (%)				
Yearlings	11.8 (1)	5.9 (1)	10.5 (2)	15.7 (2)
Mature deer	19.3 (8)	10.2 (9)	14.9 (4)	9.1 (6)
Femur marrow fat (FMF) (%)				
Yearlings	77.8 (1)	21.2 (1)	63.6 (2)	58.9 (2)
Mature deer	62.7 (8)	41.4 (9)	76.7 (4)	34.0 (6)
Paired adrenal gland weight (ADRWT) (g)				
Yearlings	1.54 (1)	2.64 (1)	1.49 (2)	2.12 (2)
Mature deer	2.58 (8)	3.06 (9)	2.54 (4)	3.23 (6)

Fat Values

All KFI values in these collections were less than 25%, except a value of 41% for a doe 8.5 years old in the early Weaverville collection. This value was included in the mean (Table 1), but excluded as an outlier in the analysis of covariance results. KFI and FMF did not differ significantly between herds. Within herds, both fat values decreased between collection periods ($p < 0.05$ for KFI and $p < 0.01$ for FMF). There were no herd × period interactions in KFI and FMF. KFI and FMF values decreased as mature deer became older ($p < 0.05$). However, yearling deer tended to have lower KFI values than did mature deer as a group (Table 1).

The KFI, developed for red deer, *Cervus elaphus,* in New Zealand, is valuable as an indicator of comparative nutrition between populations (Riney 1955). FMF decreased in white-tailed deer in New York during starvation, leaving the marrow gelatinous (Cheatum 1949*b*). As physical condition in deer declines, kidney and other visceral fat stores are mobilized before marrow fat is depleted (Harris 1945, Riney 1955, Pojar and Reed 1974). In this current study, the relationship between KFI and FMF is identical to that for mule deer, *O. hemionus,* in Colorado (Pojar and Reed 1974). FMF values less than 60% were observed only when KFI was less than 15% (Figure 3). Connective tissue around the kidneys may comprise 5 to 10 percentage points of the observed KFI; therefore, KFI values less than 15% represent minimal kidney fat deposition. Most or all kidney fat was mobilized in deer in declining condition before significant marrow fat stores were lost.

Adrenal Gland Weight

ADRWT did not differ between herds; however, deer from the late collection had significantly higher ADRWT values than those collected earlier ($p < 0.05$). Also, ADRWT increased significantly with increasing age ($p < 0.01$), a trend similar to that reported in mule deer (Anderson, Medin, and Bowden 1974) (Table 1).

Adrenal gland size increased with an irruption and die-off of sika deer, *Cervus nippon,* in Maryland, but only after a very high population density had been reached (Christian, Flyger, and Davis 1960). Adrenal gland weight was inversely correlated with KFI in black-tailed deer in Tehama County, California (Hughes and Mall 1958); no such relationship was found in this study.

Reproduction

Reproductive rates of does collected during early winter were based on corpora lutea of pregnancy. Few embryos were readily observable at that time, although most does had conceived by late December. Fetal rates were used as a measure of reproduction during late winter because all pregnant does collected were well into gestation. Reproductive rates were lower among Weaverville does than among Hayfork does. Mean reproductive rates were 0.00 fetuses per doe for two Weaverville yearlings and 0.75 fetuses per doe for four Hayfork yearlings (Table 2). Three of the Hayfork yearlings were carrying one fetus each. All mature does collected were pregnant; reproductive rates were 1.39 and 1.50 fetuses per mature doe for Weaverville and Hayfork deer, respectively. Fetal rates differed between herds because more Hayfork does were carrying twin fetuses.

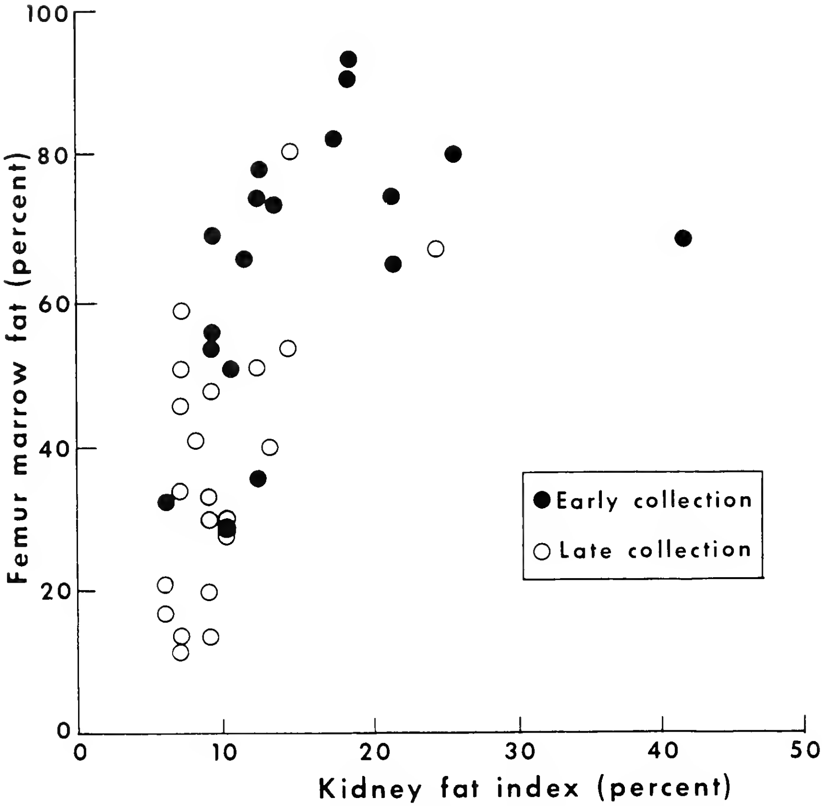

FIGURE 3. Relationship between kidney fat index and femur marrow fat for Weaverville and Hayfork deer.

Reproductive rates for Trinity County deer are similar to those for other black-tailed deer herds in northern California. Fetal rates for mature black-tailed does from Glenn, Tehama, and Siskiyou counties in California ranged from 1.54 to 1.73 embryos per doe (Bischoff 1958). In Lake County, 1.45 fawns per mature doe were produced in good quality, mixed-shrubland habitat, but only 0.71 fawns per mature doe were produced in dense, chamise chaparral habitat (Taber and Dasmann 1958). The lower mean fetal rates among Weaverville deer in this study may indicate poorer range condition.

Fetal sex ratios and fertilization rates did not differ between herds. Of the 27 fetuses examined from does collected during late winter, 12 (44%) were male. These 27 fetuses corresponded to 28 corpora lutea of pregnancy, for a 96% fertilization rate. For other black-tailed deer in northern California, fetal sex ratios ranged from 44% to 64% males, and fertilization rates from 90% to 94% (Bischoff 1958, Taber and Dasmann 1958).

TABLE 2. Mean Reproductive Rates by Age of Doe, and Conception Date Information for All Fetuses (Sample Size in Parentheses).

	Weaverville	*Hayfork*
Reproductive rate (fetuses per doe)*		
Yearling does	0.00 (2)	0.75 (4)
Mature does	1.39 (18)	1.50 (10)
Conception date		
Mean	9 Dec (15 fetuses)	9 Dec (12 fetuses)
Standard Deviation	14.9 days	5.6 days
Range	22 Nov–2 Jan	1 Dec–19 Dec

* Ovulation rates substituted for fetal rates for early collection.

Mean conception date, 9 December, was the same for both the Weaverville and Hayfork herds (Table 2). This is 9 days earlier than previously reported (Kie and Menke 1980) because a different equation was used to estimate fetal age. Most black-tailed does in Siskiyou and Tehama Counties bred in December; however, farther south in Glenn and Lake Counties, peak breeding occurred in November (Bischoff 1957, Taber 1953). Reproduction was significantly ($p < 0.01$) less synchronous in Weaverville deer (Table 2). The greater variability may be related to poor nutritional intake. Verme (1965) reported that white-tailed does fed a reduced quantity of rations exhibited delayed, irregular breeding; although no delay in mean date was noted in this current study.

TABLE 3. Frequency of Occurrence (f) and Mean Level* of Abundance ($\bar{X}$) of Selected Parasites.

Parasite	*Weaverville (n = 21)* f (%)	$\bar{X}$	*Hayfork (n = 19)* f (%)	$\bar{X}$
Ectoparasites				
Ticks	86	1.00	74	0.74
Keds	48	0.57	42	0.42
Other ectoparasites (fleas, lice, mites)	38	0.67	5	0.05
Endoparasites				
Tapeworm cysts	81	1.05	68	0.68
Nasal botfly larva	29	0.62	47	0.68
Hydatid cysts (canine tapeworm)	10	0.14	5	0.05

* Levels: 0 = negative, 1 = light, 2 = medium, 3 = heavy for all parasites except hydatid cysts, where level equals actual number found per deer.

One Weaverville doe in the late collection was estimated to have conceived as late as 2 January, but all does in the late Hayfork collection had bred by 19 December. Late breeding by Weaverville deer could have negatively biased estimates of their reproductive rates because the estimates were based, in part, on does from the early collection. However, all adult does in the early collection had ovulated, except for one Weaverville yearling. Therefore, small sample sizes in this study present greater interpretive problems than such biases.

Fetal weight was expressed as a function of fetal HFL to show patterns of weight gain for Weaverville and Hayfork fetuses (Figure 4). No differences in fetal weight gain between herds were noted. Therefore, a common allometric equation ($\hat{Y} = aX^b$) was fitted by converting both weight and HFL to base 10 logarithms, and using linear, least squares techniques (Baskerville 1972). The estimated values were: a = 0.03649 (SE = + 0.01319, – 0.00969), b = 2.072 (SE = ± 0.071), $r^2 = 0.97$, and n = 27.

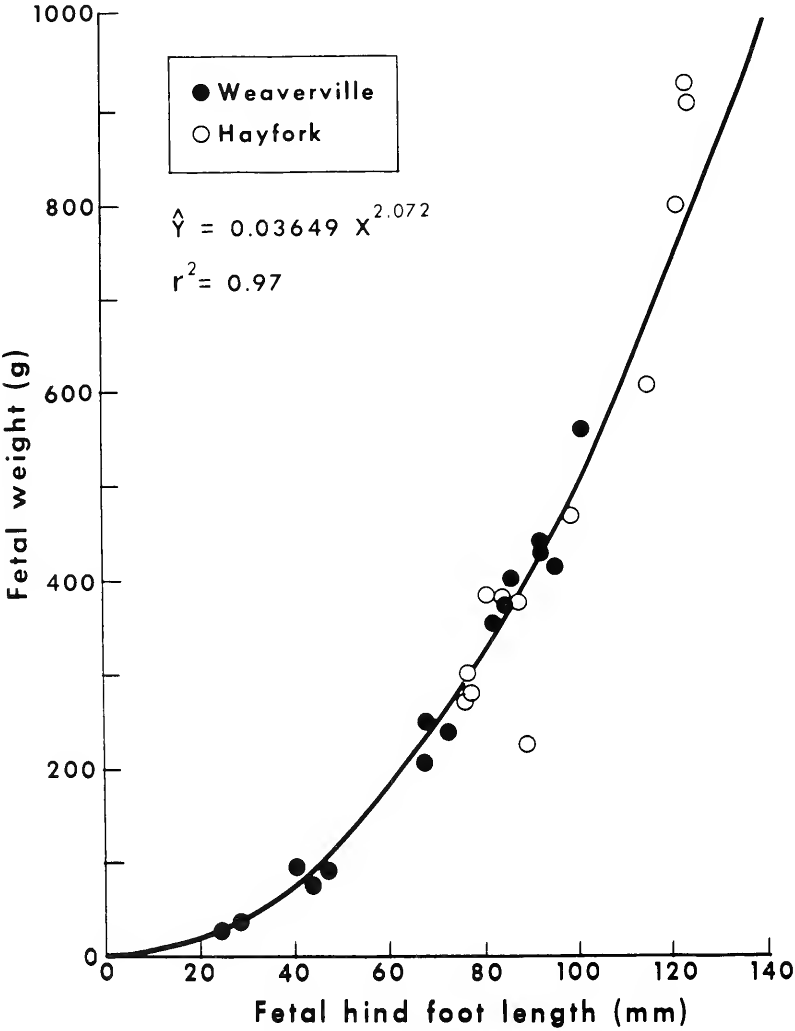

FIGURE 4. Relationship between fetal hind foot length and fetal weight for early and late collections.

Parasites

Ticks (*Dermacentor* spp., *Ixodes* spp.); keds, *Lipoptena depressa,* and other ectoparasites, such as fleas, lice, and mites, were all found with greater frequency and in greater abundance among Weaverville deer (Table 3). Tapeworm cysts (*Taenia* spp.) and hydatid cysts (canine tapeworm, *Echinococcus* *granulosus*) were also more frequent and abundant in deer collected from the Weaverville herd. Only nasal botfly larva, *Cephenemia jellisoni,* were detected with greater frequency in Hayfork deer. However, among those Weaverville deer parasitized by botfly larva, numbers of larva were greater; therefore, mean levels of abundance were only slightly different between herds. These differences in parasite occurrence and abundance between herds may be related to differences in dietary quality (Olson 1974). Despite close inspection, no evidence was found of either liver flukes, *Fasciola hepatica,* or lungworms (*Dictyocaulus* spp).

CONCLUSIONS

The construction of Trinity and Lewiston Reservoirs resulted in a loss of 6,980 ha of winter range used by the Weaverville herd. Small sample sizes make interpretation of any single parameter difficult; however, when viewed as a complex of variables, the data indicate that Weaverville deer are in poorer condition. Variables either indicated this trend with statistical significance (BCW, ECW, and reproductive synchrony), indicated the trend but were not tested for statistical significance (reproductive rates, and frequency and abundance of all parasites except nasal botfly larva), or supported a null hypothesis of no differences in condition between herds (KFI and FMF). These differences may be related to lower dietary quantity or quality, or both, among Weaverville deer. Only the frequency and abundance of nasal botfly larva suggested that Weaverville deer were in better condition. Taken as a whole, the data support the hypothesis of poorer condition among Weaverville deer, which may be related to the loss of winter range. If the loss of deer habitat in Trinity County is to be mitigated, ongoing Weaverville winter range improvement programs should be continued, improved, modified, and expanded, where feasible (Kie and Menke 1980).

ACKNOWLEDGMENTS

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PUP DEPENDENCY PERIOD AND LENGTH OF REPRODUCTIVE CYCLE: ESTIMATES FROM OBSERVATIONS OF TAGGED SEA OTTERS, *ENHYDRA LUTRIS*, IN CALIFORNIA [1]

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Pup dependency periods and length of the reproductive cycle for sea otters, *Enhydra lutris*, were estimated from observation of tagged individuals in California. Pup dependency periods were estimated to range between five and eight months and reproductive cycle lengths to range between 11 and 14 months. These are shorter than most previous estimates.

INTRODUCTION

Pup dependency periods and reproductive cycle lengths for sea otters, *Enhydra lutris lutris*, were estimated from observations of tagged individuals in California. Concern for the health of the sea otter population and concern over the loss of shellfish fisheries through sea otter predation have provided the impetus for considerable research effort. The observation of a large number of tagged individuals was part of this research effort.

There are only two estimates of the sea otter pup dependency period and reproductive cycle length based on observations of tagged individuals. Using data from three sea otters tagged in Prince William Sound, Alaska, Johnson and Jameson (1979) estimated that for some individuals the reproductive cycle length was one year and the pup dependency period was six months or longer. Loughlin, Ames and Vandevere (1981) reported estimates from observations of two tagged females through several cycles. They estimated the pup dependency period to be 8 to 8.5 months and the reproductive cycle to be approximately one year. These estimates were considerably shorter than most of those generated from indirect methods. The sample sizes, however, were very small.

Indirect methods of estimating pup dependency period and length of the reproductive cycle utilized population growth characteristics or data from female urogenital tracts. Lensink (1962) felt the wide difference in the proportion of pups in the Amchitka Island and Kanaga Island population could be

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accounted for by possible differences in the frequency that females bear young. He suggested that Kanaga Island females bred every year while Amchitka Island females gave birth every other year. After examining data obtained from studying female urogenital tracts collected in Alaska, Chapman estimated the length of the reproductive cycle to be two years (Kenyon 1969). Schneider (1971) using similar methods also suggested the average reproductive cycle was probably two years; he assumed that there was a 12-month pup dependency period. Kenyon (1969) also felt the normal period of dependency for Alaskan sea otter pups was at least a year. Vandevere (1972) thought the period was less than one year, based on an observed decline in the ratio of dependent young to adults in the months prior to the peak in pupping. Barabash-Nikiforov *et al.* (1968) reported a dependency period of six to seven months for *Enhydra lutris gracilis.*

This report is our estimate of the length of the pup dependency period and reproductive cycle for sea otters in California based upon observations of tagged pups and adults. We believe our results, from observing a large number of tagged animals, represent the best data available for sea otters in California.

MATERIALS AND METHODS

The California Department of Fish and Game has tagged sea otters since September 1977 under a cooperative agreement with the U.S. Fish and Wildlife Service. Two hundred and thirty-nine sea otters were captured and tagged with a highly visible colored plastic tag on each hind foot between August 1977 and September 1981 (Ames, Hardy and Wendell 1983). The reproductive cycle length and pup dependency period estimates were derived from observations of 139 tagged adult females and their pups, including two tagged previously by Loughlin (1978).

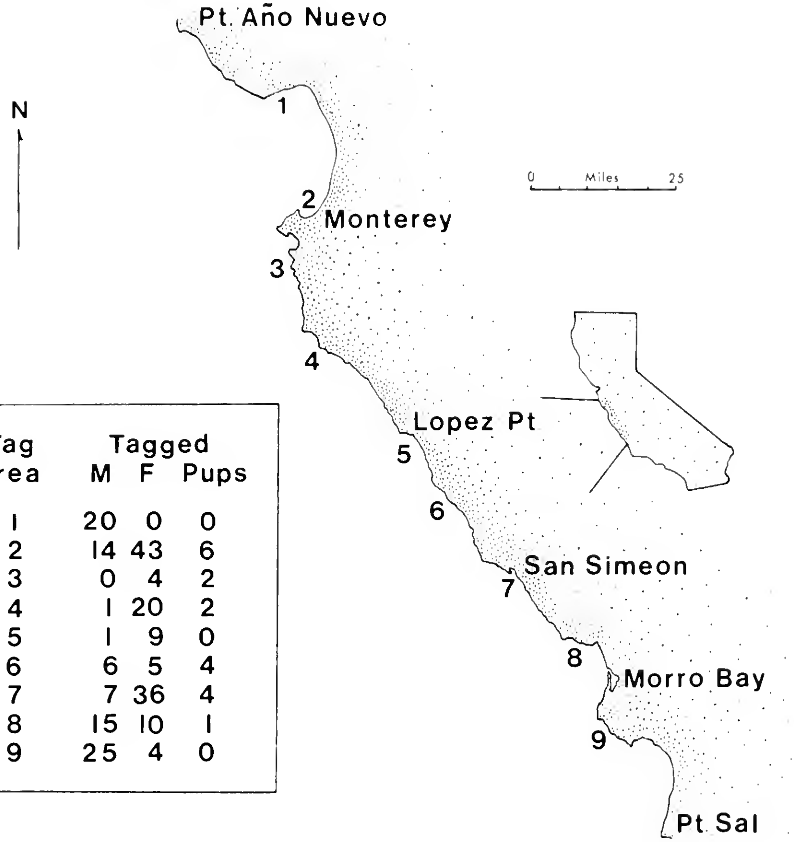
Sightings were made using a variety of observation equipment. Most observations were made using a 50X-80X Questar telescope. Observations were made throughout the sea otter's range (Figure 1). Observer effort, however, was greatest toward both ends of the range.

Estimating Pup Dependency Period

A sea otter pup's period of dependency begins with its birth and ends with separation from its mother. Weaning was assumed to occur at the time of separation. Observing the birth and weaning of a pup, however, is essentially impossible. Estimates of that period were derived from sightings of identifiable mothers and pups. The length of a pup's period of dependence was inferred using three methods. The three methods differed by the way the day of birth was inferred.

By Observation of Mother/Pup

The last date a female was sighted alone and the subsequent sighting of that female with a pup brackets the pup's birth date. The date of weaning is bracketed by a reverse sequence of sightings. An ideal series of sightings would bracket both the birth and weaning of a pup within narrow time limits. Two dependency periods (minimum and maximum) were produced for each individual using this method (Figure 2).



Tag Area	Tagged M	F	Pups
1	20	0	0
2	14	43	6
3	0	4	2
4	1	20	2
5	1	9	0
6	6	5	4
7	7	36	4
8	15	10	1
9	25	4	0

FIGURE 1. Number of sea otters tagged by area, August 1977 to September 1981.

By Natal Pelage

At birth the sea otter's fur or natal pelage has a characteristic wooley appearance. The transition from natal to adult pelage, although somewhat variable, occurs approximately 10 wks after birth (R. Jameson, USFWS, pers. commun.). Observation data collected on tagged mothers and pups included the observer's identification of the pup as a small (wooley) or large pup. These observations were used to approximate the pup's date of birth. Birth was assumed to have occurred 10 wks prior to the last identification of the pup as a wooley. This approximation of the date of birth was used to reduce the maximum length of the pup dependency period. The determination of the minimum length was not affected.

By Weight at Capture

Growth rates were used to convert weight at capture to age at capture for pups caught during tagging operations. The period from the estimated birth date to the date of capture was added to the period from capture to weaning to estimate the maximum pup dependency period. The growth rates used in this conversion were derived from observations of two tagged females and their pups. Observations bracketed the birth dates for these pups to within a 6- and a 14-d period. The pups were subsequently captured when they weighted 6.8 and 4.1 kg, respectively. By using a 1.8 kg birth weight (Kenyon 1969) both pup's growth rates were approximated (Figure 3). The most conservative growth rate of 0.058 kg/d for the female and 0.061 kg/d for the male pup from this approximation was used in converting capture weights to age at capture.

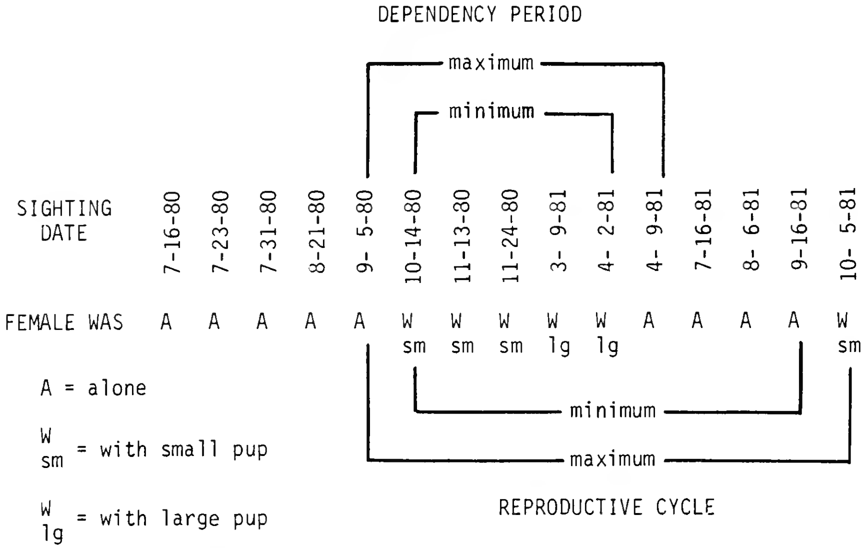


FIGURE 2. Example of a sighting record showing the minimum and maximum pup dependency period and a reproductive cycle length.

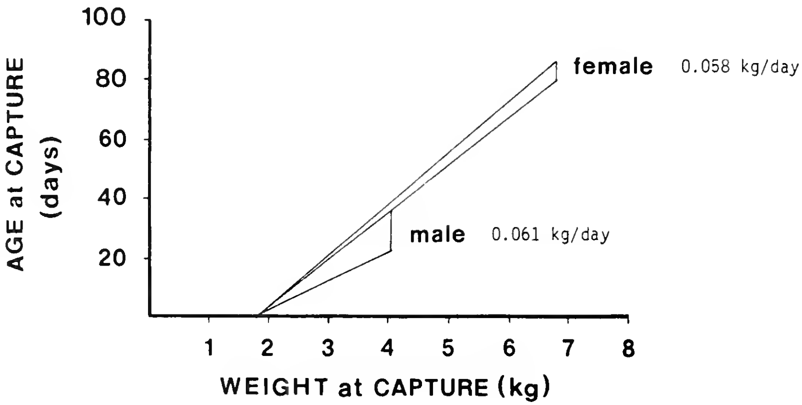


FIGURE 3. Growth rates of two wild sea otter pups (male and female) based on an assumed 1.8 kg birth weight, a birth date known to within a few days (14 and 6 days) and a subsequent weight at capture (4.1 kg 23 days after first sighting and 6.8 kg 80 days after first sighting). The growth rates used to convert weight at capture to age at capture were the slowest extremes.

With each method of estimation, the length of the interval between the minimum and the maximum dependency period for individual pups varied considerably. Since the actual period was only known to occur somewhere between these widely varying minimum and maximum periods a graphical display was used to summarize the data. This display was based on the assumption that each half-month interval between the minimum and maximum observed lengths of dependency had an equal likelihood of containing the actual dependency period. Summing comparable half-month intervals for all pups produced a peak or mode which represents the most common period of dependency for the data group.

Estimating Reproductive Cycle Length

The length of the reproductive cycle for sea otters in California was also estimated using tag sighted data. The birth of a pup, the most readily identified event in the reproductive cycle, was used to mark the beginning and end point of a cycle. The use of tag sighting data allowed only an approximation of the actual length of the reproductive cycle based on minimum and maximum lengths. Two data groups, segregated by the method of determining the date of birth of a pup, were used. These data include only those sightings where there was a potentially successful weaning of the first pup. To be conservative, five months was used as the minimum time sufficient to allow for a successful weaning.

By Observation of Mother/Pup

The dates of birth of both pups in the cycle were inferred using observations of the female alone, followed by a subsequent observation of the female with a pup (Figure 2).

By Weight at Capture

If a known-weight pup was the first pup in the cycle, the estimated interval between date of birth and capture was added to the period between capture and the first sighting of the next pup for the maximum length of the reproductive cycle. The minimum length was determined solely from sighting data.

A graph indicating the frequency distribution of comparable half-month intervals was also used to summarize the data on the length of the reproductive cycle.

RESULTS

Estimating Pup Dependency Period

By Observation of Mother/Pup

Twenty-nine series of sightings of tagged females had the observations necessary to determine a minimum and maximum period (Table 1). Analysis of these sighting data indicated a 6.5 to 7-month mode (Figure 4). The shortest maximum length was slightly over four months. The longest minimum length was slightly over eight months.

Six of the 29 series of sightings were more precise, with minimum observed lengths close to the maximum (within 60 days). All of the pups had dependency periods which were somewhere between 3 and 7.5 months in length. Summing comparable half-month intervals for this subgroup, produced a broad peak between four and seven months (Figure 4). The longest minimum was about seven months while the shortest maximum was almost four months.

By Natal Pelage

Thirteen of the 29 minimum and maximum lengths generated from observation data were modified using information on the loss of natal pelage (Table 1). The mode produced from an analysis of these minimum and maximum lengths was between 5.5 and 8 months (Figure 5). The longest minimum was slightly over eight months while the shortest maximum was 5.5 months.

TABLE 1. Minimum and Maximum Pup Dependency Periods for Sea Otters Derived from (1) Observations of Tagged Individuals, (2) Modified by Observations of Pelage or, (3) Observations and Weight at Capture.

#	*Tag Area*	*Minimum-Maximum (months)*	*Method*	#	*Tag Area*	*Minimum-Maximum (months)*	*Method*
1*	2	4.7– 5.3	1	23*	2	3.1– 5.4	1
2	2	5.7– 7.2	1			3.1– 5.5	2
3*	2	6.0–10.5	1	24	2	5.8–14.9	1
4	2	3.3– 4.1	1			5.8–12.0	2
5	2	6.9– 7.5	1	25*	2	3.5– 7.2	1
6	2	4.2– 6.0	1			3.5– 5.6	2
7	4	1.6–10.9	1	26	2	5.8–12.9	1
8	5	2.0– 8.7	1			5.8– 9.2	2
9*	6	1.4– 9.0	1	27*	4	1.1–10.8	1
10	7	0.1– 9.8	1			1.1– 7.8	2
11*	7	1.9– 5.0	1	28*	7	1.3–12.6	1
12	7	4.1– 7.4	1			1.3–11.8	2
13*	7	1.3–10.5	1	29	8	1.0– 7.1	1
14*	7	4.9– 8.2	1			1.0– 6.9	2
15	7	6.3– 6.7	1	30	2	7.7– 8.9	3
16	7	1.5–12.0	1	31	2	6.3– 7.2	3
17*	2	5.5– 8.2	1	32	2	4.7– 5.4	3
		5.5– 7.7	2	33	2	5.5–10.9	3
18*	2	1.8– 8.5	1	34	2	1.4– 6.3	3
		1.8– 5.5	2	35	2	0.3– 5.7	3
19*	2	6.4–12.9	1	36	2	5.0– 5.7	3
		6.4– 9.3	2	37	2	6.3– 6.8	3
20	2	7.7–13.0	1	38	4	4.8– 7.0	3
		7.7– 9.1	2	39	4	7.8–10.3	3
21*	2	5.9–11.1	1	40	4	7.6– 8.1	3
		5.9– 8.3	2	41	6	6.8– 7.3	3
22*	2	8.2–15.9	1				
		8.2– 9.5	2				

* pup born at least 1 year after tagging or second pup if captured with a pup

By Weight at Capture

Twelve of the pups captured and weighed during the tagging effort were also resighted at the key points necessary to estimate a length of pup dependency

(Table 1). The mode was between five and seven months (Figure 6). The longest minimum was almost eight months and the shortest maximum was 5.5 months.

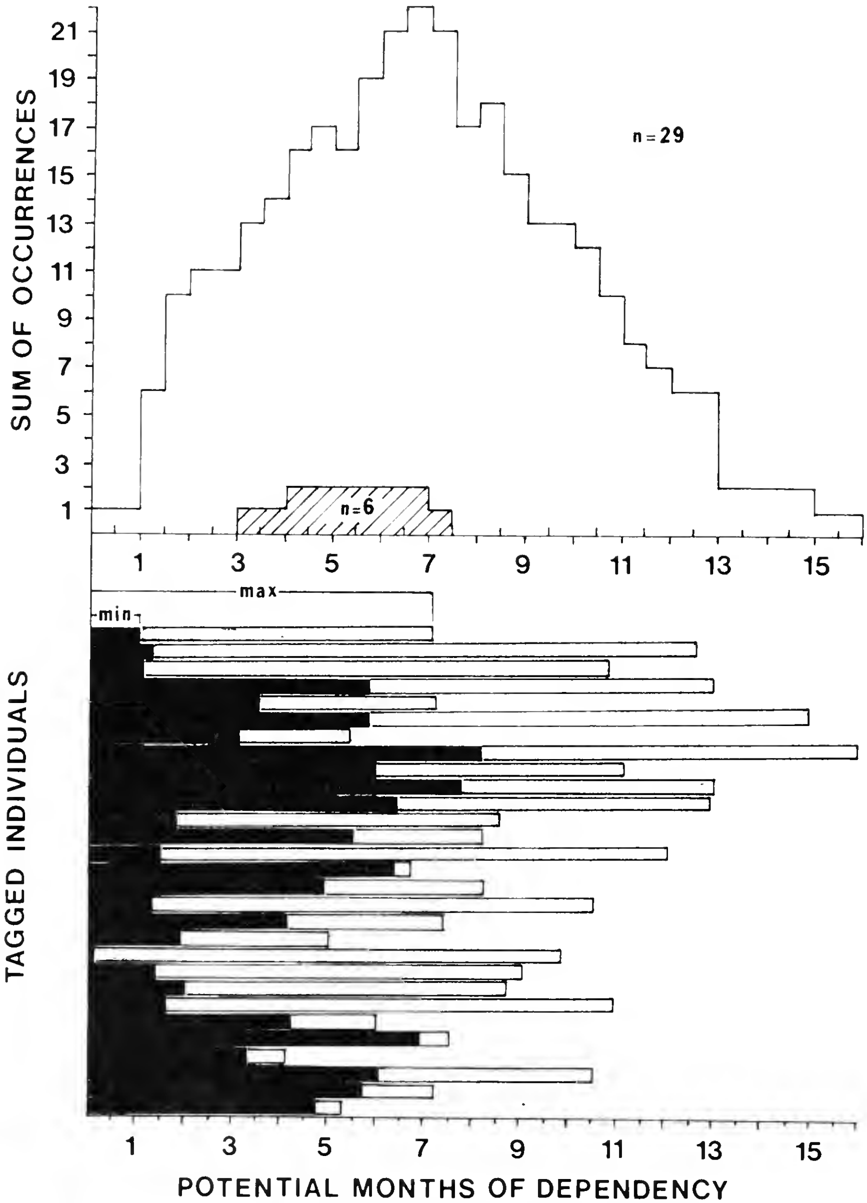


FIGURE 4. Frequency distribution of potential periods of pup dependency within half-month intervals derived from observations of tagged individuals. Subset (darkened area) derived from observations where minimum and maximum periods were within 2 months.

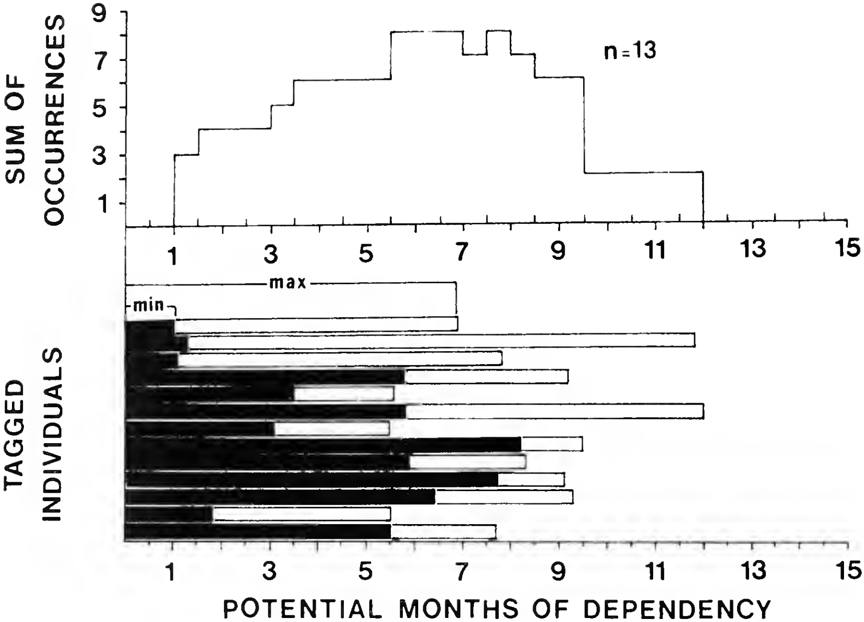


FIGURE 5. Frequency distribution of potential periods of pup dependency within half-month intervals derived from observation of tagged individuals where the maximum period was reduced by observation of loss of natal pelage.

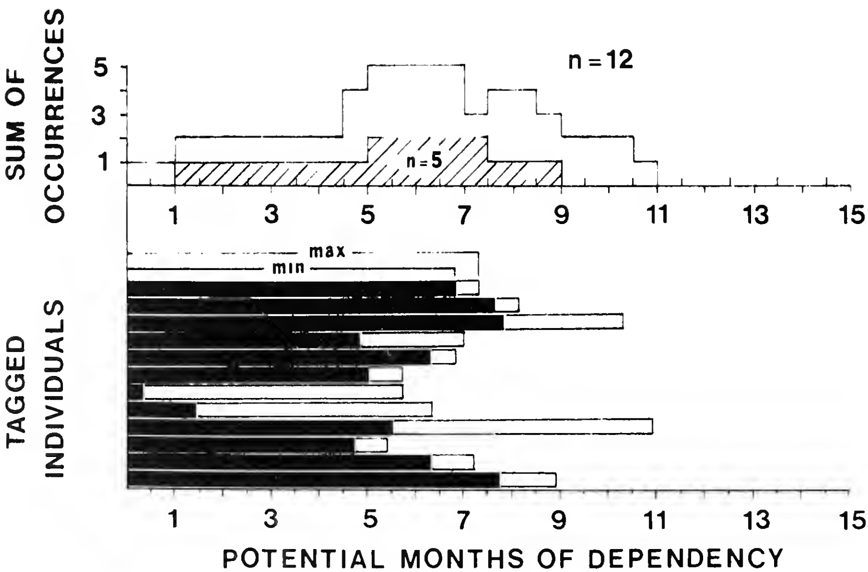


FIGURE 6. Frequency distribution of potential periods of pup dependency within half-month intervals derived from observation of tagged individuals where the maximum period was adjusted by determining a date of birth from weight at capture. Subset (darkened area) represents portion where tagged pup was known to have been sucessfully weaned.

Tagged pups, if they were subsequently observed as apparently healthy independent otters, were the only individuals for which weaning was known to be successful. Of the twelve tagged pups, five were known to be successfully weaned. A mode for this subgroup occurred between 5 and 7.5 months (Figure 6). The longest minimum was slightly over 7.5 months and the shortest maximum was almost six months.

Estimating Reproductive Cycle Length

By Observation of Mother/Pup

Seventeen series of sightings had the observations necessary to determine minimum and maximum lengths of the reproductive cycle (Table 2). An analysis of these data indicated a mode at 12.5 to 13 months (Figure 7). The shortest maximum was slightly over 12 months and the longest minimum was almost 20.5 months.

TABLE 2. Minimum and Maximum Reproductive Cycle Lengths for Sea Otters Derived from (1) Observations of Tagged Individuals or (2) Observations and Weight at Capture.

Minimum (months)	*Maximum*	*Method*
20.0	24.3	1
12.2	13.5	1
10.4	14.0	1
7.7	12.6	1
6.8	20.5	1
7.4	14.7	1
18.7	20.1	1
18.3	21.6	1
12.8	18.8	1
11.3	13.1	1
8.1	18.7	1
8.1	18.3	1
20.4	26.4	1
14.4	22.1	1
12.9	19.7	1
10.1	12.1	1
9.8	17.6	1
8.2	24.4	2
12.4	26.8	2
9.5	16.2	2
11.4	13.9	2
7.0	14.1	2
9.2	19.1	2
6.5	15.5	2
1.1	13.9	2
8.1	11.8	2

By Weight at Capture

Nine additional series of sightings used weight at capture to estimate the date of birth of the first pup in the cycle (Table 2). The modal estimate of the length of the reproductive cycle was 11 to 14 months (Figure 8). The shortest maximum was just under 12 months and the longest minimum was slightly over 12 months.

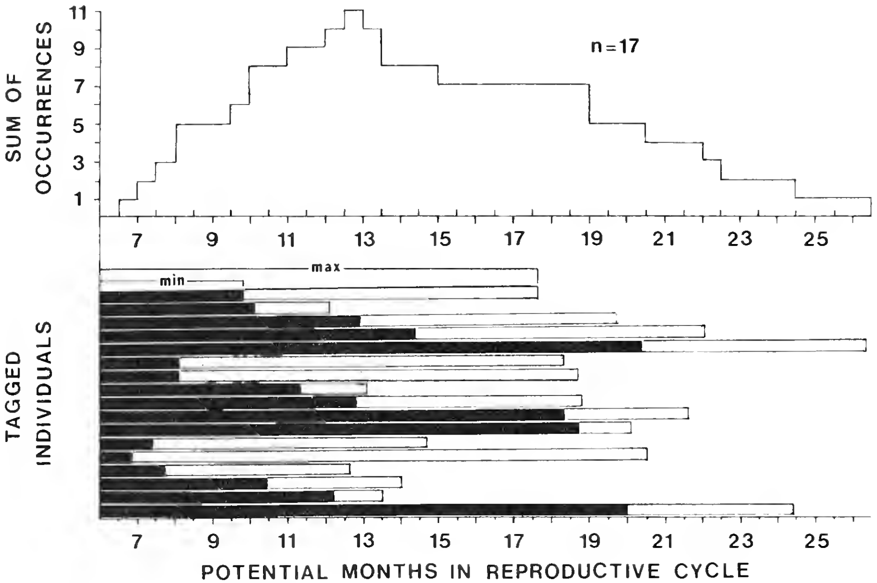


FIGURE 7. Frequency distribution of potential lengths of sea otter reproductive cycle within half-month intervals derived from observations of tagged individuals.

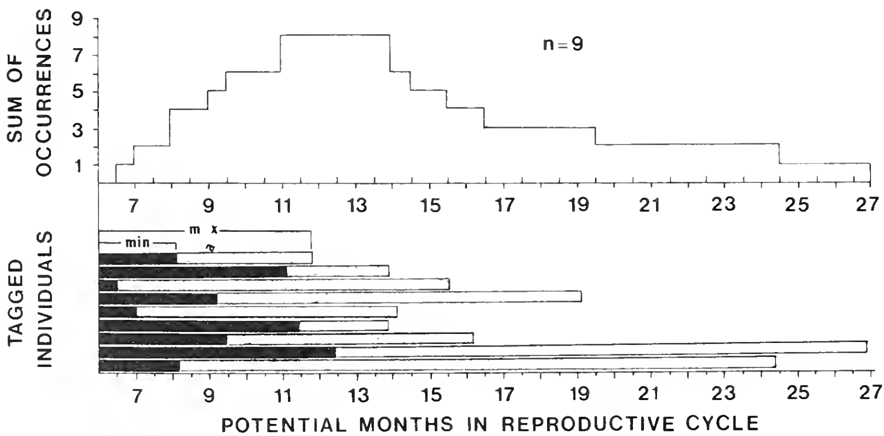


FIGURE 8. Frequency distribution of potential lengths of sea otter reproductive cycle within half-month intervals derived from observations of tagged individuals where the date of birth of first pup was determined from weight at capture.

DISCUSSION

Pup Dependency Period

The three methods of estimating pup dependency period produced similar estimates, all within the range of five to eight months. There were no appreciable differences in the estimated length of pup dependency for pups captured or born shortly after capture and that estimated for subsequent pups or pups born at least one year after capture. This strongly suggests that the capture or tagging operation did not influence the duration of the mother-pup bond. Since successful weanings occurred near the extremes of this five to eight months range, pup dependency periods are at least as variable as the range suggests. Although shorter than most estimates, our results are similar to two reported estimates (Johnson and Jameson 1979; Loughlin, Ames and Vandevere 1981).

The disappearance of some tagged females with pups, which had shown only limited movement for five to eight months, suggests that a marked shift in location may, in some instances, be part of the weaning process. The observations of one of these, a known age female, also provided the first direct measure of age at first reproduction. She was slightly over four years old at the birth of her first pup, indicating she probably became sexually mature at three years of age. This agrees closely with the suggested age of sexual maturity for some female otters in Alaska (Kenyon 1969).

Reproductive Cycle

Both estimates of the length of the reproductive cycle fall within the range of 11 to 14 months. This range is significantly shorter than most estimates based on indirect assessment methods. They are, however, similar to the estimates reported by Johnson and Jameson (1979) and Loughlin, Ames and Vandevere (1981). Four of the minimum lengths were appreciably longer than the 11 to 14 month mode. These females could be losing their second pup prematurely without observer detection, thereby adding a gestation period to what was assumed to be a normal cycle. It is also possible they could have experienced a long delay in implantation, lengthening the total gestation period.

These results suggest that in California annual reproduction is normal and that the reproductive potential of the population may be twice as high as generally accepted. Since direct observational studies in Alaska and studies on *E.l. gracilis* in the western Pacific Ocean have also shown annual reproduction occurring, we would suggest that annual reproduction is the norm throughout the range. The expression of this reproductive potential in terms of real growth of the population depends on age specific reproduction and mortality. Based on observations of identifiable mothers which apparently lost pups the mortality rate for pups may be quite high. Continued observational effort and additional tagging of dependent animals could eventually yield composite life tables and an indication of age specific reproductive rates. Efforts to manage otter populations and to resolve resource conflicts involving sea otters need to be based on these types of reliable population dynamics data.

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A REVIEW OF SELECTED REMOTE SENSING AND COMPUTER TECHNOLOGIES APPLIED TO WILDLIFE HABITAT INVENTORIES [1]

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Remote sensing and computer technologies, as applied to wildlife habitat inventories, are reviewed. Subjects covered include, aerial photography (film types, scales and formats), Landsat data (multispectral scanner, return-beam vidicom camera, and thematic mapper), and geobased computer information systems (technical prerequisites and applications). Moreover, tables are provided which address the applicability of remote sensing data for assessment of habitat diversity elements; application of remote sensing data to various project sizes; and the relationship between wildlife models, levels of inventory and the appropriate remote sensing systems.

INTRODUCTION

An important objective of wildlife management is to identify, map, assess, and manage vegetation assemblages as habitat for wildlife. In the past, these efforts have been hampered by inaccessible terrain, the lack of relatively inexpensive inventory tools which can deal with large ecological units, and the absence of appropriate management systems for data storage, management and retrieval. Fortunately, techniques have evolved from remote sensing and computer technologies which offer solutions to these problems (Anderson, Wentz, and Treadwell 1980).

Rapid advancements in the remote sensing and computer fields have made it very difficult to keep abreast of the technology. Because of new sensors with greater spectral sensitivity and resolution, and changing computer philosophy and sophistication, the wildlife biologist is now offered a variety of options from which to choose. The purpose of this paper is to provide insight to these various options and offer a clear picture of some of the more commonly accepted techniques as well as more sophisticated systems which have application to wildlife habitat inventories.

TECHNOLOGY REVIEW

Remote sensing is a relatively new name for an old concept. Simply stated, remote sensing is the process of acquiring information about a subject without actually coming into contact with it. Remote sensing, as an operational habitat inventory system, can produce useful information about a variety of habitat elements at different scales.

Most remote sensing systems require electromagnetic (EM) energy, generated by the sun. Electromagnetic energy travels in a harmonic, sinusoidal fashion at the velocity of light in various wavelengths which can be received by specialized EM sensors. Thus, many different types of information can be provided by remote sensing. EM sensors commonly used in natural resource inventories are operated from airborne and/or spaceborne platforms.

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Aerial Photography

Film Type

Aerial photographs have provided data to resource scientists for more than 100 years. There are many types of films which are sensitive to various wave lengths of EM energy. By examining different combinations of wavelengths one can highlight important attributes of a given resource. The most commonly used film types are as follows:

(i) Black and White Film. Sensitive to ultraviolet radiation (0.3 to 0.4 μ m) and that part of the EM spectrum visible to humans (0.4 to 0.7 μ m).

(ii) Black and White Infrared. Sensitive to ultraviolet radiation (0.3 to 0.4 μm), visible (0.4 to 0.7 μm), and the near-infrared portion of the EM spectrum (0.7 to 0.9 μm).

(iii) Color Film. Sensitive to the visible spectrum (0.4 to 0.7 μm). The three primary colors are blue, green, and red.

(iv) Color Infrared (CIR). Sensitive to green, red, and infrared light (0.5 to 0.9 μm). CIR is commonly called false color because during the photographic process blue images result from objects reflecting primarily green energy, green images result from objects reflecting primarily red energy, and red images result from objects reflecting primarily in the photographic infrared portion of the spectrum. Therefore, the shades of red that appear on the photograph depict vegetation reflecting different intensities of infrared light. Note that infrared refers to reflected EM energy and not emitted energy as in heat (Figure 1).

Photo Scale

Resolution and photo scale are important factors in selecting the proper data type for wildlife habitat inventories. One of the most commonly used photo scales is 1:15,840. This scale is used extensively by the United States Department of Agriculture Forest Service (USFS). A shift from use of 1:15,840 to 1:24,000 is currently underway to make the photographic scale more compatible with 7.5″ (1:24,000) quadrangle maps which are employed by many resource agencies. Small scale photography (large numbered fraction, 1:100,000) covers a large ground area, usually with low resolution (detail determination). Therefore, large scale photography usually offers higher resolution but covers a smaller ground area. The selection of an appropriate scale is dependent on information requirements. Thus it is economically important to select the smallest scale that will provide the detail required to complete the job. Furthermore, photo cost is directly proportional to the number of photos taken, film type and format (transparency and contact print) used. Selecting the proper photo criteria is very important, as trade-offs between criteria can determine the success of the inventory project. For a complete review of remote sensing principles, films and formats refer to Avery (1977), or Lillesand and Kiefer (1979).

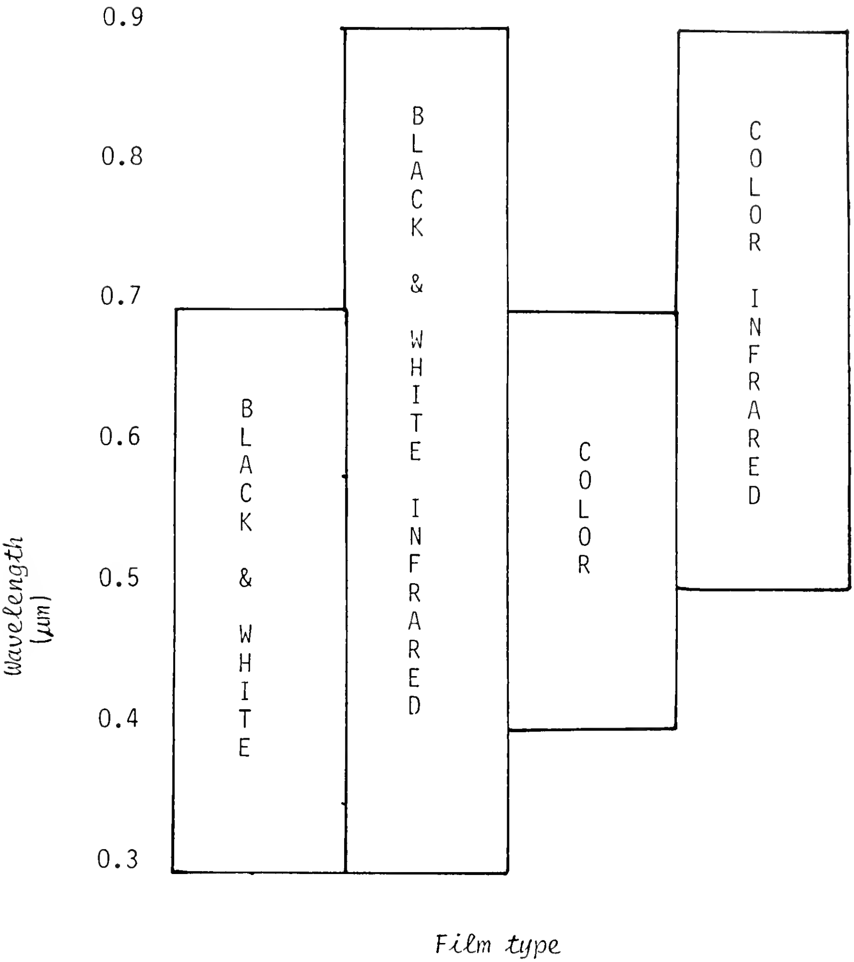

FIGURE 1. Approximate wavelength sensitivities of four common aerial films

Landsat Satellites

The Earth Resource Technology Satellite (ERTS) Program, now referred to as Landsat 1, 2, and 3, has been developed by the National Aeronautics and Space Administration (NASA) to provide a practical approach to resource management. Currently, the National Oceanic and Atmospheric Administration (NOAA) is responsible for the Landsat Satellites. The Landsat program was initiated in 1972 with the lauch of ERTS-1, followed by Landsat-2 in 1975, Landsat-3 in 1978, and Landsat-4 in 1982. Landsat is an earth-viewing satellite which operates in a sun-synchronous, near-polar orbit, at an approximate altitude of 917 km. Each image (scene/frame) encompasses roughly a square, slightly skewed geographical area approximately 184 km on a side, which covers a land area of approximately 3.5 million ha. The image is recorded in four wavelength regions (bands) of the EM spectrum 0.5 to 1.1 μm, two are in the visible and two are in the near-infrared portion of the light spectrum. Photographic film is not carried on the satellite. Instead, the satellite records data with an electro-optical device called a multispectral scanner (MSS). The amount of light reflected from the earth is recorded numerically in each wavelength band. Landsat data are basically point sources of information. The MSS scans across the scene and divides the lines of data collected into rectangular units called picture elements (pixels). As the forward progress of the satellite sets up the sensors, another scan is made, element by element, line by line. Each pixel covers approximately 0.46 ha on the ground, and thus forms the lower size limit for the smallest feature that can be resolved by the scanner. Morever, the MSS light reflectance values are averaged across each pixel. Images of the same portion of the earth's surface are obtained at 18-day intervals; two satellites in operation allow for a nine-day repeat coverage.

A source of data provided by Landsat that is often overlooked is the return-beam vidicon (RBV) camera. Landsat-3 carriers a two-camera RBV system. The cameras produce two side-by-side images with high resolution. The EM energy is stored on a photosensitive surface of the camera tube. After the shuttering is complete the image is scanned by an electron beam to produce a video output signal. The data from each camera are read out sequentially. Each of the images covers a ground area of approximately 98 x 98 km. One MSS image coincides with four RBV images.

As a continuation of the satellite program, NASA has recently launched a more sophisticated, Landsat satellite, Landsat-4. Landsat-4 carries a relatively new EM sensor, the thematic mapper (TM), which provides more spectral sensitivity (narrower spectral bands) with greater resolution than the MSS. Like the MSS the data products are output in a digital form for use within a computer or displayed in a pictorial format. The TM spectral bands range from 0.45 to 12.5 μm within the visible, infrared, and thermal parts of the EM spectrum (Table 1). In addition to the narrower spectral bands, the TM pixels have a higher resolution of approximately 30 m^2 or 0.09 ha. Currently, data from only two Landsats are available to the general public.

TABLE 1. Thematic Mapper Spectral Sensitivity and the Application to Vegetation Mapping.

Band	*Wavelength bands μm*	*Application to Mapping Vegetation*
TM 1	0.45 to 0.52	Sensitive to cholorphyll and carotinoid concentration
TM 2	0.52 to 0.60	Slight sensitivity to chlorophyll, plus green light characteristics
TM 3	0.63 to 0.69	Sensitive to chlorophyll
TM 4	0.76 to 0.90	Sensitive to vegetation density and or biomass
TM 5	1.55 to 1.75	Sensitive to water in vegetational structures
TM 6	2.08 to 2.35	Sensitive to soil minerals and water in structures and soil minerals
TM 7	10.5 to 12.5	Emitted thermal properties

Geobase (Computer) Information Systems

The term Geobase Information System (GIS) has been used in the past to describe single-purpose graphic systems, geographic data base description techniques, and information systems that retrieve, reformat, analyze, and display geographically referenced information. To clarify this point, the term GIS can be defined as a computerized resource data base that is derived from, and can be related back to a ground base. The GIS includes a set of procedures for accessing and modeling data in order to describe and possibly predict resource dynamics. A system such as described above is composed of two types of information. These types of data are (i) attribute, and (ii) graphic data. These data can be accessed together or separately. The key benefit of a GIS is that any geographical referenced data can be used. Information about habitat, wildlife species, resource dynamics, overlay data (soils, climate, erosion, etc.), as well as update information, is appropriate for the system. A successful merging of ground information and data derived from remote sensing can be completed with the GIS context. Some features of a GIS include:

(i) A data base that can be indexed by various geographic projection reference systems and linked with key words or attributes (e.g., the location of peregrine falcon eyries by latitute/longitude or Universal Transverse Mercator (UTM) projections).

(ii) Manipulation and analysis of the data base by (a) aggregating data into various categories (e.g., aggregation of specific habitat requirements for bark gleaning birds); (b) displaying or listing aggregations (e.g., maps or individual listings of wildlife occurrence information); (c) tabulation of spatially related data (e.g., quantitative habitat maps); (d) sorting, merging, filtering or arranging data layers (e.g., sorting cavity nesting birds by habitat type); and (e) performing modeling of data by attribute value or by geographic location (e.g., wildlife species/habitat relationships models linked to habitat inventories to predict species occurrence).

(iii) Display output information by geographic location and or selected attribute(s) with cartographic accuracy (e.g., maps of critical habitat areas for selected species).

(iv) The ability to quantitatively process spatially-related data as input to mathematical predictive models (e.g., the prediction of animal numbers or probability of occurrence of mule deer in habitats of specified management areas.

APPLICATION TO HABITAT INVENTORIES

Aerial Photography

Photo Scale

Selection of the proper photo scale for habitat inventories depends on information requirements and the size of the project area. The inherent limitation of each remote sensing system will require preproject planning in order to select the most accurate (adequate detail) and cost-effective data for the inventory problem (Tables 2 and 3).

TABLE 2. Applicability Ratings of Remote Sensing Data for Various Project Sizes and Planning Needs.[a] (The ratings are derived from data acquisition costs and detail that can be resolved by the system.) Project or Plan Size Key: 0—cannot be used; 1—poor; 2—average; 3—best (according to data reliability)

INVENTORY SERIES	*1*	*2*	*3*	*4*	
Altitude:	*Low-level, Aerial*	*Medium-level, Aerial*	*High-flight, U-2*	*Landsat*	
Scale:	*eg. 1:1000*	*eg. 1:10,000*	*1:30,000–1:120,000*	*False color*	*Digital data*
Resolution:	*0.3m*	*0.3–1.5m*	*3–5m*	*Composite 1:250,000 90–300m*	*Computerized 0.46 ha (1.12 ac pixel)*
PROJECT OR PLAN SIZE					
small acreage (4–41 ha)	3	2	1	0	0[b]
moderate acreage (405 ha)	2	3	2–3	1	1[b]
large acreage (405,000 ha)	1	1–2	3	3[c]	3
integrated[e]	1	2–3	1[d]	1	2–3

[a] Table developed by Kenneth Mayer, Bruce Marcont, Lawrence Fox III and R.J. Gutierrez.
[b] Higher rating (up to 3) when using an integrated resource management approach (multistage sampling) for greater cost effectiveness.
[c] Due to the small scale of Landsat false color composites, accuracy of mapping is directly related to the detail of information desired.
[d] Poor indentification of plant species at smaller scales.
[e] Preferred for use within a geobased information system with multiple resource data; a useful approach would be to select several types of remote sensing data, e.g., medium altitude and digital data Landsat systems.

TABLE 3. Applicability Ratings of Remote Sensing Data for Assessment of Habitat Diversity Elements.[1,2] Key: 0-cannot be used; 1-poor; 2-average; 3-best (according to data reliability)

Inventory series	*1*	*2*	*3*	*4*	
Altitude:	*Low-level, Aerial*	*Medium-level, Aerial*	*High flight, U-2*	*Landsat*	
Scale: / *Resolution:*	*eg. 1:1000* *0.3m*	*eg. 1:10,000* *0.3–1.5m*	*1:30,000–1:120,000* *3–5m*	*False Color Composite 1:250,000 90–300m*	*Digital Data Computerized 0.46 ha (1.12 ac pixel)*
Habitat diversity					
Vertical layering (overall)	3	2	1	0	0
multiple layering	3	2	1	0	0
composition of layers	3	2	1	0	1
height of layer	2	3	1	0	0
layer volume	2	3	1	0	0
Horizontal (Patch) (overall rating)	2	3	2	2	2
patch shape	1	3	3	2	2
patch size	1	3	3	1	3
juxtaposition	1	3	3	1	3
intrapatch heterogeneity	3	2	1	0	0
composition	3	2	1	1	2
Habitat elements (overall rating)	3	2	1	1	1
crown size	3	2	1	0	1
special habitat elements	3	1	0	1	0
cultural features	3	3	2	1	0
habitat profile assessment	1	3	2	2	3

[1] Ratings will vary according to the change in habitat size. (500 to 5,000 ha).
[2] Table developed by Kenneth Mayer, Bruce Marcot, Lawrence Fox III and R. J. Gutierrez.

Low-level (the relationship between focal length and flying altitude) aerial photos (1:10,000) with a resolution of approximately 0.3m are best suited to provide information on habitat diversity (vertical and horizontal layering) and special habitat elements (Grenfell, Salwasser, and Laudenslayer 1982) for site specific areas. Accurate measurements of these habitat parameters are possible with high resolution, large scale, photography. Furthermore, project areas must be small (4–41 ha) as the ground area covered by each photograph is small.

Medium-level aerial photos (1:10,000) can also be used at the project level (<405 ha) to obtain a variety of habitat diversity information. For example, the common USFS photos (1:15,840) can be used to identify tree species, crown diameters, crown closure, tree height; and to develop habitat profile assessments. Some data can be obtained about intrapatch variability, but the information available is usually not as detailed as compared to information available from low-level photography. One would expect a decrease in the ability to identify and measure diversity parameters as you move to a smaller scale. This does not always hold true. Many times, when the scale becomes smaller, more of the habitat element becomes visible. This is especially true when patch shape, size, and juxtaposition are important.

High altitude U-2 photography (1:30,000 to 1:120,000) has a resolution of approximately three to five metres depending on the scale. The NASA 23 x 46 cm, 23 x 33 cm, and optical bar 13 x 25 cm photography can be used to derive information about vegetation dominance, series, and plant communities. Depending upon the scale and resolution of the photography, high-altitude photos can provide reliable information on horizontal habitat parameters.

An interesting example of this type of photography is optical bar (Befort, Heller, and Ulliman 1981). Within the last few years, the USFS has made extensive use of optical bar photography. The U-2 aircraft can be equipped with a panoramic camera (Itek KA80A) which is operated at approximately 19,760 m. The image is a swath that covers a ground area approximately 69 km long, at a view angle of 120°. This attribute provides a clear picture of the mosaic patterns and relationships of habitats and associated landforms. Center photo strips of the 13 x 127 cm film format have a scale of approximately 1:30,000, with high resolution (1-2 m). Photo strips that are on the ends of the image are of smaller scale. Furthermore, the resource features on the outside portions of the strip exhibit excessive lean; although, technology is available which will correct this anomaly. Optical bar photography exists in transparency form, which makes field use difficult without special equipment. A major asset of optical bar and other types of high-altitude photography is the low cost-per-ground-area covered. Serious consideration should be given to this type of aerial data when "extensive" habitat mapping projects are undertaken.

Film Types

Selection of the proper film type depends on the type of information desired. In resource management, black-and-white and natural color are generally the most commonly used film. Color infrared (CIR) can provide detailed information about vegetation resources, especially when plant species are important. For example, there is a similarity on color and black-and-white film between hardwood and coniferous trees. However, healthy hardwood types have higher infrared reflectance than healthy coniferous species. Therefore, CIR film records distinct differences between these tree groups. Infrared film is also very valuable for detecting loss of plant vigor caused by a variety of factors. As an example, plant water loss results in reduced infrared reflectance, while the visible portion of the EM spectrum is unchanged.

Landsat

The ability of Landsat digital data to provide resource managers with intensive inventory information has improved dramatically in recent years. Landsat images are used in two basic forms. First, raw (unaltered) MSS and RBV digital images are transformed into picture-quality images. Photo-interpretation of these data can provide gross information about broad vegetation categories. Indentification of large ecological units and associated ecoclines is the primary use of this form of data. More recently, RBV and MSS data have been digitally normalized and merged to create an image with optimum color and detail (Lauer and Todd 1981). A left-hand, stereo, conjugate image can be produced by merging topographic data with the RBV and MSS data sets. The stereo image produced provides greater sharpness and resolution than MSS or RBV images alone. RBV data have been available from the beginning of the Landsat program but few scientists have taken advantage of the high resolution images. Photographic interpretation of an MSS false-color composite has been shown to be valuable for providing first-level information about forest and rangeland resources (Heller *et al.* 1975)'. However, by utilizing the merged MSS-RBV data, smaller features (i.e., streets, stream channels, and associated riparian vegetation), as well as different tree and shrub species groups, can be identified.

The most widely used form of Landsat data is the digital information obtained from the MSS. Through the use of creative computer methodologies, *a priori* classification probabilities and the incorporation of terrain data have offered the biologist a species-specific look at large vegetative units. Digital classifications are most often approached by three methods:

(i) Supervised approach. The analyst supervises the selection of spectral classes by delimiting geographical areas (training areas) that represent resource categories of interest. Multivariate clustering (grouping of spectral classes) is not performed.

(ii) Unsupervised approach. In this approach, spectral classes are generated by clustering large numbers of pixels into natural groupings which represent the spectral characteristics of the image (training areas are not selected).

(iii) Guided clustering or multicluster fields. In this approach the analyst selects training areas that represent various resources. Clustering is performed on each training area to generate spectral classes unique to the resource categories.

Of the three methods, guided clustering has been shown to be a consistently reliable (a range from 70 to 90 percent overall accuracy) approach to the classification process, providing species specific information on forest vegetation (Fleming, Berkebile, and Hoffer 1975; Fox and Mayer 1979; Gaydos and Newland 1978; Mayer, Fox and Webster 1980; Walsh 1980).

Research by Craighead (1976), Fox, Mayer, and Forbes (1980); Laperriere *et al.* (1980); Mayer and Fox (1981); Cannon, Knopf, and Pettinger (1982); and others, has shown that by using the proper classification approach, detailed information about habitat types and structure covering large geographical regions can be obtained. Moreover, the information exists as a prestratified, 0.405 ha sampling grid and is computer compatible. Landsat data, using an aggregated approach, can provide vegetation information at the formation and series levels (Parker and Matyas 1981, Paysen *et al.* 1980). It is important to remember that Landsat is not a panacea. In order for the system to be effective, a multistage sampling strategy should be used with Landsat providing information at only one or two levels.

Geobase Information Systems

Wildlife species/habitat relationship models, surface cover, species inventory data, remote sensing, terrain data, historical data, and other concomitant information can be integral parts of a GIS. Table 4 is an example of multilevel, descriptive models that relate to habitat type and wildlife species. Furthermore, the remote sensing system applicable to each level is provided.

In order for a GIS to be applicable to wildlife inventories it must have the ability to accept vector, raster, and tabular/textual data. Vector data refer to the common digitizing procedure whereby line segments are created from polygon data. Raster data are in a cellular or point-data format. For example, Landsat digital data (raster data), tabular/textual information, and digitized wildlife species occurrence information (vector data) can be processed together to produce qualitative and quantitative assessments.

The power of the GIS is in the evaluation of several data planes and information levels. For example, a GIS can process soil, vegetation descriptions, remote sensing (Landsat and/or air photo) data and information about species/habitat preference in one function to identify and spatially predict areas of management concern. (Mead *et al.* 1981; Brass, Maw, and Peterson 1981). Furthermore, output products can be listings of areas or attributes by management unit as well as plotter maps of spatially oriented information with cartographic accuracy.

CONCLUSIONS

Some of the most important problems facing resource managers today deal with human impacts on wildlands as a result of changing land use and land management policies. "Sound" decisions about resource management can be made only when accurate and adequate data are provided. Remote sensing and GIS technologies are tools, which the biologist can use to examine resources at various resolutions.

Aerial photographs provide an excellent base for resource inventories. Recent advancements in computer and space technologies provide the biologist with sophisticated tools to inventory, monitor, and predict the complex interactions of ecological systems. Landsat MSS, TM, and the RBV are high-technology systems that offer a complete view of associated ecosystems. Furthermore, with the advent of innovative computer methodologies, Landsat digital classifications can be completed with high accuracy at the pixel level. Lastly, computer software and graphics hardware that have been developed to store, manipulate and analyze georeferenced resource data offer increased accuracy for resource management decisions.

TABLE 4. Relationship between Wildlife Models, Levels of Inventory Accuracy, Project Cost, and Appropriate Remote Sensing Inventory System[1]

Wildlife Species Models Analytical Level	*Habitat Classification Level and Project Size* Formation 416,666 ha	Series 416,666 ha	Association 416 ha
Model Level 1 Relative habitat value of a single stand based on species life requisites as met by stand conditions. Primary use in species richness estimates.	*Level 1a* Species presence determined from range maps, species/habitat relationships models, and habitat data from remote sensing. —Low accuracy —Low cost —Inventory system[2] 4	*Level 1b* (See Level 1a description) —Low accuracy —Low cost —Inventory system 2, 3, 4	*Level 1c* (See Level 1a description) —Low accuracy —Low cost —Inventory system 1, 2
Model Level 2 Relative capability of a mix of stands and associated specific habitat elements to support a species or species group based on all life requisites and the average home range size of the species. Primary use in featured species habitat evaluation.	*Level 2a* Habitat capability (implied density) for featured species based on maps, probability of occurrence given a mix of stands and specific habitat elements (from species/habitat relationships models), and habitat data from remote sensing. —Moderate accuracy —Low cost —Inventory system 3, 4	*Level 2b* (See Level 2a description) —Moderate accuracy —Moderate cost —Inventory 2, 3, 4	*Level 2c* (See Level 2a description) Hich accuracy —High cost —Inventory system 1, 2
Model Level 3 Habitat capability (range capacity) of the aggregation and distribution of capable habitats for all population subgroups within an area. Primary use in determining wildlife production capability over the range from minimum viable population to "K carrying capacity" for featured species in a large area.	*Level 3a* Range capacity for featured species populations based on an aggregation of habitat capability outputs from a Level 2 evaluation using a model that deals with amounts and distribution of capable habitats. —Low accuracy —Moderate cost —Inventory system 3, 4	*Level 3b* (See Level 3a description) —Moderate accuracy —Moderate cost —Inventory system 2, 3, 4	*Level 3c* (See Level 3a description) —High accuracy —High cost —Inventory system 1, 2

[1] Table developed by the California Interagency Wildlife Task Group

[2] Inventory System—refers to the type and scale of remote sensing data. Inventory System 1 = low level air photos 1:1,000; Inventory System 2 = medium level air photos 1:10,000; Inventory System 3 = high flight—air photos 1:30,000—1:120,000; Inventory System 4 = Landsat digital data (1.12 ac) and/or False Color composite.

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IDENTIFICATION OF SALT MARSH HARVEST MICE, *REITHRODONTOMYS RAVIVENTRIS*, IN THE FIELD AND WITH CRANIAL CHARACTERISTICS [1]

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Salt marsh harvest mice can be identified in the field using the four characters of the tail described by Fisler (1965). These characters are assigned 0, 1, or 2 points and the total score is indicative of either the salt marsh harvest mouse, *Reithrodontomys raviventris*, or the closely related and often sympatric western harvest mouse, *R. megalotis*. Tail/body ratios, and to some extent the color of the venter, are useful in some populations while behavior is useful in all populations. Identification is easist when numerous traits are used.

Identification of skulls is much more difficult, depending in part on several subjective observations and on having undamaged skulls to study.

INTRODUCTION

The salt marsh harvest mouse, *Reithrodontomys raviventris*, with its two subspecies *R. r. raviventris* and *R. r. halicoetes*, is a state and federally-listed endangered species endemic to the marshes of San Francisco Bay and is similar to the unprotected and ubiquitous western harvest mouse, *R. megalotis* (Shellhammer 1982, Shellhammer *et al.* 1982). Most biologists have considerable difficulty identifying the two species even though Fisler (1965) described criteria for their identification.

The salt marsh harvest mouse is often called the "red-bellied" harvest mouse because of the intense cinnamon or buff color of the venter of many animals found in the marshes of the South San Francisco Bay. This a misnomer because most animals in this species have whitish venters, especially those in San Pablo and Suisun Bay marshes, where venters often are whiter than those of western harvest mice.

The most reliable characters, though the most difficult to use, are those associated with the diameter, pattern, coloration and shape of the tail as well as the tail/body ratio, although the latter is most usuable in Suisun and South San Francisco Bay populations (Fisler 1965).

I assign numeric values to these tail characters in an adaptation of the hybrid index technique of Anderson (1949). Total scores for all tail characters have been effective in differentiating between the two species, especially when used in conjunction with tail/body ratios, coloration of the venter and behavior. Zetterquist (1978) used this general technique and found it effective in South San Francisco Bay populations.

I present the details of my technique in this paper along with Fisler's (1965) description of venter types. His classic work is the basis for this and any other technique of identifying salt marsh harvest mice and I give him full credit. In addition, my scoring technique, described herein, adds greatly to usefulness of the features he described for identifying the two species. I have examined 116

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skulls of the two species and have discovered a few characters which can be used to identify these forms using intact, or nearly intact, skulls.

MATERIALS AND METHODS

Body Traits

Sixty-seven mice of both species were live-trapped, under endangered species permits, in the marshes near Collinsville (Solano County) at the eastern edge of Suisun Bay in 1978 and 1979 (Envirodyne Engineers 1978, Biosystems Analysis 1978). These animals were characterized as to four tail characters (diameter at 20 mm from the rump, tail pattern, color of ventral hairs, and shape of tip), tail/body ratios, color of venters, behavior, and presence or absence of orange tuffs in front of their ears.

Forty-five mice of both species were live-trapped in South San Francisco Bay marshes, 0.8 and 3.2 km north of Alviso, Santa Clara County, and in Coyote Hills Regional Park, Alameda County, during 1977. They were checked for only two tail traits (pattern of tail and shape of the tip), tail/body ratio, color of venter and behavior.

The tail traits were scored (Table 1) and summed in each case for a possible score of four in the South San Francisco Bay populations and eight in the Suisun Bay population. The scores and tail/body ratios were compared with venter coloration and behavior to establish species identifications.

TABLE 1. Values Assigned to Tail Traits.

Trait	*Value*		
	0	*1*	*2*
Tail at 20 mm from rump	2.1 or more	2.0 mm	1.9 mm or less
Tail pattern	unicolor	intermediate	bicolor
Ventral hairs on tail	tan	intermediate	white to grayish-white
Tip of tail	blunt	intermediate	pointed

The tip of the tail is seen best by holding the tail so it was backlit and hence the tip stands out from its surrounding hairs. A salt marsh harvest mouse has a tail with very little taper and a blunt tip. It looks like it has a missing tip, but without the swelling and loss of hair that usually accompanies such a condition. The tail of a western harvest mouse is thinner, more tapered towards the tip and the tip is decidedly pointed.

Adequate light was necessary to assess the color of the hairs on the venter of the tail. Salt marsh forms have tan hairs on the ventral side of their tails while western forms have a considerable number to a majority of white hairs. The intermediate condition consists of mostly tan hairs with a few white to whitish hairs. A hand lens was useful in observing this character.

The tail of a western harvest mouse in the Bay region is bicolored, but not markedly so. The three categories for this trait are best described as "nearly unicolored" for the salt marsh form, "indistinctly bicolored" for the intermediate situation and "lightly bicolored" for the western form.

The diameter of the tail was somewhat difficult to measure because of the hairs surrounding the tail. It was measured using a plastic ruler but a caliper is more satisfactory. Several measurements were necessary to correctly estimate the width to the nearest 0.1 mm.

The length of the body and the tail were measured several times to get an accurate measurement. The tail/body ratio was obtained by dividing the tail length by the body length and multiplying the answer by 100. Hind foot length or ear length were not recorded, as they add nothing to the identification process.

The animal's behavior was observed throughout the handling process. I noted the color and pattern of the venter (belly) of each animal and looked for orange tufts of hair in front of the base of the ears.

All of this information was recorded on a separate sheet in my field notebook for each animal (Figure 1).

Location:	Male ____ Female ____ Tag # ______ Date of capture ______ Recapture(s) ________
Venter coloration after Fisler (1965) 1. White, greyish white venter. 2. Cinnamon pectoral spot 3. Band of color across chest. 4. Ventral band, 3/4 of venter white. 5. Color and white mixed, 1/2 white. 6. Trace of (1/4) white. 7. All cinnamon, of varying intensity	Body length_____ Tail length______ T/B______% HFL _____ EL____- WT. ________-________=________gm Testes desc.___ Vagina per.___ PG_____ Lact. _____ Tail tip pointed ○ interm. ○ blunt ○ Tail bicolor ○ interm. ○ unicolor ○ White hairs ○ a few ○ all tan ○ Diameter of tail at 20 mm from body 1.9 mm or < ○ 2.0. ○ 2.1 or > ○ Venter coloration 1 2 3 4 5 6 7
	Behavior active interm. docile Orange tuffs in front of ears: yes no Vegetation at capture site:

FIGURE 1. Sample sheet from field notebook.

Cranial Features

Numerous skulls of both species were examined for distinguishing features. The one usable, measureable feature is the position of the posterior foramen in respect to the length of the palate posterior to the incisive foramen (Figure 2).

The measurement was made with a Helios caliper to the nearest 0.01 mm. The distance between the posterior end of the incisive foramen and the anterior end of the posterior palatine foramen was divided by the distance between the posterior end of the incisive foramen and the anteriormost part of mesopterygoid fossa. The result was expressed as a decimal.

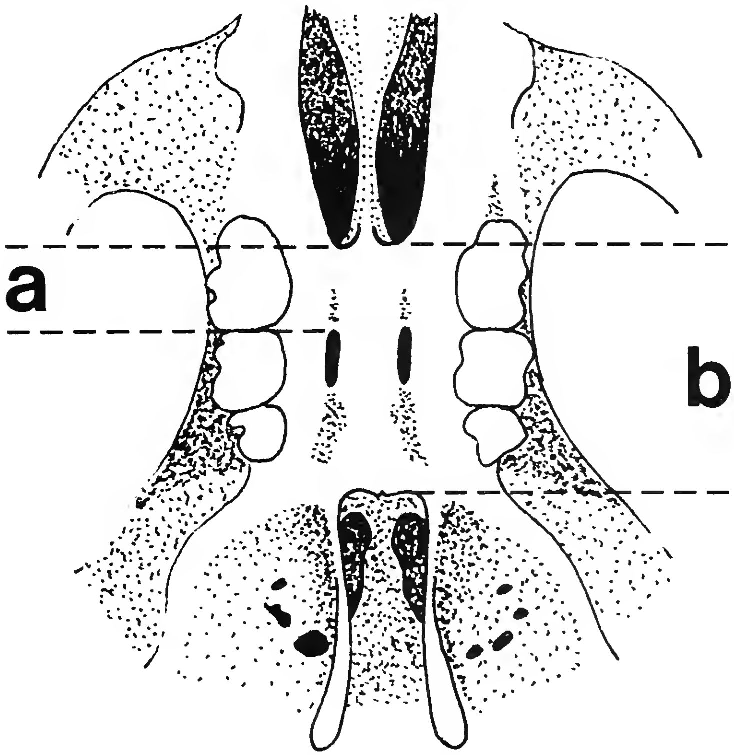

FIGURE 2. Palatine measurements. View is of the palate with the incisive foramen at the top and the posterior platine foramen in the middle.

Two more subjective cranial features were identified. The medial inflection of the zygoma (the zygomatic arch), as viewed from above, was estimated and weighted as follows: an inflection greater than one thickness of the zygoma = 0 points (the salt marsh mouse pattern), an inflection of one thickness or less = 1 point, and no inflection = 2 points (the western mouse pattern) (Figure 3). The other feature was the visibility of the sphenopalatine foramen when viewed from the side (Figure 4). A large visible foramen, extending considerably above the zygoma (the salt marsh pattern) = 0 points, a foramen with a small portion visible over the zygoma = 1 point and no foramen visible from a lateral view (the western pattern) = 2 points. The scores for these two characters were totalled for each specimen and compared with the palatine measurement. Scores ranged from 0 for skulls with the strongest salt marsh harvest mouse characteristics to 4 for those with strongest western harvest mouse characteristics.

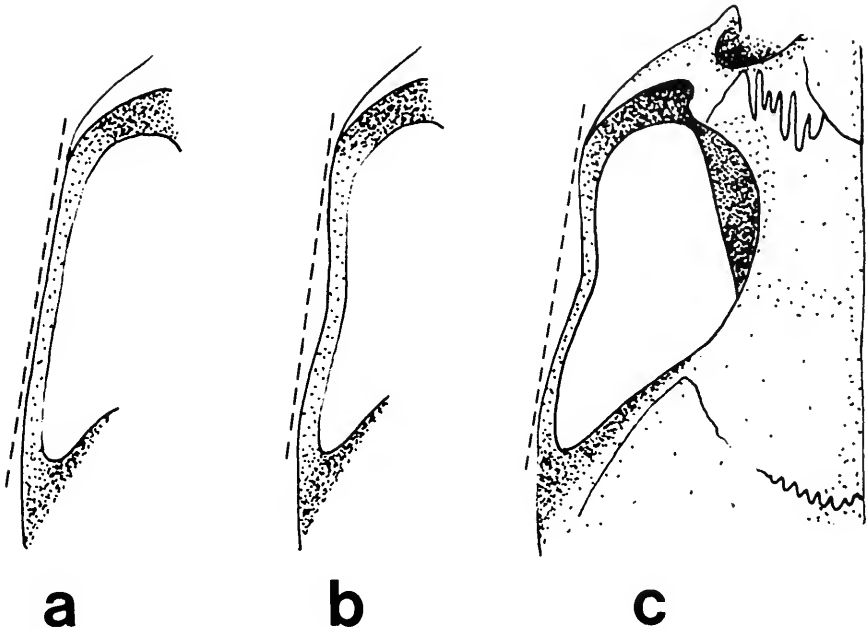

FIGURE 3. Medial inflection of the zygoma (Zygomatic arch). No inflection = a, intermediate = b, inflection of one thickness of the zygoma or more = c.

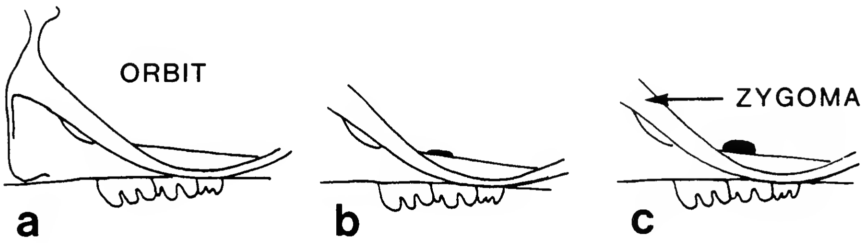

FIGURE 4. Sphenopalatine foramen as viewed from the side. Foramen not visible = a, partially visible = b, and foramen highly visible = c.

Sixty-six salt marsh harvest mice and 50 western harvest mice skulls were checked for these traits. Fifty-five salt marsh and 40 western harvest mice were from the Museum of Vertebrate Zoology at the University of California at Berkeley; the remainder were from the collection at San Jose State University. Skulls were compared from five general areas which were (with the salt marsh harvest mouse locations listed first): Gallinas Creek, Marin County, marsh versus various locations in Marin County; Sonoma Creek, Sonoma County, versus Sonoma County; Martinez marsh versus Martinez marsh, both Contra Costa County; Richmond marsh versus Richmond marsh, both Contra Costa County; and Alviso marsh, Santa Clara County, versus Santa Clara and Santa Cruz Counties.

The first three groups of sites are within the range of *R. r. halicoetes* which extends from Pt. San Pedro, Marin County, to Collinsville, Solano County, and along the Contra Costa County Coast from near Pittsburg to Martinez. The other two groups of sites are with the range of *R. r. raviventris* which extends south from Pt. San Pedro in Marin County and into South San Francisco Bay from the San Mateo Bridge on the west and the Richmond area on the east.

RESULTS

Body Traits

The pattern of the tail, the shape of its tip and tail/body ratios were sufficient to differentiate between the two species in the South San Francisco Bay populations. Tail score totals (ranging from 0 to 4) were plotted against tail/body ratios and there was a complete separation of the two populations. All 29 of the salt marsh harvest mice had red bellies (i.e., a score of 5, 6, or 7 on Fisler's scale) while none of the western harvest mice scored higher than a three. The salt marsh forms were docile while the western harvest mice were highly active and bit often.

The situation at Collinsville was similar, but not quite as clear cut. All four tail traits were used but none of the seven western harvest mice had a score higher than six out of a possible total of eight. Only two of the salt marsh forms scored higher than a two (a three and a four). Only three of the 61 salt marsh harvest mice had tail/body ratios as low as the longest-tailed western harvest mouse (i.e., 114%). One animal had a tail/body ratio percentage of 114% and intermediate traits for the other characters and could not be assigned to either species.

Cranial Traits

Palatal ratios showed highly significant differences between the means of each pair of samples tested (p values were all less than 0.001). Nineteen of the 116 skulls fell into the zone of overlap (0.44 to 0.49) for this measurement. Only one of the 50 skulls on the salt marsh harvest mouse side of the zone of overlap had a "western" score, i.e., a three using the two subjective cranial features. Eleven of the 41 skulls on the western harvest mouse side of the zone had intermediate scores of two, but only one skull had a salt marsh harvest mouse skull score of one.

DISCUSSION

It is easiest to identify salt marsh harvest mice in the northeastern and southern portions of their range, e.g., in Collinsville and Alviso. Reddish venters are the rule at Alviso and their overall coloration is very dark. The animals have very short tails (hence tail/body ratios are less than 100%). Animals at Collinsville have very long tails (tail/body ratios usually exceeding 120%), low tail scores and "thick" tails. A number of investigators including myself have noticed that the tails of animals in the Suisun Bay marshes and along the Contra Costa County coast, and even in the Napa marshes, have thicker tails than Fisler reported in 1965. Many western harvest mice have tails with diameter of 2.0 or 2.1 mm instead of 1.9 mm or less, while salt marsh harvest mice have tails which range from 2.1 mm to as high as 3.0 mm, but are usually 2.3 to 2.5 mm.

The cline in length of tail aids the observer in these two areas. The tail/body ratio, however, is not usable in the Richmond, Petaluma (generally), Sonoma Creek, Gallinas and Corte Madera areas.

Body coloration, especially that of the venter, is usable only in the southernmost part of the range. In areas where both coloration and tail/body ratios are unusable, characters associated with the tail provide the only diagnostic traits. They are not easy to use, at least not at first. Most investigators tend to score more animals as "ones" when they first start using this set of characters unless they have trapped western harvest mice previously. Investigators who have seen representatives of both species find it easier to identify tail characters and behavior.

Behavior is a moderately valuable trait. Most *R. r. raviventris,* especially those from Palo Alto to Newark, are very gentle. They are often torporous. Many *R. r. halicoetes* are moderately active and may bite, but are seldom as active as western harvest mice.

The presence of orange tuffs of hair in front of the base of the ears should be noted as most salt marsh forms have them and few westerns do. It is an obvious trait but one of relatively little value, especially by itself.

The various traits discussed in this paper are best used when an investigator has captured a number of animals in the same marsh and hence can construct a two dimensional plot incorporating tail traits and tail/body ratios.

Single individuals are easy to identify in certain populations. Animals from Suisun Bay-Collinsville-Martinez marshes with tail/body ratios of 114% or more and tail diameters of 2.2 mm or more are salt marsh harvest mice. Animals from the Palo Alto-Alviso-Newark areas of the South Bay with tail/body ratios of 98% or less and tail thickness of 2.1 mm or more are the salt marsh form. Almost any mouse in these areas with a reddish belly is a salt marsh form, although one should check the other traits.

Fisler did not find type 7 venters on any western harvest mice, hence, such a feature is diagnostic if an animal rates a seven. Such animals are found relatively more frequently in the San Pablo-Richmond and Corte Madera marshes and less frequently in the Gallinas and Petaluma marshes and along the Petaluma River. In these marshes the four tail traits are all important. A white-bellied mouse with a tail/body ratio of 109%, a tail thickness of 2.1 mm, a nearly unicolored tail with a blunt tip and only a few white hairs on its ventral side is a salt marsh harvest mouse. The sum of the tail features (Table 1) is usually a score of three or less. The pattern of the tail and the tip of the tail are often rated by cautious, novice observers as scores of one but the color of the ventral hairs of the tail and the diameter of the tail are easier to judge and score correctly. Western harvest mice generally score a five or a six, sometimes a seven or eight. Salt marsh harvest mice generally score zero to two. A score of four presents a problem, especially if the tail/body ratio and color do not provide usable information.

The identification of the skulls is difficult. The one accurately measureable feature that I have found requires at least a complete skull back to the middle of the orbit and a precision measuring device. The two subjective traits require the presence of an intact zygoma and this fragile arch is easily and often broken. Studies are under way to find other quantitative cranial features. Based on current knowledge, a skull with a palatal measurement of 43% (.43) or less is probably a salt marsh harvest mouse. An inflected zygoma and easily seen sphenopalatine foramen (viewed directly from the side of the skull) support such a diagnosis.

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A SECOND RECORD FOR CALIFORNIA AND ADDITIONAL MORPHOLOGICAL INFORMATION ON *ENTOSPHENUS*[1] *HUBBSI* VLADYKOV AND KOTT 1976 (PETROMYZONTIDAE) [2]

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***Entosphenus*[1] *hubbsi* is a nonparasitic freshwater species of lamprey described by Vladykov and Kott (1976*a*). The original 11 newly metamorphosed specimens and 1 ammocoete were obtained on 15 February 1972 by D. P. Christenson from the Friant-Kern Canal, east of Delano, California. In the present study, we describe additional material of *E. hubbsi* consisting of 1 ammocoete, 8 metamorphosing, and 119 metamorphosed specimens, collected by R. R. Menchen from the Merced River, near Merced Falls, a tributary of the San Joaquin River system in California. This lamprey was separable from other species of *Entosphenus* by a low number of trunk myomeres (50-57), and reduced dentition.**

INTRODUCTION

Entosphenus hubbsi is a nonparasitic lamprey, originally described by Vladykov and Kott (1976*a*), and dedicated to Carl Leavitt Hubbs, a distinguished friend and keen student of lamprey taxonomy.

The first specimens were collected in the Friant-Kern Canal, east of Delano, Kern Co., California. This canal, which connects the Kern River system with the San Joaquin River, is about 85% concrete lined, with a flow of at least 56.6 m^3/s. Thus, this canal cannot be considered as a normal habitat for such a small nonparasitic lamprey. Vladykov and Kott (1979) suggested that this species may be present in the Kern River, and possibly in the San Joaquin River system.

MATERIAL AND METHODS

The present study is based on an examination of 1 ammocoete, 8 metamorphosing, and 119 metamorphosed individuals of *E. hubbsi* collected by R. R. Menchen during February and March, 1977, from the Merced River, near Merced Falls, a tributary of the San Joaquin River (Figure 1). This new material not only provides additional information on distribution of this lamprey but allows for a more detailed study of its morphology.

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[1] Robins *et al.* (1980) and Shapovalov, Cordone, and Dill (1981) placed *Entosphenus* in the genus *Lampetra*. We (Vladykov and Follett 1967; Vladykov and Kott 1976*d* and 1979) maintain that *Entosphenus* is a distinct genus from *Lampetra*.

[2] Accepted for publication June 1983.

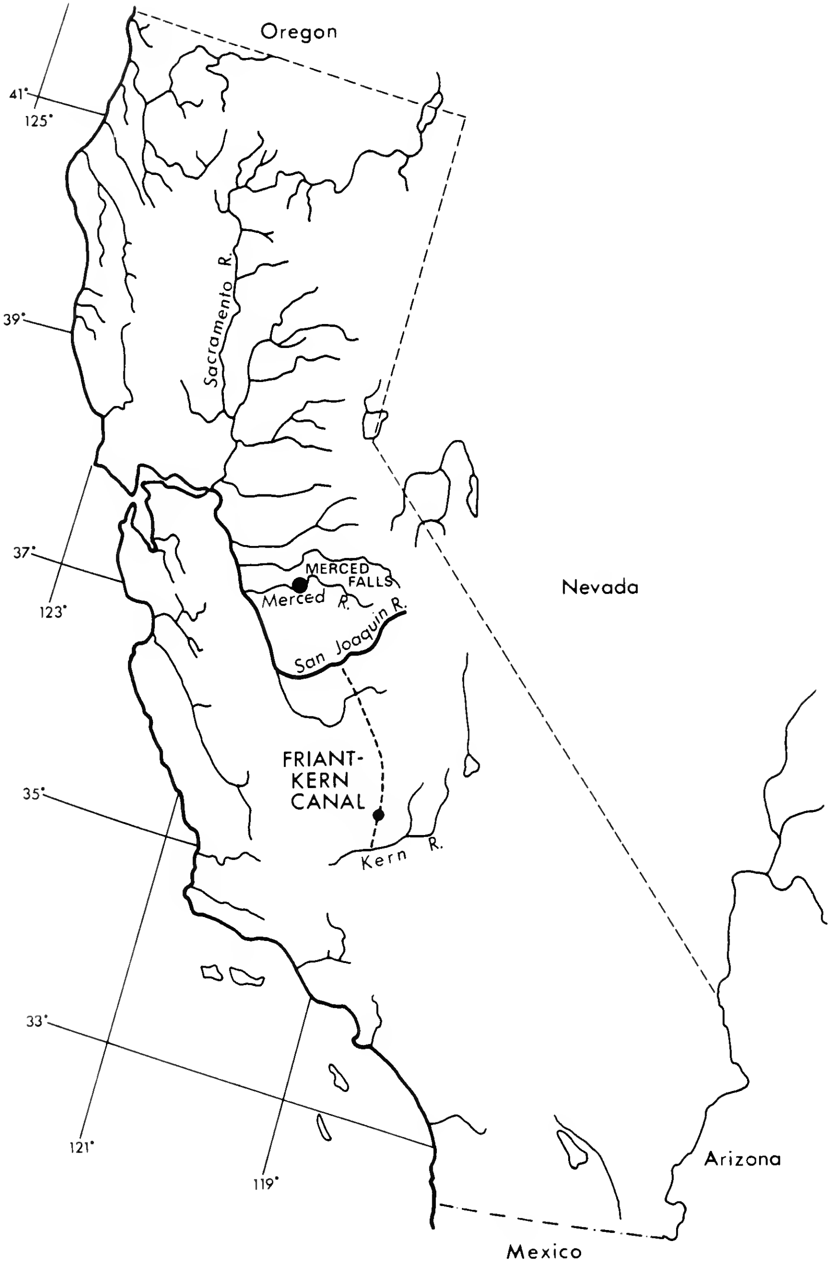

FIGURE 1 Map showing localities where *Entosphenus hubbsi* were collected.

Definitions of body proportions follow Vladykov and Follett (1965) and Vladykov and Kott (1980). Terminology of the teeth is that of Vladykov and Follett (1967). Information on dentition is derived from a study of 30 specimens from the Merced River.

Trunk myomeres were counted between the last (7th) gill opening and the anterior tip of the cloacal slit (Hubbs and Trautman 1937, Vladykov 1949). Information on velar tentacles has been published by Vladykov and Kott (1976*b*), and the taxonomic significance of male urogenital papillae of different species of lampreys was given by Vladykov and Kott (1982 *a*).

DESCRIPTION OF SPECIMENS

Metamorphosed Individuals

Ninety-eight males and 18 females were measured (Table 1). The total length of the males ranged from 95 to 139 mm (mean 112.3 mm) while the females ranged from 81 to 119 mm (mean 102.1 mm). Measurements of different body proportions are expressed in percentage of the total length. Mean values for males and females respectively were: disc length 7.0, 6.1; prebranchial length 11.2, 10.6; trunk length 47.1, 51.3; tail length 28.5, 27.0; disc length in percentage of branchial length 58.9, 56.1. The number of trunk myomeres (Table 2) ranged from 50 to 57 (mean 53.5).

TABLE 1. Body Proportions in Percent of Total Length and Disc Length in Percent of Branchial Length of Metamorphosed Specimens of *Entosphenus hubbsi* from Two Localities. Data Refer to Means (ranges in Parentheses) for Each Character.

Authority	*Present Study*		*Vladykov and Kott (1976a)*	
Locality	*Merced River*		*Friant-Kern Canal*	
Sex	*Male*	*Female*	*Male*	*Female*
No. specimens	98	18	8	3
Total length, mm	112.3	102.1	129.1	140.3
	(95–139)	(81–119)	(117–142)	(140–141)
Prebranchial length	13.1	11.7	9.4	9.0
	(7.8–14.4)	(10.1–13.5)	(8.8–10.7)	(8.5–9.6)
Branchial length	11.2	10.6	10.5	9.3
	(9.7–12.8)	(8.9–11.7)	(9.5–11.2)	(8.5–10.7)
Trunk length	47.1	51.3	54.0	54.5
	(44.6–51.1)	(46.9–55.0)	(51.3–56.9)	(53.5–55.0)
Tail length	28.5	27.0	28.5	28.6
	(25.5–30.8)	(24.3–29.6)	(27.3–30.8)	(27.5–30.1)
Eye length	1.8	1.9	1.7	1.8
	(0.8–2.8)	(1.5–2.5)	(1.4–2.1)	(1.4–2.0)
Disc length	7.0	6.1	4.3	4.4
	(4.3–8.7)	(4.2–7.0)	(3.7–4.7)	(3.9–4.6)
Disc length	58.9	56.1	—	—
Branchial length	(40.0–81.8)	(38.5–63.6)		

TABLE 2. Number of Myomeres in Metamorphosed *Entosphenus hubbsi* and *E. tridentatus*, Collected at Same Locality from the Merced River, California, February–March 1977.

Species	*No. Examined*	*Number of myomeres*																		
		50	*51*	*52*	*53*	*54*	*55*	*56*	*57*	*58*	*59*	*60*	*61*	*62*	*63*	*64*	*65*	*66*	*67*	*Mean*
E. hubbsi	119	2	6	20	20	32	25	10	4	–	–	–	–	–	–	–	–	–	–	53.8
E. tridentatus	5	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	2	1	65.2

Because the species is nonparasitic, the teeth (Table 3) were weakly cornified and often many were hardly visible. As is characteristic of the genus *Entosphenus*, a single row of posterials was present, consisting of 8 to 11 (mean 9.0) teeth that were weakly developed. Among 30 specimens, only 1 had the supraoral lamina with 3 cusps; all the others had 2 cusps. Cusps on the infraoral lamina ranged from 4 to 6 (mean 5.2). All but 3 specimens (Table 3) had 8 endolaterals, as is characteristic of the genus, but the number of their cusps may vary from 1 to 3. Cusps on the anterial field were usually arranged in a single row and were of uniform size. They ranged from 3 to 7 (mean 4.5). Cusps on the lingual laminae were not developed, hence no counts could be made.

TABLE 3. Number of Cusps on the Teeth of *Entosphenus hubbsi* from Two Localities. Data Refer to Means and Ranges for Each Character. Number of Counts in Parentheses.

Authority	Present study	Vladykov and Kott (1976*a*)
Locality	Merced River	Friant-Kern Canal
Anterials	4.5 (29)	–
	3–7	
Supraorals	2.0 (30)	2.1 (11)
	2–3	2–3
Endolaterals:		
Typical formula	1-1-1-1 (24)	1-1-1-1 (21)
Variant formulae	1-2-2-1 (12)	–
	1-2-1-1 (6)	–
	2-2-1-1 (4)	–
Formulae observed in two cases each:	1-3-2-1, 2-2-2-2	–
	2-2-2-1, 2-1-1-1	–
Formulae observed in a single case:	0-3-2-1, 0-2-1-1,	–
	1-0-1-1, 1-1-2-1,	–
	1-1-3-1, 2-2-3-1	–
Infraorals	5.2 (30)	5.0 (9)
	4–6	5
Posterials	9.0 (18)	10.3 (6)
	8–11	9–12

Velar tentacles in 15 specimens ranged from 3 to 5 (mean 4.7). Tentacles were unpigmented and short, the longest ones ranged in length from 0.5 mm to 0.9 mm. The lateral tentacles did not form dorsal wings that are typical of *E. tridentatus.*

The sides and back of specimens preserved in 4–5% formalin were gray-brown and the lower surface was whitish. Both dorsal and caudal fins had black specklings.

Sexual dimorphism was manifested by the presence in males of a relatively longer urogenital papilla (Figure 2). The average length of this papilla in 9 males was 1.6 mm (ranged from 1.0 to 2.0 mm), and as a percentage of branchial length was 13% (range 8 to 17%). Females had a much shorter papilla. However, those close to spawning time developed an anal finlike fold (Figure 2) that was absent in males.

Sexual dimorphism was also evident in the following body proportions, expressed in percentages of total length and branchial length respectively: in males, disc lengths were 7.0 and 58.9, while in females, 6.1 and 56.1. In contrast, trunk length as a percentage of total length was 47.1 in males and 51.3 for females (Table 1).

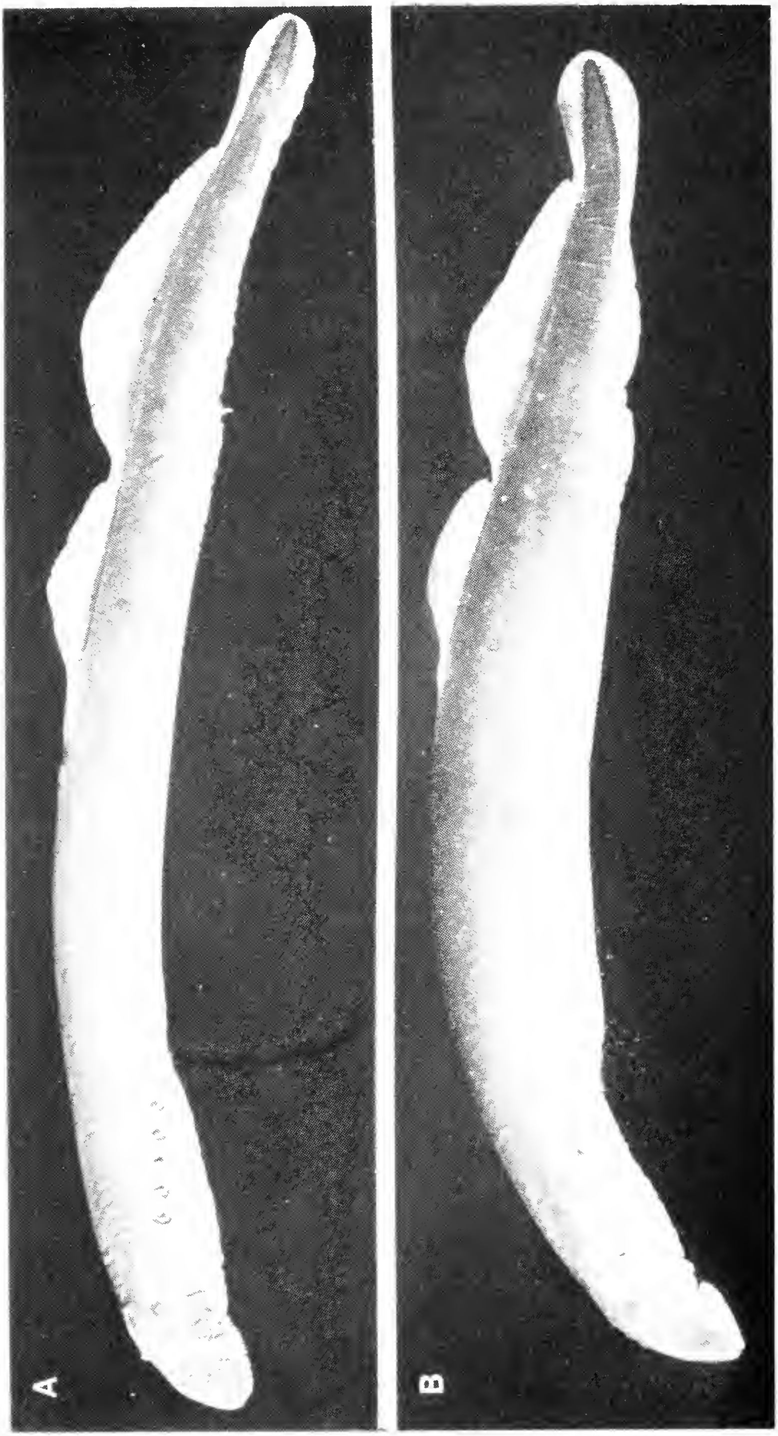

FIGURE 2. *Entosphenus hubbsi* collected close to spawning season from the Merced River, California. Male, TL 110 mm, has a relatively long urogenital papilla, but lacks an anal finlike fold. Female, TL 102 mm, has a very short papilla, but possesses a well-developed anal finlike fold.

Total lengths of males and females of *E. hubbsi* from the Friant-Kern Canal were longer than those of specimens from the Merced River (Table 1). The explanation for this was the different stages of sexual development of metamorphosed individuals. Specimens from Friant-Kern Canal were in early metamorphosis, prior to shrinkage of the body, hence the two dorsal fins were far apart. The lampreys from Merced River were more advanced in maturation, and as shrinkage had already occurred, the two dorsal fins touched each other. For further details on body shrinkage, a unique feature of lampreys, consult Vladykov and Kott (1978), and Vladykov *et al.* (1982*b*).

Specimens from the two locations also differed in disc length (Table 1). In lampreys from the Merced River, taken close to spawning time, the discs had attained their full development, but in the Friant-Kern Canal sample the discs were still small.

Ammocoetes

A single ammocoete from Merced River measured 100 mm in total length and had 57 myomeres. Body proportions in percent of total length were: prebranchial length 9.0, branchial length 12.0, trunk length 49.0, tail length 29.0. The precursor of the tongue was strongly pigmented. The bulb had heavy black pigmentation that was stronger than that in *E. folletti* (Vladykov and Kott 1976*c*) and that also extended around the elastic ridge.

COMPARISONS WITH *ENTOSPHENUS TRIDENTATUS*

Five recently metamorphosed specimens and one ammocoete of the parasitic species *Entosphenus tridentatus* were collected from the Merced River at the same time and place as *E. hubbsi.* They ranged in length from 115 to 126 mm (mean 119.8 mm) and were of a size comparable to the specimens of *E. hubbsi.* The two species are readily distinguishable on myomere counts (Table 2). In *E. hubbsi* myomeres ranged from 50 to 57, whereas in *E. tridentatus* they ranged from 62 to 67. The single ammocoete of *E. tridentatus* had 70 myomeres.

Average body proportions in the newly metamorphosed *E. tridentatus,* sexes combined, expressed as a percentage of total length were: disc length 7.0; prebranchial length 14.2; eye length 3.3; branchial length 9.0; trunk length 45.4; tail length 31.3; disc length in percentage of branchial length was 78.5. The eye length was considerably greater in *E. tridentatus* than in similarly sized *E. hubbsi.* A small eye length is typical of nonparasitic species of lampreys in general.

GEOGRAPHICAL DISTRIBUTION

The two samples of *E. hubbsi* came from south central California. The first 11 metamorphosed specimens and 1 ammocoete were obtained from the Friant-Kern Canal, east of Delano, Kern County, California (Vladykov and Kott 1976*a*). Because this habitat definitely is not suitable for such a small lamprey as *E. hubbsi,* we postulated that it could have been swept into the canal from the Kern system (Figure 1). Before construction of the canal, the Kern basin was an inland drainage system, however, no record of *E. hubbsi* was reported from the Kern area proper. Further information on the physical aspects of the Friant-Kern Canal may be obtained from Fact Sheet U.S. Dept. Interior (1974).

At present, this canal connects the Kern River with the San Joaquin River. Because of the connection between these two river systems, we were almost certain that *E. hubbsi* could be discovered in the San Joaquin River system as well. Our expectation was fulfilled by the collection of abundant material of *E. hubbsi* from the Merced River.

E. hubbsi may also live in the Sacramento River. However, at present, the San Joaquin River system should be considered as the typical habitat for this species. Because *E. hubbsi* is nonparasitic in habit and is limited in its distribution, it should be considered as an endangered species and should be saved. Other reasons why any nonparasitic lamprey must be protected were given in detail by Vladykov (1973).

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R. R. Menchen, biologist, California Department of Fish and Game, Sacramento, kindly obtained a well-preserved collection of *Entosphenus hubbsi* from Merced River, near Merced Falls. D. Hickey, Professor, Department of Biology, University of Ottawa, read the manuscript and offered some useful suggestions. The photographs of lampreys were taken by G. Ben-Tchavtchavadze of the same department. This study was supported by grants A-1736 and A-0575 from the Natural Sciences and Engineering Research Council, Canada. To the above-named persons and to NSERC, the authors extend their most sincere thanks.

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BOOK REVIEW

Fisheries Management,

Edited by Robert T. Lackey and Larry A. Nielsen; John Wiley and Sons, Inc., New York; 1980; 422 pp.; illustrated

This is an excellent introductory textbook. The sixteen chapters are contributed by authors actively working in the respective specialties. This direct familiarity gives the discussions a sense of relevance often missing from textbooks written by a single author who is forced to give a second-hand treatment of material outside his particular province. The field of fishery management is full of uncertainties and constraints which are both challenging and frustrating. This is an unusual textbook in that it conveys these feelings in addition to the usual factual material.

Fishery science is necessarily multidisciplinary. The chapters reflect this: the discussions of aquatic ecology (Charles Warren, William Liss) draw on both field ecology and recently developed theoretical ecology. The latter holds promise for understanding fishery resources, and fisheries may provide an excellent opportunity to wed theory and practice. The introduction to fish population dynamics (Albert Tyler and Vincent Gallucci) gives a sense of mathematics and modeling which is further developed in a lucid chapter on systems principles (Carl Walters). The social sciences are well represented by discussions of sociology/anthropology (Michael Orbach), planning and policy analysis (Adam Sokoloskii), and an entertaining but effective chapter on objectives of management (Peter Larkin). The discussions of actual fishery management cases show the profound difference between the natural history orientation of inland fisheries (Richard Noble, Edwin Cooper) and the analytical and political orientation of marine fisheries (J. L. McHugh, John Gulland).

The shortcomings of the book are not serious. The discussion of fishery economics (Frederik Bell) seemed overly condensed and should have been more fully developed. The chapter on environmental analysis (John Cairns, Jr.) covered the topic of pollution in detail, but did not make any mention of the controversial issue of power plant impacts on fish resources. All the chapters would benefit from expanded lists of references.

A few years ago there was a dearth of texts on fishery management. Now there are more being published than appears to be justified. This particular volume is a worthwhile contribution, and should remain a useful reference for many years.—*Alec D. MacCall*

An Artist's Catch—Watercolors

by Frank Stick, Edited by David Stick. The University of North Carolina Press. 1981. 245 color plates, 356 pp. $29.95.

This beautiful book is the result of Frank Stick's decision during the latter part of his life to put together a collection of watercolors of fishes of the southeast coast of the United States and the Caribbean. Frank's brother David both edited the book as well as wrote the introductory biographical sketch. A short preface describes why the artist began painting fish and the methods used to obtain and identify the collections. The remainder of the book is devoted to the 245 color plates of Frank Stick's excellent watercolors.

Unlike the Japanese and some early European artists, few American artists have specialized in painting fish, and even more our loss that this country has not produced any significant published collection of color paintings of North American marine or freshwater fishes. This book probably reflects the most serious American effort to date. The artist has included detailed diagnostic characters in the water colors, for each species and has illustrated the different color phases for several species.

This excellent collection should be welcomed by all lovers of fish, be they sportsmen, naturalists, students or professional scientists.—*Daniel W. Gotshall*

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