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DISTRIBUTION, ECOLOGY, AND REPRODUCTIVE ANATOMY OF A RARE LAND SNAIL, *MONADENIA SETOSA* TALMADGE [1]

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***Monadenia setosa* Talmadge 1952 is one of the first terrestrial snails to be proposed as Threatened under the Endangered Species Act of 1973. The distribution, ecology and reproductive anatomy of *M. setosa* were studied between May and September 1978. Living *M. setosa* were found in the drainage of Swede Creek, Trinity County, California. Shells were found in the adjacent drainages of Little Swede and Big French creeks. The species appears to be limited to forested areas with mixed hardwood understory, on moist, leafmold-covered talus slopes and stabilized riparian benches. Adults live on the ground; juveniles as large as 9 mm diameter live under loose bark of standing broadleaf deadwood, as high as 3 m above ground level. In terraria, juveniles show a marked climbing response. The reproductive anatomy is typical of *Monadenia, sensu stricto* and similar to that of *M. fidelis* (Gray). *Monadenia setosa* is vulnerable to fire; construction or forestry practices that would alter cover, slope stability, or local drainage would constitute threats to its survival. The vernacular name "Trinity bristle snail" is proposed as more appropriate than the "California northern river snail" used by the U.S. Fish and Wildlife Service.**

INTRODUCTION

Several terrestrial snails endemic to California have been proposed for Threatened or Endangered status by the U.S. Fish and Wildlife Service under the Endangered Species Act of 1973. The primary purpose of this law is to conserve endangered and threatened species by instituting procedures to aid their recovery and survival. In order for management or recovery programs to be effective they must be based on knowledge of the ecological and biological requirements of the species. At present, little is known of the environmental requirements, life-history, and biology of most California land snails. Most published accounts have been casual or anecdotal in nature. Here we present the results of a study of one proposed Threatened species.

Monadenia setosa Talmadge 1952 was one of the first land snails proposed for Threatened status (Federal Register, 41: 17742, 28 April 1976). It was originally described (Talmadge 1952) from specimens collected in the lower reaches of the Swede Creek drainage in northwestern Trinity County, California (Figure 1), and is known only from the vicinity of its type locality. The vernacular name, "California northern river snail," has been applied to the species (Federal Register, 39: 37078, 17 October 1974). Talmadge (1952) provided a very general

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description of its habitat. Walton (1963) reported brief survival of one individual in captivity. Roth (1972) included *M. setosa* in a list of rare and potentially endangered land mollusks in California. No other biological information has been published and, prior to the present study, no intensive, systematic survey had been made to delineate the species' geographic range.

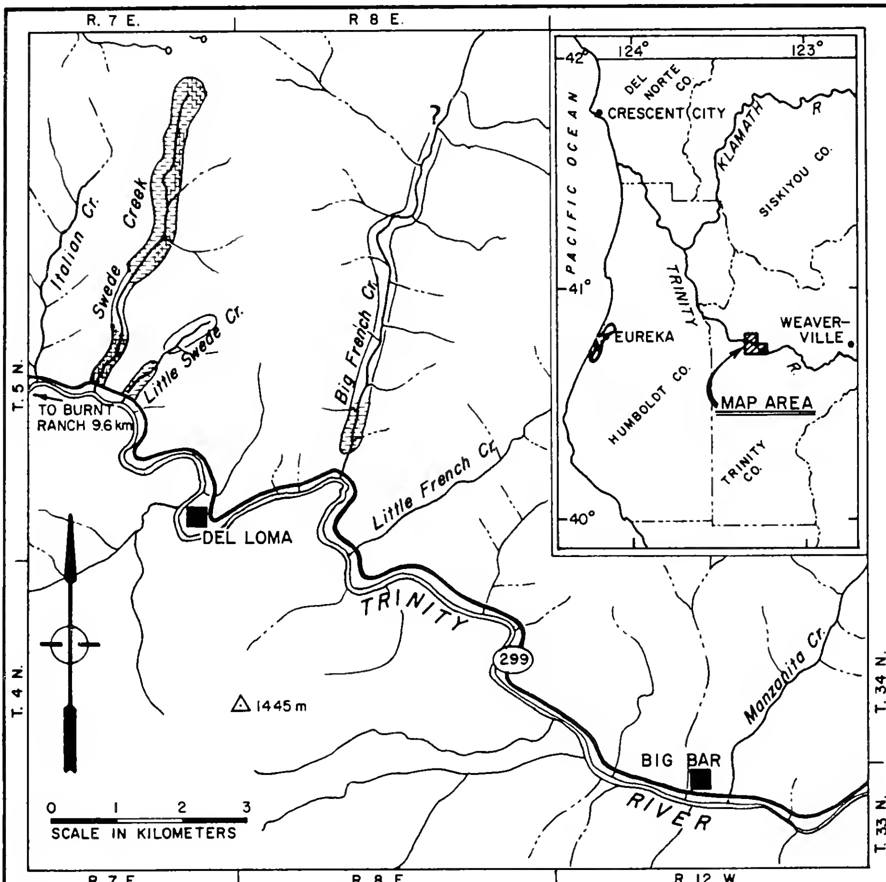

FIGURE 1. Range of *Monadenia setosa* Talmadge. Living specimens found in areas indicated by double hachure, dead shells in areas of single hachure. Other regions of apparently suitable habitat outlined.

The purpose of this study was to investigate the distribution, habitat requirements, and other aspects of the biology and ecology of *M. setosa* in order to provide a data base for preparation of a management plan for the species. These data also have implications for ecologic/evolutionary study of California land snails in general. The shell and reproductive anatomy are illustrated for the first time.

METHODS

From May to September 1978, we surveyed drainages tributary to Trinity River from Italian Creek (Secs. 14, 23, T. 5N, R. 7E, Humboldt Base and Meridian) to

Manzanita Creek (Secs. 32, 33, T. 34N, R. 21W, Mt. Diablo Base and Meridian) (Figure 1) to determine the geographic range and habitat requirements of *Monadenia setosa.* Particular attention was paid to the lower courses of Swede, Little Swede and Big French creeks, where shells or living animals were found during a preliminary reconnaissance. Swede Creek, the only drainage in which *M. setosa* was found in any numbers, was intensively surveyed from headwaters to mouth. The extremely low density of this snail and its cryptic habits precluded any quantitative studies.

During each field session, soil and rock type, vegetation, exposure, and moisture were recorded. Because hydrogen ion concentration has been shown, in some cases, to influence snail distribution (Atkins and Lebour 1923; Lee 1952), substrate samples from 15 representative sites, including sites where *M. setosa* was present and ones where it was absent, were analyzed for this parameter. Three samples from each site were analyzed for pH using a LaMotte St-1001-M soil test kit.

Living adult and juvenile snails were brought back to the laboratory and maintained in terraria (plastic 1-quart freezer boxes) with a sample of local substrate for activity and feeding observations.

We dissected two adult snails in order to study the reproductive anatomy.

THE STUDY AREA

The Klamath Mountains are a rugged mountain region including clusters of high peaks 1800–2700 m high. Peaks and ridgecrests of 1400–1900 m occur in the area of this study. The drainage pattern in this area is dendritic. Trinity River, the main stream draining the region, is here approximately 300 m above sea level, so local relief of 1100 m and more is present. The three adjacent creeks where *Monadenia setosa* was found are high-gradient streams with steep canyon slopes.

Much of the region is densely forested with stands of Douglas fir, *Pseudotsuga menziesii,* and yellow pine, *Pinus ponderosa.* Patches of Mixed Evergreen Forest, Foothill Woodland (Munz and Keck 1965) and brush also occur within the study area, particularly on the drier, more exposed slopes and in burned-over areas. The average annual precipitation is 102 cm (Elford 1970). Rain is infrequent during the summer. During late fall and winter months of heavy precipitation, runoff is high and the creeks and rivers become greatly swollen.

Rocks of the region are chiefly mixed metasediments and metavolcanics, with minor local serpentine, of the Hayfork Terrane of the western Paleozoic and Triassic belt of the Klamath Mountains (Irwin 1972). Dense crystalline limestone occurs in (a) a large pod generating rockslides north of California Highway 299 just east of Del Loma; (b) a small outcrop near the mouth of Manzanita Creek; (c) small boulder-sized outcrops on the east side of the canyon of Swede Creek, elevation about 975 m; and (d) above and below Big Mountain Road east of Italian Creek (north center Sec. 14, T. 5N 7E). Only (c) is within the known range of *M. setosa.* All rocks in the region are highly fractured internally, producing canyon slopes of talus.

RESULTS

Distribution and Habitat

Living *M. setosa* were found in the Swede Creek drainage; however, only shells were found in the adjacent drainages of Little Swede and Big French creeks (Figure 1). Neither living *M. setosa* nor shells were found elsewhere in the study area.

Monadenia setosa was found in two general situations: (a) on moist but generally well drained, somewhat stable, leafmold-covered talus slopes in mixed deciduous-coniferous forest; and (b) on stabilized, forested, riparian benches generally consisting of talus accumulations behind riffles of bed rock and having at least a 10 cm thick accumulation of leafmold resting on the talus. Such benches occur along Swede Creek from just north of Highway 299 to an elevation of about 610 m, along much of the lower course of Big French Creek, and to a limited extent along lower Little Swede Creek. A notable difference between (a) and (b) is the scarcity of standing broadleaf deadwood in the latter. *Monadenia setosa* was found from about 365 to 1169 m elevation, but not all apparently suitable sites within this range were occupied.

Monadenia setosa was found only in the presence of hardwood understory consisting variously of bigleaf maple, *Acer macrophyllum*; dogwood, *Cornus* sp.; California hazel, *Corylus cornuta* var. *californica*; sometimes tanbark oak, *Lithocarpus densiflora*; California black oak, *Quercus kelloggii*; and in the lower reaches of the range, white alder, *Alnus rhombifolia*. On riparian benches the snail does not occur farther from the stream than the growth of dogwood, although maple and hazel continue farther away from the water. Its occurrence on these benches is restricted to a zone marked by an association of alder, dogwood, ferns, California hazel, minor bigleaf maple, and California black oak. This zone is probably submerged irregularly by extreme runoff. The lower portion of the benches is dominated by *Rubus* vines, other non-woody plants, and drift accumulations, and is probably submerged annually during spring runoff. *Monadenia setosa* was never found here.

The snails are restricted to areas of moderate to deep shade. Lightly shaded areas of exposed sidehills and upper slopes with an oak-madrone-Douglas fir association have no *M. setosa*. This association occurs on the slopes above Highway 299 and at the head of the Swede Creek drainage basin. The dry, lightly forested slopes above Highway 299 support a different molluscan assemblage consisting of *Monadenia churchi* Hanna and Smith 1931 and other snail species with biogeographic affinities inland (Roth 1979 and in preparation). *Monadenia setosa* is also absent from areas of digger pine, *Pinus sabiniana*, or brush.

Both east- and west-facing canyon slopes have *M. setosa*, but not south-facing slopes fronting Trinity River. No directly north-facing slopes were surveyed. The species is also absent from the banks of Trinity River; here the substrate is either sand with willows and subject to washouts during high water or rocky without the requisite deciduous understory.

Monadenia setosa apparently utilizes different habitats during different stages of its life history. Juveniles, up to 9 mm diameter, occur under loose bark of standing broadleaf deadwood from 0.5 to approximately 3 m above ground level. At least three tree species, bigleaf maple, white alder, and canyon oak, *Quercus chrysolepis*, are utilized. No *M. setosa* were found in logs on the ground, dead trunks of madrone, *Arbutus menziesii*, or coniferous deadwood, although all of these are common in the area.

Adults and subadults were found only on the ground, either crawling on the surface of leafmold or, when inactive, sealed to loose leaves or twigs in the top 5 cm of duff. Some inactive adults were loose in the duff with a solid, whitish epiphragm completely across the apperture.

On a riparian bench along lower Swede Creek at an elevation about 365 m, an area which is typical lower elevation *M. setosa* habitat, alder and bigleaf maple comprise 75% or more of identifiable material in the duff; various oak, California hazel, madrone, and conifer needles make up the remainder. A partial soil profile (Table 1) was recorded for this site. As noted above, living *M. setosa* were found only in the first layer and upper part of the second layer; none were found at greater depth or buried among rocks of the talus. No living specimens were found where duff was predominantly either conifer needles or oak leaves nor where gravel was covered by a thin layer of loose leaves.

TABLE 1. A Partial Soil Profile of a Riparian Bench on Lower Swede Creek, Typical Lower Elevation *Monadenia setosa* Habitat

Layer	*Thickness (cm)*	*Composition*
surface	2–3	entire leaves and large leaf fragments
2	7–9	comminuted leafmold with a few pebbles, penetrated by fine roots
3	7–9	gravel, pebbles to 5 cm diameter, mixed humus and coarse sandy loam
4	>30	(parent material not reached) coarse sand, pebbles, larger roots; minor humus.

Adult shells and juvenile shells 13 mm in diameter and larger were found to a depth of about 8 cm in pockets of leafmold between large rocks or roots and at the base of rock outcrops. Many of these shells are unworn, suggesting that the animals probably died in place. Shells also occur on the surface of leafmold and in stream-drift debris accumulations. The latter shells could have been washed down from topographically higher sites and may not represent resident populations. A few shells found on the surface of game trails crossing talus slopes were almost certainly displaced from elsewhere; no living animals were found in this situation either in this study or in earlier field work by Talmadge (1952).

Soils ranged from pH 4.4 to 7.6, with most readings between pH 6.6 and 7.0. Living *M. setosa* were found at sites where soil pH ranged from 6.8 to 7.0. Shells were found in soils with pH 6.6 to 7.0. Soil samples from the limestone rockslide east of Del Loma tested pH 7.6. Snails of the genera *Helminthoglypta* and *Trilobopsis* were found in the rockslide area; limestone and/or alkaline soils may be significant in their distribution (Roth, in preparation). Another *Monadenia, M. churchi,* occurred both in the limestone rockslide and in a Douglas fir log on leafmold of pH 4.4. It is our opinion that pH is not a primary factor limiting the distribution of *Monadenia setosa*. The absence of this species from sites outside the pH range 6.6 to 7.0 is more likely related to conditions of moisture, vegetation type, and exposure.

Standing broadleaf deadwood with loose bark, the special habitat of juveniles, is very likely a limiting resource. Its absence on some of the lower levels of creek drainages may mean that, even if reproductively active adult snails are present, a second generation is not able to mature. Although no strictly quantitative data are available, the number of snails discovered during comparable periods of search was greater near the headwaters and on the talus-covered canyon slopes of Swede Creek than on riparian benches in the lower part of the drainage. It is possible that living *M. setosa* on these benches are washed down from higher elevations during times of high runoff. The apparent pattern of abundance and the absence of standing deadwood at lower levels suggest that the riparian bench populations may be transient with their members recruited from established populations upslope and upstream rather than the product of reproduction *in situ.*

Moisture may also be a limiting factor. In the Swede Creek drainage the upper limit of the hardwood association in which *M. setosa* occurs coincides approximately with the presence of spring seeps. The laterally narrower range of both hardwood and snails at lower elevations may reflect a steeper moisture gradient away from the stream. *Monadenia setosa* is probably active only in the presence of surface moisture. In the field active snails were found only on damp substrates. During July only sealed-up, inactive snails were found on the lower benches of Swede Creek; under moist conditions in May, snails here were active. In the laboratory *M. setosa* become inactive and secrete epiphragms when terraria are allowed to dry out. They can be reactivated merely by misting the interior of the terrarium. The absence of *M. setosa* in lightly shaded, exposed situations may be principally a moisture-related phenomenon.

On the other hand, excessive moisture may be hazardous. Some of the upper forested slopes near the head of Swede Creek experienced sheetwash during the rainstorms of early September; both snails and suitable leafmold cover were absent here. At all elevations, poorly drained soils with standing water had no snails.

Abundance

Adult *M. setosa* were sparse wherever found and not all apparently suitable sites were occupied. The snails were never clustered, usually occurring singly and apparently randomly within leafmold patches. We observed no evidence of homing behavior or competition for favorable homesites either in the field or in the laboratory. Juveniles were found only beneath the loose bark of standing broadleaf deadwood. Typically, several occurred under the bark of a single tree. Since it is difficult to examine the trees for snails without destroying the habitat, we did not attempt to survey all standing broadleaf deadwood. Not all the dead trees we examined had juvenile *M. setosa*.

The extremely lower numbers (fewer than 35 living snails were observed during the entire study) precluded mark-and-recapture or other techniques of population measurement. Even without quantitative estimates, it is apparent that *Monadenia setosa* is an uncommon snail within its limited range.

Food

Monadenia setosa evidently feeds largely on dead and decaying plant material without chlorophyll. This material is abundant wherever the snail is found. The first feces of *M. setosa* brought into the laboratory were reddish brown, like the substrate where the snails were collected, and consisted of comminuted leaf litter. Feces of juveniles from dead trunks were light brown and proved, on microscopic examination, to consist of reddish brown, not obviously cellular, material (possibly scrapings from the inner layer of bark), fine mineral grains (chiefly quartz), minor shreds of moss, and an unidentified brittle white substance. If the mineral grains are interpreted as wind-borne dust, this fecal composition indicates feeding on and under the bark of trees where juveniles were found, with no indication of descent to the ground for feeding.

In captivity both adults and juveniles readily ate dry rolled oats—a typical response for a snail which naturally feeds on dead vegetable matter—and also accepted bran and iceberg lettuce. Alfalfa sprouts were refused. Dry canyon oak leaves, part of the native substrate placed in the terrarium, were not eaten. Availability of leafmold for food could, theoretically, limit distribution and population size, but is probably less important than moisture and character of the cover. It is rare for food to be the limiting resource for a land mollusk (Chatfield 1976).

Behavior

Monadenia setosa is crepuscular or nocturnal in habit. We observed only a single active snail on the surface of the ground during daylight, and many hours of sorting through leaf litter produced only inactive snails. In early morning and at dusk, however, we observed adult snails crawling on the leafmold. No nighttime observations of snails in the field were attempted; however, snails in terraria are active throughout the night.

Juvenile *M. setosa* exhibit a well-developed climbing response which is apparently absent in adults. In the terrarium, juveniles crawl to the tip of twigs or rest upside-down under the lid. As mentioned above, they have been found beneath the bark of standing deadwood as high as 3 m above the ground. The climbing habit of juveniles may provide protection from predation or reduce competition. Alternatively, climbing may be an adaptation against being washed away by runoff before they are large enough to maintain their position.

The shells of these juveniles have a sharp peripheral carina, typical of snails which live in tight crevices, as between wood and bark. With growth, the peripheral angle becomes less acute. The periphery of adult shells is bluntly angular to rounded. The dull-surfaced brown shell is an excellent visual match for the leafmold substrate. As Talmadge (1952) noted, spider webs and small leaf particles often become entangled in the fine setae of the periostracum, making the snails even more difficult to see and presumably providing additional protection from predation.

Predation

Evidence of two kinds of predation on *M. setosa* was noted. A fresh fragment of shell had serrate edges which we interpret as gnawing by rodent or shrew; other shells seem to have been gnawed on the spire. One specimen was found with epiphragm in place but breached by a 4-mm hole and stained with rotted flesh. Inside the shell were vacant insect puparia. It therefore appears that *M. setosa* is parasitized by an insect, possibly a species of flesh fly (Family Sarcophagidae).

Reproduction

We did not observe reproductive activity in the course of our study. Talmadge (pers. commun.) reported that *M. setosa* in his terrarium deposited clutches of about 12 eggs, which hatched in 31 days. Still to be learned is the site of oviposition in the natural habitat: does it occur randomly in the leaf litter, requiring the newly hatched young to find their way to a dead tree trunk, or do the adult snails oviposit only at the base of suitable deadwood?

Shell

The shell of *Monadenia setosa* has not been illustrated before now. the holotype, California Academy of Sciences Geology Type Collection (CASGTC) 12184 (Figure 2*A–C*), agrees with the description by Talmadge (1952), except that—counting by the method of Pilsbry (1939: xi, Figure B)—there are 6.0 whorls rather than 6.5. Talmadge's measurements of maximum diameter include the expanded outer lip of adult specimens.

Adult shells range from 25.2 to 31.3 mm in major diameter (exclusive of outer lip) in the samples examined (N = 18; mean = 29.6 mm; V = 5.56). Talmadge (1952) reported one 35 mm in diameter. Coloration of the tract between the peripheral band and suture varies, being either yellowish brown with a darker central stripe (as in the holotype) or nearly filled by a broad chestnut-brown band a little lighter than the base of the shell. The central stripe is sometimes detectable within the broad chestnut band; so the two classes are not entirely distinct. The lightest shells are not greatly lighter than the darkest shells.

Protoconch sculpture (Figure 2*D*) consists of a dense overall granulation. The granules are closely spaced and irregular, and show some tendency to fall in diagonal series. They are coarser and less uniform than the granules of *Monadenia fidelis* (Gray 1834), which typically merge into a clothlike pattern. This embryonic sculpture persists for about 1.75 whorls, after which the granules become sparse and the neanic sculpture, consisting chiefly of incremental lines, becomes apparent. The periostracum covering the neanic whorls is minutely radially wrinkled and bears short, translucent bristles deployed in diagonal series (Figure 2E). The tips of the bristles curve forward in the direction of growth.

Four paratypes, CASGTC 9874–9877, are in the California Academy of Sciences collection.

Color

The body of the living animal is dark gray with an overall pattern of closely spaced russet or salmon-colored tubercles. The net visual effect is a light reddish brown, similar to the leafmold on which the snails crawl. There is some variation in shade from individual to individual. Very young animals are gray with a purplish cast.

Anatomy

Two adult specimens from the lower terraces of Swede Creek were dissected. One (I), with shell 25.2 mm in diameter, was drowned then transferred by stages to 70% ethanol; the other (II), with shell 30.7 mm in diameter, died in captivity, was frozen and upon thawing placed in 70% ethanol. Except as specified, the observations below pertain to both specimens.

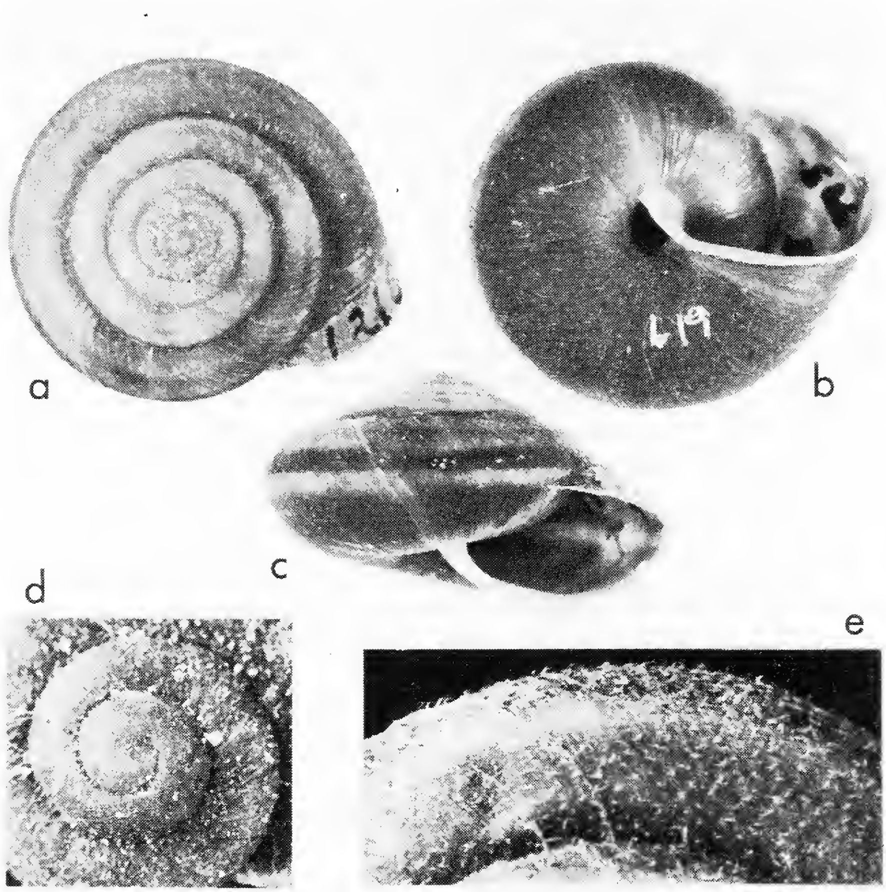

FIGURE 2. *Monadenia setosa* Talmadge, shell. A–C. Top, basal, and lateral views of holotype, CASGTC 12184. D. Detail of apical sculpture. E. Upper surface of whorl, showing periostracal bristles. (D, E, specimens in senior author's collection.) *Photography by authors.*

The mantle over the lung is light tan, either plain (II) or about 35% covered with loosely reticulate gray patches composed of minute individual black pigment spots (I). The mantle collar is purplish gray. For about 4 mm behind the collar, the mantle is tinged russet with a central russet stripe outlined in tan, corresponding to the peripheral band of the shell.

The right ocular retractor muscle (not shown) passes through the crotch between the male and female systems (Figure 3). The atrium and lower male and female systems are enveloped in a tough, membranous tunic that forms a collar around the base of the penis. The penis (I: 6 mm long) contains a cylindrical verge (I: 3 mm long), somewhat squared at the tip and longitudinally ribbed (Figure 3A). The penial retractor muscle originates on the floor of the lung and inserts in a sheathlike covering on the distal third of the epiphallus. The vas deferens runs forward along the medial side of the atrium then back along the penis and epiphallus. The epiphallic caecum is rather stout, tapering at the free end; its distal 1 mm is very fine, almost threadlike, and tipped by a 1-mm diameter bulb.

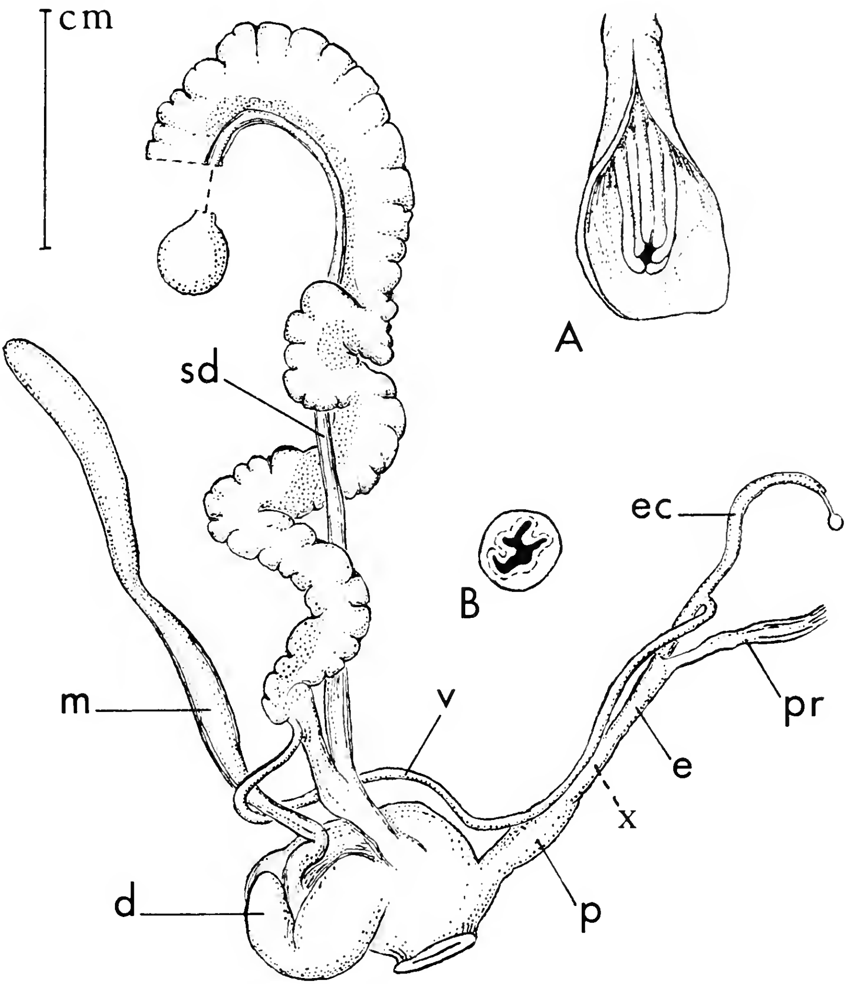

FIGURE 3. *Monadenia setosa* Talmadge, genitalia. Atrium rotated 90° to left with respect to penial complex. A. Penis opened to show verge. B. Cross-section of epiphallus at x. Abbreviations: d, dart sac; e, epiphallus; ec, epiphallic caecum; m, mucus gland; p, penis; pr, penial retractor muscle; sd, spermatothecal duct; v, vas deferens.

The atrium is broad, thick-walled and saccular. It contains two large transverse crura which, when everted, probably form a copulatory disk more or less like that illustrated by Webb (1952: Figures 9, 10) for *Monadenia fidelis.* The everted state was not observed. The female opening into the atrium is between the two crura; the male opening is anterior, in line with the upper of the two. The dart sac inserts posteriorly where the crura converge. The mucus gland (l: 29 mm long), borne dorsally in life, is constricted near its middle and bent at a right angle slightly before its insertion on the atrium next to the dart sac.

The possession of a mucus gland many times longer than the dart sac, a broad atrium, and an epiphallic caecum not longer than penis plus epiphallus clearly places *Monadenia setosa* in the nominate subgenus, *Monadenia, sensu stricto.* In the subgenus *Corynadenia* Berry 1940, the mucus gland is short and club-shaped, the atrium is elongate, and the epiphallic caecum is decidedly longer than penis plus epiphallus. In general character the genitalia are like those of *Monadenia fidelis,* type species of the genus (compare Pilsbry 1939: Figures 15A, 15B; Webb 1952: Figure 4). The epiphallic caecum of *M. setosa* appears to be proportionally shorter than that of *M. fidelis,* but the range of variation of this character in *M. fidelis* is inadequately known. A minute bulb at the tip of the epiphallus has also been reported (Roth 1975) in *Monadenia churchi* but not in *M. fidelis;* earlier workers may have overlooked it.

DISCUSSION

Monadenia setosa is a cryptic snail which occurs in low densities over a very limited range. Because of this our sample size is too small to exclude the possible effects of chance in some findings. However, the following generalizations should serve as working hypotheses for future studies and for interim management purposes. *Monadenia setosa* requires both standing broadleaf deadwood and fallen logs. Standing deadwood is essential juvenile habitat; logs on the ground help stabilize the talus and provide pockets in which leaf litter can accumulate. A well developed leafmold substrate is necessary for food, cover, and possibly oviposition; it should be seasonally moist but well drained and composed chiefly of soft deciduous leaves. The talus must be stable enough from year to year that such leafmold can develop. Deep to moderate shade is probably important for moisture regulation and temperature moderation. Because *M. setosa* has a limited range, burrows only shallowly, and requires standing deadwood during part of its life cycle, it is vulnerable to fire. Logging, road building or other forestry practices that would alter the local drainage pattern, decrease slope stability, increase runoff and erosion, or open up the shading understory would constitute threats to the species' survival.

High runoff is a natural hazard to *M. setosa* and may limit population size by washing away snails and cover. Talmadge (1960) reported the temporary occurrence of the species "twenty miles downstream" along Trinity River where it was presumably carried by flood debris. This colony lasted only 1 year. *Monadenia setosa* also "went ashore" on flats by Trinity River at Hawkins Bar during the flood of 1964 but did not persist past 1966 (Talmadge, pers. commun. 1978). The failure of these river-borne colonies may be due to the lack of suitable juvenile habitat.

Habitat differences between juveniles and adults have not been reported previously for any California land snail. Heatwole and Heatwole (1978) observed differences in site selection by juveniles and adults of several Puerto

Rican camaenids and remarked that ontogenetic habitat differences may be common among land snails.

Monadenia setosa falls in the habit/habitat class (a) of Cain (1977): "nocturnal and buried during the day, or in very shady habitats." The association of dark brown shell with this class is consistent with the pattern Cain observed among European land snails in which dull brown color correlates strongly with secretive habits and life in the shade. The modest amount of color variation in *M. setosa* is consistent with the finding that uniformity of color "is very closely associated with the woodland habitat and/or with secretive habits" (Cain 1977: 131).

No vernacular name was applied to this species prior to the 1974 usage of "California northern river snail" in the Federal Register (39: 37078, 17 October 1974). Since this terrestrial species is restricted to three small stream drainages in Trinity County, we feel that the above name is inappropriate. We suggest that when a vernacular name is desired, "Trinity bristle snail" be used since this name combines the name of the county to which *M. setosa* is limited and a prominent feature of the snail's shell.

In both shell and genital characters, *Monadenia setosa* resembles *Monadenia fidelis*. It occurs near the southeastern edge of the latter's known range. Many isolated enclaves of *M. fidelis* in the large river valleys of northern California have distinctive characters, which have led taxonomists to recognize a number of subspecies. These peripheral colonies tend to be less variable than populations along the coast or father north in Oregon and Washington where more widespread moist conditions foster less geographic isolation. They may represent small populations that have lost their store of genetic variability. *Monadenia setosa* probably speciated under such conditions of geographic isolation and population shrinkage during the changing climate of the late Pleistocene. Not only morphologic variability, but also ecotypic plasticity can be lost in such situations. Although *M. setosa* has basically good dispersal ability—as shown by its waif occurrences down Trinity River—its exacting juvenile habitat requirements limit its potential for successful colonization of new territory. At present, the necessary combination of cover, moisture and forest decadence is evidently too uncommon, too localized, and too often located beyond barriers such as dry ridgetops or sandy riverbanks to allow *M. setosa* to expand its range.

RECOMMENDATIONS

Several limiting factors have been suggested by this field study. These factors should be examined more rigorously under controlled laboratory conditions. The reproductive biology requires additional study—particularly age at maturity, time and location of oviposition, and per cent survival of young. Little Swede and Big French creek drainages, where shells, but no living *M. setosa* were found during this study, should be more intensively surveyed to determine if living colonies still exist there. Studies of daily and seasonal activity cycles, population structure and density, and additional observations on site selection by juveniles and adults could be significant in the protection of this rare and distinctive species.

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ANCESTRY OF ARTIFICIALLY PROPAGATED CALIFORNIA RAINBOW TROUT STRAINS [1]

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A historical treatment of the ancestry of the nine strains of rainbow trout artificially propagated by the California Department of Fish and Game is presented: Pit River, Eagle Lake, Junction Kamloops, Davis, Mt. Shasta, Virgina, Hot Creek, Mt. Whitney, and Coleman. The first three strains listed are descendants of collections from single populations; the other six are the result of mixing or deliberately crossing strains.

INTRODUCTION

In 1879 the United States Fish Commission began taking eggs from rainbow trout (*Salmo gairdneri*), probably from both anadromous (steelhead) and resident stocks (Needham and Behnke 1962), at Baird, on the McCloud River of Northern California (MacCrimmon 1971). Wales (1939) presented an extensive list of early egg shipments from Baird, and MacCrimmon (1971, 1972) chronicled the world-wide distribution of rainbow trout. Dollar and Katz (1964) outlined the ancestry of several important rainbow trout strains used by fish and game agencies in the U.S., demonstrating that virtually all can be traced back to the McCloud River. Recently Kinuen and Moring (1978) described the ancestry of rainbow trout strains used in Oregon.

The California Department of Fish and Game (CDFG) presently propagates nine strains of rainbow trout artificially: Mt. Whitney (RTW), Virginia (RTV), Hot Creek (RTH), Davis (RTD), Mt. Shasta (RTS), Coleman (RTC), Pit River (RTP), Junction Kamloops (RTKJ), and Eagle Lake (ELT). RTW, RTH, RTS, and RTC are general purpose strains which are produced in large numbers, accounting for 84.9% of CDFG rainbow production (Figure 1). The RTP, RTKJ, and ELT strains are used in more specialized programs and account for only 7.5% of rainbow trout production (Figure 1). The remaining strains, RTV and RTD, are general purpose strains presently being phased out of and into the CDFG program, respectively.

The maintenance of these nine strains allows the CDFG to produce rainbow trout eggs during 9 months of the year (Figure 2). The spawning season begins in August with the RTV, RTD, and RTH strains producing eggs which will provide catchable trout for spring planting the following year. The later-spawning RTH fish plus the winter spawning of RTC and RTS provide the eggs used to produce catchables for the summer planting season. The spring spawning of RTW allows for catchable trout production for the fall and winter as well as producing fingerlings used in the summer planting of high mountain lakes. In addition, these strains provide the CDFG with a wealth of genetic material to maintain genetic

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diversity and to use in inter-strain crosses. Because of the extensive overlapping of spawning seasons, numerous crosses are possible, many of which have proven useful in management programs.

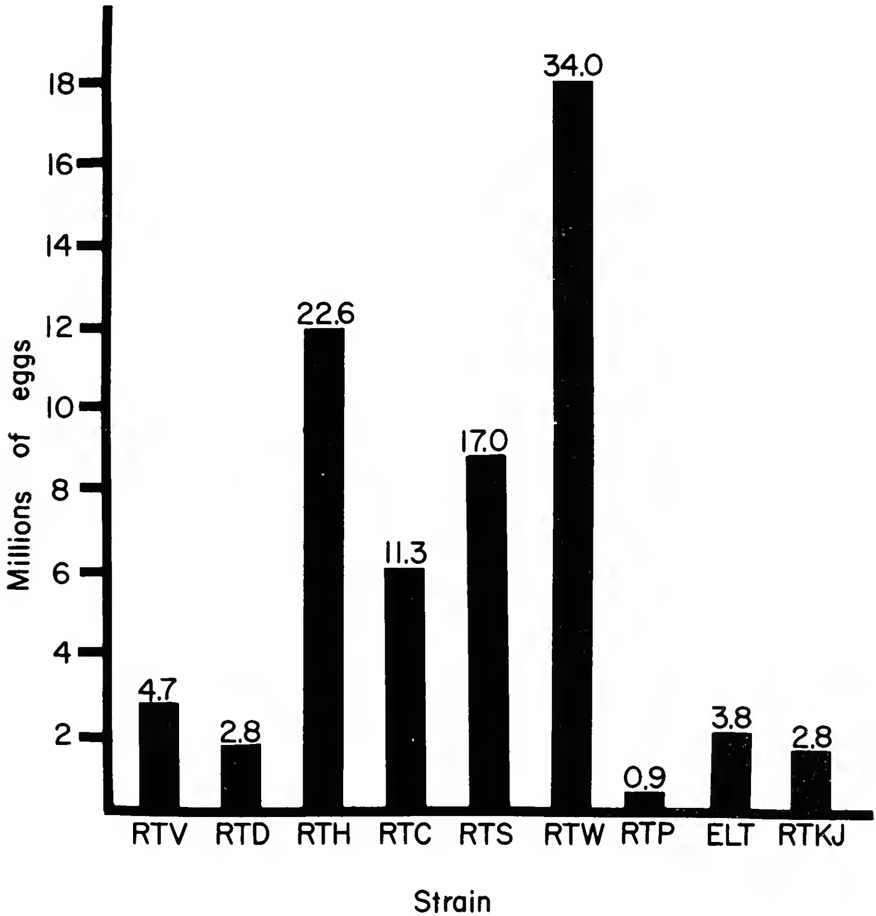

FIGURE 1. Projected 1979 production, in millions of eggs, for the nine artificially propagated CDFG rainbow trout strains. Numbers above bars indicate each strain's percentage contribution (rounded to the nearest tenth of a percent) to total rainbow trout production.

The general purpose strains are "domestic", maintained entirely within hatchery waters and selected for higher production and greater ease of handling. Most of these are now under a sophisticated selection program described by Gall (1979). In contrast, two of the special purpose strains, ELT and RTKJ, are "wild"; they are maintained in lakes but spawned by hatchery personnel and reared to some extent in hatcheries before being returned to the lakes.

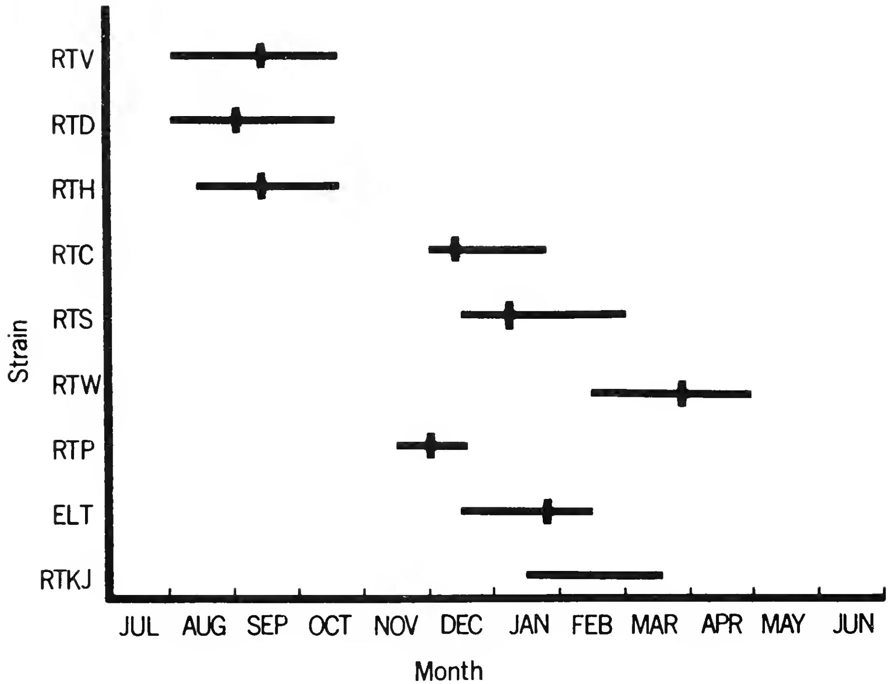

FIGURE 2. Ranges of the spawning seasons (horizontal lines) and peak spawning times (vertical lines) for the nine artificially propagated CDFG rainbow trout strains. Range and peak of RTW may vary greatly from year to year. RTKJ spawning typically has no discernible peak.

The CDFG rainbow trout strains represent at least three subspecies: *S. g. kamloops,* the rainbow of the Kamloops region of British Columbia (RTKJ); *S. g. aquilarum,* a form naturally occurring only in Eagle Lake, Lassen County (ELT); and *S. g. stonei,* the rainbow of the Sacramento River drainage (all other strains). Descriptions of the ancestry of some of these strains have appeared as background material in the studies of Cordone and Nicola (1970), Rawstron (1972), Gall and Gross (1978), and Busack, Halliburton, and Gall (1979), but nowhere has there appeared a comprehensive presentation of the ancestry of all the strains. This, then, is the purpose of this paper.

ANCESTRY OF THE RAINBOW TROUT STRAINS

Mt. Whitney Strain (RTW)

The ancestry of this strain is more complex than that of any other because the strain developed over a period of approximately 10 years (1920–1930) through the retention as brood fish of fingerlings from assorted egg collections sent to the Mt. Whitney hatchery (Lewis and White 1955*a*). The hatchery was built during World War I at Independence, Inyo County. One of the reasons for choosing this site was that a good source of rainbow trout eggs existed in the nearby Rae Lakes, Fresno County (Calif. Fish and Game Commission (CFGC), 24th Biennial Report, 1915–1916, p. 75). These lakes had been planted around 1900 with fish from Charlotte Lake, Fresno County, which were originally of Kings River origin (CFGC, op. cit.). Eggs from the Rae Lakes were taken to the Hatchery several times in its first years of operation. Other early egg collections handled by the Hatchery included: (1) Big Bear Lake, San Bernardino County (Hatchery Notes (HN), *Calif. Fish and Game (CFG)* 4: 148, 1918). These fish were of Klamath River origin (HN, *CFG* 1: 187, 1914) and were probably steelhead (memorandum by L. E. Nixon, ca. 1962). (2) Snow Mountain, south fork of Eel River, Mendocino County (HN, *CFG* 3: 127, 1917). These fish were endemic Eel River steelhead. (3) Tahoe hatchery (HN, *CFG* 3: 127, 1917). These were Lahontan cutthroat; their ultimate origin is impossible to determine, but cutthroat eggs from a number of lakes were routinely mixed in hatcheries (Behnke 1960).

All the above shipments agree with accounts by George McCloud, an early superintendent of the hatchery, of the possible ancestors of the Mt. Whitney strain. McCloud, in two interviews (Cordone and Nicola 1970; memorandum by L. E. Nixon, ca. 1962) also mentioned fish from Lake Almanor, Plumas County. These were likely a mixture of native and hatchery stocks, since this area of the state was liberally planted with rainbow trout from the Sisson (now Mt. Shasta) hatchery at least as early as 1912 (CFGC, 22nd report, 1912, p. 68ff). The rainbow trout strain then used at the Sisson hatchery was largely derived from Klamath River steelhead (interoffice memorandum from W. H. Shebley to G. H. Lambson, 25 January 1929). The Nixon memorandum also mentioned June Lake, Mono County, as a source of cutthroat influence. Steelhead were planted in the Lake in 1921, and it was used as an egg taking station by the Mt. Whitney hatchery beginning in 1926 (CFGC, 29th report, 1926, p. 55); but eggs may also have been taken from the Lahontan cutthroat previously introduced into June Lake. Another possible ancestor of the Mt. Whitney strain suggested by the Nixon memorandum is the Kern River rainbow trout, *S. g. gilberti,* but particulars of this possible introduction are not known.

In recent years the only fish introduced into the Mt. Whitney strain has been Kamloops trout, probably of a Pennask Lake, British Columbia, strain, in the mid-1950's (W. Rowan, Supervisor of Regional Fish Hatcheries, Calif. Dept. of Fish and Game, pers. commun.).

Previous accounts of the ancestry of the RTW strain, those of Cordone and Nicola (1970) and Gall and Gross (1978), have been incomplete in listing sources of fish, but basically correct in suggesting the strain is a mixture of rainbow trout, steelhead, and Lahontan cutthroat.

Virginia Strain (RTV)

The CDFG has twice imported a rainbow trout strain from the federal hatchery at Wytheville, Virginia. The first of these strains was imported in 1956 and discarded in 1971; at that time a new supply of eggs was received from Wytheville from which the present Virginia strain, maintained by the Mt. Shasta and Darrah Springs hatcheries, is descended. The Wytheville superintendent, S. A. Scott, in a 1956 letter to Earl Leitritz stated the Wytheville strain was based on an 1882 shipment of McCloud River eggs, but felt there was not much McCloud rainbow left in the Wytheville strain because of numerous importations of eggs from the Rocky Mountain states in the years before 1930. Dollar and Katz recorded two introductions of other strains into the Wytheville strain: in 1925 from the federal hatchery at Springville, Utah, and in 1926–1927 from the federal hatchery at Bozeman, Montana. Since these were McCloud River strains (Dollar and Katz 1964), the Wytheville strain may have just been a composite of at least three McCloud strains.

Hot Creek Strain (RTH)

A McCloud strain long maintained at the federal hatchery at Springville, Utah, was imported into California in 1933 and became the Hot Creek strain, maintained by the Hot Creek hatchery (Lewis 1944; Lewis and White 1955*b*). In 1952 and 1953 RTH females were bred to RTW males (Lewis and White 1955*b*) to increase genetic variability in the RTH strain. What percentage of the continuing broodstock these crossbred families comprised is not known, but it was likely to have been substantial (W. Richardson, Fisheries Management Supervisor and N. Nyberg, Supervisor of Regional Fish Hatcheries, Calif. Dept. Fish and Game, pers. commun.).

Davis Strain (RTD)

The Davis strain was developed from a 1968 cross of the RTH and RTV strains described by Gall (1975) and has undergone four generations of selection at the Fisheries Biology Research Facility at the University of California at Davis. Beginning with egg shipments from Davis in 1978, the RTD strain will replace the RTV strain at the Mt. Shasta and Darrah Springs hatcheries over a period of 3 years.

Mt. Shasta Strain (RTS)

In 1950–1952 the RTH strain was crossed to a strain from Meader's Trout Farm, Pocatello, Idaho (report from Carl Hill to Broodstock Committee, 2 September 1958), to produce the progenitors of the Mt. Shasta strain, maintained by the Mt. Shasta and Darrah Springs hatcheries. Trout from the Meader establishment, once one of the largest commercial hatcheries in the country, figured prominently in the development of many strains propagated in the U.S. (Dollar and Katz 1964) but their origin is uncertain. Dollar and Katz suggested the Meader strain may have come from the federal hatchery at Neosho, Missouri. We interviewed Mrs. May Meader, the wife of the founder of the Hatchery, and her son Phillip, who managed the hatchery for several years, concerning this matter. Neither of them knew where the original fish came from or recalled importations from federal hatcheries, but they agreed that the Meader broodstock was developed over many years through the importation of many trout strains, some from as far away as Massachusetts. There was also a possibility that cutthroat trout were introduced into the Meader strain through occasional straying from the Portneuf River into the hatchery ponds.

Coleman Strain (RTC)

The Coleman strain, maintained by the Hot Creek hatchery, is the result of a 1968 importation of fish from the Coleman National Hatchery, Anderson, California. The strain was established at Coleman in 1949 from a shipment of Kamloops trout eggs from Pennask Lake, British Columbia (H. Clineschmidt, former Calif. Dept. Fish and Game Commissioner, pers. commun.). Over the years at

Coleman it was mixed with steelhead and resident rainbow trout (Rawstron 1972) from Battle Creek, a Sacramento River tributary, and it is no longer regarded as a Kamloops strain by the CDFG.

Pit River Strain (RTP)

This strain, maintained by the Crystal Lake hatchery, was developed from native Pit River rainbow trout (22 females and an unknown number of males) which ran up Sucker Springs Creek to the Pit River hatchery between 1968 and 1970 (Broodstock Committee Minutes, 69th meeting, 1972). This strain is used for planting *Ceratomyxa* infested waters, because Pit River rainbow trout are noted for being resistant to *Ceratomyxa.*

Junction Kamloops Strain (RTKJ)

The Junction Kamloops strain, maintained by the Hot Creek hatchery, was established in 1964 in Junction Reservoir, Mono County, from eggs obtained from the Oregon Department of Fish and Wildlife's egg-taking stations at Diamond Lake, Douglas County, Oregon (Hume 1967). A fishery with Kamloops trout as the sole salmonid present had been established in Diamond Lake in 1955 with eggs from Pennask Lake, British Columbia (H. Clineschmidt, pers. commun.). There is a possibility that some of the eggs sent to California from Diamond Lake may have been taken from or fertilized by domestic rainbow trout, because nearly 500,000 McCloud rainbow trout fingerlings from two strains were planted in the lake in 1962 (planting record mimeo furnished by C. Jensen, ODFW). Although these fish would have been expected to mature as 3-year-olds, some of them may have been ready to spawn in the spring of 1964 (C. Jensen, pers. commun.). However, Chris Jensen of Oregon Fish and Wildlife regards the possibility of mixing Kamloops and domestic rainbows at this time as slight.

Fish from eggs taken at Junction Reservoir are reared at Hot Creek and returned to the Reservoir. Some are reared at the Shasta hatchery to maturity and spawned to produce trout for planting, but no continuing hatchery broodstock exists; all fish returned to the Reservoir are from eggs taken at the Reservoir.

Eagle Lake Strain (ELT)

In this case the strain is the entirety of a subspecies, *S. g. aquilarum.* A variety of causes had inhibited spawning in Pine Creek, virtually the sole spawning tributary of Eagle Lake, to the point that the CDFG began trapping spawners in 1956 and rearing their progeny for return to the Lake. As a result of this program involving the Darrah Springs and Crystal Lake hatcheries, the spawning run has greatly increased from its 1959 low of 16 fish. There is virtually no natural spawning at Eagle Lake, so the entire population is dependent on these infusions of hatchery-reared fish.

Two nominal stocks of Eagle Lake trout are used by the CDFG: the wild or Pine Creek stock (ELT), and a hatchery stock (referred to as Eagle Lake Domestic). This nomenclature can be misleading, because there is virtually no difference between the two stocks. "Wild" Eagle Lake trout are those raised from eggs taken at the Lake; "domestic" Eagle Lake trout are the progeny of "wild" trout raised to maturity and spawned at the hatchery. There is no continuing hatchery broodstock. Thus, the broodstock program used for ELT is similar to that used to maintain RTKJ. Both stocks have been used in restocking Eagle Lake, although since about 1970 the domestic stock has been used almost exclusively in restocking the Lake and providing fish for management programs. (D. Weidlein, Associate Fishery Biologist, Calif. Dept. Fish and Game, pers. commun.)

Eagle Lake, probably because of its extreme alkalinity, is notoriously resistant to introductions of exotic fish species; plants of salmonids invariably fail (McAfee 1966). Therefore, although both rainbow trout and Lahontan cutthroat have been planted in the lake in the past (Region 1 planting records furnished by D. Weidlein and V. King), it is unlikely these forms contributed significantly to the ancestry of the present day Eagle Lake trout.

DISCUSSION

Dollar and Katz (1964), suggested that ancestry information may be useful in tracing the occurrence of hepatoma in various U.S. rainbow trout strains. More recently Busack et al. (1979) have examined the RTW, RTV, RTS, and RTH strains for biochemical genetic variation. RTW, which has been shown in the present study to have had the most diverse origins of all the strains, was found to have the highest level of genetic variability. In contrast, RTV, which has been shown here to have had a relatively simple ancestry, was found to have the lowest level of genetic variability. Thus, the level of genetic variability in a domestic rainbow trout strain may be partially explained by the complexity of the strain's ancestry.

The record presented here of the ancestry of CDFG rainbow trout strains is almost certainly incomplete. Early trout cultural operations were much more concerned with production than the maintenance of particular strains. Therefore culturists freely mixed strains, probably seldom recording the mixing. Needham and Gard (1959) stated that this attitude extended even to the mixing of different species and cited as an example the occasional occurrence of cutthroat trout characteristics in RTH trout. There is, however, no record of cutthroat introduction into this strain either at Springville, Utah, or at Hot Creek other than the indirect introduction through the RTHxRTW crossbreds produced in 1952–1953.

Perhaps records will be found in the future to supplement or supersede the information presented in this report, more clearly delineating the ancestry of the strains. For the present it is important to record what is known of the strains' ancestry before that information is lost. A vital part of the management of trout or any other animal is possessing as clear as possible a definition of what the organism is; knowledge of its ancestry is a valuable complement to knowledge of its biology.

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THE EFFECTS OF MOSQUITO CONTROL RECIRCULATION DITCHES ON THE FISH COMMUNITY OF A SAN FRANCISCO BAY SALT MARSH [1]

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Effects of mosquito control recirculation ditches on species composition, density, and size and age structure of a pickleweed (*Salicornia virginica*) salt marsh fish community were analyzed in Albrae Slough marsh near Fremont, Alameda Co., California. Collections from January through August 1978 revealed that 10 species occupy ditched areas but only 5 species unditched areas. In an August 1978 inventory, fish density was three times greater in ditched (11.0 fish/m^2) than unditched (3.7 fish/m^2) areas. Size and age structure of the dominant species, *Gambusia affinis*, indicated that the ditched area populations have a greater proportion of immatures than found in unditched areas. The high proportion of immatures in the ditched area and in a recolonizing population examined 4 weeks after inventory indicates differential immigration by immatures. Ditching may increase diversity and density through improved habitat accessibility for fish from other areas and a ditch design which allows water retention at low tide, providing refuge for fish and their food.

INTRODUCTION

San Francisco Bay wetlands, subjected to over a century of filling and diking (Nichols and Wright 1971), have only recently been recognized as a valuable resource. Public concern for preservation of marshland has been expressed by regulatory agencies and conservation groups, and has resulted in close scrutiny of practices potentially disruptive to the remaining unaltered wetlands. Due to a lack of information about the consequences of many marshland management practices, a "hands-off" policy has generally been found necessary. Unfortunately, this policy conflicts with the goals of mosquito abatement districts (MAD), which are charged with the responsibility of controlling insect pests, including salt marsh mosquitoes (e.g. *Aedes dorsalis* and *Aedes squamiger*). In an attempt to restrict the use of expensive and environmentally disruptive pesticides on salt marsh mosquitoes, MAD's have returned to a physical control practice, the recirculation ditch.

Recirculation ditches, in extensive use prior to the introduction of DDT (Provost 1977), connect depressions in the marsh surface to natural channels. Such depressions, which fill with water only during spring tides (i.e. those bimonthly tides of greater than mean amplitude), provide breeding sites for salt marsh mosquitoes. The addition of ditches may be successful in controlling mosquito populations in two ways: (1) the complete draining of pools so that no water remains at low tide (Smith 1904); this results in removal of the larval habitat; and (2) the increased accessibility of larval habitat for predatory fish (Connell 1940, Ferrigno and Jobbins 1968); this occurs when pools are sufficiently deep to allow water to remain at low tide.

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The alterations in aquatic habitat caused by ditching suggest potential impact on salt marsh fish communities. The hypothesis tested in this study was that ditching has a negative effect on salt marsh fish populations. The approach used in testing this hypothesis was to examine three specific parameters of salt marsh fish communities: (1) species composition; (2) population density; and (3) population size and age structure. We proposed that a negative impact from ditching would result in fewer species in the fish community and reduced density. Size and age structure were examined to determine changes in distribution patterns.

Previous studies of salt marsh fishes have analyzed seasonal composition of communities (Subrahmanyam and Drake 1975, Cain and Dean 1976), community feeding preferences (Harrington and Harrington 1961), and the life cycles and ecology of individual species (Krumholz 1948, 1963; Rickards 1968; Cichoki 1977; Kneib 1977, 1978; Taylor, DiMichele, and Leach 1977). In the only previous study of fish populations in ditched marshes, Kuenzler and Marshall (1973) compared seine captures in ditches, natural creeks, and an open estuary in North Carolina. Generally, species composition of fishes in creeks and ditches was similar to the open estuary with the creeks and ditches often serving as breeding and juvenile feeding habitats.

This study is part of a multidisciplinary project to analyze the effects of recirculation ditches on marsh ecology and includes considerations of terrestrial arthropod diversity, primary productivity, physical-chemical parameters, and aquatic invertebrate relationships (Resh and Balling 1979). The project is a joint effort between the University of California, Berkeley, and the California Mosquito and Vector Control Association Coastal Region.

SITE DESCRIPTION

The southern margin of San Francisco Bay, once marshland, is now dominated by a mosaic of salt evaporation ponds. The remaining marsh occurs in long, narrow strips, characteristically associated with major sloughs that have been preserved from salt pond impoundment (Carpelan 1957). The sloughs are meandering, steep-sided tidal channels that open into the bay. A detailed description of the hydrology and soil characteristics of San Francisco Bay salt marsh drainage channels has been given by Pestrong (1965).

This study was conducted at the upper end of Albrae Slough, a 3.5-km long channel, whose width varies from 25 m at its outlet to less than 1 m at the study site. The slough receives freshwater solely from winter rainfall; there is no freshwater seepage or runoff. This results in relatively high salinities, ranging from 16‰ in late winter to 25‰ in autumn. The vegetation of the marshland surrounding the slough is dominated by pickleweed, *Salicornia virginica.*

The marsh at the landward end of the slough is characterized by numerous shallow pools and blocked channels (Figure 1). Usually channels are obstructed by slumping of banks due to lateral erosion (Pestrong 1965) and subsequent heavy growth of pickleweed. The pools and channels, isolated from tidal flushing except during spring tides, have water temperatures that fluctuate with ambient air temperature. They range in depth from 5–50 cm and have bottoms of soft, flocculent mud. Throughout much of the year the filamentous green alga, *Enteromorpha clathrata,* occurred in the open sunny areas. The waterboatman, *Trichocorixa reticulata,* and an amphipod, *Anisogammarus confervicolus,* were extremely abundant throughout the study period and, based on analysis of fish stomach contents, it was apparent that they provided ample food for the fish. Mosquito larvae were generally rare or absent after ditching.

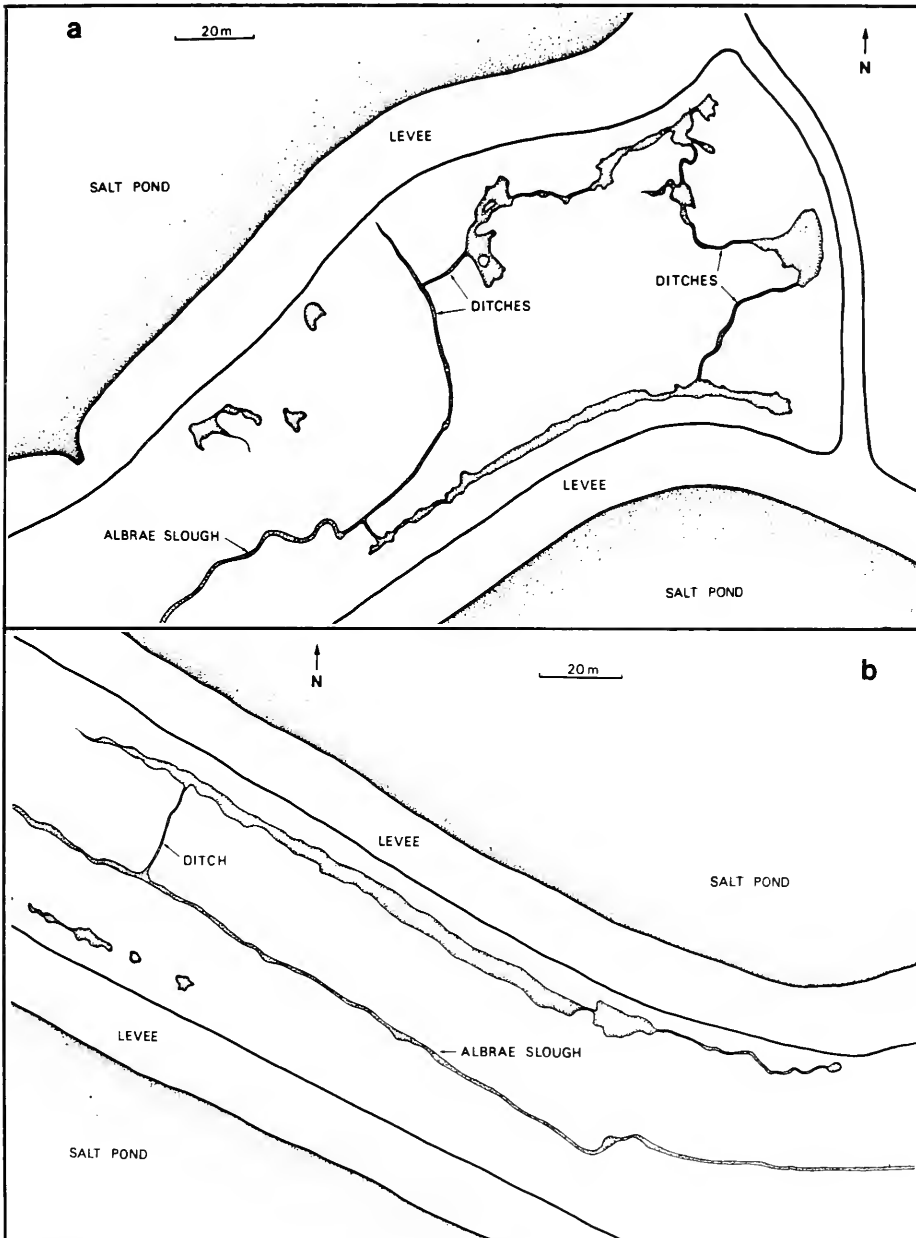

FIGURE 1. The landward end of the Albrae Slough marsh, Fremont, California: a) the ditched area showing pools and blocked channels connected by recirculation ditches; b) the unditched area showing the single ditch constructed during the population density inventory.

In 1977, the Alameda County Mosquito Abatement District began hand-digging ditches to connect pools and blocked channels to channels already open to tidal flushing. Such ditches are vertical sided, 40-cm wide and up to 80-cm deep. The ditches increase tidal circulation to marsh pools yet occasional shallow sections allow water to remain in the deeper areas of pools and ditches, providing refuge for aquatic fauna. This treatment, the "ditched" area (Figure 1A), comprises 551 m^2 of aquatic habitat, 89 m^2 of which represent recirculation ditches.

The control, the "unditched" area, comprises 404 m^2 of aquatic habitat. It lies 200 m west of the ditched area and probably was a natural channel that connected a series of pools, but is now blocked by natural slumping. Although linear in shape (Figure 1b), the unditched area is similar to the treatment area in substrate, marginal vegetation, water depth, and invertebrate fauna. Inundation of the unditched area occurs only during spring flood tides, but water volume is sufficient to keep the channels and pools from drying out during interim periods.

MATERIALS AND METHODS

Species Composition

Unbaited minnow traps (mesh size = 6 mm), augmented by handnetting with 40-cm wide D-frame nets (mesh size = 1 mm) were used periodically (usually biweekly) to sample fishes in both the ditched and unditched areas from January to August 1978. The traps were left in narrow areas of channels and ditches, where passage was restricted to the space occupied by the trap. The D-frame net was also used in the general survey to sample those fishes either too large or small to be caught by the minnow traps. Since the width of the frame was approximately equal to that of the hand-dug ditches, this technique was very successful. All collected specimens were preserved in 15% formalin for 1 week, then transferred to 70% alcohol.

Population Density

A complete inventory of fish populations in the ditched and unditched areas was taken during ebb tide, when water volumes were low and fish easily captured. At peak flood tide on 28 July 1978, the only incurrent and excurrent channel to the ditched area was screened off to trap both resident fish and fish that moved into the ditched area with tidal flow. This screening process allowed water to drain off during the low tide. During ebb tide of 1 August 1978, all channels, pools, and hand-dug ditches in the ditched area were divided into approximately 15-m sections with 1.5-mm mesh screen and all fish were removed from each section with a D-frame net. The catch gave absolute population counts for the fishes in the ditched area.

Equal sampling reliability was ensured in the inventory of the unditched area by construction of a single incurrent and excurrent ditch from the lowest point of the unditched area to the main slough. A 1-m earthen plug was left until low tide of 28 July 1978, at which time the ditch was screened off, the plug removed, and the area drained. Inventory procedures followed those in the ditched area and, similarly, produced an absolute count of the fishes in the unditched area. On 24 August 1978, after the initial removal, the unditched area was again screened off and all fish recolonizing the area were collected. This second inventory was designed to determine the extent of recolonization and the species composition and abundance of this recolonization population.

A map based on a series of measurements transverse to the axis of each pool, channel, or ditch, was drawn for the ditched and unditched areas. The distance between each transverse measurement coincided with changing marginal configurations (Welch 1948: 21). The weight of each individual habitat map, divided by the weight of the paper per unit area, gave the surface area of that habitat (Welch 1948: 85). The complete process was done independently by two workers and results differed by < 1.5%.

Size and Age Structure

Population size and age structure of the dominant marsh fish, *Gambusia affinis,* was based on specimens captured during the August inventory. Size structure was analyzed by measurement of total length to the nearest millimetre. Sex was determined by the degree of anchylosis of the anal fin (Turner 1941); age structure was then estimated by maturity indices specific to each sex. Male maturity was indicated by the presence of a gonopodium (Krumholz 1948); convexity of the abdomen (indicating presence of eggs) was used as the measure of female maturity. Although this latter technique has also been used in other studies (Krumholz, pers. commun.), abdominal convexity may not indicate maturity because females in late summer are often distended with fat (Krumholz 1963, pers. commun.).

To determine whether abdominal convexity of female *G. affinis* was a sufficiently accurate measure of maturity for the purposes of this present study, a sample of 400 females (200 mature, 200 immature, based on abdominal convexity) was chosen, with maturity determined by examining the egg development levels in dissected specimens. These two methods gave different determinations for < 4% of all specimens, an error rate that we concluded was sufficiently small for our study objectives.

RESULTS

Species Composition

From January through August 1978, 10 species of fish were collected in the Albrae Slough marsh; all were found in the ditched area, whereas only 5 species were found in the unditched area (Table 1). Three fish, *Gambusia affinis, Gasterosteus aculeatus,* and *Lucania parva,* were common in both areas throughout the study, although *Gambusia affinis* was by far the most abundant. These three fish can probably be considered resident species of the marsh.

The two gobiids found in the marsh, *Gillichthys mirabilis* and *Clevelandia ios,* commonly live on tidal mudflats of coastal sloughs (Barlow 1963). In the ditched area, both species were found in low densities throughout the study, whereas in the unditched area only one specimen, a juvenile *Gillichthys mirabilis,* was found.

Carpelan (1957) reported *Atherinops affinis* to be the most abundant fish in salt ponds of southern San Francisco Bay, where it survived salinities of 55‰. Wild (1969) found that *A. affinis* comprised 82% of the fishes collected during ebb tides at the mouth of a southern San Francisco Bay slough. In the Albrae Slough marsh, we found that *A. affinis* and another atherinid, *Atherinopsis californiensis,* to be generally uncommon. Similarly, *Leptocottus armatus,* a marine euryhaline fish whose young-of-the-year and yearlings frequent coastal sloughs (Jones 1962), was found only occasionally during winter and spring in the ditched area, but never in the unditched area. *Engraulis mordax,* which enters San Francisco Bay in spring and summer, presumably to spawn (Roedel 1953), was abundant on a single mid-June sampling date in the ditched area. Occasionally, a dead individual was found during the summer, apparently carried in by the tide. Two specimens of *Dorosoma petenense,* normally a freshwater inhabitant originally introduced from the Mississippi River drainage (Moyle 1976), were collected in early winter in the ditched area.

TABLE 1. Fishes Collected From the Ditched and Unditched Areas of Albrae Slough Marsh During the Survey, January through August, 1978.

Species	*Common name*
Poeciliidae	
Gambusia affinis	mosquitofish
Gasterosteidae	
Gasterosteus aculeatus	threespine stickleback
Cyprinodontidae	
Lucania parva	rainwater killifish
Gobiidae	
Gillichthys mirabilis	longjaw mudsucker
**Clevelandia ios*	arrow goby
Cottidae	
**Leptocottus armatus*	staghorn sculpin
Atherinidae	
Atherinops affinis	topsmelt
**Atherinopsis californiensis*	jacksmelt
Clupeidae	
**Dorosoma petenense*	threadfin shad
Engraulidae	
**Engraulis mordax*	northern anchovy

* absent from the unditched area

Population Density

Fish density in the ditched area was almost three times that of the unditched area, due largely to their respective *Gambusia affinis* populations (Table 2). The density of *Gasterosteus aculeatus* was also greater in the ditched area, but *Lucania parva* population densities were equal. The two gobiids were virtually absent from the unditched area, whereas numbers of *Atherinops affinis* were very low in both areas.

The three resident species, *Gambusia affinis, Gasterosteus aculeatus,* and *Lucania parva,* recolonized the unditched area (by means of the new ditch) within 4 weeks after the initial collection. The densities of these three species in the recolonization population (Table 2) were similar to those observed previously in the unditched population. However, these recolonization densities are probably somewhat underestimated because of our inability to adequately sample a pool that was virtually unoccupied during the unditched area inventory; once the blocked channel to the pool was opened, it became a refuge for fish during low tide. Its large size and depth prevented effective sampling during the recolonization inventory.

TABLE 2. Densities and Percentage Composition of Ditched, Unditched, and Recolonization Fish Populations Captured During August 1978 Inventory in Albrae Slough Marsh.

Population	*Density (per m²)*		*% of total*	
Ditched area (551 m²)				
G. affinis	10.5		94.9	
immature ♀♀		3.0		26.9
mature ♀♀		3.2		28.7
immature ♂♂		1.3		12.5
mature ♂♂		3.0		26.8
G. aculeatus	0.4		3.7	
L. parva	0.1		0.6	
C. ios	<0.1		0.5	
G. mirabilis	<0.1		0.2	
A. affinis	<0.1		<0.1	
	11.0		100.0	
Unditched area (406 m²)				
G. affinis	3.4		91.7	
immature ♀♀		0.6		15.4
mature ♀♀		1.1		30.4
immature ♂♂		0.1		2.7
mature ♂♂		1.6		43.2
G. aculeatus	0.2		5.0	
L. parva	0.1		2.8	
G. mirabilis	<0.1		<0.1	
A. affinis	<0.1		0.4	
	3.7		100.0	
Recolonization area (406 m²)				
G. affinis	2.7		93.0	
immature ♀♀		1.2		41.8
mature ♀♀		0.3		8.5
immature ♂♂		0.4		15.2
mature ♂♂		0.8		27.5
G. aculeatus	0.1		4.3	
L. parva	0.1		2.7	
	2.9		100.0	

Size and Age Structure

Length frequency distributions (Figure 2) for *Gambusia affinis,* which comprised 94% of the 7,574 fish captured, were used to compare population size structure between areas. Examination of both male and female distributions for the ditched, unditched, and recolonization populations indicates that the most important differences are in the proportion of immature individuals (Figure 2, shaded area). The percent immatures is 61% in the recolonization population, 41% in the ditched population, but only 20% in the unditched population.

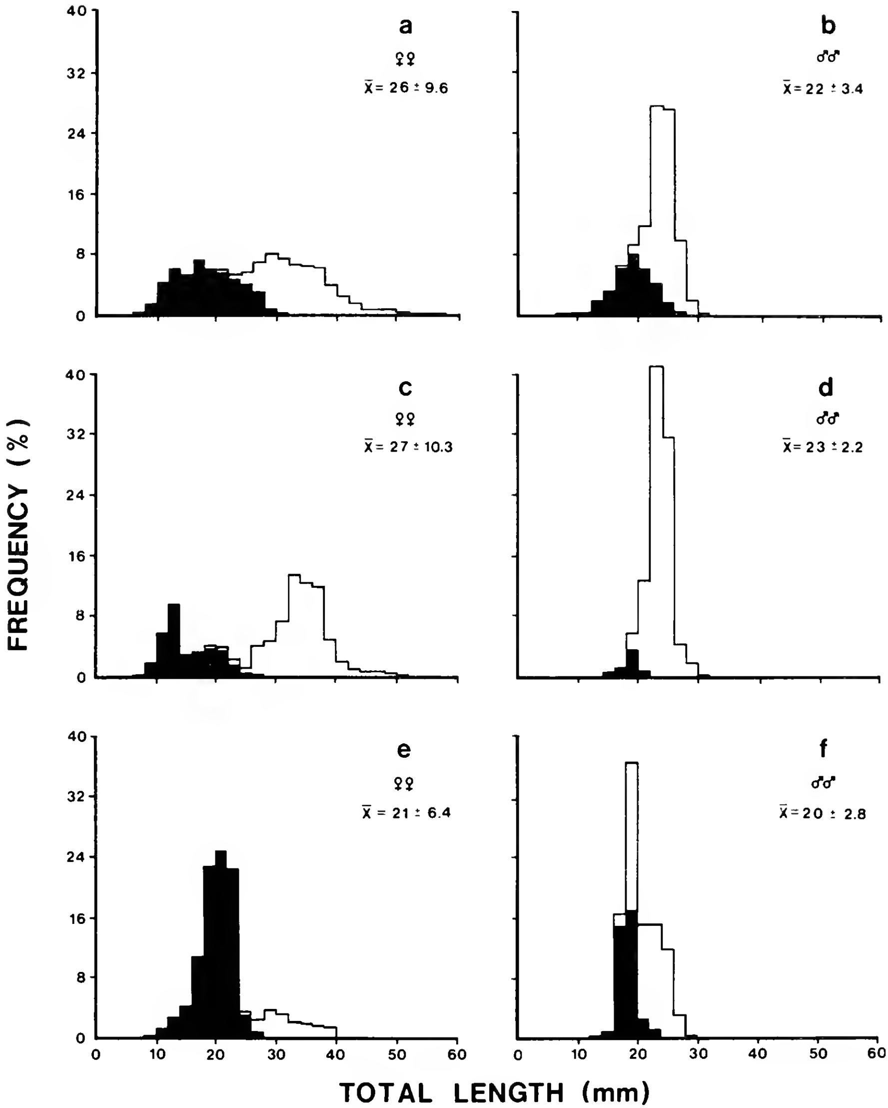

FIGURE 2. Length frequency distributions for female (left) and male (right) *Gambusia affinis* collected in August 1978 from Albrae Slough marsh, Fremont, California. a, b) ditched population; c, d) unditched population; e, f) recolonization population. The shaded areas indicate the immature specimens, the unshaded areas, the mature. Total length axis is based on 2-mm size intervals.

DISCUSSION

Analysis of the three main parameters of the study design (species composition, density, age structure) indicates that the ditched area has: (1) a greater number of species; (2) a greater fish density; and (3) a greater proportion of immature individuals than the unditched area. The greater density and species richness provide evidence for the rejection of our initial hypothesis that ditching has a negative effect on Albrae marsh fish populations and, in fact, suggest that the opposite is true, i.e. that ditching may enhance these populations. What factors might explain this conclusion?

The results of the recolonization study suggest that a major factor may be that the addition of ditches improves immigrant fish access. In fact, proponents of ditching (e.g. Ferrigno and Jobbins 1969) have predicted that increased fish utilization and consequently increased predation of mosquito eggs and larvae may result from the addition of ditches.

The rapid recolonization of the unditched area by *Gambusia affinis*, *Gasterosteus aculeatus*, and *Lucania parva*, which occurred following removal of the original population and the connection of the unditched area to the main slough, supports our contention that migration occurs between the main slough and the backwaters. Nearby studies underway at the Petaluma marsh, located on northern San Pablo Bay, indicate that such migration is absent when pools are not connected to tidal channels (Balling and Resh, unpublished data). Greater accessibility may also explain the higher numbers of fishes, such as *Engraulis mordax* and *Dorosoma petenense*, that use the ditched areas for spawning or foraging. Besides accessibility, other factors that were not directly studied but which could have influenced the greater diversity and density of fish observed in the ditched areas include: the moderation of temperature and salinity fluctuations, increased food availability, or decreased predation.

The high proportion of immature *Gambusia affinis* in the recolonization population could result from differential migration by younger age group fish into the newly ditched area, or migration of gravid females. In the latter case, the immature fish collected would represent the progeny of these gravid females. However, few large, mature females were found in the recolonization population. Since female *G. affinis* have a long post-reproductive life (Krumholz 1948), this favors the speculation that immature fish rather then gravid females recolonized the newly ditched area. Such a differential migration by the young could also explain the higher proportion of immature *G. affinis* in the ditched as compared to the unditched area.

Caution must be exercised in extrapolating results and conclusions from ditching operations in Albrae Slough to other salt marshes. In this study, the shallow ditches only serve to connect pools and allow tidal flushing. The deeper, wider channels that are often used in other ditching efforts drain aquatic habitats completely and do not provide refuge for either fish or their food; our results would not apply to such methods. We feel that under conditions similar to those at Albrae Slough, ditching does not have a detrimental effect on fish communities. Instead, the increase in accessibility to fish breeding and foraging habitats appears to be beneficial.

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MORTALITY AND SURVIVAL OF TAGGED SMALLMOUTH BASS, *MICROPTERUS DOLOMIEUI*, AT MERLE COLLINS RESERVOIR, CALIFORNIA[1]

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A tagging study initiated in 1976 at Merle Collins Reservoir, Yuba County, provided estimated rates of exploitation (0.66), expectation of death from natural causes (0.18), and survival (0.16) for smallmouth bass, *Micropterus dolomieui*, comparable to rates recorded for largemouth bass, *M. salmoides*, at California reservoirs. A 305-mm (12.0-inch) minimum size limit on largemouth bass apparently protected smallmouth under the size limit and was probably instrumental in maintaining an attractive smallmouth bass catch despite high exploitation.

Loss of shoreline habitat in the form of trees and brush has led to a decline in largemouth bass abundance and subsequent smallmouth bass dominance of bass catches at several older reservoirs.

INTRODUCTION

Increased angling pressure on black bass populations in recent years has elevated the importance of smallmouth bass at California reservoirs. Smallmouth now constitute a sizeable segment of the catch at older reservoirs where habitat in the form of trees and brush has deteriorated, leaving largely rocky areas which are more suited for production of smallmouth than of largemouth bass.

This phenomenon is apparently occurring at Merle Collins Reservoir, an impoundment described by Hashagen (1973). Largemouth bass habitat, which was very abundant when the reservoir opened to fishing in 1965, has become comparatively sparse (observations by Rawstron, coauthor). A rocky shoreline, lacking adequate shelter for young largemouth bass and more suited for smallmouth reproduction, has led to a considerable increase in the smallmouth bass population in recent years. The mean annual catch of smallmouth bass from 1973 through 1976 was 1,352 compared to 928 for the years 1968 through 1971, an increase of about 46% (Pelzman 1979). Young-of-the-year smallmouth were well represented in fall electrofishing surveys from 1975 through 1977, exceeding those of largemouth bass in the 1975 survey (unpublished data).

The expansion of smallmouth bass populations as a function of reservoir aging has generated an increasing need to acquire life history information of management significance for this species. Studies showed that largemouth bass were being overharvested at Merle Collins Reservoir (Rawstron and Hashagen 1972) and at other waters (Rawstron 1967; von Geldern 1972; Rawstron and Reavis 1974). Limited information was available, however, on the extent of angler

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harvest of smallmouth bass in California. Rawstron (1967) reported a first-year exploitation rate of 0.57, based on angler return of nonreward tags from 23 tagged smallmouth at Folsom Lake, Sacramento County. First-year exploitation, expectation of death from natural causes, and survival rates of 0.68, 0.24, and 0.08, respectively, for reward tagged smallmouth bass at Shasta Lake, Shasta County, in 1973 were reported by W. F. Van Woert, Fishery Biologist, Dept. Fish and Game (MS). Respective values for fish tagged in 1975 were 0.71, 0.28, and 0.01. He related this high exploitation to heavy angler pressure and high vulnerability of young fish to natural baits, particularly crickets. Anglers using only crickets for bait caught 42% of the smallmouth landed from April through September 1973 (Van Woert, unpublished data).

Unlike the Shasta Lake fishery, a substantial proportion of the smallmouth bass caught at Merle Collins Reservoir are taken by anglers using lures. Anglers using only lures caught 37.2% of the smallmouth landed during 1975 and 1976, while 16.5% were taken by anglers using natural baits only (unpublished data).

Considering the high exploitation (rates to 0.65) of largemouth bass at Merle Collins there was concern that smallmouth were also being overharvested. Consequently, we initiated this study in April 1976 to estimate mortality and survival rates, necessary for determining if special experimental management techniques were required.

METHODS AND MATERIALS

Three hundred smallmouth ≥203 mm (8.0 inches) fork length (FL), the size at which fish entered the catch in the absence of a largemouth size limit, were collected by electrofishing and tagged during April 1976. Fish of this length or larger constituted 86% of the annual catch of smallmouth bass (Hashagen 1973). Each fish was tagged onboard the boat within a few minutes of collection and returned to the water approximately 182.9 m (200 yards) from point of capture. No anesthetizing agent was used. A disk dangler tag advertising a $5 reward was attached to each fish below the dorsal fin, approximately a third to a half the distance from the longest spine to the lateral line. Chadwick (1963) described the application technique for the disk dangler tag. Posters advertising the tagging study were placed at conspicuous locations around the Reservoir. Envelopes for tag returns were placed with the reservoir concessionaire. Estimates of mortality and survival follow Ricker (1958).

RESULTS AND DISCUSSION

First-year exploitation was estimated at 0.65, based on return of 196 tags through March 1977 (Table 1). Anglers returned a total of 234 tags (78.0%) during the 3-year period ending March 1979, providing a weighted estimate of mean annual exploitation rate of 0.66. Rates of expectation of death from natural causes and survival were estimated to be 0.18 and 0.16, respectively.

Estimated exploitation of tagged fish was probably higher than that of untagged fish. Considering the 1,718 smallmouth bass ≥203 mm FL that anglers reported releasing from May 1973 through 1976 and the increase in mean size of smallmouth in the catch following imposition of the largemouth size limit (Pelzman 1979), anglers likely retained fish with tags that they otherwise would have released.

TABLE 1. Number of Tags Returned by Month

Month	*Year 1 1976–77*	*Year 2 1977–78*	*Year 3 1978–79*
April	25	7	1
May	70	10	1
June	51	10	0
July	26	3	0
August	7	2	1
September	6	0	0
October	3	1	0
November	0	0	0
December	1	0	0
January	3	1	0
February	2	0	0
March	2	1	0
TOTAL	196	35	3

In the first year, length frequency of fish for which tags were returned was comparable to that of all tagged fish. Fish ranging from 203 to 304 mm FL made up 85.2% of the return group and 84.7% of the total number tagged. No size group was harvested disproportionately.

There is no concensus among fisheries workers as to maximum rates at which bass can be safely harvested, however, Graham (1974), Ming (1974), and Redmond (1974) reported that a 40% harvest of largemouth bass appeared to be the maximum removal rate for maintaining proper predator-prey structure. For this reason, the exploitation rate of 0.66 for smallmouth bass at Merle Collins Reservoir would be considered high by many fisheries workers. Smallmouth catch data compiled from 1973 through 1976 as part of an evaluation of a 305-mm minimum size limit on largemouth bass at the reservoir suggest, however, that the smallmouth bass population can withstand this rate of exploitation when small fish are protected:

(1) The estimated annual catch, which ranged from 1,006 in 1973 to 1,562 in 1976, did not decline (Pelzman 1979).

(2) The mean fork length (305-mm in 1973, 303-mm in 1974, 317-mm in 1975, and 308-mm in 1976) did not decline (Pelzman 1979).

(3) There were no appreciable shifts in length frequency of the catch, although there were considerably fewer small fish in the catch when compared to pre-size limit data (unpublished data).

The largemouth bass size limit, imposed in 1972, likely protected some smallmouth less than 305-mm total length in that they were released by anglers unable to distinguish them from largemouth. An increase of over 25.4-mm in the mean length of smallmouth in the catch following imposition of the size limit suggests that anglers selected for fish that met the largemouth size requirement (Pelzman 1979). At Shasta Lake, which has no size limit on largemouth bass, high exploitation and extensive use of small baits were apparently responsible for the comparatively small average size of smallmouth in the catch (Van Woert, MS).

Results of this study indicate that mortality rates for smallmouth bass at California reservoirs are comparable to the high rates recorded for largemouth bass. Catch data compiled during the study suggest, however, that smallmouth bass populations of older reservoirs may continue to provide a quality catch despite high exploitation. The largemouth bass size limit, thought to play a role in maintaining the smallmouth catch, was extended to all black bass at Merle Collins Reservoir in 1977 and at other waters with size limits in 1978.

Smallmouth bass now dominate the bass catches at several California reservoirs including Oroville Reservoir (Butte County), Folsom Lake, and Shasta Lake. Oroville Reservoir opened to fishing in 1968. Anglers censused there in 1970 caught over twice as many largemouth bass (493 fish) as they did smallmouth bass (199 fish). Those censused in 1971 caught nearly equal numbers of the two species (R. A. Flint, Fishery Biologist, Dept. Fish and Game, unpublished data). From 1973 through 1978, however, anglers harvested 133,515 smallmouth compared to only 67,872 largemouth. During this period, smallmouth outnumbered largemouth in the annual catch by an average of 2.1 to 1 (J. I. Hiscox, Fishery Biologist, Dept. Fish and Game, unpublished data).

Folsom Lake, described by Tharratt (1966), opened to fishing in 1955. For a few years thereafter, largemouth bass were more common than smallmouth bass in the catch (G. E. Geibel, Fish Hatchery Manager, Dept. Fish and Game, unpublished data). By 1962, however, smallmouth made up 55% of the bass catch (von Geldern 1972). Data from periodic creel surveys conducted from April through August of both 1974 and 1975 showed that 375 boat anglers landed 161 smallmouth and only 13 largemouth (R. L. Reavis, Fishery Biologist, Dept. Fish and Game, unpublished data).

In the 1950's, largemouth bass fishing was considered excellent at Shasta Lake (Van Woert, MS). Since 1968, however, smallmouth have outnumbered largemouth in the catch (Weidlein 1971; T. P. Healey, Fishery Biologist, Dept. Fish and Game, MS). In 1973, smallmouth outnumbered largemouth by about 13 to 1 (T. P. Healey, MS).

The fluctuation zones of many California reservoirs were naturally revegetated during a severe drought which reduced water levels in late 1975, in 1976, and in 1977. Indications are that largemouth bass production increased as a result of this improved habitat of small plants. Young-of-the-year largemouth bass outnumbered those of smallmouth bass in electrofishing surveys at Shasta Lake in fall 1978 (Van Woert, unpublished data). Surveys of young-of-the-year bass at Oroville Reservoir in spring 1978 yielded 385 largemouth and 397 smallmouth per mile of shoreline. This represented about a 70% increase over the 226 largemouth per mile collected in 1975, a high for previous years (J. I. Hiscox, unpublished data).

Drought-created habitat should lead to an increased incidence of largemouth bass in the catch for a few years. However, unless efforts begun by the Department in 1977 to establish willows (*Salix* spp.) and other plants in the fluctuation zones of older reservoirs effectively improve largemouth production, the trend toward smallmouth bass dominance will likely prevail in the long term. Accordingly, future management of smallmouth bass populations will require greater attention to meet ever-increasing angler demands.

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ESTIMATING THE SIZE AND TREND OF THE CALIFORNIA CONDOR POPULATION, 1965–1978.[1]

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During 1965–1978, three principal methods were used to measure the size and trend of the California Condor (*Gymnogyps californianus*) population. An October survey conducted by as many as 136 observers had limited value because daily activity patterns of condors were unpredictable and because analysis of results could not be standardized. Evaluation of 4,381 condor observations by cooperators, and results of comparative surveys done in 1970–1971 and 1977–1978 show declines in numbers of condor sightings, numbers of condors per sighting, and in the numbers of sightings including more than one immature-plumaged bird. The data cannot be evaluated statistically, but they suggest a marked decline in the condor population between 1965 and 1978. Future refinements of survey techniques are dependent on having individually recognizable condors in the population.

INTRODUCTION

Although a number of population figures for the California Condor (*Gymnogyps californianus*) appeared in print before 1940, the first systematic attempt at enumeration was made by Koford (1953). He based his estimate of 60 condors on simultaneous and nearly simultaneous counts of over 40 condors, to which he added additional uncounted birds based on his understanding of distribution and population structure. Fifteen years later, using Koford's methods but in a much shorter and less detailed study, Miller, McMillan, and McMillan (1965) estimated that there were 40 condors. This apparently major decrease in such a short time indicated the need for regular and more refined monitoring of the condor population. In later years, various techniques were tried to develop either a reliable population index or an estimate of total numbers. These attempts and their outcomes are described below.

METHODS

Koford (1953) thought that "only by a simultaneous count by many trained observers at strategic locations could one discover the total number of condors". His thought has carried over into most subsequent attempts at condor counting. The principal attempt at an index has been a large-scale October survey. Also, estimates of total population or total use of certain areas have been made based on simultaneous counts and cumulative reports by an organized system of cooperators. Comparing results of field work in different years has also been tried.

The October survey has been described by Mallette and Borneman (1966); modifications and survey details are reported by Mallette et al. (1967, 1970, 1972, 1973), Sibley et al. (1968, 1969), Carrier et al. (1972), and Wilbur, Mallette, and Borneman (1977, 1979). For two consecutive days in mid-October, many observers look for condors from strategic observation points in various parts of condor habitat. They record observation times, number of condors, age classification, flight direction, and distinguishing characteristics (e.g., missing

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flight feathers) of the birds seen. Following the survey, an evaluation committee reduces the total sightings to probable number of individual condors seen.

In the second method of measuring population trends, interested observers (including ranchers, birders, hikers, biologists, fire control personnel, and others) have been asked to contribute sightings of condors, which are entered in a keysort filing system. These card records include such information as county and location of sighting, date, time of day, number of condors, age classification, and type of activity (such as feeding or roosting). Reports are evaluated for accuracy. Obvious misidentifications are discarded, and well-documented sightings are recorded as such. Observations received from cooperators with unknown qualifications or those which include only partial information are recorded as "neutral" sightings and are evaluated only as they correlate with other confirmed sightings. From time to time, accumulated observations have been analyzed and summary reports prepared (Wilbur et al. 1972, Wilbur 1976). In the current analysis, yearly comparisons were made of numbers of condors per sighting, average immature birds per sighting day, average simultaneous counts (birds seen at one or more locations at the same time), and average monthly composite counts. A composite count is the sum of the highest counts reported each month in various locations throughout the condor range. Based on current understanding of condor seasonal distribution (Wilbur 1978*a*), these groups are probably composed of different birds.

In a third attempt to measure population trends, in 1977 and 1978 I tried to duplicate my field work of 1970 and 1971. I visited the same locations on about the same dates and watched condors during the same times of day. Comparisons were made of average number of field hours required per condor sighting, average number of condors per sighting, and frequency at which immature-plumaged condors were seen.

RESULTS AND DISCUSSION

October Survey

No trends in the 1965–1978 October surveys are obvious in either total sightings or estimated number of birds (Table 1) and results are too variable to permit reasonable setting of confidence limits (Robert G. Heath, statistician, Environmental Protection Agency, pers. commun.). Verner (1978) concluded that lack of standardization of procedures was one main failing of the survey, but I think that daily variability in condor movements and uncertainties inherent in data analysis are much more significant.

Numbers of survey stations and observers have varied from year to year, but this probably had a significant effect on count results only in years when fewer than 20 stations were manned. Although Verner (1978) found that estimated total counts were significantly correlated with the number of counting stations (using Spearman's rank order correlation), this was apparently coincidental. Each year almost all observations were made among the same 30 to 35 stations in the southern part of the condor range (Figure 1). All these stations were manned in 1965–1969, 1975, 1978, and the ones where observers record the majority of condors were manned in 1970–1972 as well. Adding more stations makes little difference in either total sightings or estimated number of condors seen. For example, observers at 17 stations in the Sierra Nevada north of the Kern River (14 manned four or more years) together recorded condors in only three of seven possible years. Observers at 18 stations in the Coast Ranges north of Santa Barbara County (nine of them manned three or more years) collectively recorded condors in only three of 10 possible years. In 1968, these northern stations in the Sierra Nevada and Coast Ranges accounted for five additional condors for the total count, but in other years they accounted for two birds or fewer. Apparently a few condors are always in these northern areas in October, but the chances of seeing them on a survey are remote.

TABLE 1. Results of October Condor Surveys, 1965–1978.

Date	*No. of stations*	*No. of observers*	*Stations seeing condors*	*Total sightings*	*Estimated no. condors*
10/16/65	69	98	16	48	33
10/17/65	63	91	16	58	38
10/18/66	65	133	15	45	29
10/19/66	65	133	23	122	51
10/17/67	67	130	19	150	46
10/18/67	68	130	21	75	33
10/16/68	66	137	18	77	33
10/17/68	66	136	20	174	52
10/15/69	51	94	27	228	53
10/21/70	16	45	11	36	15
10/22/70	16	43	8	84	28
10/13/71	18	45	13	174	34
10/14/71	18	45	10	227	34
10/11/72	20	50	15	128	36
10/12/72	20	50	14	101	21
10/02/73	4	9	4	17	14
10/03/73	4	9	3	28	9
10/25/73	5	11	4	70	19
10/26/73	5	10	3	38	18
10/16/74	9	21	7	41	19
10/17/74	9	21	8	106	23
10/18/74	9	21	8	92	15
10/21/75	41	80	18	134	29
10/13/76	12	36	9	60	18
10/14/76	12	36	11	100	22
10/12/77	7	23	6	55	13
10/13/77	7	23	6	40	10
10/17/78	50	110	11	36	12
10/18/78	50	110	15	50	13

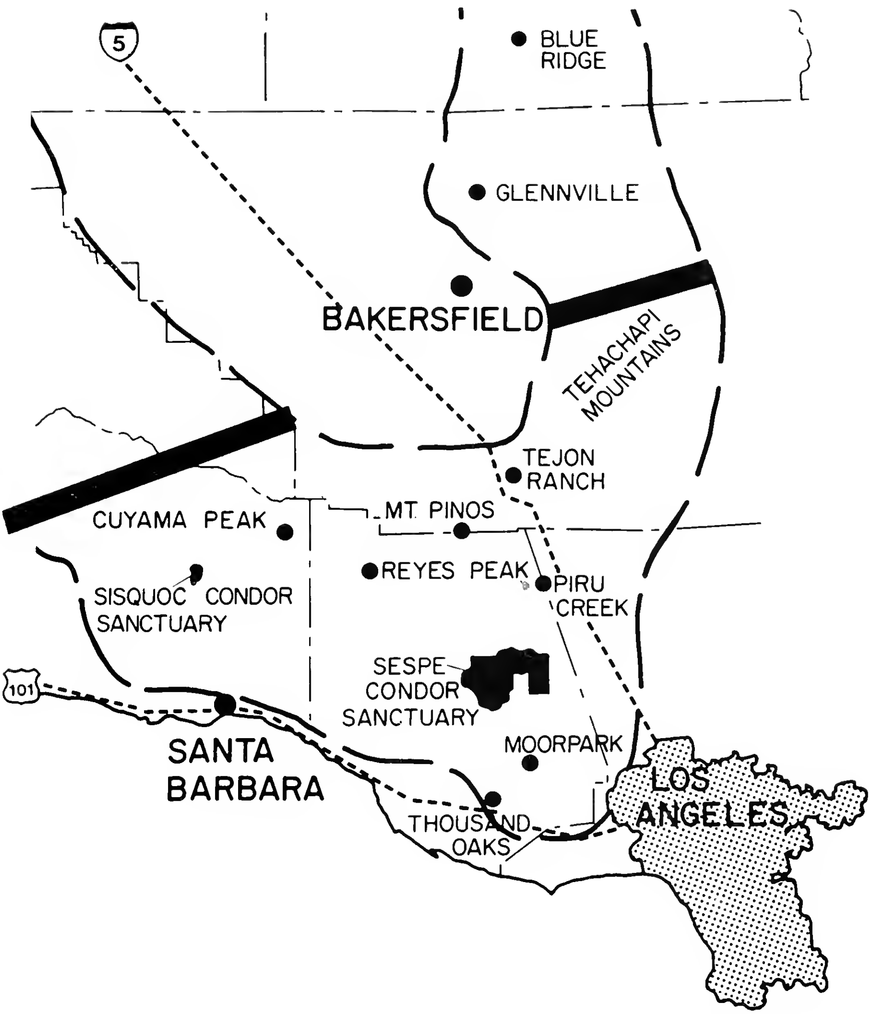

FIGURE 1. Southern portion of the range of the California condor. Almost all observations made during the October surveys are at stations south of the solid dark lines.

Although October geographical distribution of the condor population is consistent from year to year, and survey coverage is adequate most years, daily activity by condors is unpredictable. Numbers of sightings on consecutive days have varied by 100 to 200%. Some variation is weather-related, but other factors such as location of food and length of time since condors last fed probably are also important. There is no correlation between number of stations (or number of observers) and number of sightings. For example, the two highest numbers of sightings came on days when there were 51 stations (94 observers, 228 sightings) and 18 stations (45 observers, 227 sightings). Over 100 sightings were made by observers at nine stations on 17 October 1973, but only 45 observations were made at 65 stations on 18 October 1966. No trend based on number of sightings can be determined from a 2-day count. A 3-day count in 1974 resulted in 2 days when the numbers of sightings were similar, but even then the actual number of individual birds seen was thought to be quite different.

In my opinion, the most serious defect in the October survey is lack of comparability of results. From survey data, there are few condors that can be positively separated from all others based on time, location, or distinguishing plumages. The rest of the sightings can be interpreted in a number of ways. It is the responsibility of the evaluators, using their knowledge of condor behavior, to convert total sightings to a reasonable estimate of the actual number of different condors seen. In the best of circumstances, the results must be somewhat subjective. When evaluators change, and as new information about condor activity modifies our earlier ideas, year-to-year comparisons become even more difficult.

For example, the evaluation team from the 17 October 1968 survey estimated that 52 different condors were seen (43 adults, 5 immatures, and 4 unclassified). At a later date, I used the same data and the same general rationale to reanalyze the count; my estimate was only 31 birds (24 adults, 4 immatures, 3 unclassified). Similarly, the official count for 15 October 1969 was 53 condors (39 adults, 6 immatures, 8 unclassified); my reanalysis (assisted by J. C. Borneman) indicated a total of only 39 (25 adults, 6 immatures, and 8 unclassified). Neither figure is "right" or "wrong", but each represents an equally possible interpretation of the available data. The spread between estimates is certainly too great to be useful for monitoring the population of such a rare species.

Cooperator Records

Cooperator records (Table 2) show a decrease of about 50% in the size of average monthly composite counts in 1974–1978 compared with 1966–1970, and a decrease of about one-third in the size of average simultaneous counts between those time periods. Since 1974, there have been only two reports of flocks containing 10 or more condors, and there have been no flocks of 20 or more reported since 1972. In the late 1960s, flocks of 10 or more condors made up 2 to 4% of all sightings. No obvious change has occurred in the average number of immatures reported per sighting day.

High simultaneous counts and high monthly composite counts are somewhat dependent on having many observers reporting their condor sightings on a regular basis. Reporting declined steadily in the years following establishment of the voluntary reporting system (Wilbur 1978*b*), and at first it appeared that the combined counts had declined in direct relationship to reports received. To see if declining counts were a result of real decreases in condor numbers or if they merely reflected decreases in observer effort, I attempted to reestablish the condor observer network in late 1976. A letter was sent to all former cooperators still known to be residing in or regularly visiting condor habitat. The letter asked for continuing or renewed cooperation for 1977 and 1978, and a supply of report forms was enclosed. All conservation agencies with personnel in the area were contacted, and training sessions in condor identification and reporting procedures were held with field personnel of the U.S. Forest Service. Despite this renewed effort, fewer sightings were received in 1977 and 1978 than in the previous 2 years, suggesting that observers were just not seeing condors as regularly as they once had.

TABLE 2. Records of California Condors from Cooperators, 1966–1978.

Year	*Total sightings*	*Number of sightings birds per sighting (% of total)*				*Avg. immatures per sighting day*	*Average simultaneous count*	*Average monthly composite*
		1–3	*4–9*	*10–19*	*20+*			
1966	405	330 (81.5)	62 (15.3)	10 (2.5)	3 (0.7)	0.405	3.805	16.333
1967	532	430 (80.8)	80 (15.0)	20 (3.8)	2 (0.4)	0.595	4.400	19.000
1968	475	405 (85.3)	60 (12.6)	6 (1.3)	4 (0.8)	0.511	3.436	19.500
1969	434	366 (84.3)	60 (13.8)	7 (1.6)	1 (0.2)	0.428	3.347	16.417
1970	492	396 (80.5)	81 (16.5)	14 (2.8)	1 (0.2)	0.464	4.294	20.666
1971	440	378 (85.9)	52 (11.8)	10 (2.3)		0.498	3.847	17.417
1972	359	295 (82.2)	57 (15.8)	6 (1.7)	1 (0.3)	0.639	3.571	14.583
1973	189	148 (78.3)	34 (18.0)	7 (3.7)		0.336	3.059	12.167
1974	174	161 (92.5)	12 (6.9)	1 (0.6)		0.264	2.070	10.417
1975	242	201 (83.1)	41 (16.9)			0.301	2.712	9.917
1976	234	214 (91.5)	20 (8.5)			0.530	2.383	10.583
1977	223	211 (94.6)	12 (5.4)			0.382	1.952	9.750
1978	182	154 (84.6)	27 (14.8)	1 (0.6)		0.454	2.807	9.333

Two-thirds of those observers reporting large flocks of condors since 1966 are still in the area and reporting regularly. There is no indication that there have been changes in condor distribution or flocking behavior that would contribute to smaller congregations over a period of years (Wilbur 1978*a*), so the marked decline in records of 10 or more condors together is probably related to a corresponding decline in the population.

Comparative Counts

In 1970–1971, I watched for condors during 749 hourly periods. I observed condors on 222 occasions, an average of one sighting per 3.37 hours. Of the total sightings, 160 (72.1%) included one or two condors, 38 (17.1%) included three or four condors, and 24 (10.8%) included five or more. Forty-three sightings (19.4%) included at least one immature-plumaged condor (Table 3).

TABLE 3. Condor Observations Made During Comparative Counts.

	1970–1971				*1977–1978*			
No. of condors	*Total observations*	*Percent*	*Obs. with immatures*	*Percent*	*Total observations*	*Percent*	*Obs. with immatures*	*Percent*
1	101	45.5	37	16.7	42	55.3	17	22.4
2	59	26.6	6	2.7	23	30.3	1	1.3
3	20	9.0			7	9.2		
4	18	8.1			3	3.9		
5–10	22	9.9			1	1.3		
+10	2	0.9						
Totals	222	100.0	43	19.4	76	100.0	18	23.7

In 1977–1978, 485 observation-hours resulted in 76 condor sightings or one sighting every 6.38 hours. Sixty-five sightings (85.5%) were of one or two condors, 10 (13.2%) were of three or four, and only one (1.3%) included five or more. Eighteen sightings (23.7%) included at least one immature (Table 3).

I tried to pattern my 1977–1978 field work to closely approximate that of 1970–1971, but weather conditions and other work assignments interfered. Distribution of observer effort by time of day was very similar during the two periods, but in 1977–1978 only two-thirds as much observation time was expended as in 1970–1971. Also, distribution of time between different geographical areas varied somewhat, with more observations made in nesting areas and less in summering areas in 1977–1978. Taken together, these differences in technique make it impossible to compare results statistically. Nevertheless, the results are similar to those obtained from cooperator records: i.e., much more effort is required to see condors; number of condors per observation has decreased; and although the relative number of sightings of immature-plumaged condors has remained similar, the number of sightings including more than one immature has decreased greatly.

Other Methods

I researched thermal scanning techniques (e.g., McCullough, Olson, and Queal 1969), but they apparently have not been perfected enough for use in a condor survey (Bill J. Van Tries, Earth Satellite Corporation, pers. commun.). Condors have been seen from fixed-wing aircraft, but even when condors are congregated in limited habitat, counts are variable. For example, R. D. Mallette and I observed 19 condors on an aerial survey in the Tehachapi Mountains, Kern County, on 12 November 1970. A similar survey on 24 February'1971 produced only four condors, although our long-term information on the Tehachapi Mountains indicated that the actual number of condors in the area was similar both days. Regular severe turbulence over mountain areas restricts low level aircraft operation, and it would be easy to miss condors sitting at a carcass, flying low in canyons, or roosting in trees.

CONCLUSIONS

Data accumulated from 1965 through 1978 suggest considerable decrease in the size of the California Condor population, but no technique yet devised permits statistical treatment of results or the setting of reasonable confidence limits on population estimates. If the trends observed in cooperator reports and comparative counts are valid, then the current population may include 25 to 35 individuals, compared with 50 to 60 in the late 1960's (Wilbur et al. 1972).

Knowing that a population is declining is important, but much more precision is required if we are to properly manage this rare species. Rigorous standardization of the October survey may be a first step toward a reliable index (Verner 1978), but that will not remove the subjectivity and personal bias in survey analysis. If there were some positively identifiable birds in the population (e.g., marked with conspicuous tags or equipped with radio transmitters), it might be possible to determine the average number of times individual condors were being seen. Possibly a population estimate could be derived from "recapture" (i.e., subsequent observation) frequencies (Jolly 1965, Seber 1965). However, it is likely that the condor population violates some of the basic premises of randomness necessary for such calculations (L. Lee Eberhardt and Robert G. Heath, pers. commun.). I think that it is desirable to attempt this refinement, but we may always have to depend on various partial surveys and cumulative observations.

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SEASONAL BENTHIC DISTRIBUTION OF ADULT FISH IN PYRAMID LAKE, NEVADA [1]

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Relative densities of five fish species were determined at successive depth intervals during September, December, March, and June 1976–1977. For the total study period, an inverse relationship existed between depth and fish density for all species. Sacramento perch, *Archoplites interruptus,* were taken exclusively inshore. Inshore sampling stations accounted for 97% of the mean cui-ui, *Chasmistes cujus,* catch, and 73% of the Tahoe suckers, *Catostomus tahoensis.* Lahontan cutthroat trout, *Salmo clarki henshawi,* and tui chub, *Gila bicolor,* exhibited more complex distribution patterns, which varied on a temporal basis in relation to temperature and dissolved oxygen regimes. Tui chubs composed about 98% of the total catch at depths greater than 61 m. Trout production in this profundal zone was assumed to be negligible since the numbers present were low and the temperature was less than 7°C during all seasons.

INTRODUCTION

Limited data exist regarding the spatial and temporal distribution of Pyramid Lake fish populations in relation to environmental conditions. Snyder (1917) made observations on the life histories, seasonal movements, and spawning migrations of the fishes occurring in the Lake. Sumner (1939) documented the decline of the Pyramid Lake fishery and the factors responsible for the apparently inevitable doom of the original Pyramid Lake Lahontan cutthroat trout. After successful reintroduction of salmonids into Pyramid Lake, the Nevada Fish and Game Department conducted life history investigations of the fish species between 1954–1958, including a limited population inventory (Johnson 1958). Koch (1972, 1973) studied the ecology and reproductive characteristics of the endangered, endemic cui-ui, with reference to the environmental conditions that may become limiting to this species. During recent years, the U. S. Fish and Wildlife Service has been monitoring cui-ui population trends in the vicinity of the Truckee River delta and spawning runs of Lahontan cutthroat trout through the Marble Bluff fish passage facility.

Due to conflicting utilization of the limited water resource of the Truckee River-Pyramid Lake ecosystem, the distribution of fish in Pyramid Lake must be understood in relation to environmental parameters in order to evaluate habitat requirements of the fish species. Such baseline data will facilitate predicting the impact of potential environmental changes and provide a basis for evaluating how long-term management of the system may affect the fishery resource.

The purpose of this research, conducted during 1976 and 1977, was to describe seasonal relative fish densities with respect to depth and associated temperature and dissolved oxygen (DO) regimes in Pyramid Lake. This information provides further definition of the environmental requirements of the fish species in Pyramid Lake.

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STUDY AREA

Pyramid Lake is the deepest remnant of Pleistocene Lake Lahontan which once occupied an area of approximately 5 million ha from west-central Nevada north to the Oregon border (Russell 1885). Pyramid Lake is approximately 40 km long and 6.5 to 16 km wide. The northern two-thirds of the Lake has an oval shape and a north-south axis, while the relatively narrow and shallow southern third is rectangular, with a southeasterly axis (Figure 1). At the mean 1976 elevation of 1,157 m (United States Geological Survey 1977), the Lake had a surface area of 44,637 ha, a volume of 2.638×10^{10} m^3, a mean depth of 59 m and a maximum depth of 103 m (Harris 1970).

Being the terminal water body of the Truckee River system, the only outflow from Pyramid Lake is by evaporation. However, due to water diversions from the Truckee River, the water level of Pyramid Lake has declined 22 m since 1909. At present the lake water is highly ionic, being saline and alkaline (mean pH = 9.2). The 1976 total dissolved solids (TDS) concentration of 5,235 mg/1 was composed of 68% sodium chloride (Lider 1978). The Lake is biologically productive, supporting large populations of plankton and fish. Surface water temperature seasonally ranges from 0.6 to 25.5°C (Koch 1973). As winds subside and surface water temperature increases, a thermocline develops during June and persists through December. Following physical destratification, the turnover begins in early winter and mixing extends to spring. Pyramid Lake is thus classified as monomictic according to Hutchinson's (1957) criteria.

METHODS

Bottom-set variable mesh gill nets were fished overnight at 27 sampling stations at depths up to 98.5 m during September 1976 (late summer), December 1976 (late fall), March 1977 (late winter) and June 1977 (late spring), (Figure 1). One sample was taken at each station during each period. Eight inshore (0–15 m) and six offshore (46 m) sampling stations, stratified by horizontal lake area, were established. In the deep central area of the Lake, 13 additional stations were sampled at depths exceeding 46 m.

The gill nets, each 6 ft by 250 ft, were composed of 10 equal panels of the following mesh sizes: 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.50, 3.00, 3.50 inches (bar measure). The nets were built of multifilament nylon thread, graduated according to mesh size.

In conjunction with each net sample, temperature and DO were measured from surface to bottom at 10-m increments with an InterOcean Model 513D probe. Exact bottom depth of each net set was also measured with the probe.

RESULTS AND DISCUSSION

Fish Distribution

For the entire study period, all fish species decreased in abundance as depth increased (Figure 2). Tui chubs comprised 80% of the total species catch at depths down to 46 m, with their magnitude, relative to other fish species increasing at greater depths. In the profundal zone ($>$ 60m), tui chubs constituted about 98% of the species composition.

Sacramento perch were captured exclusively inshore. During the 4 months sampled, 19 Sacramento perch were captured in 32 inshore net samples; none were taken in 76 samples at greater depths.

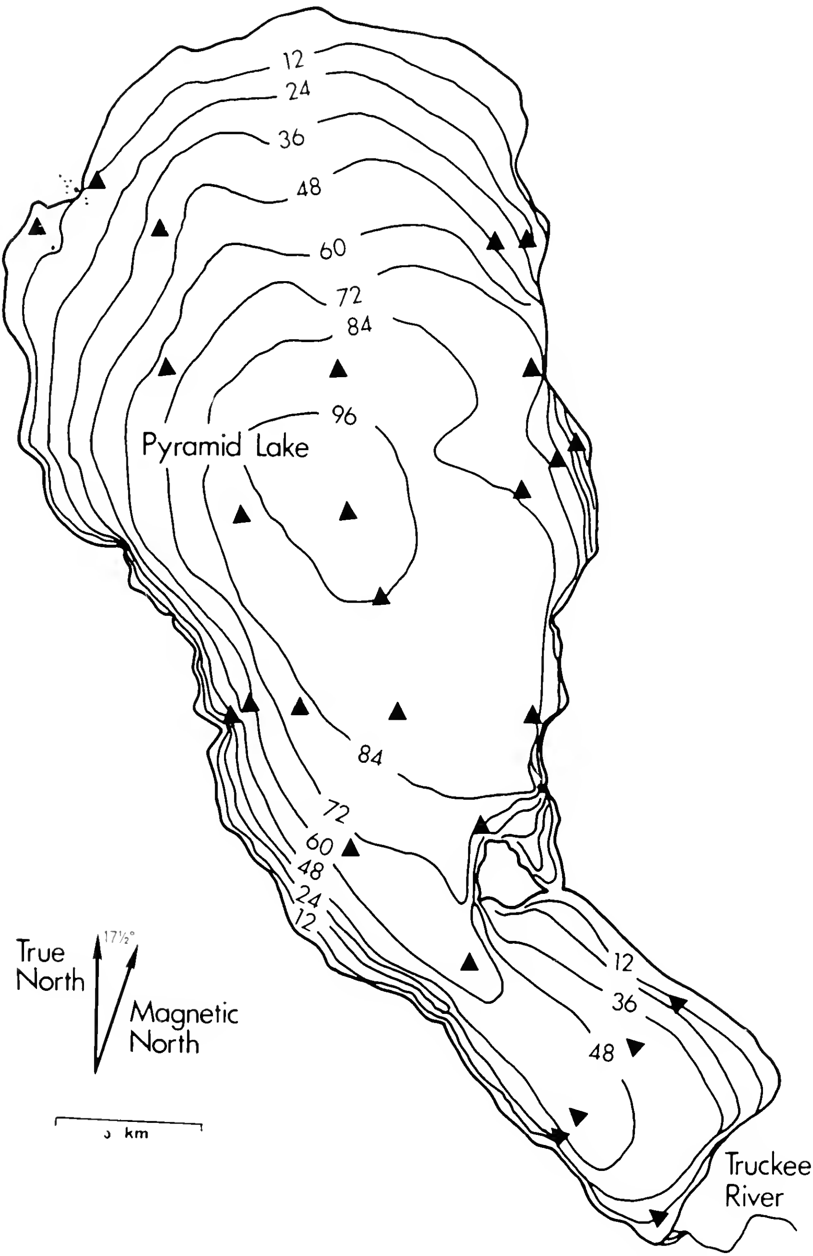

FIGURE 1. Location of 27 bottom-set gill net sampling stations in Pyramid Lake, Nevada.

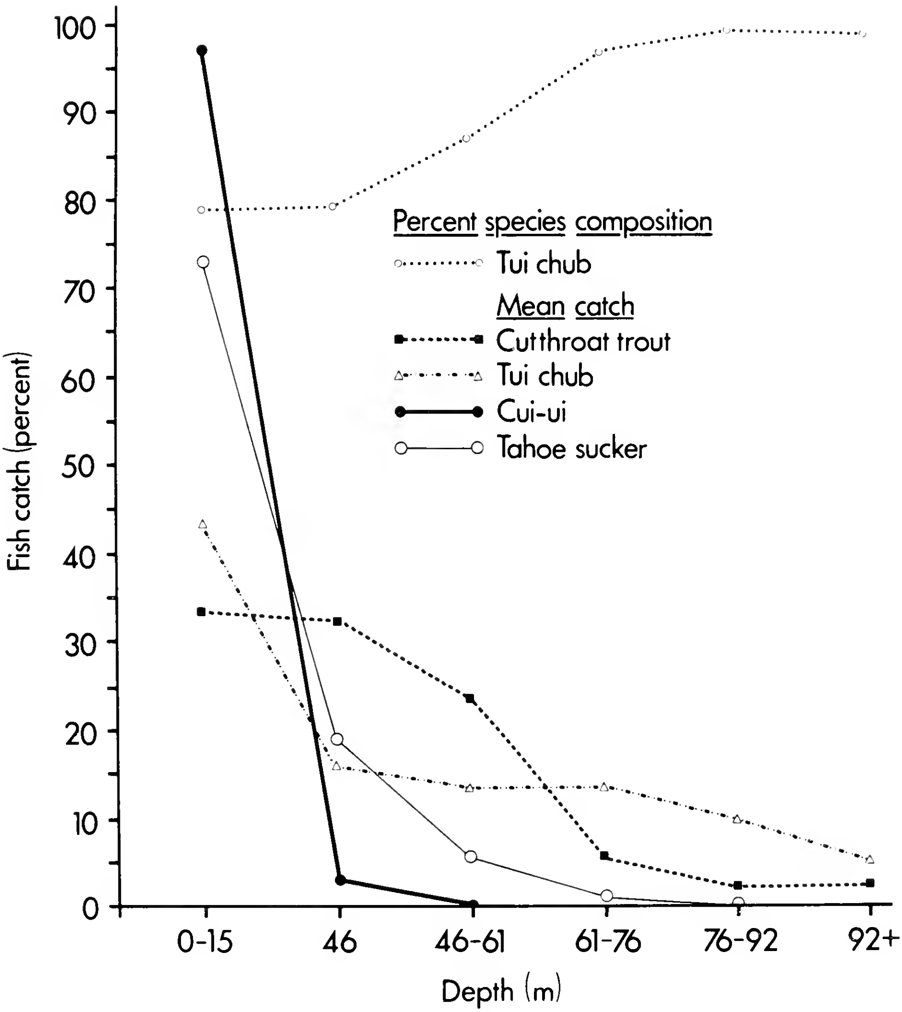

FIGURE 2. Percent species composition of tui chub and percent of the mean catch of cutthroat trout, tui chub, cui-ui, and Tahoe sucker by depth in Pyramid Lake, Nevada. Data are derived from the total catch of 108 bottom gill net sets on a quarterly basis (September, December, March, and June) during 1976–1977.

Ninety-seven percent of the mean cui-ui catch was taken in the relatively shallow areas (0-15 m), none were captured deeper than the 46 m depth. Perch and cui-ui consistently exhibited a preference for littoral areas during all seasons during 2 years of intensive sampling (Vigg 1978). Tahoe suckers were likewise inshore-oriented, with 73% of the mean catch taken at depths of 0-15 m, a steadily decreasing proportion was taken to depths of 76 m, and negligible numbers were taken at greater depths (Figure 2). With the exception of a slight offshore trend at the onset of cold water temperatures during late fall, the Tahoe sucker population was always highest in the littoral areas.

Almost half (43%) of the mean tui chub catch was taken inshore; at greater depths the proportion gradually decreased from 16 to 5%. The total mean cutthroat trout catch was nearly equally represented in the bottom depth intervals to 61 m. However, the entire profundal zone accounted for a relatively small proportion of the mean catch (about 10%).

Unlike other species, tui chub and Lahontan cutthroat trout populations exhibited seasonal changes in bottom depth distribution patterns; these changes were associated with concurrent changes in temperature and DO (Table 1, Figure 3). During September, about 79% of the mean catch of cutthroat trout was taken at 46 m. The littoral catch rate increased to the annual maximum (9.1 trout/net) by December when the trout population began to move inshore. About 55% of the mean cutthroat trout catch was taken in littoral areas during March. Trout catches in June were nearly equal inshore and at 46 m, with about 3.5 trout/net. This change illustrated the beginning of the offshore population movement which culminated in late summer, when 79% of the mean cutthroat trout catch was taken at 46 m.

In contrast, the tui chub population was primarily offshore at 46–61 m during March and moved inshore during June. The mean catch of over 200 tui chubs per sample at 0–15 m constituted over 86% of the total June catch. September and December catches were highest inshore, although in deeper areas the tui chub population was evenly dispersed on the lake bottom.

Environmental Relationships

Temperature and DO levels, which exhibit characteristic and predicable seasonal patterns in Pyramid Lake, are probably the two most effective environmental influences on fish distribution in natural lakes. Likewise, temperature and oxygen, through metabolic effects, are crucial to the bioenergetics and growth of fish (Warren 1971). Evaluation of benthic zones in terms of optimum environmental conditions conducive to maximum energy potential of the trout and chub populations helps explain the observed seasonal benthic distribution of these species.

The minimum inshore bottom water temperature of 6.5°C occurred in March, when the Lake was isothermal. The Lake was thermally stratified by June and the maximum water temperature of 20°C occurred in September. Offshore bottom water temperatures exhibited little seasonal variation, ranging from 6.4 to 7.7°C at 46 m and 6.0 to 6.8°C in deeper areas.

Upper and lower lethal temperatures set the limits of existence for fish, but distribution and abundance of populations in nature are primarily determined by temperature interacting with other environmental factors to affect reproduction and growth (Warren 1971). The optimum temperature for salmonid production generally ranges from 12 to 16°C (Pentalow 1939, Leitritz 1969, Baldwin 1957, and Cheng 1975).

Growth rate of rainbow trout, *Salmo gairdneri,* at temperatures at and below 7.2°C is drastically reduced (Leitritz 1969). A fish species' scope for activity is a valid indication of the long term survival potential of a population where it must coexist and compete with other species (R. Behnke, Assoc. Prof., Colo. St. Univ., pers. commun.). Active metabolism and scope for activity of cutthroat trout over a range of five temperatures were lowest at 5°C and highest at 15°C, with subsequent decreases at higher temperatures (Dwyer and Kramer 1975).

TABLE 1. Quarterly Mean Overnight Bottom-Set Variable-Mesh Gill Net Catches and Concurrent Environmental Parameters by Bottom Depth Intervals in Pyramid Lake, Nevada, 1976–1977

Month (Year)	*Depth (m)*	*Number of samples (n)*	*Mean catch by species*					*Mean environmental parameters*	
			Cutthroat trout	*Cui-ui*	*Tahoe sucker*	*Tui chub*	*Total*	*Temperature (°C)*	*Dissolved oxygen (mg/l)*
September	0–15	8	1.0	1.4	31.9	49.3	83.6	19.95	8.70
(1976)	46	6	5.5	0.2	5.8	38.3	49.8	7.70	7.53
	61–76	5	0.5	0	0.1	34.5	35.1	6.49	6.87
	76–92	4	0	0	0	30.5	30.5	6.24	3.84
	92+	4	0	0	0	23.8	23.8	6.14	3.75
December	0–15	8	9.1	0.5	3.6	117.0	130.2	9.62	10.89
(1976)	46	6	5.5	0	6.0	55.0	66.5	7.07	6.48
	46–61	2	6.5	0	0.5	49.5	56.5	6.24	5.41
	61–76	6	0.7	0	0.5	53.7	54.9	6.17	3.34
	76–92	3	0.3	0	0	52.7	53.0	6.08	2.63
	92+	2	0	0	0	0.5	0.5	6.00	0.13
March	0–15	8	5.0	0.6	18.8	36.0	60.4	6.47	11.57
(1977)	46	6	3.0	0	2.8	50.7	56.5	6.36	11.11
	46–61	1	0	0	5.0	51.0	56.0	—	—
	61–76	4	1.1	0	1.0	31.6	33.7	6.33	10.96
	76–92	6	0.08	0	0.08	14.5	14.7	6.38	10.85
	92+	2	0	0	0	14.5	14.5	6.35	10.76
June	0–15	8	3.3	3.1	33.0	218.5	257.9	14.01	9.94
(1977)	46	6	3.7	0	8.3	8.5	20.5	7.02	8.36
	46–61	2	1.5	0	1.5	7.0	10.0	6.76	8.14
	61–76	4	1.3	0	0	5.5	6.8	6.73	7.87
	76–92	3	1.0	0	0	8.7	9.7	6.65	5.70
	92+	4	0.8	0	0	4.0	4.8	6.65	6.67

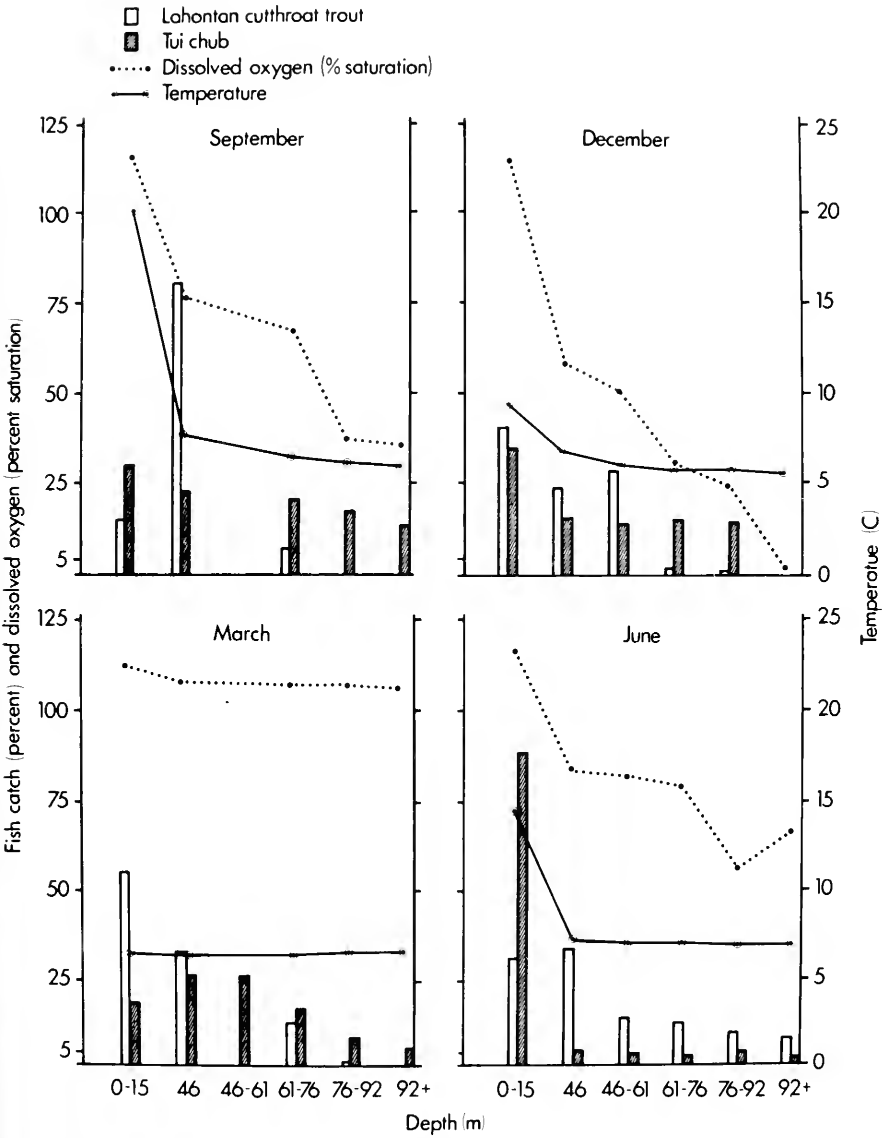

FIGURE 3. Relative densities of Lahontan cutthroat trout (clear bars) and tui chub (hatched bars) by depth and season in relation to bottom temperatures (solid line) and dissolved oxygen (dotted line).

Temperatures at depths greater than 61 m in Pyramid Lake were less than 7 °C during all seasons; cutthroat trout densities were likewise at a minimum at these depths during all seasons. The absence of light in the profundal zone may also limit fish distribution, since trout are sight-feeders. The absence of illumination also affects thyroid metabolism which indirectly affects growth patterns (Lagler et al. 1962). Since a small proportion of the trout catch was taken in this region and water temperatures are too cold for appreciable growth, production of cutthroat trout must be negligible in the profundal zone of Pyramid Lake.

During spring, summer, and fall, the benthic zones less than 61 m had a range of temperatures within which trout production could be maximized. Temperature selection by the cutthroat trout population largely accounts for the observed depth distribution patterns. Relative densities of trout during June were about equal inshore (14°C) and at 46 m (7°C), but were much less at 46–61 m (6.8°C). During this late spring month, the offshore movement of cutthroat trout had begun and the maximum density was between shore and 46 m in the vicinity of the developing thermocline. The catch rate of four supplemental gill net samples at 23 m was 7.2 trout/net, more than twice that of inshore and 46-m depths. The final temperature preferendum of 11.3°C for rainbow trout (McCauley et al. 1977) approximates the mean bottom temperature of 10.1° C measured at 23 m in Pyramid Lake. The offshore trout movement culminated during summer; mean inshore bottom temperatures of 20°C during September were associated with the highest proportion of cutthroat trout at 46 m. By December, inshore waters cooled to about 9.6°C and highest trout densities occurred in this zone.

During winter, the Lake was physically and chemically homogeneous and the water temperature was less than 6.5° C. Thus, there was no range for thermal selection, and temperatures were too cold for appreciable trout growth to occur at any depth. Under these conditions the cutthroat trout predominantly inhabitated the shallow inshore areas, apparently due to spawning-related behavior. Snyder (1917) reported Pyramid Lake Lahontan cutthroat trout spawn from December through March. This time period corresponds to the highest activity of the current cutthroat trout population as indicated by monthly gill net catch rates during 1976–1977 (Vigg 1978).

The lowest catch rates of tui chub occurred during the winter period when the population was predominantly offshore at 46–61 m. It is apparently advantageous to the tui chub population, the forage species of trout, to be distributed in deeper water during winter inactivity. This offshore winter movement of *Gila* spp. has been observed by Snyder (1917) in Pyramid Lake, Miller (1951) in Lake Tahoe, Kimsey (1954) in Eagle Lake, and Graham (1961) in Hebgen Lake.

The inshore movement of tui chubs was obvious in June and was apparently related to temperature and spawning behavior. Gaufin (1964) observed that Utah chubs, *Gila atraria,* generally concentrate in the warmest areas of Fish Lake. Food consumption and assimilation, growth, and metabolic rates of Utah chub are directly related to temperature, and are highest at 20°C (Cheng 1975). In Flaming Gorge Reservoir, the majority of the Utah chub population moved into the warming littoral and eulittoral waters prior to spawning (Varley and Livesay 1976). Eagle Lake tui chubs spawned in shallow water when the temperature was about 15.6°C (Kimsey 1954). In 1976, the Pyramid Lake tui chub population exhibited peak spawning during June at the mean temperature of 15.3°C as evidenced by the gonadal somatic index (Kucera 1978). During June 1977, the inshore surface temperature from the north to south end of Pyramid Lake ranged from 15.4 to 19.7°C respectively, with a mean temperature of 17.7°C. In summary, increasing spring water temperatures are generally associated with increased tui chub activity, spawning, and the inshore population movement.

Dissolved oxygen was super-saturated during all seasons in the littoral benthic zone, with mean concentrations ranging from 8.7 to 11.6 mg/l. During March, super-saturation of dissolved oxygen occurred over the entire lake bottom; all DO measurements exceeded 10 mg/l. Oxygen depletion in the deep waters began following thermal stratification in late spring and was most severe in December prior to lake mixing. During December, the mean DO concentration was less than 4 mg/l at depths greater than 61 m and less than 0.2 mg/l at depths greater than 92.

Salmonids are capable of detecting oxygen changes and have been observed to avoid oxygen levels as high as 6 mg/l (Whitmore et al. 1960). In general, the minimum acceptable DO level for fish is 4 mg/l (National Academy of Sciences 1972), although the mean lethal DO tension for three species of salmonids was reported to be less than 2 mg/l at temperatures below 13° C (Burdick et al. 1954). During the late summer and fall, cutthroat trout were almost absent from deep areas of Pyramid Lake which exhibited DO concentrations below 4 mg/l. Dissolved oxygen can limit growth of salmonids (even at saturation levels) when food availability is unrestricted; however, when energy is restricted DO becomes limiting only at levels below 4 mg/l (Fisher 1963, Warren 1971). Thus, oxygen could possibly limit adult trout production in all lake areas when tui chub availability is high; but would certainly limit growth at depths greater than 76 m in Pyramid Lake during summer and fall.

Tui chubs have been known to venture into areas of low oxygen concentration of Eagle Lake (Kimsey 1954). Tui chubs were likewise captured in relatively high numbers in Pyramid Lake at DO concentrations less than 4 mg/l, but were absent at depths greater than 92 m in December when DO fell below 0.2 mg/l.

SUMMARY AND CONCLUSIONS

Sacramento perch, cui-ui, and Tahoe suckers primarily inhabit the littoral zone of Pyramid Lake. The annual catch rate of Lahontan cutthroat trout and tui chub is likewise highest inshore; however, Lahontan cutthroat trout are offshore, below the thermocline, during summer and tui chubs are in deep water during winter. The profundal zone (>61 m) is inhabited almost exclusively by tui chubs during all seasons. A range of environmental conditions exists in Pyramid Lake with respect to bottom depth zones during all seasons except winter. Temperature, and to a lesser extent dissolved oxygen, affect the benthic spatial distribution of fish in Pyramid Lake.

ACKNOWLEDGMENTS

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NOTES

A HEAD-OFF METHOD OF MEASURING CHINOOK AND COHO SALMON

INTRODUCTION

In 1978 a change in California commercial salmon fishing regulations allowed salmon fishermen capable of freezing or saltwater chilling their catches to land fish with the head removed. This change necessitated the development of an alternative minimum legal length comparable to that required for fish landed whole. This study was designed to determine such a minimum length and to establish a mathematical relationship between the two measurements so that conversions could be made between them.

METHODS AND MATERIALS

I measured 113 chinook (*Oncorhynchus tshawytscha*) and 268 coho (*O. kisutch*) at commercial fish plants in Eureka during April and May 1978. Fish were selected at random from those graded as "small" (less than 3.63 kg for chinook or 2.04 kg for coho) by the fish dealer. The fork length to the nearest millimetre for each fish was obtained with the fish laying on a measuring board with a head plate. The alternate length for the same fish was then obtained with a tape measure.

To obtain the alternate length the end of the tape measure was hooked over the leading edge of the wedge-shaped cleithrum and positioned so that the top edge of the tape laid as closely as possible along the lateral line (Figure 1). The tape was allowed to follow the contour of the fish and the length to the fork of the caudal fin was recorded to the nearest millimetre.

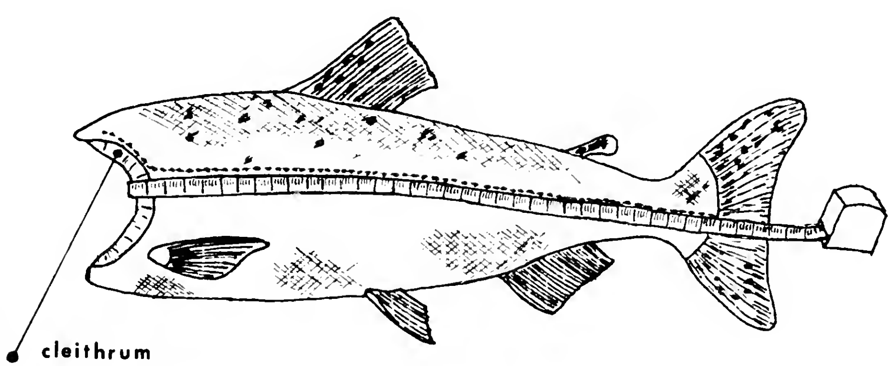

FIGURE 1. Method for measuring alternate length.

RESULTS AND DISCUSSION

CHINOOK

Fork length for chinook with the head on ranged from 577 mm to 770 mm and with the head off from 480 mm to 638 mm. I calculated a least squares linear regression to express the relationship between the two measurements in an equation (Figure 2). The equation is $y = 0.00215 + 0.81920x$, where y = alternate length in centimetres and x = fork length in centermetres. The equation may be used to convert from one measuring method to the other. The coefficient of determination (r) between head on and head off lengths of 0.949 indicates a close fit between the sample and the regression for chinook.

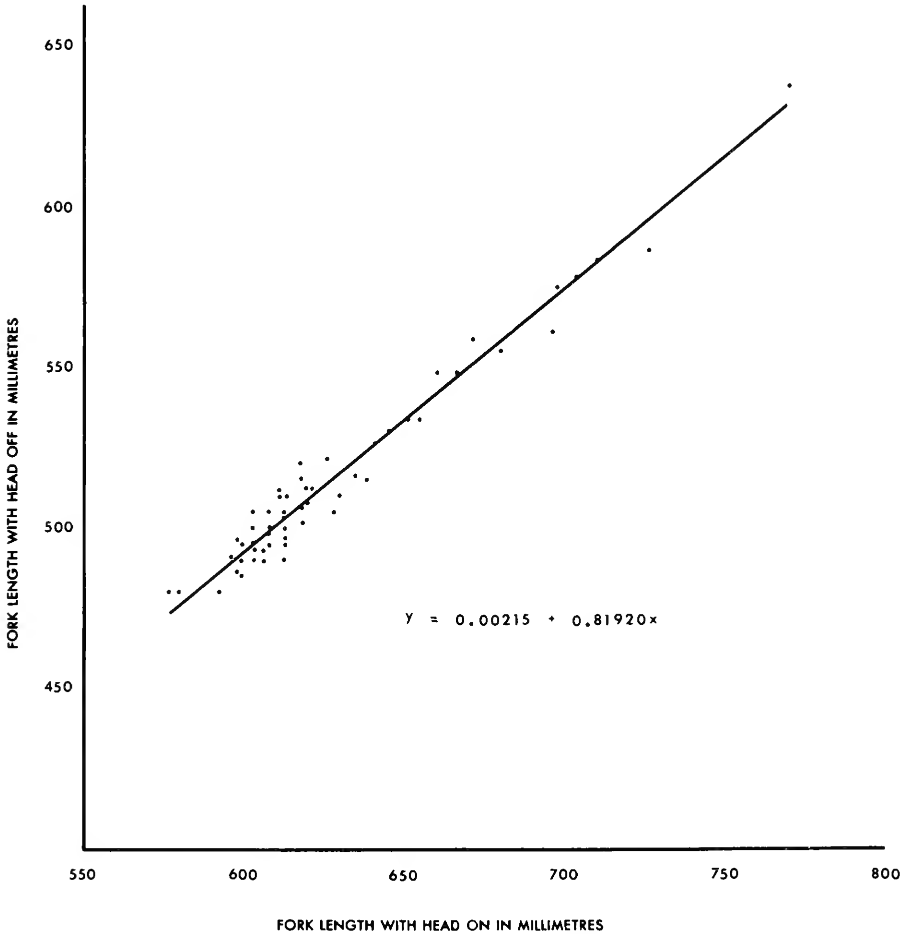

FIGURE 2. Linear regression for chinook salmon measured with the head on plotted against fish measured with the head off.

The current minimum legal size for chinook is 660 mm (26 inches) total length with the caudal lobes extended. The alternate length range for 21 chinook measuring 660 mm was 495 mm to 505 mm. The predicted alternate length is 499 mm.

The legal minimum alternate length for chinook was set at the lowest limit of the alternate range (495 mm or 19.5 inches) rather than at the predicted length.

This was done to prevent legal entanglements that might ensue from fishermen cutting heads off salmon that meet the legal minimum total length, but do not meet the predicted alternate length because of natural variation among fish.

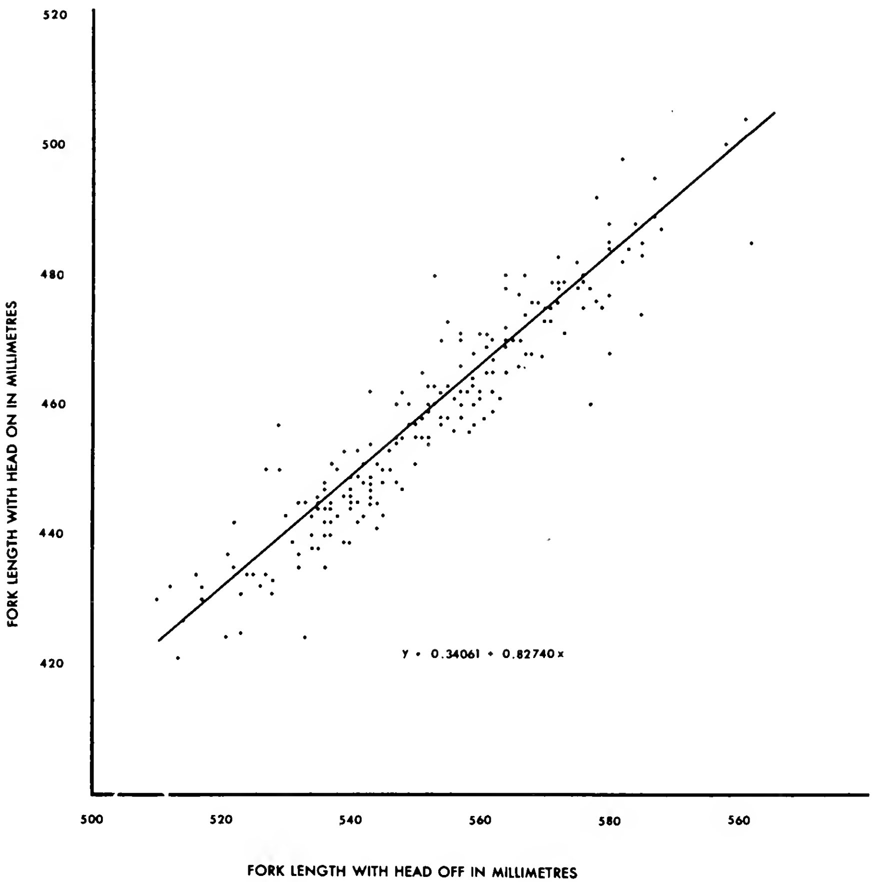

FIGURE 3. Linear regression for coho salmon measured with the head on plotted against fish measured with the head off.

Coho

Fork length for coho with the head on ranged from 508 mm to 600 mm and with the head off from 421 mm to 504 mm (Figure 3). The association between the lengths made by these two measuring methods for coho is expressed by the equation $y = 0.34061 + 0.82740x$. The coefficient of determination (r) of 0.7424 also indicates a close fit of sample data to the regression for this species.

The current minimum legal size for coho is 559 mm (22 inches) total length. The alternate length range for 12 coho measuring 559 mm was 425 mm to 442 mm. Our equation predicts an alternate length of 435 mm.

The legal minimum alternate length for coho was set as close as possible to the lowest limit of the alternate range (419 mm or 16.5 inches) for fish having a total length of 559 mm rather than the predicted length. The reasoning was the same as for chinook.

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THE INTRODUCTION OF SOUTHEASTERN BLUEGILL, *LEPOMIS MACROCHIRUS PURPURESCENS*, INTO LAKE PERRIS, CALIFORNIA, WITH NOTES ON THE GROWTH OF THE INITIAL YEAR CLASS

The common bluegill, *Lepomis macrochirus macrochirus*, which is widespread in California, has exhibited a tendency toward slow growth or small size in some California impoundments (Bell 1959; Beland 1960; Fast 1966). This characteristic has resulted in the underutilization of many bluegill populations by California anglers. The southeastern bluegill, *Lepomis macrochirus purpurescens*, is a genetically distinct subspecies of the common bluegill (Avise and Smith 1974), characterized by longer fins, higher meristic counts, and different coloration (Hubbs and Allen 1943; Martin 1963). It is reported to exhibit faster growth, larger size, and superior overall sporting qualities than the common bluegill. Federal and State fish hatcheries in Texas and North Carolina have cultured and stocked southeastern bluegill in preference to the common form for many years (King 1947; Miller and Winn 1951).

In 1975 the California Fish and Game Commission approved the experimental introduction of southeastern bluegill in the State. One hundred adult bluegill, supplied by the Florida Game and Fish Commission, were flown by commercial air freight from Florida to Los Angeles on 4 June 1975. Examination revealed no serious parasite or disease organisms and, following removal of the left pelvic fin for later identification, 88 fish were released into Lake Perris, Riverside County, the following day.

Impounded in 1973, Lake Perris has a surface area of 938 ha and 16.1 m of shoreline. As is characteristic of many newly impounded waters, this reservoir is highly fertile and fish growth has been exceptional (Brown, Aasen, and von Geldern 1977). Lake Perris was selected as the initial introduction site because common bluegill were absent. In addition to the southeastern bluegill, Lake Perris currently sustains populations of Alabama spotted bass, *Micropterus punctulatus*, channel catfish, *Ictalurus punctatus*, green sunfish, *Lepomis cyanellus*, and threadfin shad, *Dorosoma petenense*. Brown trout, *Salmo trutta*, and rainbow trout, *Salmo gairdneri*, are stocked on a regular basis.

Gill net, creel, and electrofishing surveys were employed to follow the establishment of a reproducing population of southeastern bluegill in Lake Perris. Boat electrofishing surveys were conducted along randomly selected shoreline areas twice monthly from June 1975 until June 1977.

Age-growth determinations were made from fish caught by anglers in the spring of 1977. Fish were measured to the nearest millimetre fork length (FL) and weighed to the nearest gram. Scales were removed from an area immediately posterior to the left pectoral fin for later analysis.

Progeny of the 1975 introduction initially appeared in electrofishing collections in July 1976. At that time four bluegill, ranging in size from 108–125 mm FL, were collected. However, netting surveys failed to capture bluegill progeny until February 1977, when two specimens were collected. Low bluegill density in the Reservoir and the selectivity of gill nets against small fish are two factors responsible for the delayed detection of bluegill progeny by netting surveys. Initial meristic analysis of these specimens agreed with reported values for *L. m. purpurescens* and supports my conclusion that these fish are progeny of the 1975 plant.

Southeastern bluegill entered the fishery in relatively small numbers in February 1977, accounting for 2.1% by number of panfish in the creel during the 1977 angler survey period. Green sunfish composed the remaining 97.9% of the panfish taken. The 28 bluegill observed in the creel during 1977 averaged 173 mm FL and ranged in length from 107–198 mm. The fish had a mean weight of 128 g and ranged from 30–200 g. All of these fish were determined by scale analysis to be from the 1975 year-class (Age II). Interviewed anglers expressed satisfaction with the size of harvested bluegill at Lake Perris.

Growth of the initial year class of southeastern bluegill at Lake Perris has been exceptional. The mean size of Age II bluegill reported here represents one of the most rapid growth rates reported in the literature for either the common or southeastern subspecies (Carlander 1977). Common bluegill growth rates in California for Age II fish are substantially less than that reported here, averaging 116 mm FL (Table 1).

Results of growth determinations thus far for southeastern bluegill are encouraging. Lake Perris, however, is a recently impounded reservoir, and rapid growth of a newly introduced species is not unexpected. A more intensive study of the Lake Perris population is in progress to further assess growth and other life history parameters of this subspecies. In addition, studies have been initiated to assess the growth characteristics of the common and southeastern forms under controlled conditions. If the results of further growth studies are favorable, southeastern bluegill may be more desirable than common bluegill in California lakes and reservoirs.

TABLE 1. Mean Fork Length of Selected Bluegill Populations in California.

Locality	*Length at second annulus (mm FL)*	*Source*
Millerton Lake	79	Miller 1971
Folsom Lake	79	Tharratt 1966
Sutherland Res.	132	La Faunce, et al. 1964
Pine Flat Res.	122	Miller 1971
Cachuma Res.[1]	86	Puckett 1965
Lower Otay Res.[1]	108	Puckett 1965
Clear Lake [2]	165	Murphy 1951
San Vicente Res.[2]	150	Bell 1959
Lake Havasu	128	Beland 1954
Lake Perris	173	Present study

[1] Reported in TL, converted to FL as described in Carlander 1977, pg. 75.

[2] Mean FL at capture during 3rd year of life.

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