# CALIFORNIA
# FISH AND GAME

"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

VOLUME 68      APRIL 1982      NUMBER 2

# CALIFORNIA FISH AND GAME

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VOLUME 68 APRIL 1982 NUMBER 2

# CONTENTS

# EFFECTS OF WATER LEVEL FLUCTUATION ON REPRO-
# DUCTION OF LARGEMOUTH BASS, *MICROPTERUS*
# *SALMOIDES,* AT MILLERTON LAKE, CALIFORNIA, IN 1973[1]

DALE F. MITCHELL
California Department of Fish and Game
1234 E. Shaw Avenue
Fresno, California 93710

Water level fluctuation was evaluated as a limiting factor to largemouth bass, *Micropterus salmoides,* nesting success at Millerton Lake, Madera and Fresno counties. Spawning behavior, nesting success, and associated physical parameters were examined during reservoir drawdown and refilling in 1973.

Reproduction was adversely impacted by rising water levels, through temperature reduction, and by lowering water levels, through nest destruction. Successful nesting was observed only during periods of water stability in March and June.

Where springtime water level manipulation is an essential part of reservoir operation, staged drawdowns are recommended to minimize impact on largemouth bass nesting. Methods for determining criteria for reservoir operation are described.

## INTRODUCTION

For many years, water level fluctuation has been a major obstacle to the management of largemouth bass stocks in large multiple-use reservoirs. Rising and lowering water levels have contributed to many problems including soil erosion and loss of shoreline vegetation. The most serious problem occurs, however, when water level fluctuation coincides with gamefish spawning seasons. Reproduction of shallow, sessile-nesting species, such as largemouth bass, is often impeded.

Bross (1967), von Geldern (1971) and Miller and Kraemer (1971) noted favorable associations between gradually rising water levels and the formation of large initial largemouth bass year classes. Little detailed information has been published, however, on the effects of substantial water level fluctuation on bass reproduction. Millerton Lake, where water levels typically fluctuate rapidly during spring drawdown and refilling, offered an ideal location to evaluate the effects of water level fluctuation on largemouth bass spawning. Consequently, this study was initiated in March 1973 to (i) determine the magnitude of upward and downward fluctuation tolerable to nesting largemouth bass, and (ii) describe the physical and behavioral events which occur when bass spawn during periods of rapid water level change. These objectives were accomplished through daily observations of bass nests.

## Study Area

Millerton Lake is located on the San Joaquin River about 40 km northeast of Fresno in the western foothills of the Sierra Nevada Mountains. At maximum

pool it covers 1,983 ha, with a maximum surface elevation of 177 m. The upstream half of the reservoir lies in a narrow, steep-sided, granitic canyon, while the downstream half is broader, occupying a 5-km wide oak-savannah valley (Figure 1).
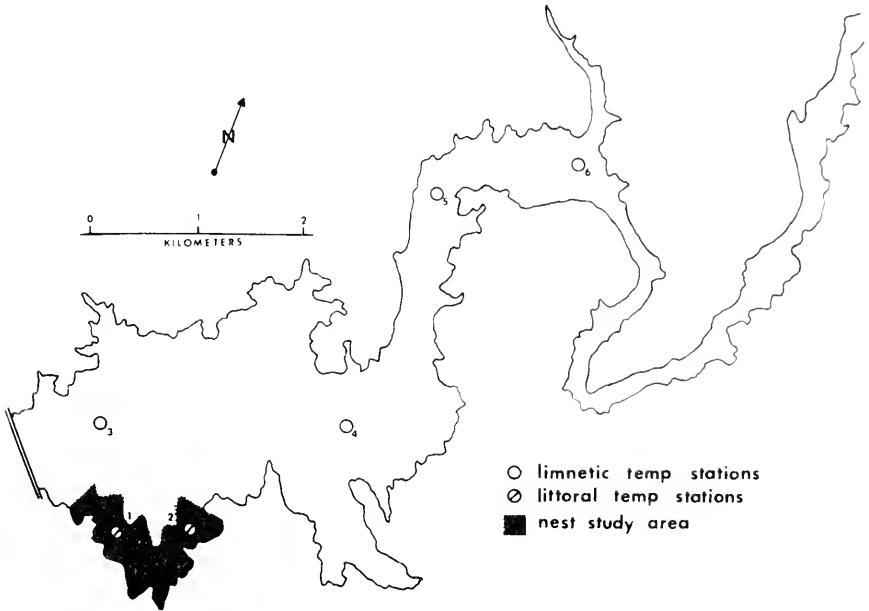


FIGURE 1.   Millerton Lake sampling stations.

Seasonal water level fluctuation is rapid due to the reservoir's function in flood control and its role in providing irrigation water to southern San Joaquin Valley. The reservoir capacity is approximately 641 $hm^3$, which represents only about a third of the mean annual water yield of the upstream drainage; consequently, there is considerable annual water exchange through the lake. This occurs principally during spring runoff periods.

The lake thermally stratifies in summer; however, its entire volume is typically well-oxygenated. Dissolved $O_2$ concentrations throughout the reservoir usually exceed 9 mg/l (ppm) (unpubl. data).

Dill (1946) gave a detailed physical description of Millerton Lake. His assessment of the fishery has been outdated, however, by later introductions of striped bass, *Morone saxatilis* (Cloyd and Ehlers 1960); American shad, *Alosa sapidissima* (von Geldern 1965); threadfin shad, *Dorosoma petenense* (unpubl. data); and Alabama spotted bass, *Micropterus punctulatus henshalli*, introduced in 1975. Salmonids are scarce and are no longer a part of the management program.

## METHODS AND MATERIALS

A lakewide snorkel survey was used to determine when nesting behavior or nest construction first began. Beginning 1 March and continuing until spawning was first observed on 16 March, two observers snorkeled daily along various lengths of randomly selected shoreline, noting nests or spawning largemouth bass. After documenting the onset of spawning, the frequency of the surveys was reduced to 1 d per week. Surveys were conducted until spawning was no longer evident, in late June.

During late March, ovaries were examined from 24 adult angler-caught largemouth bass, providing information about the proportion of unspawned bass and peak spawning period.

Effects of lowering and rising water levels on bass reproduction were assessed during May, when partial reservoir drawdown and subsequent refilling occurred (Figure 2). This segment of the study included monitoring of temperature and water elevation, as well as direct observations of individual bass nests.
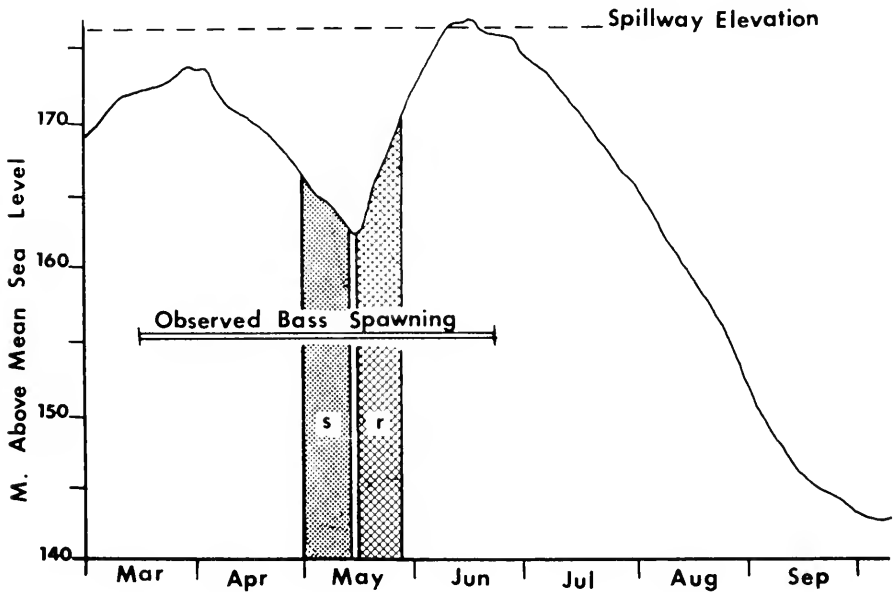


FIGURE 2.    Millerton Lake surface elevation, largemouth bass spawning season, and nest study periods during subsiding (s) and rising (r) water levels.

## Measurement of Physical Parameters

Surface temperatures were recorded from 1 March to 19 September. Measurements were made with a mercury thermometer at four limnetic and two littoral stations each day, beginning at 1300 h (Figure 1).

Nest site (bottom) temperatures were measured daily between 1 May and 25 May by two divers using hand-held thermometers. Depth-temperature data were also collected daily at the two littoral surface temperature stations located

within the nest study area (Figure 1). Hydrolab Ft-3 thermisters were used. After measurement of the surface temperature, the thermister probe was gradually lowered to the bottom. Water depth was recorded at the level of each successive 0.55° C increment of temperature change. These temperature profiles were used to substantiate nest site temperature measurements, and to help understand the observed day-to-day temperature changes at specific nest sites.

Lake elevation data, recorded daily by a fluid gauge inside Friant Dam, were supplied by the Bureau of Reclamation, U.S. Department of the Interior.

## Bass Nesting Observations

Effects of rapidly lowering water levels were studied in a 4-km long littoral area located on the south side of the reservoir in late March (Figure 1). As water levels receded, bass nests were located, marked, and observed daily.

Generally, nests were initiated in shallow depths and their dark color against the pale, silted substrate made them easy to locate. The location, depth, temperature, contents, and status of each nest was recorded daily. Observations were made during early morning, to avoid increased littoral turbidity caused by daytime boat and wind disturbance.

Effects of rapidly rising water levels on bass nesting success were evaluated from 15 May to 24 May. Due to scarcity of nesting bass at the time, only five nests were located. These were marked with buoys, and observed for 30 min at about the same time each day to ascertain changes in nest status or parental behavior. Using scuba gear, divers recorded nest depth, bottom temperature at nest sites, nest contents, parental defense behavior, and size of the defended territory. Although parent fish were temporarily disturbed during diver's visits, it was not felt that this affected eventual nesting success.

Information gathered during lowering and rising water levels was used to determine the tolerance limit to water level fluctuation of spawning largemouth bass, and to develop methods for prescribing acceptable reservoir operations.

## Fry Abundance

A concurrent study (unpubl. data) provided information on the abundance of largemouth bass fry. Fry were collected during their first summer of life to determine their abundance, growth, survival rate, and diet. These indices of abundance were used to interpret or verify observations made during the spawning period.

## RESULTS

### Water Temperature

Surface water temperatures reached 15.5°C on 16 March, coinciding with the onset of bass spawning. The mean afternoon surface temperature from the six stations increased almost daily thereafter until 11 August, when it reached 29.4°C. Temperatures then decreased gradually to 23.3°C on 19 September, when measurements were discontinued (Figure 3).
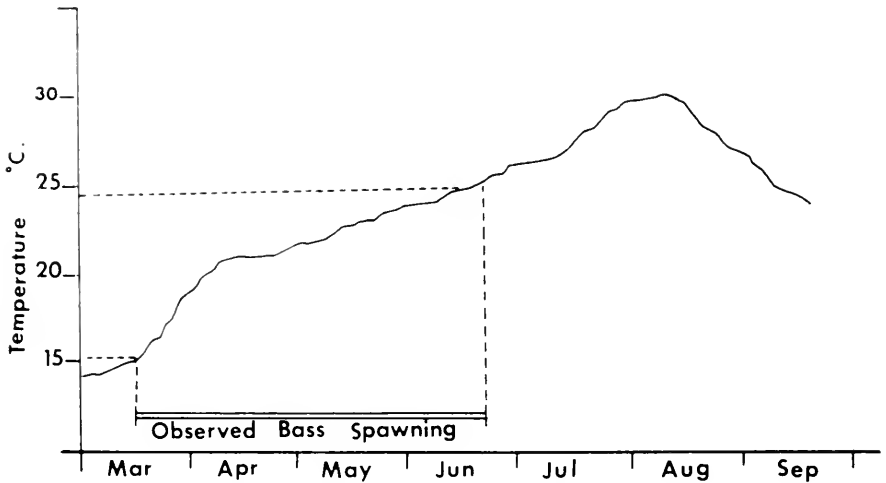
FIGURE 3.   Millerton Lake surface temperature trends, 1973.

## Water Level Fluctuation

Between 1 and 31 March the reservoir level fluctuated moderately, rising 4 m. During April, it receded at a mean rate of 0.24 m per day, resulting in a total drawdown of 7.1 m. From 1 May to 15 May, the lake level dropped at a mean rate of 0.25 m per day. Then, with heavy inflow from snow runoff, it increased rapidly. From 16 May to 8 June, the mean daily increase in water level was 0.69 m. The greatest rate of increase occurred on 18 and 19 May, when the water level rose 2.3 m over a 48 h period.

Millerton Lake attained its maximum capacity on 8 June and then spilled for 9 consecutive days, during which the surface elevation remained almost stable.

## Onset of Spawning

Spawning was first observed on 16 March, when peak afternoon surface temperatures reached 15.5°C. Twenty-one bass engaged in nest construction, spawning, or nest protection were observed during the following 9 d. Of the nesting attempts, only three progressed to the point of actual egg deposition.

Of 24 adult female bass examined in late March, 22 had ovaries containing ova in widely varying stages of development. Only two individuals showed indications of recent spawning. Based on these observation, it was surmised that the onset of spawning came rather gradually and that peak spawning activity would probably not take place until at least several weeks later.

By late March, low numbers of fry were observed in scattered schools along the shoreline. The index of fingerling abundance on 29 and 30 March was only 4.9 fish per km of shoreline (unpublished data).

## Receding Water Levels

That segment of the largemouth bass nesting study dealing with receding water levels was completed in early May (Figure 2). Ninety-two nests were located between 1 and 13 May. These included 36 guarded largemouth bass nests in which egg deposition had occurred, and an additional 56 abandoned nests in which no spawning was evident. The species associated with the abandoned nests could not be accurately determined, since smallmouth bass, *Micropterus dolomieui,* were also abundant in Millerton Lake. Also, it was not known if these nests had previously been used for successful spawning or were new nests that had been abandoned prior to egg deposition. At initiation, mean depth of the 36 guarded nests was 1.1 m and bottom temperatures ranged from 20 to 22°C. Although no significant temperature changes occurred, nest depth was dramatically altered as water levels dropped, and 55% of the nests were abandoned within 2 d after egg deposition. All nests were abandoned and/or destroyed by wave action or dessication within 6 d. No successful fry production could be documented, either from the study nests or from the reservoir in general.

## Rising Water Levels

Spawning was less frequently observed during the period of reservoir filling. Only five nests were located in which no successful spawning was observed. Two nests were abandoned prior to egg deposition, two were abandoned during egg incubation, and one was abandoned while containing 2-day-old fry (Figure 4). As water levels rose, mean depth of the five nests changed from 1.7 m at first observation to 5.8 m at the time of nest abandonment (Table 1). The mean depth increase ($\Delta D$) was 4.1 m. Nest cooling (a function of increasing water depth) occurred at all nests, despite rising surface temperatures. Total observed temperature reduction ($\Delta T$) at individual nests ranged from 3.8 to 8.9°C (Table 1). The magnitude of these temperature changes varied according to the length of time the nests were maintained and the amount of coincidental water level fluctuation which occurred.

**TABLE 1.  Physical Changes at Individual Study Nests Resulting from Rising Water Levels.**

| Nest ID number | Days maintained | Nest depth (initial) m | Nest depth (abandonment) m | Net depth change ($\Delta D$) | Nest temp. (initial) °C | Nest temp. (abandonment) °C | Net temp. change ($\Delta T$) |
|---|---|---|---|---|---|---|---|
| 1.................... | 3 | 1.9 | 4.8 | 2.9 | 23.2 | 19.4 | 3.8 |
| 2.................... | 6 | 1.6 | 6.7 | 5.1 | 23.3 | 14.4 | 8.9 |
| 3.................... | 5 | 2.1 | 6.5 | 4.4 | 23.0 | 15.0 | 8.0 |
| 4.................... | 5 | 1.6 | 6.1 | 4.5 | 23.3 | 15.7 | 7.6 |
| 5.................... | 4 | 1.4 | 4.8 | 3.2 | 23.4 | 18.0 | 5.4 |
| $\bar{x}$.................... | 4.6 | 1.7 | 5.8 | 4.1 | 23.2 | 16.5 | 6.7 |
| $S_x$.................... | 1.14 | .25 | .92 | .93 | .15 | 2.12 | 2.09 |

Following egg deposition, male bass typically defended the nest and an irregularly-shaped territory 2 to 3 m in radius around the nest. Protective behavior decreased substantially, however, as the water became deeper and bottom temperatures declined. Male fish then moved away from their nests when divers
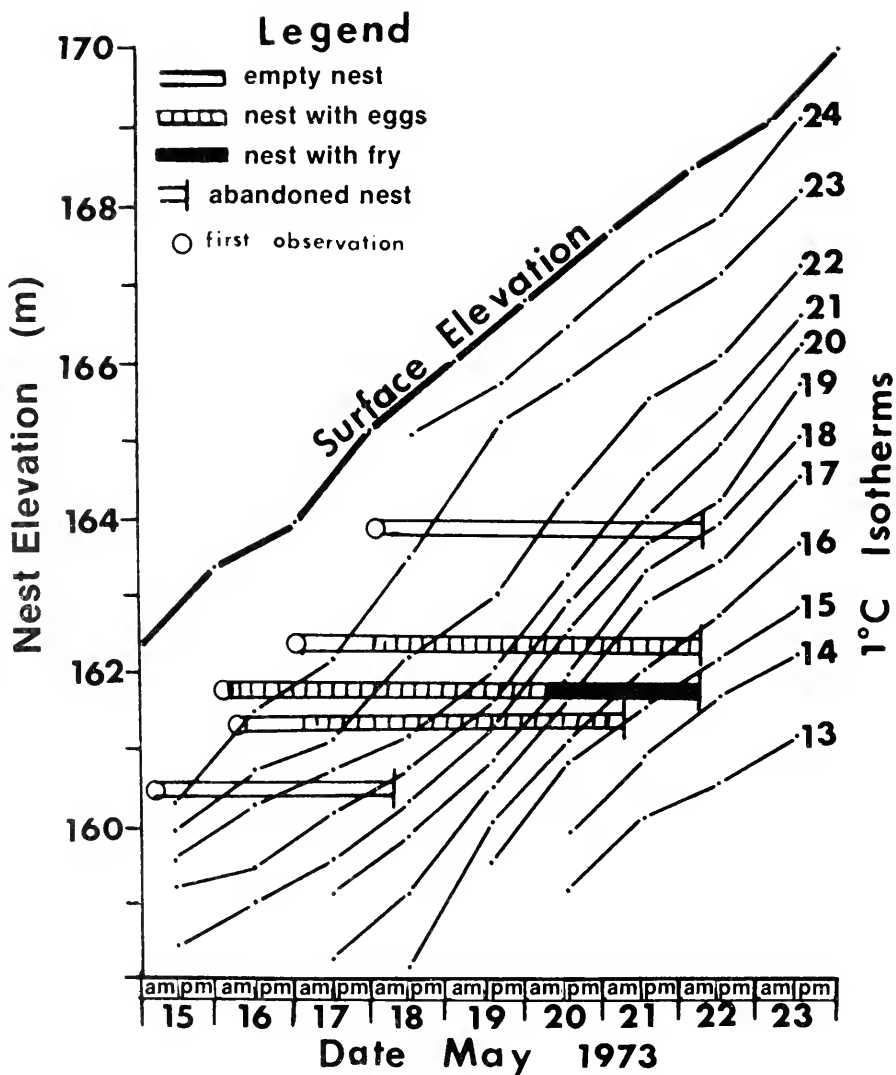
FIGURE 4.   Results of nest observations under rising water conditions.

approached. Subsequently, bluegill, *Lepomis macrochirus;* carp, *Cyprinus carpio,* and on one occasion, threadfin shad were observed feeding within the nests, presumably on eggs or fry. The nests were not defended against these fishes, even though the parental bass remained nearby. No fry survival was observed in any of the study nests during the period of rising water levels. Although the number of nests studied was small, the effect of rising water levels upon them was consistently detrimental. Based upon an apparent lack of fry

production in the reservoir during the rising water period (unpublished data) I suspect that any other nests attempted at the time were similarly affected.

## Successful Bass Reproduction

With the exception of limited reproduction in March, spawning success was not observed until 5 June, when the water level stabilized. From 5 June to 20 June, fry were observed in 15 nests. These nests were initiated long after daily temperatures exceeded 23.3°C. Nest depth, which initially ranged from 0.6 m to 2.5 m and averaged 1.4 m. remained fairly constant during much of the egg-fry development period due to the full status of the reservoir.

In general, the relative sizes of fingerling bass collected and the time period during which they were collected (unpublished data) supported the contention that successful spawning occurred only during March and June. Indices of fingerling abundance remained low until early July, when June-spawned fry began to enter the samples. Indices of abundance then increased from 71.4 fish per km on 1 June to 514.2 on 1 July. Over 90% of the July-captured fry were probably less than 30 d old, based on their relative size.

# DISCUSSION

## Lowering Water Levels

Because largemouth bass normally initiate spawning in depths less than 1.5 m (Kraemer and Smith 1962), their nests are subjected to the adverse impact of fluctuating springtime water levels. At Millerton Lake, drawdown rates averaged 23.7 cm per day during the spawning season. Concurrently, largemouth bass were observed initiating nests at a mean depth of 1.1 m. These fish successfully deposited eggs; however, all of the observed nests were stranded above water after a period of 2 to 6 d, precluding egg development. Kraemer and Smith (1962) reported development times in excess of 6 d. They determined that at temperatures of 14.4 to 16.6°C largemouth bass eggs require up to 12 d to develop into free-swimming larvae. The larvae then spend an additional 4 to 5 d at the nest site. In considering tolerance criteria for largemouth bass, reservoir drawdown would be expected to impact reproduction when drawdown rate approaches the quotient of nest depth divided by egg-larval development time. At Millerton Lake, mean nest depth was 1.2 m and mean egg-larval development time was estimated at 15 d. These values would generate a mean tolerance limit of 8.0 cm of drawdown per day. There are inherent limitations to the applicaiton of this tolerance limit at other waters. Since the tolerance limit is computed on the basis of mean values, it would theoretically not protect about half of the nests with respect to each parameter (the shallowest or slowest developing nests would be damaged). Thus, such criteria should be considered absolute minimum values. Also, since bass nesting depth and development time may vary considerably from water to water, the Millerton Lake criterion would likely not be applicable at some waters. Criteria need to be developed on an individual water basis.

## Rising Water Levels

Bross (1967) noted a favorable association between slowly rising water levels in spring and the formation of large initial year classes of largemouth bass at

Canton Reservoir, Oklahoma. Strong year classes of bass in 1965 and 1967 at
Lake Nacimiento, San Luis Obispo County, were associated with stable or rising
water levels during the spawning season by von Geldern (1971). He reported
rates of increase of 1.3 cm per day in 1965 and 6.1 cm per day in 1967. These
rates are considerably less than the mean rate of 0.69 m per day (with a peak
increase of 2.3 m over one 48-h period) at Millerton Lake in May and June
(Figure 2). Results of five individual nest studies conducted in late May, during
the period of reservoir filling, indicated that as water depth over bass nests
increased, temperatures at nest sites dropped rapidly (Figure 4). These changes
coincided with observed reductions in the protective behavior of parental bass.
The bass soon discontinued nest maintenance and protection, allowing eggs or
fry to fall prey to other fishes. Nest abandonment was the result in each case
observed.

Miller and Kraemer (1971) reported successful spawning of largemouth bass
under conditions of rapid reservoir filing at Lake Powell, Utah. Their findings
appear contradictory to the observations of this study. Major physical differ-
ences between the two reservoirs, however, may account for the variations
observed. Lake Powell is very clear, with light penetration to great depths. This,
in combination with the warm local climate, accounts for stable nest tempera-
tures which were observed by Miller and Kraemer over periods of time when
actual nest depth was increasing. In contrast, Millerton Lake is more turbid, with
shallower light penetration. This lake has a summertime mean secchi disk read-
ing of about 2 m and midday light transmittance of only 11% to a depth of 15
m (unpubl. data). This condition results in a considerable temperature transition
at shallow depths.

Development of tolerance criteria with respect to reservoir filling is far less
precise than under conditions of drawdown. During rising water, nest tempera-
ture, egg development, and tenacity of fish to maintain nests may vary consider-
ably.

Disparity between observations at Millerton Lake and Lake Powell character-
ize the difficulty in prescribing universal criteria. The conditions measured at
Millerton Lake clearly exceed bass tolerance limits by some unknown margin.
At best, these observations provide minimum criteria as a single point of refer-
ence.

Since the mean $\Delta$ D for abandoned nests at Millerton Lake was 4.02 m over
a highly variable 15-d development period, the quotient of these values (27
cm/d) is the calculated limit of tolerance. This value, however, is known to
exceed the true tolerance limit of the fish. Further, its application at other waters
is quite limited. Refinement of this criterion for use at other waters would require
an analysis of additional data, to be generated by either (i) experimental
manipulation of water levels at a subject reservoir over a series of spawning
seasons, or (ii) a correlation analysis of past reservoir filling rates which are
known to have either permitted or precluded bass reproduction. This process
may generate different tolerance limits for each water examined.

## Delayed Bass Reproduction

Based on the results of this study, the net effect of both upward and downward
fluctuation at Millerton Lake was to delay bass reproduction by reducing the

success rate of early largemouth bass spawning attempts. This apparently left only the late-spawned fry as the basis for the 1973 year class. Late spawning occurred in June, after the reservoir filled and its level stabilized. Ambient temperatures at that time were far above the normal reported spawning range for this species.

It is likely that even though water level fluctuation may sometimes preclude early spawning, delayed reproduction may still occur up to several months later. For a full month after peak spawning occurred at Millerton Lake, conditions apparently remained within the spawning tolerance range of some individual bass. In the absence of successful early spawning, reproduction by relatively few late-spawning adults may be sufficient to produce a satisfactory year class.

## CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Results of this study have definite implications with respect to the maintenance of largemouth bass populations in impounded waters. The apparent inability of largemouth bass to reproduce successfully under conditions of rapidly fluctuating water levels poses a need to alter traditional reservoir operations if bass stocks are to be sustained.

To insure adequate largemouth bass reproduction water levels should be stabilized during the spring, beginning shortly after the onset of spawning. Using Millerton Lake data as a reference point, reservoir drawdown in excess of 8 cm per day will likely destroy about half of the bass nests, leaving only deeper-than-average nests to provide recruitment. Increasing rates of water drawdown would destroy a larger percentage of nests. Water levels that rise in excess of those discussed by Bross or von Geldern should be avoided.

Where extreme springtime fluctuation is an essential part of reservoir operation, it would be desirable, where possible, to fluctuate water in stages, with at least 3 wks between major periods of fluctuation. This procedure would be more favorable than long, gradual drawdowns or buildups. Staged drawdowns would likely prevent reproduction during the periods of change; however, it would allow a portion of the bass population to spawn successfully during intermittent periods of water level stability.

Fisheries managers should attempt to identify strains of largemouth bass which (i) spawn deeper, (ii) spawn earlier, and (iii) produce fry with shorter in-nest development time. Stocking such fish would optimize bass spawning in reservoirs where fluctuation is unavoidable.

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# TROPHIC INTERRELATIONS AMONG INTRODUCED FISHES IN THE LOWER COLORADO RIVER, SOUTHWESTERN UNITED STATES [1]

W. L. MINCKLEY
Department of Zoology
Arizona State University
Tempe, AZ 85281

Analysis of 1,050 stomachs of 18 species of fishes from the lower Colorado River mainstream indicates a relatively simplified food web based on autochthonous detrital materials, algae, and macrophytes. Aquatic insects, clams, and crayfish eaten by larger fishes fed directly on detritus or particles filtered from the water. Threadfin shad and red shiner, both depending principally on detritus as food, were major forage for piscivores.

## INTRODUCTION

The lower Colorado River has one of the most highly modified channels in western North America. The most characteristic feature of aquatic habitats in arid zones, extreme variability in time and space, has been suppressed, and this notoriously fluctuating, formerly turbid stream now flows under essentially complete control by mainstream and tributary impoundments. Its native fishes, highly endemic but comprising only about nine species, are extirpated from the mainstream, or are rare. A new fauna, consisting of exotic species, is becoming established. So far, 44 non-native taxa have been recorded from the reach between Davis Dam and the U. S. and Mexican Boundary, 20 of which are locally or regionally abundant (Minckley 1979, Nicola 1979). Most published data on fishes of the river consist of faunal listings (Evermann 1931, Miller 1961, Miller and Lowe 1967, Bradley and Deacon 1967), general discussions of the fisheries (Moffett 1942, Dill 1944, Jonez *et al.* 1951, Wallis 1951, Kimsey 1958), keys for identification (Miller 1952, Winn and Miller 1954, Minckley 1971*a*), and numerous shorter works dealing with species introductions, and observations on distribution and ecology (reviewed by Minckley 1973 and Moyle 1976). Part of an ecological survey of the mainstream lower Colorado River, conducted from 1974 through 1976, was to identify general food relations within the fish fauna. Food habits of 18 species of fishes were studied to obtain an outline of trophic structure for the system. Edwards (1974) reported on foods of striped bass, *Morone saxatilis,* and his data are also summarized herein.

## DESCRIPTION OF THE AREA

The study area was delimited upstream by Davis Dam and below by the International Boundary. The Colorado River forms the border between Nevada and Arizona to the north, California and Arizona through much of the study reach, and Baja California Norte, Mexico, and Arizona, at the southern extreme (Figure 1). The International Boundary lies about 120 km upstream from the Gulf of California. Historically, the only perennial tributaries entering this 453-km reach are the Gila and Bill Williams rivers. The former is now maintained below dams by return flow from irrigation and domestic wastewaters except in periods

of unusually high runoff (Brown, Carmony, and Turner 1978). The latter is also impounded and sometimes ceases to flow at its mouth. Local precipitation seldom exceeds 12 cm per year, summer air temperatures often rise to greater than 40°C, and winter temperatures rarely drop below freezing for more than a few hours.
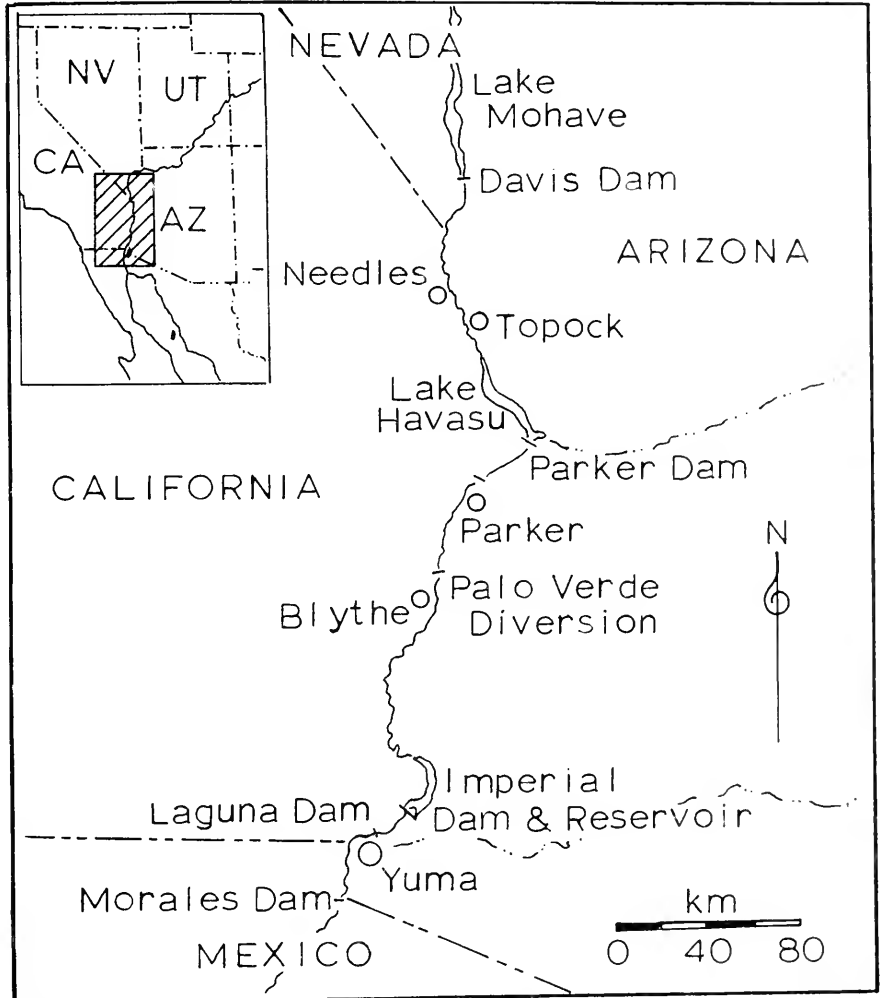


FIGURE 1. Map of the lowermost Colorado River, southwestern United States, with some place names mentioned in text.

Terrain along the river ranges from precipitous cliffs, where the stream has eroded through mountain ranges, to low, broad floodplains. Slopes and terraces are stony along mountain fronts. Lower terraces and floodplains are composed of fine sands and silts.

The sparse natural vegetation of the region is classified as Sonoran desertscrub (lower Colorado River subdivision; Brown and Lowe 1980). Plant communities,

especially those of riparian zones, are highly modified by agricultural development, by alteration of stream banks and channels, and through other direct influences of early and later settlers (Ohmart, Deason, and Burke 1977).

## METHODS AND MATERIALS

An attempt was made to use fishes from throughout the reach, and from different seasons, to obtain comprehensive coverage. However, this was realized only for some of the more common species such as carp, *Cyprinus carpio;* red shiner, *Notropis lutrensis;* channel catfish, *Ictalurus punctatus;* largemouth bass, *Micropterus salmoides;* and bluegill, *Lepomis macrochirus,* where 11 to 50 individuals were studied each season. Foods of other fishes were studied in spring through autumn. All rainbow trout, *Salmo gairdneri,* were obtained from fishermen and from Arizona Game and Fish Department personnel near Davis Dam. Most smallmouth bass, *Micropterus dolomieui,* examined were caught by anglers near Blythe, California. Threadfin shad, *Dorosoma petenense;* flathead catfish, *Pylodictis olivaris;* yellow bullhead, *Ictalurus natalis;* sailfin molly, *Poecilia latipinna;* mosquitofish, *Gambusia affinis;* warmouth, *Chaenobryttus gulosus;* striped mullet, *Mugil cephalus* (the only native fish taken); and the mouthbrooder, *Sarotherodon mossambica,* all were from the reach below Blythe. Redear sunfish, *Lepomis microlophus;* green sunfish, *L. cyanellus;* and black crappie, *Pomoxis nigromaculatus,* were obtained near Parker and/or Yuma, Arizona. Specimens taken by hook and line or with various seines were sacrificed for analysis to avoid prolonged restraint and loss of food items through continuing digestion which occurs in fishes taken in gill, trammel, and hoop nets of various sizes and meshes (Minckley 1979).

Food habits were determined by examination of stomach contents under appropriate magnifications. In species with ill-defined stomachs (*e.g.* carp) the anterior few centimetres of digestive tract was examined. Stomachs were excised from larger fishes, after ligation of the esophagus and pyloric regions, and preserved in 10% formalin. All stomachs were tagged for later identification. Small fishes were preserved intact in the field and their viscera removed in the laboratory.

Data were reduced as "frequency of occurrence," which tends to underestimate importance of large items and over-estimate importance of small items. However, this technique develops comparative data, expressed as percentage, among diverse species, and avoids ambiguities of assigned (estimated) "points" (Hynes 1950) or attempted reconstruction of live volumes of animals from fragments present (Ricker 1937). Stomach contents were teased apart in water and identified through use of keys of Edmondson (1959) and Usinger (1956). Reference collections were used to identify fishes and larger crustaceans.

## RESULTS

### General Food Habits

Detritus formed the major proportion of stomach contents of threadfin shad, red shiner, mouthbrooder, sailfin molly, and striped mullet (Table 1), and was common in carp, channel catfish, and yellow bullhead. Most detritus was identifiable as fibrous particles of higher plants, typically aquatic macrophytes. A small percentage was dark, gelatinous material identical in appearance to *gytjja*-like

organic deposits along the channel and in backwaters of the river. A liberal occurrence of sand in stomachs of detritivores indicated direct feeding from the bottom. Amorphous detrital materials in stomachs of carp and channel catfish often included unicellular algae, some of which was likely recorded as phytoplankton (Table 1). The high incidence of Asiatic clams, *Corbicula fluminea*, in stomachs of these fishes, and field observation of carp feeding upon and among clams, indicates probable use of pseudofeces of the mollusk (Prokopovich 1969) by the fishes as food. This material, bypassed by a clam when particulates exceed its capacity for ingestion, includes a large percentage of detritus, plus organisms bound in a mucoid secretion. Detritus in stomachs of sailfin molly and mouthbrooder was associated with the high frequency of occurrence of benthic (or epiphytic) algae, and in the case of the latter, with substantial amounts of higher plant tissues. Both of these fishes often grazed within beds of aquatic plants.

Although much of the algae eaten by fishes in the lower Colorado River could easily have been ingested while foraging for other items, rainbow trout contained considerable volumes of *Cladophora glomerata,* a large filamentous alga that formed a major component of organic drift observed and caught on nets near Davis Dam. Drifting algae may be taken as an innate feeding response by visually-oriented fishes such as hatchery-reared trout, or may be consumed indiscriminately by facultative planktivores such as threadfin shad and striped mullet. Some algal species that appeared to be true phytoplankters (desmids and some diatoms) were found in stomachs of the last two species (Table 1).

Zooplankton in stomachs of rainbow trout, threadfin shad, red shiner, and bluegill included cladocerans and copepods characteristics of limnetic populations in Colorado River reservoirs, presumably having been entrained through penstocks into the channel. Zooplankters in stomachs of carp, largemouth bass, green sunfish, and black crappie also included ostracods and thus included near-bottom or benthic microcrustaceans. Only trout and shad contained what might be considered more than trace amounts of zooplankton.

Benthic invertebrates were present in stomachs of essentially all fishes examined, with chironomid dipteran larvae almost universally represented. Rainbow trout from below Davis Dam ate about equal amounts of chironomid and simuliid dipteran larvae and also contained a substantial frequency of hydropsychid trichopteran larvae. Carp fed on chironomids, ephemeropteran nymphs, trichopteran larvae, and a few odonate naiads. The last three groups only occurred in stomachs of fishes from below Parker Dam. Red shiners ate chironomids, and a few ephemeropterans and trichopterans. The low frequency of occurrence of chironomids in channel catfish (5.1%) indicated little dependence on benthic insects. No other insect groups were used by channel catfish, which is surprising in light of findings in other streams (*e.g.* Bailey and Harrison 1948). Yellow bullheads used chironomids extensively, but young flathead catfish ate only large odonates and trichopterans.

Most mosquitofish examined had eaten tiny, soft-bodied larvae of chironomids, culicids, dixids(?), and undetermined insect groups. About 43% fed on terrestrial invertebrates (aphids, ants, and spiders) and aerial adults of aquatic insects (included with terrestrial insects in Table 1). Sailfin mollies did not feed on animal materials (see, however, Harrington and Harrington 1961).

**TABLE 1.  Summary of Frequency of Occurrence of Various Food Items in Stomachs of Fishes from the Lower Colorado River, 1974–76, as Percentages of All Stomachs Examined for Each Species.**

| Items in stomachs | Salmo bairdneri | Dorosoma petenense | Cyprinus carpio | Notropis lutrensis | Ictalurus punctatus | Ictalurus melas | Pylodictis olivaris | Gambusia affinis | Poecilia latipinna | Micropterus dolomieui | Micropterus salmoides | Chaenobryttus gulosus | Lepomis cyanellus | Lepomis macrochirus | Lepomis microlophus | Pomoxis nigromaculatus | Morone saxatilis | Sarotherodon mossambicus | Mugil cephalus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of stomachs | 38 | 49 | 135 | 79 | 137 | 16 | 23 | 42 | 52 | 27 | 189 | 16 | 51 | 47 | 34 | 29 | 100 | 65 | 21 |
| Total lengths, limits in millimetres | 152–440 | 37–193 | 175–864 | 33–56 | 236–737 | 93–325 | 178–813 | 21–37 | 27–64 | 118–432 | 99–560 | 82–155 | 75–205 | 78–213 | 85–305 | 173–327 | 540–893 | 95–289 | 381–495 |
| Percentage empty | 18.4 | 0.0 | 7.8 | 11.4 | 16.1 | 12.5 | 39.1 | 2.4 | 0.0 | 29.6 | 11.6 | 31.3 | 31.6 | 0.0 | 5.9 | 0.0 | 45.0 | 0.0 | 0.0 |
| *Inorganic Materials* | | | | | | | | | | | | | | | | | | | |
| Sand, gravel, etc. | – | 81.8 | 30.4 | 3.8 | – | – | – | 2.4 | 19.4 | – | 3.7 | 12.5 | 2.0 | 2.1 | 8.8 | – | – | 20.0 | 95.2 |
| *Vegetative Materials* | | | | | | | | | | | | | | | | | | | |
| Detritus | – | 98.0 | 42.2 | 62.0 | 32.9 | 12.5 | – | – | 100.0 | – | – | – | – | – | – | – | – | 63.1 | 100.0 |
| Macrophytes | 2.6 | – | 1.5 | – | 40.9 | 18.8 | – | – | – | – | – | – | – | – | – | 41.4 | – | 44.6 | 4.8 |
| Benthic and epiphytic algae | 42.1 | 16.3 | 3.7 | 2.5 | 8.0 | – | – | 54.8 | 82.7 | – | – | – | – | – | 5.9 | – | – | 27.7 | 14.3 |
| Phytoplankton | – | 16.3 | 33.3 | – | 0.7 | – | – | – | – | – | – | – | – | – | – | – | – | – | 14.3 |
| *Animal Materials* | | | | | | | | | | | | | | | | | | | |
| Crustacea | 34.3 | 20.4 | 7.4 | 26.6 | 24.8 | 56.3 | 26.1 | – | – | 29.6 | 15.3 | – | 7.8 | 63.8 | – | 10.3 | 7.0 | – | – |
| Copepoda | 29.0 | 20.4 | 0.7 | 21.5 | – | – | – | – | – | – | 10.6 | – | 7.8 | 51.1 | – | 6.9 | – | – | – |
| Cladocera | 5.3 | 4.1 | 3.0 | 11.4 | – | – | – | – | – | – | 4.8 | – | – | 19.1 | – | 3.4 | – | – | – |
| Ostracoda | – | – | 0.7 | – | – | – | – | – | – | – | 1.6 | – | 2.0 | – | – | 3.4 | – | – | – |
| Decapoda | | | | | | | | | | | | | | | | | | | |
| Astacidae | 5.3 | – | 3.7 | – | 21.2 | 56.3 | 26.1 | – | – | 29.6 | 3.7 | 12.5 | 3.9 | – | – | 6.9 | 7.0 | – | – |
| Paleomoneidae | – | – | – | – | 3.7 | – | – | – | – | – | 8.5 | 6.2 | 7.8 | – | – | 41.4 | – | – | – |

Note: this page presents a single rotated data table. The topmost italic number row corresponds to the "Benthic Insecta" row; no column headings are printed on this page (they appear on a facing page). Columns are numbered 1–20 below for reference. Dashes (—) indicate no value.

| Food item | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Benthic Insecta | 4.8 | 16.9 | — | — | 8.8 | — | 46.8 | 35.3 | 43.8 | 9.0 | 29.6 | — | 61.9 | 8.7 | 37.5 | 5.1 | 24.1 | 33.3 | 26.5 | 26.3 |
| Ephemeroptera | — | — | — | — | — | — | — | — | — | — | 29.6 | — | — | — | — | — | — | — | — | 3.8 |
| Odonata | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
|   Zygoptera | — | 1.5 | — | — | — | — | — | 9.8 | — | 2.1 | — | — | — | 8.7 | — | — | — | 0.7 | — | — |
|   Anisoptera | — | — | — | — | — | — | — | 5.8 | — | 1.6 | — | — | — | — | — | — | — | — | — | — |
| Megaloptera | — | — | — | — | — | — | — | — | — | — | 11.1 | — | — | — | — | — | — | — | — | — |
| Trichoptera | — | — | — | — | — | — | — | — | — | 0.5 | 3.7 | — | — | 4.4 | — | — | 1.3 | — | — | 18.4 |
| Diptera | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
|   Tipulidae | — | — | — | — | — | — | — | 2.0 | — | — | — | — | — | 4.4 | — | — | — | 0.7 | — | — |
|   Culicidae | — | — | — | — | — | — | 4.2 | 2.0 | — | — | — | — | 45.2 | — | 6.2 | — | — | — | — | — |
|   Simuliidae | — | — | — | — | — | — | — | — | — | — | — | — | 9.5 | — | — | 5.1 | 24.1 | 33.3 | 4.1 | 23.7 |
|   Chironomidae | 4.8 | 16.9 | — | — | 8.8 | — | 46.8 | 35.3 | 6.2 | 9.0 | — | — | 26.2 | — | 37.5 | — | — | — | — | 26.3 |
|   Dixidae (?) | — | 1.5 | — | — | — | — | 2.1 | — | — | — | — | — | 19.0 | — | — | — | — | — | 4.1 | — |
|   Undetermined taxa | — | — | — | — | — | — | 8.5 | — | 12.5 | — | — | — | — | — | — | — | 5.1 | 2.2 | — | 2.6 |
| Terrestrial | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
|   Invertebrates | — | 3.1 | — | — | — | — | 2.1 | 9.8 | 12.5 | — | — | — | 42.9 | — | — | — | — | — | — | — |
|   Hymenoptera | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
|   Formicidae | — | — | — | — | — | — | — | 3.9 | 12.5 | — | — | — | 16.7 | — | — | — | — | — | — | — |
|   Homoptera | — | — | — | — | — | — | — | — | — | — | — | — | 9.5 | — | — | — | — | — | — | — |
|   Aphididae | — | — | — | — | — | — | — | — | — | — | — | — | 9.5 | — | — | — | — | — | — | — |
|   Araneida | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
|   Undetermined taxa | — | — | — | — | — | — | — | 7.8 | — | — | — | — | 21.4 | — | — | — | — | — | — | — |
| Undetermined taxa | — | — | — | — | — | — | 2.0 | 2.0 | 2.0 | — | — | — | — | — | — | — | — | — | — | — |
| Mollusca | — | 26.2 | — | — | 58.8 | — | — | 2.0 | 31.2 | 1.6 | — | — | — | — | 6.3 | 29.2 | — | 46.7 | — | — |
|   Sphaeriidae | — | 23.1 | — | — | 55.9 | — | — | — | 12.5 | 1.6 | — | — | — | — | 6.3 | 29.2 | — | 46.7 | — | — |
|   Physidae | — | 3.1 | — | — | 5.9 | — | — | — | — | — | — | — | — | — | — | 1.5 | — | — | — | — |
| Oligochaeta | — | 1.5 | — | — | — | — | — | — | — | — | — | — | — | — | 37.5 | 19.7 | 3.8 | 2.2 | 6.7 | — |
| Vertebrata | — | — | 51.0 | 55.2 | 2.9 | — | — | 5.8 | 25.0 | 55.0 | 11.1 | — | — | 43.5 | — | 19.7 | 3.8 | 2.2 | — | 34.2 |
| Salmonidae | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
|   *Salmo gairdneri* | — | — | 13.0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Clupeidae | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
|   *Dorosoma petenense* | — | — | 35.0 | 20.7 | 2.9 | — | — | — | — | 53.4 | 11.1 | — | — | 4.3 | — | 5.1 | — | 2.2 | — | 34.2 |

**TABLE 1. Summary of Frequency of Occurrence of Various Food Items in Stomachs of Fishes from the Lower Colorado River, 1974–76, as Percentages of All Stomachs Examined for Each Species.—Continued**

| Items in stomachs | Salmo gairdneri | Dorosoma petenense | Cyprinus carpio | Notropis lutrensis | Ictalurus punctatus | Ictalurus melas | Pylodictis olivaris | Gambusia affinis | Poecilia latipinna | Micropterus dolomieui | Micropterus salmoides | Chaenobryttus gulosus | Lepomis cyanellus | Lepomis macrochirus | Lepomis microlophus | Pomoxis nigromaculatus | Morone saxatilis | Sarotherodon mossambicus | Mugil cephalus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cyprinidae | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Cyprinus carpio ......... | – | – | – | – | – | – | 4.3 | – | – | – | – | – | 3.9 | – | – | – | 1.0 | – | – |
| Notropis lutrensis ......... | – | – | 1.4 | – | 7.3 | – | 13.0 | – | – | 3.7 | 7.9 | 18.8 | – | – | – | 34.5 | – | – | – |
| Ictaluridae | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Ictalurus punctatus......... | – | – | – | – | – | – | 4.3 | – | – | – | – | – | – | – | – | – | – | – | – |
| Poeciliidae | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Gambusia affinis | – | – | – | – | – | – | – | – | – | – | – | 18.8 | – | – | – | – | – | – | – |
| Poecilia latipinna | – | – | – | – | – | – | – | – | – | – | – | 6.2 | – | – | – | – | – | – | – |
| Centrarchidae | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Micropterus salmoides......... | – | – | – | – | – | – | – | – | – | – | 0.5 | – | – | – | – | – | 3.0 | – | – |
| Lepomis cyanellus ......... | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 1.0 | – | – |
| Undetermined species ......... | – | – | – | – | 2.9 | – | 4.3 | – | – | 7.4 | 1.6 | – | 2.0 | – | – | – | – | – | – |
| Undetermined fishes ......... | – | – | – | – | 3.6 | – | – | – | – | – | 1.1 | – | 2.0 | – | – | – | – | – | – |
| Ambystomatidae | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Ambystoma tigrinum ......... | – | – | – | – | 0.7 | – | – | – | – | – | – | – | – | – | – | – | 2.0 | – | – |
| Undetermined vertebrates (?) .. | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 6.0 | – | – |

Smallmouth bass stomachs contained large numbers of ephemeropteran nymphs and megalopteran larvae. Odonate naiads, including both damsel- and dragonflies, were taken by juvenile largemouth bass, warmouth, and green sunfish. Included were species of clambering damselfies typically found in beds of aquatic plants (see also Weaver and Zeibell 1976). Chironomids also were taken by the last three fishes. Bluegill depended strongly on chironomids, along with zooplankton (Table 1). Redear sunfish ate chironomid larvae only infrequently.

Mouthbrooder and striped mullet contained a few tiny chironomid larvae that may have been consumed along with detritus (especially in the latter). Mouthbrooder, however, contained a few terrestrial insects and a number of other benthic groups.

Introduced palaemoneid shrimp, *Palaemonetes paludosus,* are common in the lower Colorado River, but contributed to the diet of only five fish species. Black crappie appeared to select the food item. Largemouth bass, warmouth, and green sunfish all fed on shrimp at about the same proportion. Channel catfish contained them at a frequency of only 3.7%. Perhaps its semi-transparent body makes the shrimp relatively immune to all except special predators, especially when in dense aquatic vegetation.

The introduced crayfish, *Procambarus clarki,* was a major food of almost all large carnivores, especially catfish and smallmouth bass. Rainbow trout, carp, largemouth bass, warmouth, green sunfish, and black crappie also ate the decapod. Edwards (1974) reported crayfish from striped bass stomachs. Introduced softshelled turtle, *Trionyx spiniferus,* also depended heavily on them (present in 10 animals dissected, along with odonate naiads as the only other food item).

Asiatic clams were eaten by carp, channel catfish, yellow bullhead, redear sunfish, largemouth bass, and mouthbrooder (Table 1). In all but redear sunfish, clams were digested without breakage of valves, with the shell simply passing through the intestinal tract. The redear sunfish is especially adapted for crushing mollusks, with molariform teeth on its pharyngeal bones; however, less than 20% of shells in redear stomachs had been physically damaged. Crushing of clams is obviously not requisite to digestion since shells in hindguts of redear sunfish and other species alike were devoid of flesh. Consumption of clams by carp was spectacularly high in some instances, with some fish containing more than 30. Some clams eaten by carp and channel catfish exceeded 2.5 cm across the valves, but most were less than 1.0 cm.

Rainbow trout, two of the catfish, and all sunfishes excepting bluegill contained other fishes. Channel and flathead catfishes, largemouth bass, warmouth, and black crappie were the most piscivorous species. Edwards (1974) demonstrated that striped bass in the Colorado River were also voracious piscine predators (Table 1).

Threadfin shad was the exclusive fish eaten by trout. Largemouth bass also ate shad, followed by red shiner, unidentified sunfish, unidentified fish, and other largemouth bass. Channel catfish fed on shad and red shiner, unidentified centrarchids, and other unidentified fish. Flathead catfish ate mostly red shiner and mouthbrooder. Four flathead catfish each had eaten a single fish, each of a different species (threadfin shad, carp, channel catfish, and undetermined centrarchid). The warmouth was a specialized piscivore, feeding on poeciliids and red shiner. Green sunfish were more opportunistic, eating small carp and uniden-

tified fishes. Only one redear sunfish took a juvenile shad, but black crappie ate them frequently, along with red shiner. Striped bass ate threadfin shad, rainbow trout, crayfish, centrarchids, carp, tiger salamander, *Ambystoma tigrinum,* and unidentified animal material (Edwards 1974). The salamander is a common bait animal along the Colorado River (Minckley 1971*b*); and a single specimen also was eaten by a channel catfish (Table 1).

Percentages of empty stomachs in fishes of the lower Colorado River were related to principal food habits. No empty stomachs were found among detritivores and facultative planktivores. Species that depended upon a broader food base, including significant frequencies of benthic invertebrates, also had relatively low percentages of empty stomachs. Large piscivores tended to have a high incidence of empty stomachs (*e.g.* flathead catfish, 39.1%). Edwards (1974) reported 45% of 100 stomachs of adult striped bass as empty. Smallmouth bass, warmouth, and green sunfish also had an incidence of empty stomachs that exceeded 20%, but largemouth bass displayed a wider food base and all but 11.6% contained foods.

## SPATIAL VARIATION

Trophic structure within the fish community of the lower Colorado River differs substantially in different reaches of stream. Near Davis Dam, waters of the upstream reservoir (Lake Mohave) provide a major proportion of basic foodstuffs. Substantial amounts of plankton and detritus pass through the dam and this is reflected in a large proportion of filter-feeding invertebrates (*e.g.* simuliids) in stomachs of fishes from that reach. Threadfin shad also drawn through the dam form a major portion of the food supply for striped bass (Edwards 1974), and likely for larger rainbow trout. Cold water resulting from hypolimnic releases from Davis Dam exclude many temperate (and obviously tropical) species of fishes from that area. Primary production is relatively high, since aquatic vegetation is abundant (no quantitative data available), but essentially no fishes are present to utilize that level in the food web.

Downstream in Topock Gorge, deep, swift areas continue to be influenced by hypolimnic water from Lake Mohave. A few major backwaters provide habitat for temperate fishes. It seems likely that this reach is relatively devoid of foods for piscivores, since red shiners were rare and threadfin shad almost non-existent (Minckley 1979).

Lake Havasu is a relatively stable, mainstream reservoir that differs greatly from the remainder of the reach under consideration. Few stomachs of fishes were examined from the lake (none of those presented in Table 1), but food relations seemed similar to those described by Rinne, Minckley, and Bersell (1981) from reservoirs in central Arizona. Fishes were distributed relative to their food supplies: planktivorous threadfin shad were most abundant near nutrient inputs, thus near phyto- and zooplankton concentrations, and piscivorous largemouth bass tended to be near threadfin shad. Benthic predators were more generally distributed within the reservoirs, in keeping with a more general distribution of benthic invertebrates. Zooplankton was not studied in Lake Havasu, but Chlorophyll *a* concentrations were highest near nutrient inputs at the uppermost end of the lake and in the Bill Williams River arm (Portz 1973, Minckley 1979). Benthic invertebrates in Lake Havasu were also similar in diversity and general abundance to those elsewhere in low desert impoundments (Rinne *et*

*al.* 1981), with fewer animals and biomass where currents were present (Minckley 1979, Cowell and Hudson 1967), presumably in response to changes in sediments (Schulback and Sandholm 1962). Shoreline populations of benthic invertebrates were locally dominated by Asiatic clams, reflecting high plankton populations in the lake. These were eaten by carp, channel catfish, and redear sunfish, at frequencies comparable to those in the river channel (based on qualitative examination of stomachs).

Epilimnetic penstock intakes in Parker Dam allow warm water to flow downstream, thus enhancing habitat for warmwater fishes in the river below Lake Havasu. Particulate materials, including plankton, in turn enhance filter-feeding benthic animals, as do hard bottoms and an abundant micro- and macroflora. Macrophytes, benthic algae, and phytoplankton made up a significant part of the diet of all but centrarachids near Parker, Arizona, with phytoplankton being derived in part from the pseudofeces of Asiatic clams. Detritus, both from auto- and allochthonous sources, also was present in stomachs of many species at high frequencies, especially threadfin shad, carp, and channel catfish. Benthic insects, consisting mostly of chironomid dipteran larvae, comprised major parts of the diet of all species present. Other invertebrates, excepting clams and crayfish, were broadly represented, but far less significant than chironomids. Clams were eaten by specialists (carp, channel catfish, and redear sunfish), forming major parts of their diets. Crayfish were generally taken by piscivores, with the exception of smallmouth bass, who appeared to feed selectively upon them. Other fishes were important in the diets of six species, and especially so for channel and flathead catfishes, largemouth bass, and black crappie. Fishes lowest in the food web of the system, threadfin shad and red shiner, were eaten by other fishes most frequently, and were the most abundant species in the river (Minckley 1979). Other prey species were mostly juvenile centrarchids, for the most part secondary consumers in the system.

In the lowermost reaches, detritivory became a major mode of life for sailfin molly, striped mullet, and mouthbrooder. Accumulation of organic materials from upstream, resulting from high rates of production, lack of flooding, and in part from diminution in discharge as a function of progressive water use, allows these fishes to maintain and expand their populations. However, constraints of temperature upstream (too low in winter or near Davis Dam) for the molly and mouthbrooders, and distance from the sea plus intervening barriers for the mullet, undoubtedly limit their over-all distribution more than food.

## DISCUSSION AND CONCLUSIONS

Although the Colorado River provides a relatively low food diversity, food habits of introduced fishes of the Colorado River do not differ substantially from those of the same species within their native ranges (see reviews in Calhoun 1966). Many abundant forage species are introduced (probably not so for most insects and oligochaetes) and are characterized by high reproductive rates and high-density, monospecific populations. These features are also evident in the new fish fauna, with many species now populating transitory habitats where populations may explode, stunt, then eventually stabilize at low levels or disappear.

The food web of the Colorado River is based upon autochthonous materials. Fishes in other large rivers often depend upon allochthonous inputs. In the

Missouri River (Berner 1951), 54% of materials ingested by fishes was of terrestrial origin. The sparse terrestrial vegetation of most of the Colorado River basin, and relatively large size of the stream in proportion to its narrow, water-limited riparian zone, diminishes the importance of allochthonous input. As emphasized by Minshall (1978), autochthonous conditions are far more prevalent in open, western streams than has been generally recognized.

Organic and inorganic transport in the Colorado River are curtailed by reservoirs, excepting for downstream passage of plankton and associated suspended debris through penstocks. These materials and nutrients not trapped by impoundments (Paulson and Baker 1980), nonetheless form a basis for downstream production. The few backwaters that remain along the river appear highly productive, supporting large standing crops of plankton, rooted aquatic vegetation, and fishes (Minckley 1979, Nicola 1979), all of which are flushed into the channel by almost-tidal fluctuations in the stream resulting from hydroelectric generation and pulses of irrigation deliveries. Less modified reaches of the river and those which are relatively stabilized have proportionately more backwater habitat. In-stream productivity is also locally high, enhanced by current under abundant insolation without interference of shading by turbidity or riparian vegetation, and is at present further augmented by addition of nutrients through return flow of irrigation systems. A trophic economy based upon autochthonous detritus establishes quickly under such conditions.

Introduced forage species that have survived and flourished in the lower Colorado River mainstream all depend heavily upon detritus or primary producers, or upon secondary consumers such as zooplankton, chironomids, or other invertebrates. Large fishes with less piscivorous tendencies feed directly upon detritus- or plant-dependent clams or crayfish. The introduced fish fauna thus appears to have relatively simple food interrelations.

## ACKNOWLEDGMENTS

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# LIMNOLOGY OF A EUTROPHIC RESERVOIR: BIG BEAR LAKE, CALIFORNIA [1,2]

CLIFFORD A. SIEGFRIED
Biological Survey, NYS Museum
The State Education Department
Albany, New York 12230

PERRY L. HERRGESELL
Bay-Delta Fisheries Project
California Department of Fish and Game
Stockton, California 95205

MARK E. KOPACHE [3]
College of Fisheries
Fisheries Research Institute
University of Washington
Seattle, Washington 98195

The limnology of Big Bear Lake, San Bernardino County, a high mountain reservoir in the San Bernardino Mountains of southern California, was studied from November 1976 through November 1978. Although the first year of study covered a period of severe drought, involving the lowest water levels in 10 years, and the lake was at or near capacity during the second year, the general limnology was similar each year. The lake typically stratifies in early spring and surface temperatures reach about 22 °C by mid-summer. Complete mixing occurs by September. Anoxia develops in the hypolimnion during stratification, increasing internal nutrient loading from sediments.

The annual phytoplankton cycle peaks in the spring and late summer. Diatoms dominate in early spring, green algae briefly dominates in early summer, and blue-green algae dominates from mid-summer to fall. In 1977, *Anabaena* and *Chroococcus* were the most abundant algal genera. In 1978, *Anabaena* dominated the early summer community, but *Aphanizomenon flos-aquae* dominated from late summer to fall. Algal growth appears to be limited by phosphorus from winter to spring, while nitrogen is limiting in the fall. Phosphorus and nitrogen loads from tributaries draining the urbanized southeast portion of the drainage are disproportionately high. Nutrient loading rates are excessive, and well into the eutrophic range. Trophic status was similar in both years. Big Bear Lake will likely remain eutrophic because of its shallow morphology, high nutrient content, and basin orientation and development.

## INTRODUCTION

Big Bear Lake (Figure 1), was the subject of limnological study from November 1976 through November 1978. It was originally constructed for storage of irrigation water for the Redlands-San Bernardino area of southern California, but is now used chiefly for recreation. Although the resident population of Big Bear Valley is estimated to be about 7,000, weekend populations can exceed 100,000 through recreational visitation (Neste, Bruding and Stone. 1970).

Big Bear Lake is currently experiencing rapid eutrophication. Blue-green algae blooms and profuse growths of macrophytes attest to the nutrient enrichment of the lake. The lake has been studied sporadically since 1968 (Irwin and Lemons 1974, Goldman 1975, James 1975). Our limnological study was initiated to

establish a data base for the evaluation of lake restoration options. The study covered 2 years with significantly different meteological conditions. This included a year of drought, resulting in the lowest water levels in 10 years and a wet year in which the lake was at or near capacity.
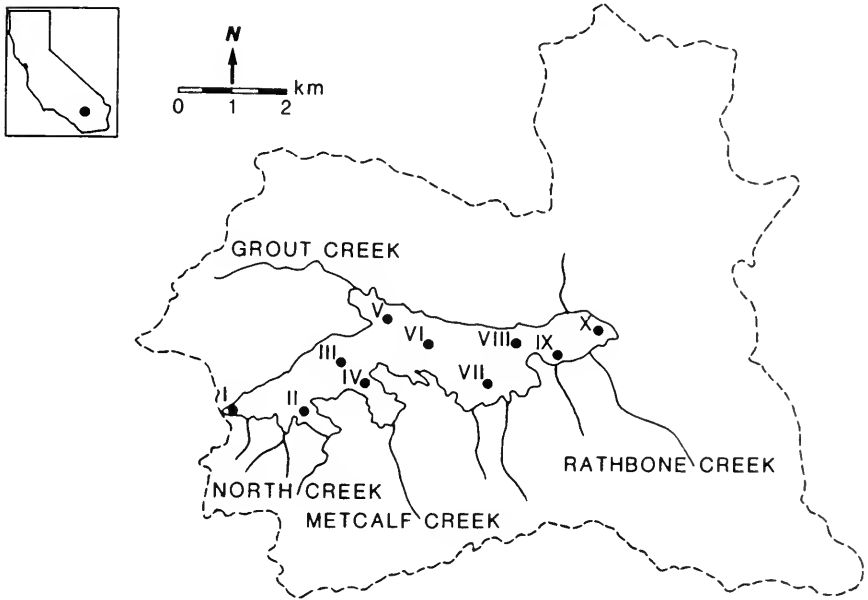


FIGURE 1.  Map showing location of Big Bear Lake, drainage basin, sampling sites, and major tributaries.

## Geographic and Morphometric Description

Big Bear Lake occupies a relatively small, east-west oriented basin (Figure 1). It was created in 1885 by the construction of a single arch dam across Bear Creek, a tributary of the Santa Ana River, and was enlarged in 1911 by a new, higher dam. At maximum pool it now has a surface area of 12.1 km $^2$, is 9.05 km long, averages about 1.34 km in width, and is 7.3 m deep. At capacity, it contains $89.3 \times 10^6$ m $^3$ of water. The ratio of lake surface area to drainage area is about 1:8. The morphology of Big Bear Lake (Table 1) was quite variable during this study.

The drainage basin encompasses 99.7 km $^2$. It is drained by more than a dozen mostly intermittent streams, most of which are less than 3 km in length. Grout Creek, the largest tributary, is only 6.1 km long. The average height of the drainage basin is 2,200 m above mean sea level.

Runoff, including snow melt, is the main source of water for Big Bear Lake. The average seasonal precipitation in the drainage area is 61 cm, but varies from 96.5 cm at the dam to 31 cm at the east end of the lake. Air temperature varies from a summer high of 30 °C to winter lows below −15 °C. The lake surface freezes during most winters. Spring and summer are characterized by afternoon winds out of the west.

**TABLE 1. Morphology of Big Bear Lake, 1977–1978.**

| | At capacity | 1977 Low (Dec)–High (May) | 1978 Low (Jan)–High (June) |
|---|---|---|---|
| Area ($A_o$) | 12.1 km$^2$ | 8.00–8.88 km$^2$ | 8.34–11.58 km$^2$ |
| Mean depth ($\bar{z}$) | 7.38 m | 4.78–5.13 m | 4.93–7.10 m |
| Maximum depth ($\bar{z}_M$) | 22.0 m | 16.9–17.8 m | 17.3–21.3 m |
| $\bar{z}{:}z_M$ | .33 | .28–.29 | .28–.33 |
| Length (1) | 9.05 km | 9.05 km | 9.05 km |
| Mean breadth (b) | 1.34 km | .88–.98 km | .92–1.28 km |
| Volume (v) | 89.3 x 10$^6$ m$^3$ | 38.24–45.52 x 10$^6$ m$^3$ | 41.15–82.18 x 10$^6$ m$^3$ |
| Area of shoal * | 33% | 53%–48% | 50%–35% |
| Shore length (s) | 38.4 km | 24.9–29.4 km | 26.6–36.5 km |
| Shoreline development | 3.11 | 2.48–2.78 | 2.60–3.03 |
| Altitude | 2055 m | | |
| Latitude | 34 ° 15 N | | |
| Longitude | 116 ° 55 W | | |
| Drainage area | 99.7 km$^2$ | | |
| $A_o{:}A$ | 1:8 | | |
| Precipitation | 61 cm (mean) | 33.4 cm | 60.7 cm |

* $\left(\dfrac{A_o - A_s}{A_o} \times 100\right)$

The Big Bear basin supports three communities: (i) Fawnskin on the north shore (1,400 residents); (ii) Big Bear Lake (3,760) on the south shore; and (iii) Big Bear City (1,610) on the southeast end. Each community is now sewered but numerous septic tanks and several nonsewered residences remain on the western end of the lake.

## METHODS AND MATERIALS

Three study sites (stations I, III, and VIII) were monitored in 1977 and 1978 (Figure 1). To determine phytoplankton density, composition, productivity, and basic physical-chemical parameters (water temperature, pH, conductivity, dissolved oxygen content, and macronutrient concentration), each site was sampled monthly in fall and winter of both years. Sampling was carried out biweekly during the spring and summer of 1977 and triweekly in 1978.

Dissolved oxygen concentration, pH, conductivity, temperature, and oxidation-reduction potentials were determined at each site at 1-m intervals from the surface to the bottom with a Hydrolab Surveyor Model VI Delta in-situ water quality analyzer. Macronutrients were assayed at 3-m intervals from the surface to the bottom at each site in 1978 and at 1 m in 1977. Nitrates were determined by the brucine method after boiling to remove organic interference and ammonia by direct nezzlerization (APHA 1975). Orthophosphorus was determined by the ascorbic acid method (APHA 1975) as was total phosphorus after persulfate digestion. Ionic composition was determined by atomic absorption spectrophotometry from samples collected at each site on 12 April and 20 November 1977. Analysis included determination of $Ca^{+2}$, $Mg^{+2}$, $Na^{+1}$, $K^{+1}$, $SO_4^{-2}$, $Cl^{-1}$, $CO_3^{-2}$, and $HCO_3^{-1}$.

Phytoplankton samples were collected at 1 m below the water surface at each site using a weighted hose attached to a diaphragm pump and were immediately preserved in Lugol's solution (Schwoerbel 1970). Samples were analyzed by use of the membrane filter technique (APHA 1975). Phytoplankton cells were identified and recorded to the generic level using a binocular microscope at 200X.

Phytoplankton productivity was determined by the light-dark bottle oxygen method as outlined by Strickland and Parsons (1972). All water samples used for productivity estimates were collected at each station at 1 m using a 3 1 Van Dorn water bottle and incubated together in 125 m1 BOD bottles on a harness anchored near station III (Figure 1). Incubation times were near mid-day and lasted about 6 hrs (1000–1600 h). Productivity estimates were converted to daily rates by multiplying the production measured during the incubation time $(mgC \cdot m^{-3})$ by the ratio of total daily incident sunlight to incident sunlight during the incubation period. Incident radiation was not measured, but data were obtained from nearby Lake Arrowhead.

Nutrients potentially limiting algal productivity were assayed by the *Selenastrum capricornutum* Prinz Algal Assay Bottle Test (Miller, Greene, and Shiroyama 1978). Assays were run on samples collected from station III at 1 m on 12 April and 17 October 1978, and from 1 and 7 m on 5 July 1978.

## RESULTS AND DISCUSSION
### Temperature

Temperature profiles for Big Bear Lake in 1977 and 1978 indicate a fairly consistent thermal regime (Figure 2). Stratification sets in by late May or June of each year. Surface temperatures reach a maximum of about 22°C by late July or early August. The shallow morphology and frequent winds characterizing the basin prohibit lengthy periods of thermal stratification. A mixed layer forms in the spring and deepens throughout the summer. The lake may mix completely as a result of strong winds. For example, stratification had begun in April 1977, but a storm in May mixed the lake and lowered temperature by > 2.5°C. By August only weak thermal stratification remains and complete mixing occurs by September.

Big Bear Lake has a large littoral to hypolimnion ratio, that is, a relatively small volume of the lake is below the termocline during stratification (Figure 3). The hypolimnion was restricted to the west end of the lake in 1977, but extended beyond mid-lake in 1978. The shallow east end mixed to the bottom throughout the spring and summer and was generally warmer than the west end. The hypolimnetic volume and area was considerably larger in 1978 than in 1977 because of the greater volume of water in the lake in 1978.

The total annual heat budget for 1977 was 8,483 cal/cm², comprised of a summer income of 8,163 cal/cm², and a winter income of 320 cal/cm². The annual heat budget for 1978 was considerably higher, 11,725 cal/cm², comprised of a summer income of 11,337 cal/cm² and a winter income of 388 cal/cm². The difference is attributable to the greater volume of the lake through which heat was mixed in 1978 compared to 1977. Surface temperatures were similar each year but bottom temperatures were nearly 2°C cooler in 1978 (19.2°C in 1977 as compared to 17.3°C in 1978).
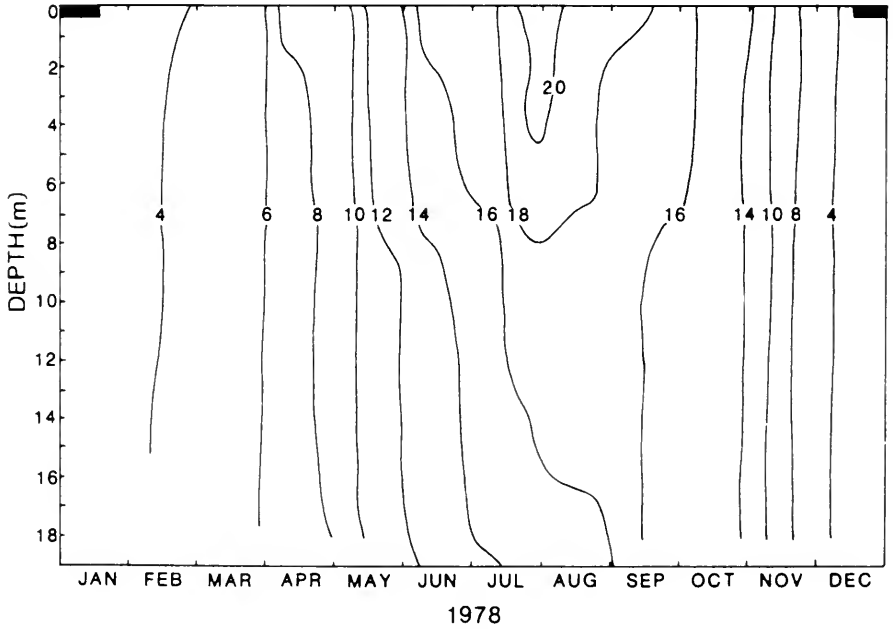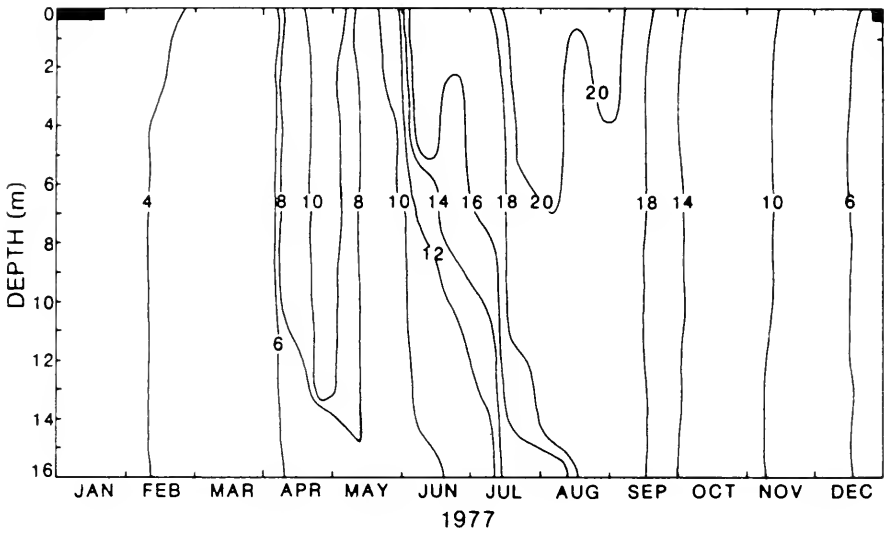
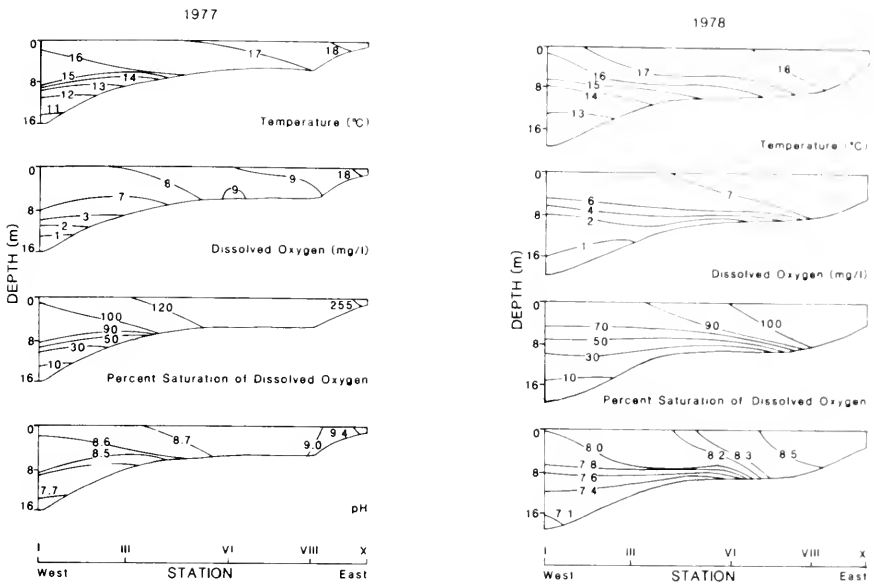FIGURE 2.   Depth time diagrams of isotherms (°C) at Station I, Big Bear Lake, California, 1977–1978.

FIGURE 3. Diagram illustrating differences in temperature (°C), dissolved oxygen concentration (mg/l) and percent saturation, and pH along longitudinal axis of Big Bear Lake, California, 24 June 1977 and 5 July 1978.

## Dissolved Oxygen

Dissolved oxygen exhibited stronger stratification characteristics than did temperature in Big Bear Lake. Slight temperature stratification can restrict mixing and lead to strong dissolved oxygen stratification. Anoxia was the dominant feature of the dissolved oxygen profiles (Figure 4). Dissolved oxygen was at or near saturation throughout the water column in the spring but declined rapidly in bottom waters as the lake stratified. During summer, a sharp stratification occurred between the mixed layer and the hypolimnetic waters where dissolved oxygen concentrations often decreased 3–4 mg/1 in 1 m. A much greater volume of the lake was depleted of dissolved oxygen in 1978 than in 1977. The breakdown of thermal stratification in 1978 led to rapid mixing of water low in dissolved oxygen throughout the water column and resulted in the entire water column at Station I being less than 50% saturated with dissolved oxygen.

Dissolved oxygen levels were generally higher at the eastern end of the lake than at the west end (Figure 3). The bottom waters of the west end showed severe oxygen depletion, while the shallow east end was generally saturated with dissolved oxygen. This difference is due to the strong mixing action in the shallow east end and the influence of macrophyte production.
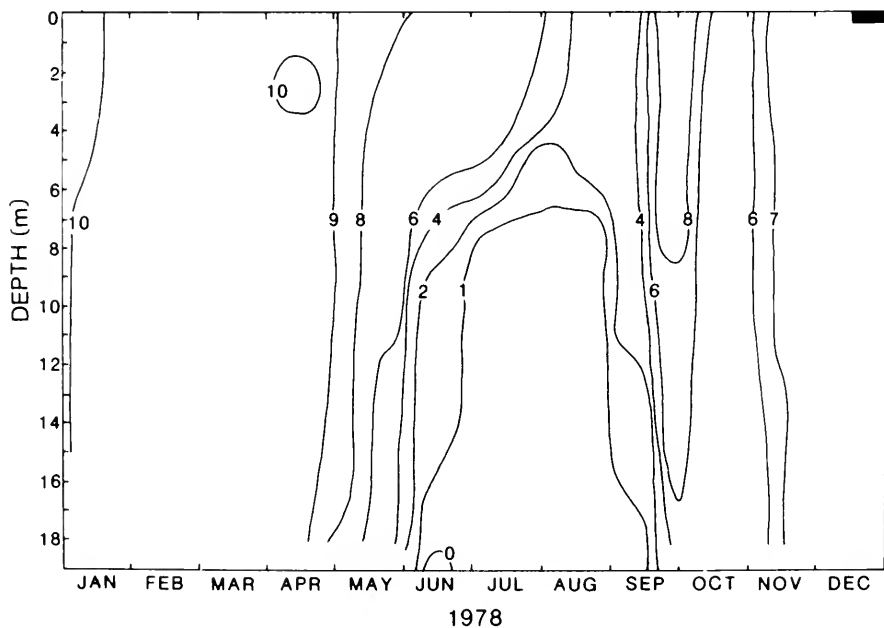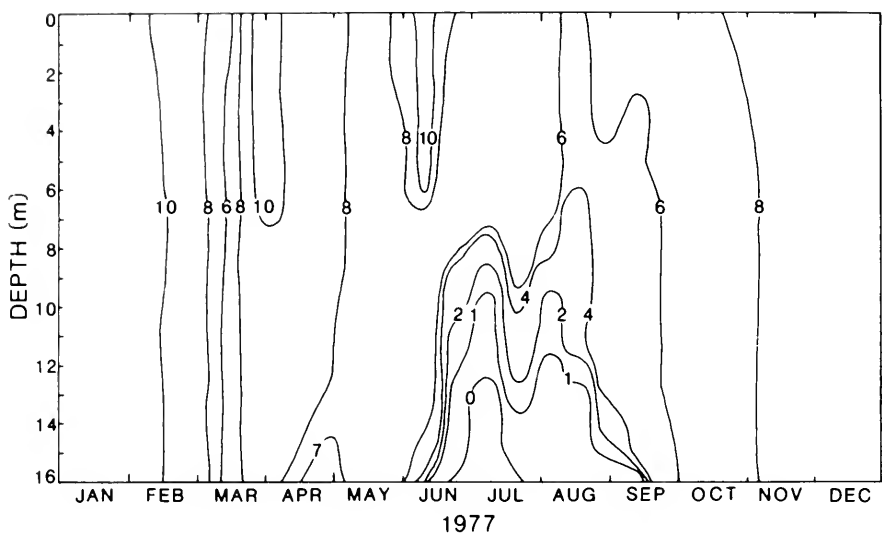
FIGURE 4.    Depth-time diagram of isopleths of dissolved oxygen concentrations (mg/l). Station
           I, Big Bear Lake, California, 1977–1978.

## pH

The pH of Big Bear Lake was relatively high throughout 1977 and 1978 (Figure
5). In 1977, pH typically exceeded 8.5 at all stations. Over the 2-yr study period,

pH values were cyclic in response to biological activity. Minimum values of less than 7.5 occurred in hypolimnetic waters during stratification, while surface values exceeding 9.0 occurred in the fall during periods of high productivity. The mixing of hypolimnetic waters into the rest of the water column in August 1978 brought surface pH to the lowest recorded levels, < 8.0.

The east end of the lake generally showed the higher pH values (Figure 3). A study high of 10.0 was recorded there in the fall of 1978. Surface pH was typically high, dropping below 8.0 only during periods of strong mixing.

## Specific Conductance, Ionic Composition

The ionic composition of Big Bear Lake was determined from samples collected on 12 April and 14 November 1977 (Table 2). The ions assayed were consistent throughout the lake.

TABLE 2. Concentration of Major Cations and Anions in Big Bear Lake, California, 12 April and 14 November 1977.

| Ions | 12 April 1977 | | 14 November 1977 | |
|---|---|---|---|---|
| | milliequiv/1 | mg/1 | milliequiv/1 | mg/1 |
| Cations | | | | |
| Ca $^{+2}$ | 1.92 | 38 | 1.30 | 26 |
| Mg $^{+2}$ | 0.96 | 12 | 1.19 | 14 |
| Na $^{+1}$ | 0.70 | 16 | 0.83 | 19 |
| K $^{+1}$ | 0.10 | 4 | 0.10 | 4 |
| | 3.68 | 70 | 3.42 | 63 |
| Anions | | | | |
| HCO$_3$ $^{-1}$ | 3.10 | 189 | 2.11 | 128 |
| Cl $^{-1}$ | 0.45 | 16 | 0.50 | 18 |
| SO$_4$ $^{-2}$ | 0.21 | 10 | 0.22 | 11 |
| CO$_3$ $^{-2}$ | 0.00 | 0 | 0.68 | 41 |
| | 3.76 | 215 | 3.51 | 198 |
| Total hardness | | | | |
| (CaCO$_3$) | | 144 | | 125 |

Conductivity was considerably higher in 1977 than in 1978 (Figure 6). In 1977, conductivity exceeded 300 micromhos/cm throughout the year while in 1978 conductivity did not exceed 300 micromhos/cm at any time except in the bottom waters during stratification. The highest conductivity recorded each year was in the bottom waters during stratification. After the return of dissolved oxygen to the bottom waters, conductivity decreased in both years.

## Nitrogen and Phosphorus

The pattern of phosphorus and nitrogen concentrations reflect the effects of oxygen depletion accompanying stratification (Figure 7). Similar patterns were evident in 1977 (Siegfried *et al.* 1978). Epilimnetic concentrations of soluble reactive phosphorus were generally above 0.01 mg/1 throughout the summer. Regeneration of phosphorus from the sediments is indicated by increased phosphorus content of bottom waters during stratification. Release of nitrogen from sediments during stratification is reflected in the curve of ammonia-nitrogen concentrations in the bottom waters of Big Bear Lake (Figure 7).
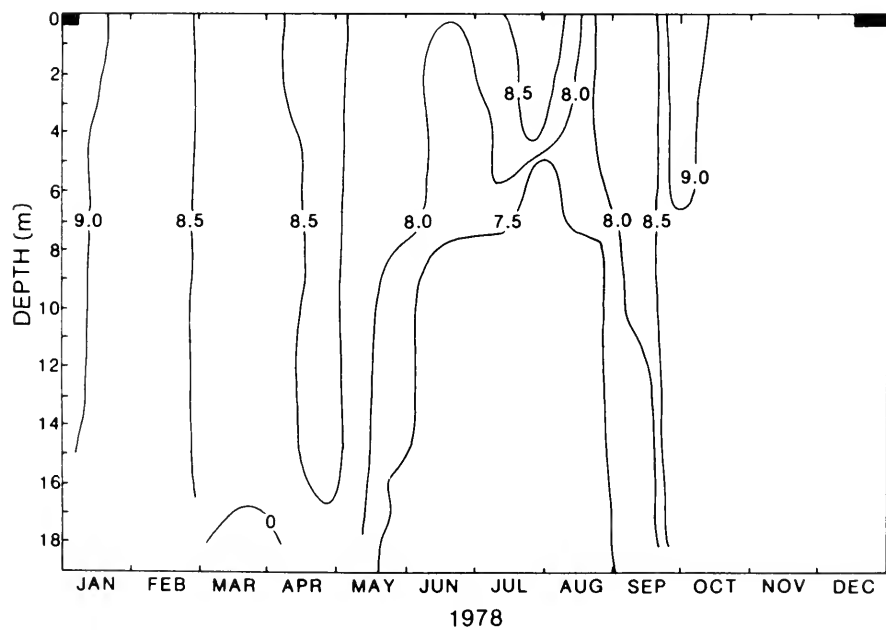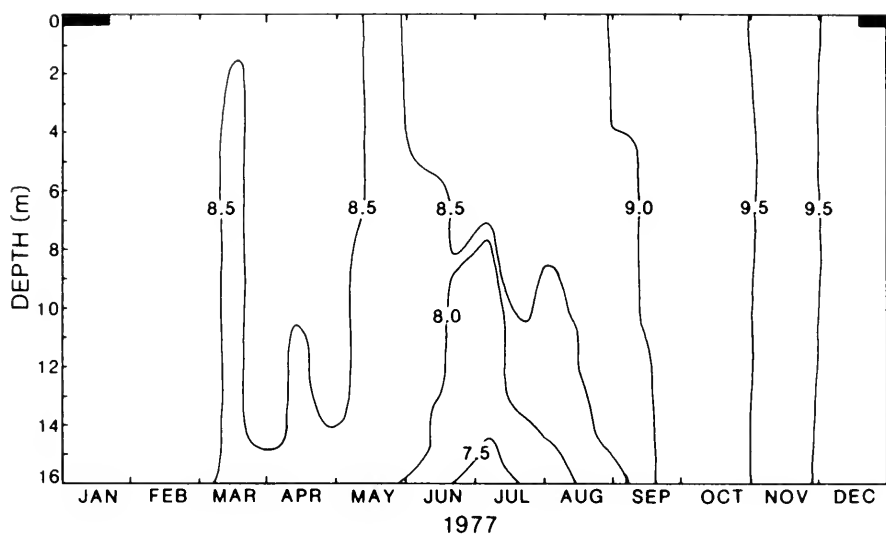
FIGURE 5.    Depth-time diagram of isopleths of pH at Station I, Big Bear Lake, California, 1977–1978.
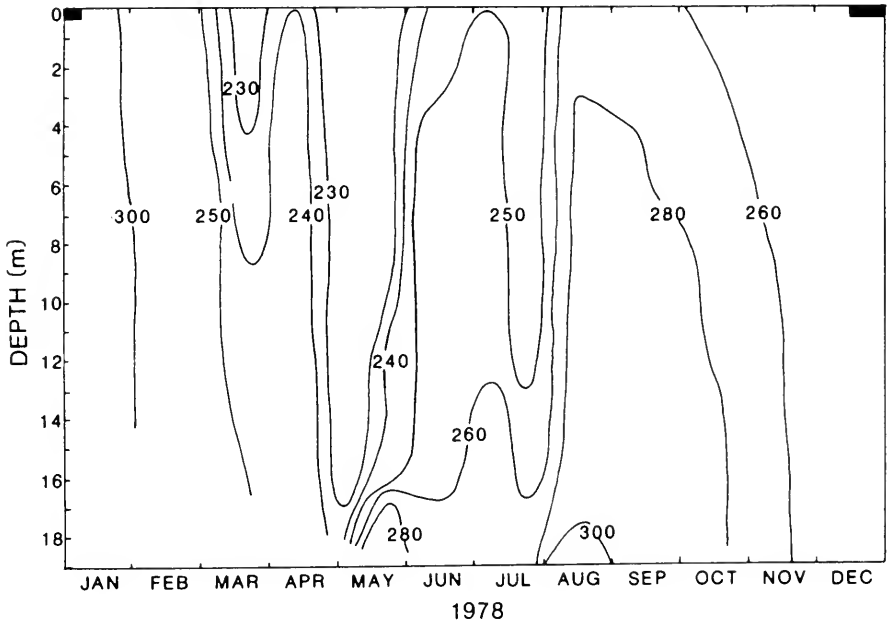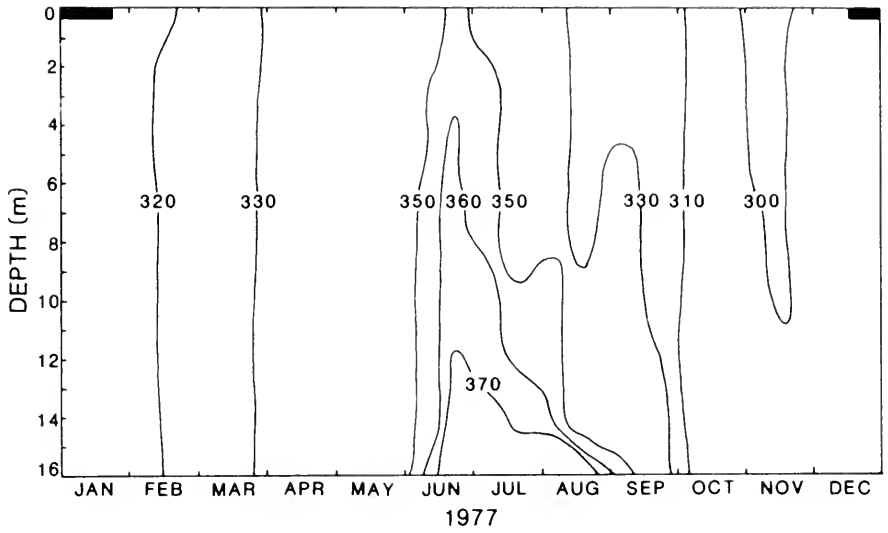
FIGURE 6.   Depth-time diagram of isopleths of conductivity, Station I, Big Bear Lake, 1977–1978.
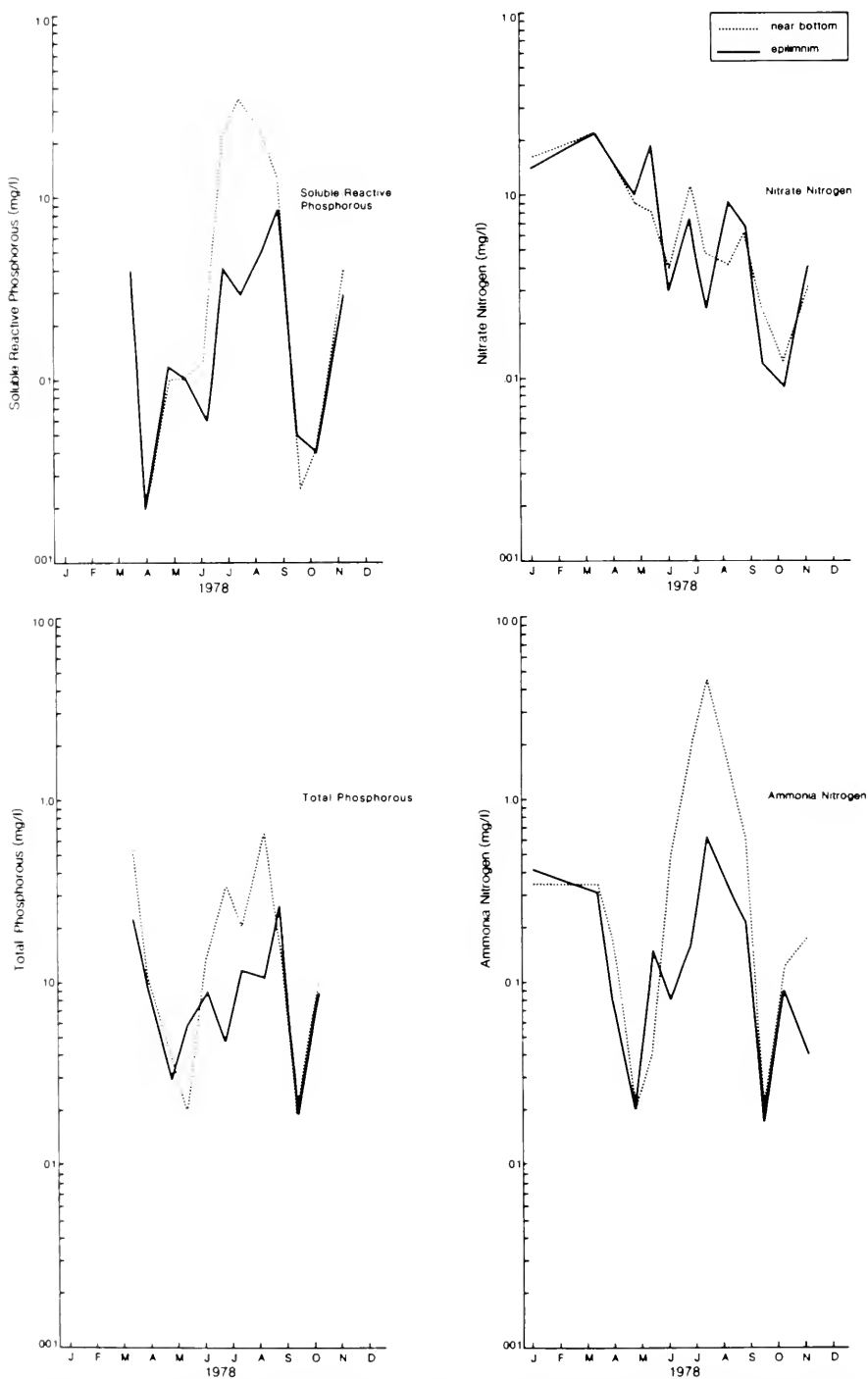
FIGURE 7.   Concentration (mg/l) of nitrate-nitrogen ammonia-nitrogen, soluble reactive phosphorus and total phosphorus at Station I, Big Bear Lake, California, 1978.

Ammonia was present at detectable levels throughout most of each year. The main source is decomposition of organic materials in sediments (Keeney 1972). In fall 1977, ammonia concentrations were much higher than in 1978. During late summer and fall, a significant fraction of the ammonia present was in the un-ionized form. The European Inland Fisheries Advisory Commission has set a concentration of 0.025 mg/1 un-ionized ammonia as the maximum allowable level present to protect all life stages of fish. This level was exceeded at all stations from September through December 1977 in the lake. Even if the un-ionized ammonia levels recorded in Big Bear Lake are not directly toxic, they can have sublethal effects. Sublethal ammonia levels may reduce growth, damage gills and other organs, and lead to bacterial disease (Burrows 1964, Robinette 1973, Larmoyeaux and Piper 1973, Thurston, Russo and Smith 1978).

The sediments of Big Bear Lake appear to pay an important role in the nutrient dynamics of the lake. One of the most important factors determining the amount of sediment-water nutrient exchange is the amount of mixing at the sediment-water interface. The rate of phosphorus release from sediments about doubles if the sediments are disturbed by agitation from turbulence (Zicker, Berger, and Hasler 1956). Several factors lead to high mixing rates and thus high exchange rates in Big Bear Lake. The regular occurrence of afternoon west winds, in conjunction with the east-west orientation and shallow morphology of much of Big Bear Lake, creates water currents which stir the sediments. Additional currents are set up by boating activities and biological activities. One of the most important biological activities leading to increased sediment-nutrient exchange in many lakes is the activities of carp and goldfish. Carp have been shown to be effective in increasing nutrient loading in lakes by stirring up sediments during their feeding activities (Miller, Brydnildson, and Threiney 1961) and through their digestive activities that produce nutrient releases from the sediments (Lamarra 1975). In addition, rooted macrophytes and benthic invertebrates also cycle nutrients (particularly phosphorus) from the sediments into the water column.

Nutrient loading from the tributaries of Big Bear Lake in 1978 was estimated to be 21,560 kg of phosphorus and more than 29,000 kg of nitrogen. The largest loads were contributed by Rathbone Creek. Generally, those tributaries draining the south-east (urban) portion of the drainage area contributed nutrient loads that were large relative to their contribution of surface inflow (Siegfried and Herrgesell 1979).

## Transparency

Secchi depth transparency was generally greater in 1977 than in 1978 (Figure 8). Secchi depth at Station 1 exceeded 10 m in March 1977 but did not surpass 5 m throughout 1978. Transparency was generally high in spring, declined into summer, was high again during the stratified period and was generally greatest at the west end (Station 1) and least at the east end of the lake (Station 8).

## Phytoplankton

Nearly 50 genera of phytoplankton were identified from Big Bear Lake samples collected in 1977 (Table 3). Green algae, largely chlorococcales, and diatoms accounted for the largest number of genera. The phytoplankton assemblage of

Big Bear Lake in 1977–1978 was characteristic of algal associations of eutrophic alkaline lakes (Hutchinson 1967).
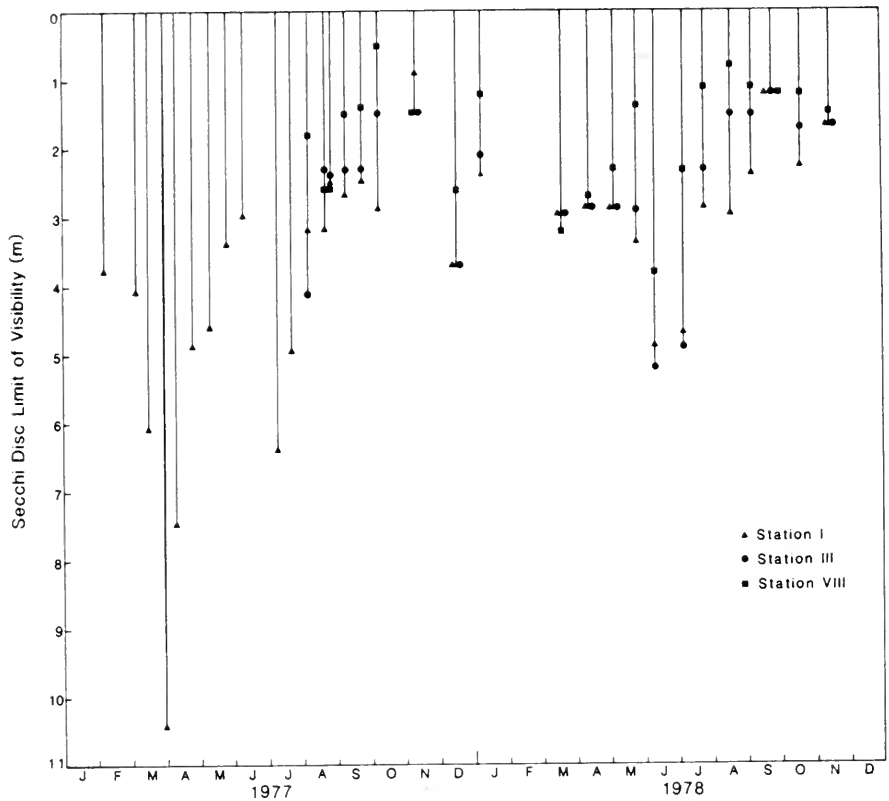


FIGURE 8. Variation at Secchi disk transparency at selected stations in Big Bear Lake, California. Station I, February 1977–November 1978, Station III and VIII, August 1977–November 1978.

The typical annual cycle of phytoplankton at Big Bear Lake appears to be bimodal with maxima occurring in the spring and late summer (Figure 9). The spring peak is associated with increased solar insolation and nutrient supply from runoff. The fall peak is associated with the return of nutrients from bottom waters to the epilimnion. The seasonal succession of algal groups was similar each year. Diatoms dominated in the early spring, green algae briefly dominated in the early summer, and blue-green algae in mid-summer-fall.

Blue-green algae (Cyanophyta) dominated the phytoplankton community for much of the summer and fall of 1977 and 1978, accounting for more than 90% of the total phytoplankton population. In late 1976, *Aphanizomenon flos-aquae* was abundant throughout the lake but in 1977 *Anabaena* and *Chroococcus* were the most abundant blue-greens. In 1978, *Anabaena* dominated the early summer bloom (late May) and was also abundant in the late summer-fall. *Aphanizomenon flos-aquae* was the most abundant algae in 1978.

**TABLE 3.** **Phytoplankton Genera Identified from Big Bear Lake, California, November 1976–November 1978.**

Chlorophyta (green algae)
  Ankistrodesmus
  Chlamydomonas
  Chlorella
  Closterium
  Cosmarium
  Eudorina
  Euglena
  Gloeocystis
  Hydrodictyon
  Pandorina
  Pediastrum
  Scenedesmus
  Sphaerocystis
  Spirogyra
  Staurastrum
  Volvox
  Zygnema
Chrysophyta (diatoms)
  Amphora
  Anomoeoneis
  Asterionella
  Caloneis
  Chrysococcus
  Cocconeis
  Cyclotella
  Cymatopleura

Chrysophyta (cont.'d)
  Cymbella
  Dinobryon
  Fragilaria
  Gyrosigma
  Lemanea
  Navicula
  Nitzschia
  Opephora
  Roya
  Stauronesis
  Stephanodiscus
  Surrirella
  Synedra
Cyanophyta (blue-green algae)
  Anabaena
  Aphanizomenon
  Chroococcus
  Coelosphaerium
  Gloeotrichia
  Microcystis
  Nodularia
  Oscillatoria
  Undetermined B–G
Pyrrhophyta (dinoflagellates)
  Ceratium
  Peridinium
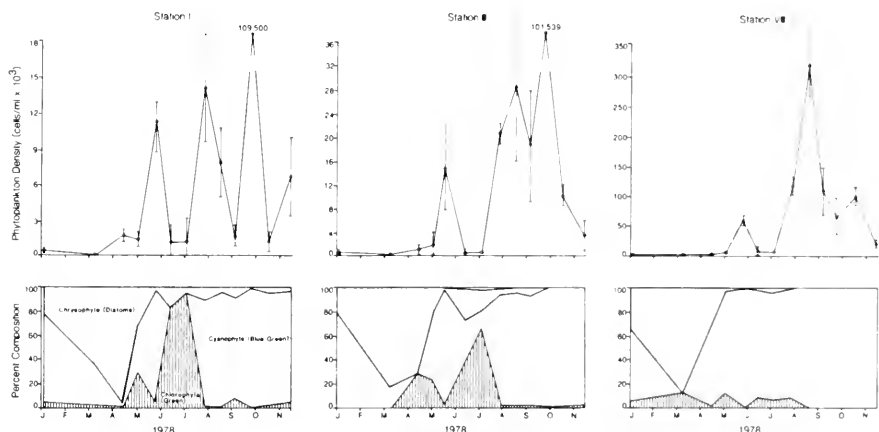


FIGURE 9.   Mean density and composition of phytoplankton in Big Bear Lake, Stations I, III, and VIII, 1978. Vertical lines in upper figures represent mean ± standard deviation.

A distinct gradient in phytoplankton composition and density develops in Big Bear Lake (Figure 9). The east end of the lake generally has higher densities and a larger percentage of blue-green algae. This gradient is the result of persistent west winds that characterize Big Bear Valley. West winds transport the buoyant

blue-green algae to the east end of the lake. The gradient was also evident in secchi depth transparency (Figure 8).

Previous productivity studies in Big Bear Lake utilizing $^{14}C$ during May 1973 indicated high net productivity near shore and low productivity at midlake (Goldman 1975). The shoreline effects were thought to result from nutrients contributed by groundwater seepage and shoreline activities.

The pattern of primary productivity in Big Bear Lake in 1977 and 1978 can be related to nutrient availability and solar insolation. Productivity initially increases in the spring as solar insolation increases and remains relatively high throughout the year (Figure 10). There is a dramatic increase in production after stratification is disrupted and the lake turns over in late summer.
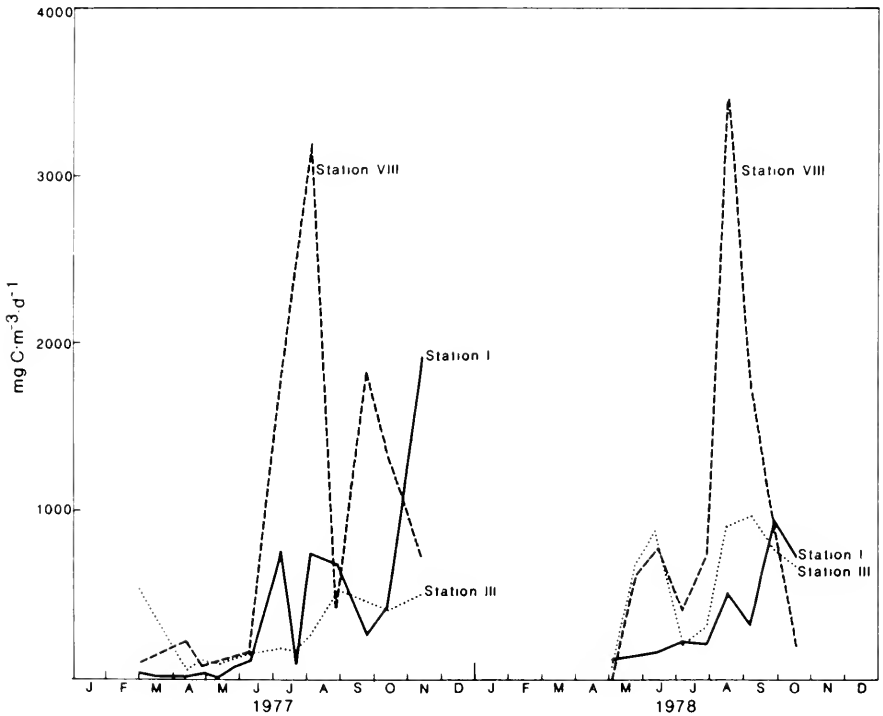


FIGURE 10.    Seasonal pattern of primary productivity ($mg^C/m^3$/day) at Stations I, III, and VIII, Big Bear Lake, California, 1977–1978.

The N:P mass ratios in the surface waters of Big Bear Lake indicate phosphorus limitation in winter and spring and nitrogen limitation in the fall. Algal assays confirm this pattern of nutrient limitation (Figure 11). In the spring, prior to stratification, phosphorus limited algal growth. Spikes of phosphorus in the algal assays resulted in significantly greater production than in controls (no nutrient additions) or those spiked with nitrogen or trace elements. In July, during stratification, phosphorus was limiting in the epilimnion and nitrogen in hypolimnetic

waters. This reflects the release of phosphorus from the sediments during stratification. After the breakdown of stratification, nitrogen became limiting in the surface waters.

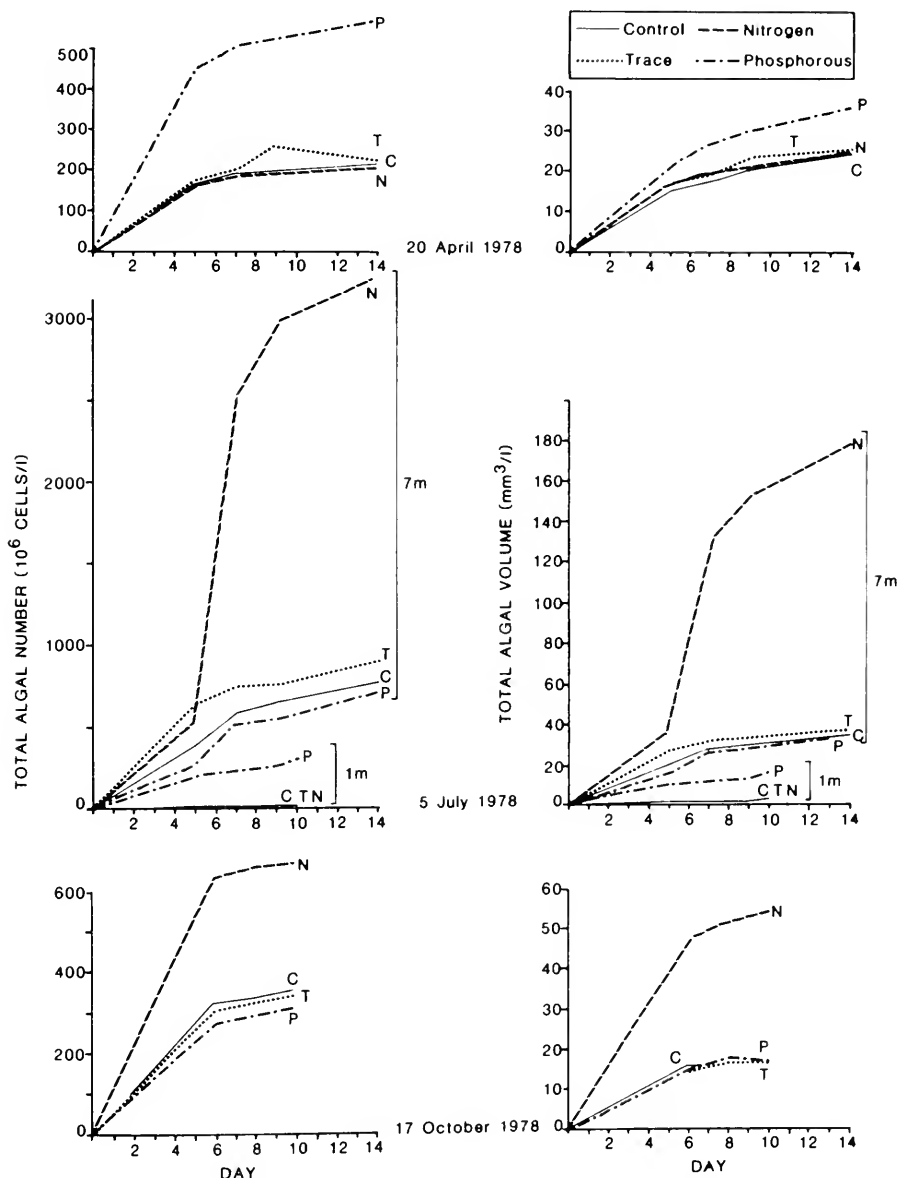Selenastrum capricornutum Printz Growth Response



FIGURE 11. Results of algal assays conducted on Big Bear Lake waters, 1978. (P = 0.05–0.07 mg/l phosphorus spike, N = 1.05–1.68 mg/l nitrogen spike, T = trace metals spike, C = control—no nutrient additions)

## TROPHIC STATUS

The relationship between phosphorus loading and lake trophic status has received extensive treatment (Vollenweider 1968 and 1976; Vollenweider and Dillon 1974; Dillon 1975; Larsen and Mercier 1976). The relationship between nutrient loading and lake morphology has been used to determine permissible or excessive loading levels. Phosphorus loading on Big Bear Lake in 1978 was 1.94 g/m²/yr (Siegfried and Herrgesell 1979). Vollenweider's (1976) model of phosphorus loading in relation to the relative residence time of phosphorus was used to determine critical loading levels, i.e.:

$$L_c = 10 \cdot q_s \, (1 + \sqrt{\overline{z}/ q_s})$$

where $L_c$ = critical loading level (mg $\cdot$ m$^{-2}$ $\cdot$ yr$^{-1}$), z = mean depth (m) [at maximum pool], and $q_s$ = hydraulic load (m $\cdot$ yr$^{-1}$) = mean depth/lake filling time. Lakes with phosphorus loading below $L_c$ would tend to be oligotrophic, those with loading levels $\geq$ 2X $L_c$ would tend to be eutrophic, while lakes with intermediate loading levels would be mesotrophic. The critical loading level for Big Bear Lake is 84 mg P $\cdot$ m$^{-2}$ $\cdot$ yr$^{-1}$, loading levels above 168 mg P $\cdot$ m$^{-2}$ $\cdot$ yr$^{-1}$ would thus lead to eutrophic conditions in the Big Bear Lake. Direct precipitation alone accounts for 96 mg P $\cdot$ m$^{-2}$ $\cdot$ yr$^{-1}$. Thus, it would be necessary to reduce phosphorus loading from tributary runoff by more than 95% to achieve mesotrophic conditions. This is a practical impossibility, so Big Bear Lake will remain eutrophic.

Carlson (1977) developed a trophic state index (TSI) based on Secchi depth (SD). Secchi depth, in the absence of turbidity and colored materials in the water, is a direct measure of planktonic-algal-manifested eutrophication processes in natural waters (Rast and Lee 1978). Calculation of TSI is accomplished by use of the following equation:

$$TSI_{(SD)} = 10 \, (6\text{-}\log_2 SD)$$

Carlson (1977) expanded the TSI concept to include a TSI based on total phosphorus (TP):

$$TSI_{(TP)} = 10 \left(6\text{-}\log_2 65 \, \frac{1}{TP}\right)$$

Rast and Lee (1978) suggest that TSI values in excess of 40 indicate eutrophic conditions.

In 1978 $TSI_{(SD)}$ ranged from 37–57 (mean = 45) at Station I and from 41–64 at Station VIII (mean = 51). In 1977 $TSI_{(SD)}$ ranged from 26–61 (mean = 41) at Station I and up to 70 in late 1977 at Station VIII. The $TSI_{(TP)}$, however, ranged from 53–77 and was consistently higher than $TSI_{(SD)}$ at both stations. This discrepancy could result from increased transparency due to nutrient uptake by macrophytes and the lack of phosphorus limitation on some dates. Big Bear Lake would still be classified as a eutrophic lake based on the above TSI values which may be low for $TSI_{(SD)}$ and high for $TSI_{(TP)}$. Although tributary nutrient loading was much higher in 1978 the trophic status of Big Bear Lake was similar each year. This can be attributed in part to the importance of internal loading to the nutrient dynamics of the lake.

The completion of Big Bear Dam appears to have created a "naturally" eutrophic reservoir. It has been shown that nutrient loading is excessive at Big Bear Lake. Calculations based on Vollenweider's (1976) phosphorus loading

model and phosphorus export coefficients (Rast and Lee 1978) indicate that the lake would tend to be oligotrophic only if the Big Bear Lake drainage basin were completely forested. However, any land clearance, urbanization, or other disturbance would increase loading rates above permissible levels, and thus accelerate eutrophication. By itself, reduction of nutrient loading to Big Bear Lake will not be sufficient to restore water quality since it is highly unlikely that loading rates can be reduced to that comparable to a completely forested drainage. However, the first step in any long-term lake management approach must still be directed toward control of nutrient influx. Because of its shallow morphology, high nutrient content, and basin orientation, Big Bear Lake will continue to be a productive lake, however, proper management can enhance its resource potential.

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# DEER POPULATIONS AND RESERVOIR CONSTRUCTION IN TRINITY COUNTY, CALIFORNIA [1]

JOHN G. KIE [2]
Department of Agronomy and Range Science
University of California, Davis 95616

TIMOTHY S. BURTON
California Department of Fish and Game
Redding 96001

JOHN W. MENKE
Department of Agronomy and Range Science
University of California, Davis 95616

**Deer herd sizes in Trinity County were reconstructed from harvest data and herd composition counts. The construction of Trinity and Lewiston reservoirs in the early 1960's inundated 6,980 ha of winter range used by the Weaverville deer herd, resulting in a decline in the herd of over 4,000 deer. Other factors such as logging and wildlife have also influenced deer numbers, which peaked in the mid-1960's and have declined since.**

## INTRODUCTION

Black-tailed deer, *Odocoileus hemionus columbianus,* are an important wildlife resource in Trinity County. They provide a sport hunting opportunity for thousands of people each year and a less tangible, but also extensive, opportunity for non-consumptive use. Between 1960 and 1963, about 6,980 ha in Trinity County were inundated by the filling of Trinity (Clair Engle) and Lewiston reservoirs. Much of this area was deer winter range. The purpose of this paper is to review the estimates of deer lost as a result of this habitat destruction, to quantitatively describe deer population changes in Trinity County over the last 20 years, and to suggest reasons for those changes.

## STUDY AREAS

Deer in Trinity County are divided into three herds (Figure 1). Ecological boundaries include the Hayfork Divide between the Weaverville and Hayfork herds and South Fork Mountain between the Hayfork and Ruth herds. However, other boundaries are drawn along county lines, thereby defining deer herds for administrative purposes. These differ somewhat from ecologically defined herds (Longhurst, Leopold, and Dasmann, 1952).

The Weaverville herd occupies about 3,625 km² and was the only deer herd in Trinity County directly impacted by the construction of Trinity and Lewiston reservoirs. Eighty to ninety percent of the herd consists of migratory deer (USFWS 1975). Summer ranges occupy about 70% of the total area, transitional ranges about 20%, and winter ranges about 10% of the area. Vegetation consists of coniferous forest, predominantly Douglas-fir, *Pseudotsuga menziesii,* and ponderosa pine, *Pinus ponderosa,* with lesser amounts of incense cedar, *Libocedrus decurrens,* sugar pine, *P. lambertiana,* and white fir, *Abies concolor.* Digger

pines, *P. sabiniana,* occur at lower elevations on drier sites. Interspersed within the coniferous forest are patches of hardwoods, such as California black oak, *Quercus kelloggii;* Oregon white oak, *Q. Garryana;* interior live oak, *Q. Wislizenii;* and madrone, *Arbutus menziesii,* as well as shrub species such as wedge-leaf ceanothus, *Ceanothus cuneatus;* lemon ceanothus, *C. lemonii;* deerbrush, *C. integerrimus;* manzanitas, *Arctostaphylos* spp.; silk-tassel, *Garrya fremontii;* and mountain mahogany, *Cercocarpus betuloides.*
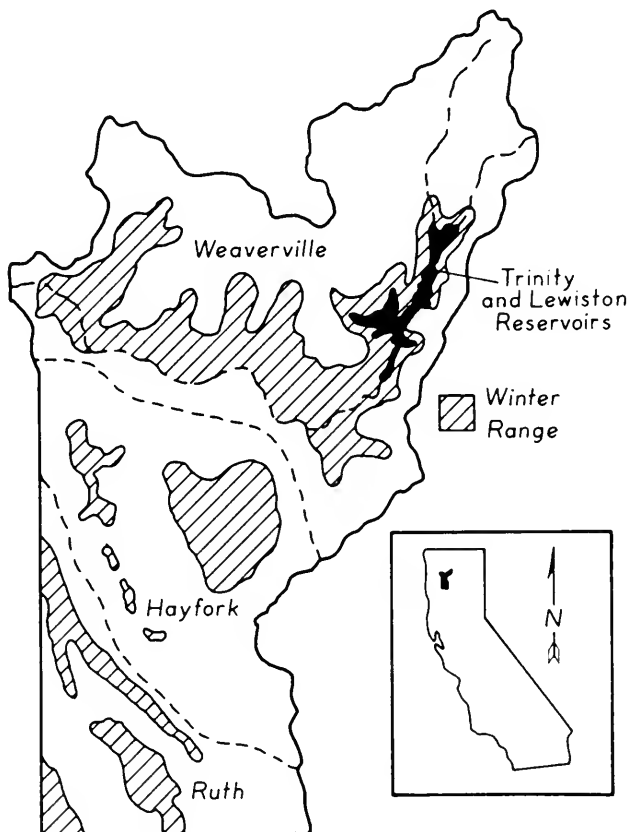


FIGURE 1.    Ranges of the Weaverville, Hayford, and Ruth Deer herds in Trinity County.

Summer ranges generally occur above 1,200 m elevation in the Salmon-Trinity Primitive Area. They consist of coniferous forest with scattered meadows and montane brushfields. Summer ranges are important as fawning habitat. Transitional ranges usually occur between 900 and 1,500 m and consist of coniferous forest with patches of hardwoods and brush. Deer use these areas during periods of migration and during mild winters. Critical or key winter ranges occur below 1,000 m and are restricted to slopes with southern exposures. Key winter ranges are located adjacent to Trinity and Lewiston reservoirs as well as downstream along the Trinity River and its northern tributaries.

The Hayfork and Ruth deer herds have not been directly influenced by reservoir construction. The seasonal ranges of these herds occur at similar elevations and consist of similar vegetation as those of the Weaverville herd with the addition of chamise, *Adenostoma fasciculatum,* as a common shrub species on the Hayfork deer winter range. Key winter ranges for the Hayfork herd occur in Hyampom and Hayfork valleys. These areas also contain grassland and oak woodland-grass habitat types as well as pastures improved for livestock. Key winter ranges for the Ruth herd occur along the Mad and Eel rivers.

## ESTIMATES OF WEAVERVILLE DEER LOSS

The U.S. Forest Service (1960) estimated that construction of Trinity and Lewiston reservoirs would impact the habitat of between 4,000 and 6,000 deer. Post-project estimates of deer lost as a result of reservoir construction have generally confirmed the original prediction. The U.S. Fish and Wildlife Service (1975) found that deer use adjacent to the project area, as measured by fecal pellet group counts, increased from 30 deer days use (DDU) per acre annually in 1960, to 89 DDU per acre in 1963. Using the difference as a measure of the deer displaced from the flooded areas, and assuming that the deer were displaced from the 6,980 ha inundated to a surrounding area of similar size, it was estimated that approximately 5,000 migratory deer and 550 resident deer had been affected (Table 1).

**TABLE 1. Estimates of Deer Loss as a Result of Reservoir Construction in Trinity County.**

| Source | Migratory deer | Resident deer | Total deer | Bias |
|---|---|---|---|---|
| USFWS (1975)—original acreage ................................. | 5,000 | 550 | 5,500 | ? |
| USFWS (1975)—revised acreage ................................. | 3,600 | 400 | 4,000 | — |
| CDFG (unpublished data) ............................................. | 6,000 | 1,500 | 7,500 | + |
| This study ...................................................................... | — | — | 4,000+ | ? |

If it is assumed that the increase of 59 DDU per acre occurred only on areas designated as key winter range (5,100 ha, after Dunaway 1964) adjacent to the reservoirs, the estimate of deer loss is reduced to 3,600 migratory and 400 resident deer (Table 1). This is likely an underestimate, as some lesser increase in deer use probably occurred on other less important winter ranges.

Unpublished data collected between 1960 and 1969 by the California Department of Fish and Game (CDFG) documented deer use downstream from Trinity and Lewiston reservoirs at the site of the proposed Helena reservoir. This area was similar to that flooded by the reservoirs upstream. Applying those data to the acreages involved in the Trinity and Lewiston reservoirs yields an estimated loss of 6,000 migratory deer and 1,500 resident deer (Table 1). This estimate is probably high as it is based in part on data gathered during the abnormally severe winter of 1968–69 when most deer were concentrated on key winter ranges. Also, winter range in the Helena area may now be supporting higher deer densities than pre-project ranges upstream.

Furthermore, these unpublished CDFG pellet group counts can be extrapolated to acreages of key winter range used by the Weaverville deer herd to arrive at an average population size of 32,500 deer for the period 1960–1969. Although these estimates of deer use per acre are probably high, the acreages used in this

calculation consist of key winter range only. As a result, the direction of bias in this estimate is unknown.

The CDFG (1970) reported that deer kill within the project's zone of influence declined by 27% following the flooding of the reservoirs (1956–59 average kill = 306 deer, 1960–69 average kill = 222 deer). Before the completion of reservoir construction, kill from the Weaverville deer herd consistently made up a majority of the kill in Trinity County, averaging 57% of the county-wide kill between 1958 and 1961 (Figure 2). However, between 1962 and 1972, the Weaverville kill averaged only 41% of the Trinity County kill. In this paper, we use data on reported buck kill from the Weaverville, Hayfork, and Ruth herds, along with assumptions about unreported kill, crippling loss, harvest level of legal bucks, and post-season herd composition counts, to reconstruct estimates of pre-season herd sizes.
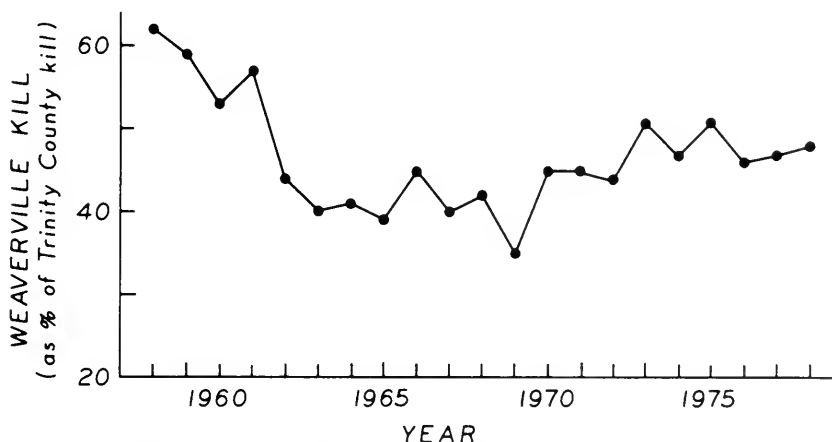


FIGURE 2.   Reported Weaverville kill as a percentage of the total reported Trinity County kill.

## METHODS

Reported kill from the Weaverville herd was subtracted from the reported Trinity County kill to obtain reported kill for the Hayfork and Ruth herds (Table 2). Craig and Ashcraft (unpubl. data) found that about 35% of successful deer hunters in Trinity County in 1968 and 1969 failed to return the appropriate portions of their tags. Hunters were allowed to validate their own tags those years. No subsequent Trinity County data are available, but Craig and Ashcraft found that when official tag validation was reinstituted in 1970, statewide non-return of tag percentages did not change significantly. Therefore, to convert to total kill, reported kill was multiplied by a factor of 1.54 (1/(1-0.35) = 1.54). It was further assumed that some bucks were crippled and not recovered by hunters. The estimate of total kill was inflated by 20% to account for this crippling loss.

To estimate pre-season numbers of legal bucks (those with two or more antler points on one side), a critical assumption had to be made about the percentage of legal bucks that are harvested. Deer seasons in Trinity County usually begin

in mid-September and end in mid-October to early November. We believe that higher kills are sustained when various weather factors force migratory deer down from less accessible summer ranges to lower elevations late in the season, when most of the kill occurs. Correlation analyses using reported Weaverville herd deer kill, a variety of October temperatures (average, mean maximum, mean minimum) measured at Weaverville, October precipitation levels, season length, and buck bag limits revealed that only buck bag limit was significantly correlated with Weaverville kill. Since 1958, buck bag limits in Trinity County have been set at two deer, except in 1970, 1971, and 1972, when the bag limit was one deer. Reported kill for those 3 years averaged 418 deer, while the average for the 18 other years was 877 deer (Table 2). Although significant correlations could not be found between Weaverville herd deer kill and weather variables as measured at Weaverville winter range elevations, we still believe that a complex of unrecorded weather factors at higher elevations does influence deer migration.

Anderson *et al.* (1974) modeled black-tailed deer populations in Mendocino County and stated that harvest averaged about 25% of the legal buck population annually. For purposes here, it was assumed that total harvest (reported kill, unreported kill, and crippling loss) averaged 25% in years when the buck bag limit was two deer, and 15% when the buck bag limit was one deer. These assumed harvest rates are probably high for Trinity County. Post-season buck per doe ratios are consistently higher in Trinity County (Table 2) than in Mendocino County (Anderson *et al.* 1974) indicating a lighter harvest. Using these higher harvest levels results in conservative pre-season population estimates. Pre-season legal buck numbers were then calculated by multiplying the total kill by 6.67 (1/0.15 = 6.67) when buck bag limit was 1, and by 4 (1/0.25 = 4.0) when buck bag limit was two.

Post-season ratios of spike bucks per legal buck (Table 2) were applied to estimates of legal bucks remaining after the season to estimate spike buck numbers. Buck per doe ratios (Table 2) were applied to the estimates of total bucks (spikes plus legal bucks) remaining after the season to estimate doe numbers. Fawn numbers were calculated by using post-season fawn per doe ratios (Table 2) and estimates of doe numbers. Post-season herd composition data were available only for the Weaverville deer herd, but were also applied to the Hayfork and Ruth herds.

Estimates for all classes of deer were adjusted to pre-season numbers by assuming that the only mortality over the course of the season was kill and crippling losses of legal bucks. Total pre-season deer numbers were calculated by adding the numbers of legal bucks, spike bucks, does, and fawns (Table 2, Figure 3).

## RESULTS AND DISCUSSION

Many of the sharp, annual fluctuations in deer numbers in Figure 3 are artifacts of the method of calculation, particularly when the two populations show identical responses such as in 1965 and 1967. It is likely that variations in the percentage of legal bucks killed are responsible for these fluctuations. For example, 1977 data (Table 2) indicate very high population densities (Weaverville = 55,700 deer, Hayford and Ruth = 63,200 deer) which are not graphed in Figure 3. It is possible that low rainfall during spring that year resulted in poor forage

conditions on the summer ranges, early migration, and a higher than usual harvest of legal bucks. This would result in over-estimates of actual deer numbers.

TABLE 2.   **Weaverville Herd and Trinity County Reported Kills, Post-season Herd Composition Data, and Reconstructed Herd Sizes. Composition Figures in Parentheses are Extrapolated or Interpolated Values.**

| Year | Reported Weaverville kill | Reported Trinity Co. kill | Bucks per doe | Fawns per doe | Spikes per legal buck | Weaverville herd | Hayfork, Ruth herds |
|------|------|------|------|------|------|------|------|
| 1958 | 879 | 1,415 | 0.45 | 0.66 | (0.13) | 27,500 | 16,800 |
| 1959 | 950 | 1,619 | 0.46 | 0.61 | (0.13) | 28,600 | 20,100 |
| 1960 | 903 | 1,706 | 0.47 | 0.51 | 0.13 | 25,500 | 22,700 |
| 1961 | 1,145 | 2,012 | 0.41 | 0.30 | 0.12 | 31,800 | 24,100 |
| 1962 | 844 | 1,923 | 0.40 | 0.42 | 0.23 | 27,800 | 35,500 |
| 1963 | 890 | 2,219 | 0.37 | 0.68 | 0.35 | 38,600 | 57,600 |
| 1964 | 1,096 | 2,687 | 0.36 | 0.66 | 0.30 | 46,400 | 67,400 |
| 1965 | 911 | 2,322 | 0.34 | 0.53 | 0.25 | 36,400 | 56,400 |
| 1966 | 1,153 | 2,556 | 0.29 | 0.69 | 0.33 | 60,200 | 73,300 |
| 1967 | 578 | 1,431 | 0.31 | 0.60 | 0:34 | 27,600 | 40,700 |
| 1968 | 737 | 1,763 | 0.30 | 0.63 | 0.44 | 39,300 | 54,600 |
| 1969 | 676 | 1,906 | (0.29) | (0.60) | (0.37) | 34,700 | 63,200 |
| 1970 | 349 | 777 | 0.28 | 0.56 | (0.14) | 28,100 | 34,400 |
| 1971 | 412 | 918 | 0.30 | 0.59 | 0.08 | 30,200 | 37,000 |
| 1972 | 493 | 1,125 | 0.32 | 0.59 | 0.20 | 37,900 | 48,600 |
| 1973 | 1,040 | 2,051 | 0.43 | 0.63 | 0.32 | 38,400 | 37,400 |
| 1974 | 669 | 1,409 | 0.40 | 0.53 | 0.16 | 22,000 | 24,400 |
| 1975 | 801 | 1,576 | 0.48 | 0.43 | 0.33 | 25,000 | 24,200 |
| 1976 | 621 | 1,356 | 0.37 | 0.57 | 0.21 | 23,000 | 27,200 |
| 1977 | 1,192 | 2,545 | 0.38 | 0.64 | 0.52 | 55,700 | 63,200 |
| 1978 | 709 | 1,481 | 0.49 | 0.49 | 0.43 | 24,000 | 26,200 |
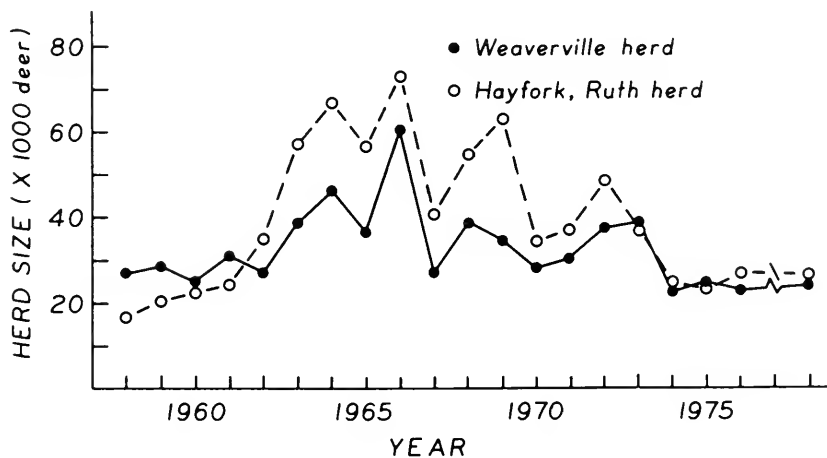


FIGURE 3.   Deer population trends in Trinity County, 1958–1978.

Before 1962, the Weaverville deer herd appeared to be larger than the combined Hayfork and Ruth herds (Figure 3). This trend was reversed between 1961 and 1962, when Trinity and Lewiston Reservoirs were being filled. The loss was estimated at just over 4,000 deer, which is lower than previous estimates of deer loss as a result of reservoir construction (Table 1). Although the reversal of estimated herd sizes in 1962 is believed to reflect actual reductions in the Weaverville deer herd, the estimated size of the loss is imprecise. Its bias is unknown but previous estimates suggest that it is conservative (Table 1).

Between 1962 and 1972, the combined Hayfork and Ruth herds were larger than the Weaverville herd (Figure 3). Around 1962, all deer herds in Trinity County began increasing in size. Several factors may have contributed to these increases. Timber harvest in Trinity County had increased steadily from less than 100 million board feet in 1946 to over 400 million board feet in 1959 (Figure 4). The creation of favorable successional stage forage in cutover areas undoubtedly affected deer numbers.
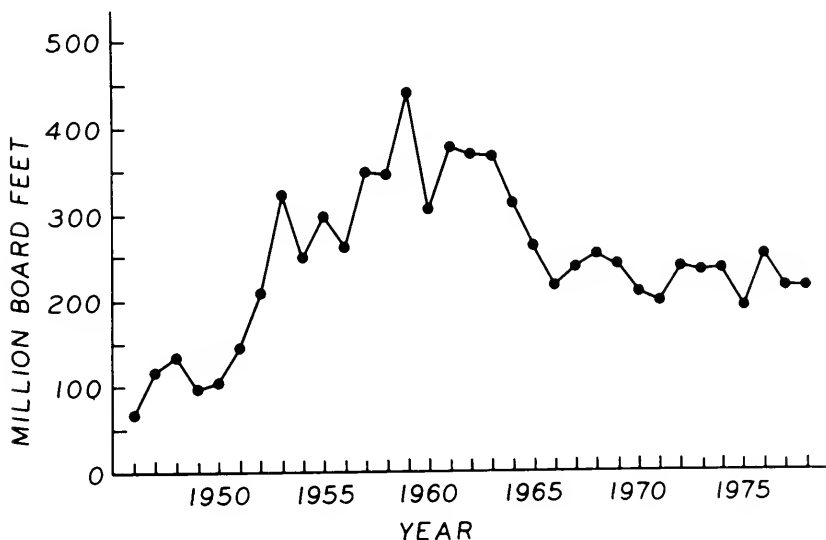


FIGURE 4.   Annual timber harvest in Trinity County.

Two large wildfires occurred in 1959, the 1,000-ha Frethy Burn and 4,000-ha Ramshorn Burn, which affected the Weaverville deer herd. The Hayfork herd was impacted by the 2,000-ha Jones Burn in 1959, and the 7,000-ha Hayfork Summit Fire in 1964. Deer population response normally lags a few years behind a wildfire until some browse species begin sprouting vigorously or until other new browse seedlings become established. The apparent peak in Trinity County deer herds in the mid-1960's corresponds well with the favorable deer foraging habitat created by these wildfires.

The actual size of the peak populations presented in Figure 3 are probably overestimated. As discussed previously, pellet group data suggest an average Weaverville herd size of about 32,500 deer for the years 1960 to 1969. Compara-

ble data presented in Figure 3 lead to an estimate of about 36,800 deer. The same type of activities that create favorable deer foraging areas, such as logging and fire, also increase hunter access. Deer harvest levels may have been slightly higher in the mid-1960's as a result, thereby inflating total population estimates. This contention is supported by relatively low post-season buck per doe ratios during that time period (Table 2).

There has been a general decline in all herds since 1966. Annual timber harvest in Trinity County has fallen to between 200 and 250 million board feet in recent years, producing less early successional stage foraging areas for deer. However, some of this decline in timber volume harvested may be a result of less old growth being cut rather than decreased acreages being cut. Earlier cutover areas are being reforested at an increasing rate, by both artificial methods and natural processes, lowering their value as deer habitat. Conversely, although the volume of timber harvested is declining, current logging practices, such as smaller clear-cut blocks, may favor deer. Additional potential exists for providing deer foraging habitat by optimizing size, shape, and location of cut blocks (Thomas *et al.,* 1979).

Successional stage vegetation created by earlier wildfires is decreasing in value as deer habitat. Browse species present have matured and become decadent, providing less nutritious forage for deer. No major wildfires have occurred since the 1964 Hayfork Summit fire. Loss of early successional stage foraging habitat for deer has resulted in deer declines since 1966. Since 1973, the combined Hayfork and Ruth herds have been essentially equal in size to the Weaverville herd (Figure 3).

## CONCLUSIONS

The construction of Trinity and Lewiston reservoirs, and the accompanying loss of 6,980 ha of winter range, resulted in a decrease in the Weaverville herd of 4,000 or more deer. Additional habitat changes associated with logging and wildfire have also impacted deer in Trinity County over the last 20 years. It is tempting to de-emphasize the effects of reservoir construction in light of the apparent magnitude of the effects of other factors. However, it is impossible to state what deer numbers would have been if the reservoirs had not been built. Presumably, the Weaverville herd would have continued to make up a majority of the deer in Trinity County, as it had between 1958 and 1961. If this were the case, the loss of some 4,000 plus deer would convert to an even greater potential loss in subsequent years (Figure 3). The method of reconstructing pre-project herd sizes presented here is dependent upon a number of assumptions that cannot be readily verified. Current legislation will require future water developments to better assess the potential impacts of project construction. Regardless of supposition, the 6,980 ha inundated by the Trinity and Lewiston reservoirs have been lost as winter deer range.

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# NOTES

# HARBOR SEAL CENSUS IN SOUTH SAN FRANCISCO BAY
## (1972–1977 and 1979–1980)

One of the principal harbor seal, *Phoca vitulina richardii,* rookeries in northern California is located on the San Francisco Bay National Wildlife Refuge in the Mowry Slough area of south San Francisco Bay (Figure 1). This note summarizes harbor seal census data collected in this area from 1972 through 1977 and 1979 through 1980 (Fancher, 1979, Risebrough *et al.* 1980).
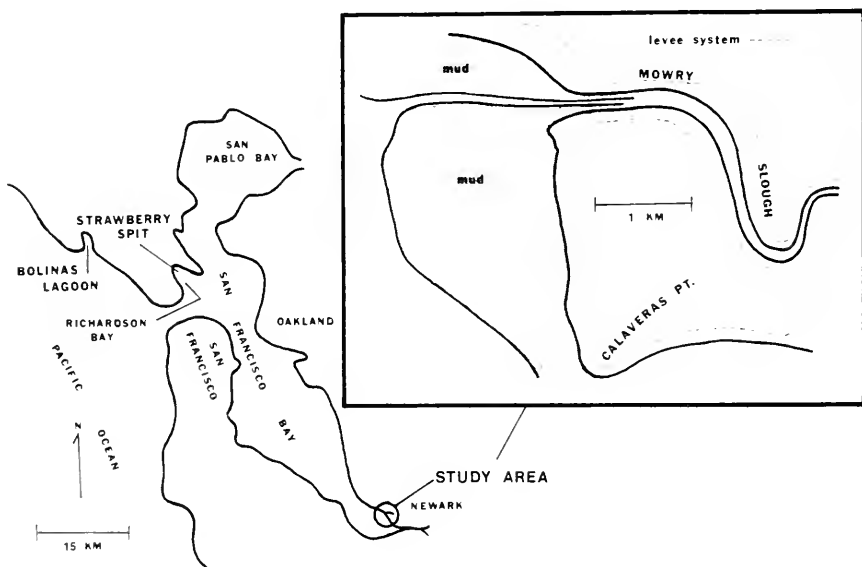


FIGURE 1.   Map of San Francisco Bay and the Mowry Slough study area.

The study area is located about 50 km SSE of the Golden Gate (lat. 37°30'N., long. 122°2'W.). It is a saltmarsh habitat consisting principally of *Spartina foliosa, Salicornia ambigua,* and *Distichlis spicata.* Our study area included the shoreline of Mowry Slough for about 3 km inland, the east Bay shoreline to a point 1 km north of Mowry Slough and 2.5 km south to Calaveras Point, and the mudflats next to the channel running west from Mowry Slough at low tide (Figure 1).

Mowry Slough is one of the larger sloughs in south San Francisco Bay. It is about 180 m wide at the entrance and has an average width, within the study area, of about 61 m at low tide.

Bonnot (1928) reported that in 1927 and 1928 there were 75 and 100 harbor seals, respectively, at Calaveras Point (Figure 1) and that there were "extensive rookeries" in the Mowry Slough area. Skinner (1962) commented that a number of pups were born in the Mowry Slough area but included no counts. In a

biological survey of San Francisco Bay from 1963–1966 Alpin (1967) reported that there were 50–60 "non-migrating" harbor seals in the Mowry Slough area. Specific dates and tidal conditions were not mentioned in these reports, thus it is impossible to compare the data contained in them with our data.

We counted hauled-out seals using both ground and aerial surveys. Risebrough *et al.* (1980) found that ground and aerial methods in the study area yielded comparable results.

Ground surveys were conducted from saltpond levees (Figure 1) with the use of 7x35 binoculars or a 20-45X spotting scope.

Aerial surveys were conducted from a Cessna 182 or 172 at about 200 m. Seals were photographed during the flight and counted later from photographs or color slides. The best results were obtained with a 35-mm camera equipped with a 135-260 mm or a 100-300 mm zoom lens, using Kodak Ektachrome ASA 200 or 400 film, and a shutter speed of 500-1000/sec.

Throughout the year harbor seals hauled-out in maximum numbers about 3–4 hours following peak high tide and during most of the year ground and aerial surveys were scheduled accordingly. However, during the pupping season, when the seal population in the Mowry Slough area was more widely distributed, ground surveys had to be made during low tide because seals were more easily observed than during high tide.

Although an attempt was made to census in the study area at least once each month, this was often not possible because of muddy roads or difficulties in scheduling aerial survey flights due to lack of aircraft or unfavorable weather. The number of counts made each year ranged from 3 (in 1977) to 34 (in 1973). No counts were made during the 1975 pupping season or during the year of 1978. Most of the 1972–1974 and 1976 counts were made during the pupping season. During the 1979 census seals were counted from 2–4 times per month from March 1979–January 1980, with more intensive censusing in the fall during and after a sewage spill (Alcorn, Fancher, and Gull 1980).

The harbor seal population in the Mowry Slough area fluctuated seasonally (Figure 2, Table 1). The lowest numbers were seen during the Fall-Winter period (Figure 2, Table 1). Highest numbers were observed during the pupping season, April–May. Loughlin (1978), and Rosenthal (1968) have described a similar seasonal fluctuation in harbor seal numbers in Humboldt Bay, California.

Pups are born in the Mowry Slough area from late March to mid May, which coincides with a rapid increase in the number of adults and subadults in the study area (Figure 2). The maximum number of adults and subadults ranged from 226 in 1980, to 266 in 1973 (Table 2). The maximum number of pups ranged from 53 in 1973, to 93 in 1976, and the total population (maximum number of adults and subadults plus maximum number of pups) ranged from 281 in 1977 to 327 in 1976.

Seals hauled-out on vegetation at high tide and on mud at low tide. At the height of pupping season seals were distributed along the north and south side of Mowry Slough for about 2 km inland, and, during periods of high tide, along the portion of the east San Francisco Bay shoreline described earlier (Figure 1). During periods of low tide, those seals hauled-out along the east Bay shoreline retreated to Mowry Slough or the mudflats next to the channel running west from Mowry Slough.
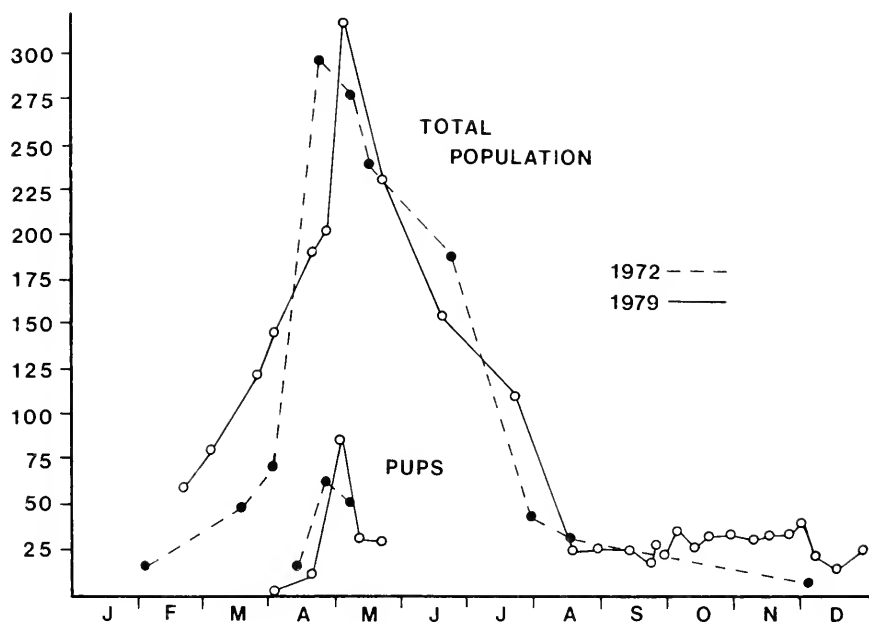
FIGURE 2. Harbor seal counts in the Mowry Slough area for 1972 and 1979 showing the pattern of seasonal fluctuation in seal numbers.

TABLE 1. **Maximum Monthly Counts of Harbor Seals in the Mowry Slough Area for 1972–1977 and 1979–1980**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1972 [1] | nc | 15 * | 47 | 297 | 277 | 192 | 44 | 31 | 25 | nc | nc | 6 * |
| 1973 [1] | 23 | nc | 67 | 314 | 216 | 161 | nc | nc | 21 | 29 | 29 | 3 * |
| 1974 [1] | nc | 50 | 106 | 318 † | 111 * | 111 | 59 | 23 | 17 | nc | 15 * | nc |
| 1975 [2] | nc | nc | 32 † | nc | nc | nc | 23 † | nc | nc | 22 † | 13 † * | 10 † * |
| 1976 [2] | nc | 91 † | 141 † | 306 | 316 | 244 | 99 | nc | nc | 23 † | nc | nc |
| 1977 | 24 | nc | nc | nc | 281 † | nc | nc | nc | nc | nc | 21 | nc |
| 1979 | nc | 59 † | 121 † | 203 | 320 | 155 | 138 | 25 | 27 | 35 | 40 | 24 |
| 1980 | 28 | nc | 72 † | nc | 285 † | 160 | 99 | 90 | 28 | 24 | nc | nc |

nc = No count
* = count made during unfavorable tide conditions
† = aerial survey
[1] = Fancher 1979
[2] = Risebrough et al. 1980

Currently available information indicates that many seals leave Mowry Slough after pupping season and may move outside of San Francisco Bay. An increase in seal numbers following pupping season has been noted on the coast at Bolinas Lagoon (Figure 1). Strawberry Spit (Figure 1) may be the eventual destination of some of the seals that leave Mowry Slough because seal numbers at Strawberry fluctuate reciprocally with those of Mowry Slough (Fancher 1979; Risebrough et al. 1980). However, seals do not appear at Strawberry Spit in peak numbers until the winter Pacific herring, *Clupea harengus pallasii*, run into Richardson Bay; the highest number of seals observed at Strawberry in January 1976 repre-

sented only 28% of the transient portion of the Mowry Slough population (Risebrough *op. cit.*).

TABLE 2. **Maximum Number of Harbor Seal Adults and Subadults, and Maximum Number of Pups Seen in the Mowry Slough Area During the Pupping Season for the Years Indicated**

| Year | Maximum number adults and subadults | Maximum number pups | Total | Number pups / Number nonpups | X 100 |
|------|------|------|------|------|------|
| 1972 | 246 | 63 | 309 | | 25.6 |
| 1973 | 266 | 53 | 319 | | 19.9 |
| 1974 | 248 * | 70 * | 318 | | 28.2 |
| 1976 | 234 * | 93 * | 327 | | 39.7 |
| 1977 | 224 * | 57 * | 281 | | 25.4 |
| 1979 | 238 | 82 | 320 | | 34.5 |
| 1980 | 226 * | 59 * | 295 | | 26.1 |

* = aerial survey

From mid August through January, a small group of seals hauled-out together daily at various sites along the first kilometre of the north shore of Mowry Slough following high tide or occasionally on the north side of the mudflat channel west of Mowry Slough at low tide. From 1972 through 1977, this group of seals ranged in size from 22 in 1975 to 31 in 1972 (Table 1).

The extent of daily fluctuations in the 1979 "fall-winter" seal population was examined. Counts (N = 19) made between 18 August and 31 January (Figure 2) showed the average number of seals hauled-out to be 27.5 ± 6.43 (Range 15–40). A sewage spill in September 1979 had no apparent immediate effect on harbor seal numbers in Mowry Slough (Alcorn, Fancher, and Gull 1980).

Although the Mowry Slough harbor seal population fluctuates seasonally, the census data do not show a significant change in the monthly counts from mid August–January, in the maximum number of adults and subadults present at the height of pupping season, or in the number of pups in the Mowry Slough seal population each year. Thus, it appears that from 1972–1980 the "fall-winter" population and the "pupping season" population have been relatively stable.

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—*Lyman E. Fancher, National Audubon Society, Western Education Center, 376 Greenwood Beach Road, Tiburon, California 94920 and Doris J. Alcorn, 6248 Merriwood, Oakland, California 94611. Accepted for publication December 1980.*

## OCCURRENCE OF A PACIFIC LOGGERHEAD TURTLE, *CARETTA CARETTA GIGAS* DERANIYAGALA, IN THE WATERS OFF SANTA CRUZ ISLAND, CALIFORNIA

A small loggerhead sea turtle, captured near Santa Cruz Island, California, on 15 March 1978, during a Bureau of Land Management (BLM) Cetacean Survey, was encountered three nautical miles off Valley Anchorage at lat 33° 56′ N long 119° 39′ W. The turtle was first observed floating at the sea surface and resembled a piece of the reddish-brown kelp common to the area. Sea surface conditions were calm with bright sunlight and high glare levels.

As the BLM survey vessel approached to within 10m, the animal rapidly submerged. It resurfaced within 3 to 4 min at which time a diver entered the water and physically guided the turtle towards the vessel. It was brought on board for examination, measurement, photographs, and then released.

Straight line measurements of the keeled carapace were 457 mm (length) and 381 mm (width). The animal weighed 8.6 kg. Commensals attached to the animal included three small pelagic crabs and a single species of barnacle. John S. Garth of the Allen Hancock Foundation, University of Southern California, identified the crabs as *Planes cyaneus* Dana. The author retains the crabs. William A. Neuman of Scripps Institution of Oceanography, La Jolla, California, identified the barnacle as *Chelonibia testudinaria* Linnaeus and retained the specimen in the Scripps collection.

The author identified the animal as a Pacific loggerhead sea turtle, *Caretta caretta gigas* Deraniyagala, based on the following observations: 5 central laminae, 5 pair of lateral laminae, 12 marginals on each side, 3 pair of enlarged poreless inframarginals on the plastron bridge, and a broad head with 2 pair of large prefrontal scales.

This turtle's marginal laminae count did not conform to the number (13 on a side) described by Carr (1952) for Pacific loggerheads. Caldwell (1960) noted that the difference between the Atlantic and Pacific loggerheads is slight and not externally visible. Six of seven Pacific loggerhead turtles reported by Márquez (1969) had 12 marginal laminae on each side. Only one specimen had a marginal pattern of 12 on one side and 13 on the other. In a personal communication regarding the capture (Archie Carr, Graduate Research Professor, Dept. of Zoology, Univ. of Florida, Gainesville), Carr acknowledged that the distinction between Atlantic and Pacific stocks has never been made. The geographical location, external characteristics, and size of the animal reported here indicate to the author it was in all probability a Pacific loggerhead.

The presence of sea turtles in the Southern California Bight is not an unusual occurrence. Van Denburgh (1905), Shaw (1947), Lowe and Norris (1955), Caldwell (1962), Márquez (1969), and Hubbs (1977) substantiate that several species of sea turtles visit this area. Species reported by these authors include the Pacific leatherback turtle, *Dermochelys coriacea schlegeli* Garman; the Pacific loggerhead turtle, *Caretta caretta gigas* Deraniyagala; the Pacific green turtle, *Chelonia mydas carrinegra* Caldwell; and the Pacific (or olive) ridley turtle, *Lepidochelys olivacea* Eschscholtz.

Reports of sea turtles frequently occur in casual conversation with boat opera-

tors familiar with the southern California coast. Between 1975 and 1978, BLM survey personnel incidentally reported nine additional sightings of sea turtles in the Southern California Bight. During these surveys, the turtles were only briefly observed and pursuit for identification was impractical. Most sightings were in the vicinity of the Channel Islands and along underwater ridges and escarpments. The capture and identification of the young loggerhead described in this report may well be a northern record for the species.

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—*Robert C. Guess, Center for Coastal Marine Studies, University of California, Santa Cruz, CA 95064. Accepted for publication December 1980.*

# A HARBOR SEAL, *PHOCA VITULINA RICHARDI,* TAKEN FROM A SABLEFISH TRAP

On 2 October 1979, the skull, scapulae, and some vertebrae of an adult harbor seal were taken from a sablefish, *Anoplopoma fimbria,* trap set 4.9 km off Partington Point, Monterey County, California. The depth of the trap was stated to be 558 ± 40 m. The traps were set by Loran-bearings and landmarks by the ALOHA; Captain Benji Shake. The trap had been in the water for 3 months prior to recovery. The largest opening was a broken cotton twine escape opening of approximately 40 cm circumference. We assume the seal entered while the trap was on the botton through the escape opening, became trapped, and drowned. Because of the arrangement of the trap opening it is quite unlikely that the seal could drift into the trap while dead. We also suspect that it entered after the trap had been set and had accumulated fish, thus attracting the seal. We assume that the missing bones were lost through the trap mesh after decomposition.

This depth approximately matches the deepest dive known for a pinniped; 600 m, for a Weddell seal, *Leptonychotes weddelli,* wearing an attached depth recorder (Kooyman 1966).

The skull has been deposited at the California Academy of Sciences, Department of Mammalogy; CAS 21376.

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—*Patricia M. Kolb, P.O. Box 6509, Carmel, CA 93921 and Kenneth S. Norris University of California, Santa Cruz, California 95064. Accepted for publication July 1981.*

# BOOK REVIEWS

### Marine Mammals

**Edited by Delphine Haley; Pacific Search Press, Seattle, WA 98109; 1978; 256 p; illustrated; $26.50.**

It is not often that one has the opportunity to review a natural history book which covers its subjects with factual exactness, and, at the same time, presents a balance between hard facts and enlightened behavioral anecdotes of human experiences with many of the species described. Pacific Search Press, with the able editorship of well-known naturalist-writer Delphine Haley, has published this exceptional book describing all the marine mammals found in the eastern north Pacific Ocean. Twenty-two marine mammalogists were called upon to contribute their expertise, resulting in a thorough presentation of the pertinent aspects of life history, physiology, behavior, ecology, and evolutionary trends of 51 taxa (49 described species, one undescribed whale, and one subspecies) recorded for the area from the southern tip of Baja California west to the Leeward Islands of Hawaii and north into the Arctic Ocean. There is also reference to 11 additional taxa from the southern hemisphere and the north Atlantic Ocean. Thus this book includes a description of or reference to one-half of the world's marine mammals, several of which are cosmopolitan in distribution.

The excellently written preface and introduction by Haley sets the theme of the book, depicting the general evolution and adaptation of these fascinating and divergent forms. A brief resume of whaling practices and fur hunting leads into contemporary values wherein ecological concern has fostered appreciation of the aesthetic values of animals and the ecosystems of which they are an integral part. Haley's approach is welcomed in light of the recent plethora of overly emotional and anthropomorphic publications and articles written in response to our search for ecological awareness. As Haley states in the preface: "This book is factual in approach, centered . . . on what is known of the marine mammals. It contains no poems, no legends, no mystical stories—only facts. However, a lack of lyrics does not mean a lack of love—and facts have a certain practical eloquence all of their own. Surely it is this type of knowledge that will ultimately help us conserve the marine mammals that share our world."

There are either black and white or color photographs of all but three rare species of the 51 north Pacific taxa. Forty-three photographs are full page in the 8.5 by 11 inch format. There are 98 exceptionally clear and often highly artistic black and white photographs, 21 high quality color photographs, 12 drawings of the probable appearance of extinct species or their structures as well as several dozen artistic reproductions of whales and porpoises. There are range distribution maps for 42 species. Pacific coast shoreline observers will be especially interested in the chapters on the killer whale, California gray whale, the vocalizing humpback whale, the lovable harbor seal and sea otter, the comical, monstrous elephant seal, and the highly visible and vocal sea lions. There are little known bits of information such as the fact that the voice of the blue whale can travel across the expanse of an ocean, that whales may have adapted to the water from a land mammal of the Order Ungulata (a goat?), and that there were now-extinct algae grazing animals similar to dugongs as well as walrus-type animals along the California coastline millions of years ago. Discussion of extinct species is a reminder that a vast multitude of animals have become extinct without the final push to oblivion coming from man. However, the highly-specialized Steller sea cow did become extinct shortly after western man discovered the last small stock at the Commander Islands in 1742. It was apparently delicious to eat.

Only one factual "error" came to the attention of the reviewer. This was the reference by Victor Scheffer about a killer whale attack on a human: the attack on a surfer near Monterey in 1972. This review, immediately after the attack and in consultation with sharkologists, analyzed all information available, including the razorlike slits in the surfer's wet suit made by the teeth, and concluded that the attacking animal was definitely a great white shark. Fortunately, and in keeping with the factual theme of the book, Scheffer did not have confirmation of the attack and qualified his report by asking "Might it have been a shark?" It definitely was a shark, and the killer whale still has not achieved the ultimate "status" in animal predation, i.e., preying upon man.

Karl Kenyon's section on the sea otter is factual and relates several endearing behavioral experiences encountered during his long association with the animal. However, there is some reference to man-sea otter interactions that may be misinterpreted. Kenyon refers to the sea otter "conflict" as being between two opposing forces: the "Friends of the Sea Otter" and the "Friends of the Abalone". There has not been an organization that could be considered "Friends of the Abalone" for many years. Recently, a group of concerned recreational and commercial users of shellfish resources have joined forces who wish to protect both the sea otter and the remaining shellfish

fisheries that the sea otter can preclude, i.e., clam, urchin, abalone, lobster, and certain crabs. Unfortunately, the high energy consuming sea otter is the one marine mammal that does present a serious threat to fisheries in the southern part of its range in Washington, Oregon, and California. If certain shellfish fisheries are to remain viable at least somewhere along the Pacific coastline, the otter must eventually be contained. Man cannot "compete" with the otter at the same time and place as may be incorrectly interpreted.

Of note to field naturalists and researchers: this book does relate diagnostic color patterns, size, and some morphological distinctions for use in identification, but it is not a field guide in that there are no diagnostic keys to the species and teeth numbers are given for only 6 species. Unfortunately, this book appeared at the time when there is a taxonomic debate as to whether the pinnipeds are in an Order of their own as they have been for many years (Order Pinnipedia) or are to now be included in Order Carnivora. Throughout the text they are referred to as pinnipeds but are designated as being in Order Carnivora in the introductory chapter on these animals and in the taxonomic listing of marine mammals. It would possibly have been proper, if one wishes to follow the new classification, to have included the Suborder Pinnipedia in the taxonomic listing and lessen the chance of confusion to the unaware.

In today's enlightened interest in marine mammals, this book should be included in every school and community library because of its factual, pictorial, and aesthetic value. The price may seem to be a bit stiff, but it is a bargain to any naturalist or student of marine life. It is a library of many books in one and includes new information that cannot be found elsewhere.—*Daniel J. Miller.*

## The Outdoors Survival Manual (Revised Edition)

By Droke Publishers, Inc., New York, NY 10016; 1979; 188 p; illustrated; $6.95.

The Outdoors Survival Manual appears to be a reprint of a U.S. Air Force general survival manual. Constant reference throughout the book to *aircrew, burning aircraft fuel, put on antiexposure suit, stay away from aircraft,* and *use emergency radio* would lead one to believe this to be true.

This does not mean that Air Force survival manuals are bad, but this one does not contain a lot of important survival information needed by backpackers, hikers, campers, skiers, hunters, and fishermen for use in North America.

Examples of omissions are too plentiful to list completely, but here are a few:

*Poisonous Plants*
Poison ivy and poison oak are mentioned but no illustration of the plants can be found among the 33 pages of plant drawings.

*Glacier Travel*
Information on roped travel on glaciers is inadequate. Even the lengths of climbing ropes listed are no longer standard and not normally available.

*Snow Shelters*
There is no mention of snow caves. They do mention that *an evader must protect himself from enemy observation as well as from the natural elements.*

*Fire and Firemaking*
Much of the information concerns building small fires that cannot be seen by the enemy. The information on fuels, fireplaces, and fire making, however, is very good.

The *Outdoors Survival Manual* does have some good information scattered here and there throughout the book—but not enough to make a good buy for the sportsman.—*Jim L. White.*

## Wild Mammals of New England

By Alfred J. Godin; Johns Hopkins University Press, Baltimore, MD; 1977; 304 p; illustrated; $25.00.

This is the first comprehensive work on the classification, distribution, ecology, and behavior of the wild mammals of the six New England states, an area of about 70,000 mi.[2] The author researched more than 1,000 scientific publications, including some in preparation, and personally examined over 20,000 specimens of wild New England mammals. Data collection was terminated at the end of December 1975.

The book is divided into three sections. Chapter 1 is the introductory section and briefly covers the general characteristics of mammals, including adaptations and classification. The discussion of mammal classification includes a key to the orders and dichotomous keys to the orders and species of adult wild animals of New England. The second section, chapter 2, covers the physiographic features, original forest, forest zones, and climate of the New England area. Section 3, chapters 3–12, comprises the main text. this section discusses the general characteristics of each order, family,

species, and subspecies found in New England. Included are original and current classifications, descriptions, distribution, ecology, behavior, methods of age and sex determination, specimens examined, and references. Included are species that are extinct, extirpated, or in danger of extirpation, and those mammals which have been introduced and become permanently established. In all, 9 orders and 100 species are covered. Many of the species descriptions include anatomically detailed and accurate skull and jawbone drawings, as well as dentition.

An important contribution of this volume is its excellent coverage of 27 species of marine mammals, including whales, dolphins, and seals.

The artistic and accurate pencil drawings of each species are superb, which greatly enhances the value of the book. The volume is extremely well referenced and includes a very handy glossary. It is free of typographical errors and is refreshingly written in a readable style. Wildlife biologists, mammalogists, conservationists, and sportsmen will find this excellent volume an extremely valuable addition to their reference library.—*M. L. Johnson.*

### Caribbean Reef Invertebrates and Plants

By Patrick L. Colin, T.F.H. Publications, Inc., Ltd., Neptune City, NY; 1978; 512 p; illustrated; $30.00.

The Caribbean attracts more divers than any other area in the world. At least two factors are responsible for this popularity: its close proximity to the United States and the very rich assemblage of fish and invertebrates that occur around the islands and reefs.

Divers going to the Caribbean have had no trouble finding field guides for the fishes, including guides that can be used under water, but only a couple of books have been available for use in identifying the sponges, corals, and other invertebrates. *Caribbean Reef Invertebrates and Plants* was published to fill this need.

Unfortunately, it does fall short in a couple of areas. First, the narrative is far too technical for most non-biologist divers and, to compound this problem, the author has failed to provide a glossary. Secondly, there are no keys to help the reader locate the animal he is trying to identify. On top of all this, the photos of the animals and plants are not placed near the narrative descriptions, nor is there any way of quickly locating a photo by reading the description. Thus, the reader is forced to flip through the photo plates until he accidentally happens upon an animal that looks something like the one he is trying to identify, and then he must try to find the description on some other page and hope that he is successful in matching up the two.

The photos are generally satisfactory and, with few exceptions, are adequately presented. However, one photo on page 269 is upside down. Despite its limitations, however, I believe marine biologists will find the book very useful, particularly because of the large number of species that are described and illustrated. Obviously a lot of work and scholarly research has gone into the preparation of this very handsome book and, hopefully, in future editions the shortcomings will be rectified, thus making it of equal value to nonprofessionals.—*Daniel W. Gotshall.*

### Pacific Coast Inshore Fishes

By Daniel W. Gotshall; Sea Challengers, Los Osos, CA; 1981; 96 p; $11.50 (paperback), $22.95 (hardback).

The expressed intention of Dan Gotshall's newest book is for " 'fishwatchers'—people who, through their interest in fishing, snorkeling, SCUBA diving, natural history or ecology, have come into contact with the fascinating and somewhat bewildering world of the fishes, and have sought to learn more about them." *Pacific Coast Inshore Fishes* accomplishes exactly that stated purpose. I only wish that such a book was available when I took an ichthyology class.

This book is a new edition of Dan Gotshall's first book "Fishwaters' Guide to the Inshore Fishes of the Pacific Coast", which became the source book of fishes for fishermen and divers. The earlier book had several deficiencies, mostly related to the printing process, which have been corrected in this new guide. Many of the photographs used have been recropped, or replaced, and the color separations were printed in Japan, where the fine art of color printing is obviously practiced. In addition, the number of species included has been increased by 33, to a total of 126.

"Pacific Coast Inshore Fishes" is organized into sections, some of which will be of more or less use, depending on the proclivities of the reader. The introduction includes a brief discussion of the use and layout of the guide, followed by an illustrated glossary of fish structures.

Two keys to the families of fishes are included. The first is a narrative or dichotomous key, which requires that a fish being identified is in hand. When an identification of the family has been made, the reader is referred to the proper section of the photographs where the fish may be finally identified by comparison with the pictures. There is also a picture key to families, using the fine line drawings of Daniel Miller. This key might be of more use to fishwatchers who do not have the fish available

to handle. It can be used to recognize the general family characteristics, which is an invaluable aid in field identification.

The photographic section is the *piece de resistance* of "Pacific Coast Inshore Fishes". Here are full color photographs, arranged by family, of 120 species of fishes. The printing quality is the best I have seen in such a guide. Even the cover photo is clear and well cropped. The photographs appear on the right-hand page, with information on identification, size, range and habitat on the facing page. This arrangement allows for quick flipping through the 63 pages of photographs when you want to look for that fish you recognize but whose name persists in remaining on the tip of the tongue.

There is a short bibliography, indices to common and scientific names of the fishes, and a listing of the "habits of common fishes by geographic areas". The latter would be useful in comparing the habitat of an identified species, as a final check in identification, or as a guide of where to go to find a particular species. Maps of the range covered, which is from Alaska to central Baja California, are included in both inside covers, and the last few pages of the book.

I feel there are several minor faults in this guide. The first is the lack of sufficient life history information for the fishes. Once a fish has been identified, there are always questions about how it lives, what it eats, etc. Some of the species do some very pecular things during their lives, and the inclusion of this information may spark the interest of the reader or at least, it might develop a better appreciation of the fishes.

Another minor fault, and it is not glaring in this guide, is the use of nature photography in depicting some species. Nature photography, by definition, pictures an animal in its natural surroundings, and if cryptic species are included, such photographs may not be adequate for identification purposes. Dan Gotshall has, in most cases, selected well in this respect, but in two photographs, the plainfin midshipman and perhaps the coralline sculpin, a line drawing next to the photograph would be useful.

All in all, Pacific Coast Inshore Fishes is an excellent, beautifully illustrated guide to the fishes. The quality, plus the price, make the book an outstanding bargain. It is inexpensive enough so that this field guide can be taken into the field, without fear of excessive financial loss if it is inadvertently ruined. I heartily recommend it.—*Peter L. Haaker.*

### Aquatic Oligochaete Biology

Edited by Ralph O. Brinkhurst and David G. Cook; Plenum Press, 227 W. 17th St., New York, NY 10011; 1980; 529 p, $55.00.

*Aquatic Oligochaete Biology* is the Proceedings of the First International Symposium on Aquatic Oligochaete Biology held in Sydney, British Columbia, Canada, May 1–4, 1979. This book provides a summary of the current knowledge of oligochaete biology presented by specialists from throughout the world. Both review papers and original research on oligochaete taxonomy, zoogeography, life history and production, ecology, and pollution biology are presented.

The taxonomic papers cover many of the contemporary problems in oligochaete taxonomy including sibling species and ecophenotypic variation. Other papers discuss the worldwide distribution of oligochaetes and present data on the aquatic oligochaete fauna of Argentina, Southern England and the St. Lawrence Great Lakes region. Ecological studies from Europe, Asia, and North America provide information on marine and estuarine oligochaetes as well as freshwater forms. Pollution biology, heavy metal tolerance and other studies on oligochaetes in relation to human activity in Europe and North America are discussed in a series of six papers. A postscript by the senior editor summarizes the symposium, emphasizing the highights and tying together the diverse papers.

*Aquatic Oligochaete Biology* is a valuable overview of what is known and, perhaps more importantly, what is not known of aquatic oligochaete biology. Although a few species have been studied in considerable detail, one is impressed with what is not known about most oligochaetes. This book provides important baseline information illustrating both the need and the opportunity for additional research.

*Aquatic Oligochaete Biology* is well written and most of the papers are readily comprehensible to the nonspecialist. This comprehensibility can be attributed in part to the senior editor who admits that "The various language problems involved often led to an extensive rewriting on my part . . . ." Whatever the cause the final result is a book which is both readable and informative. It will be a valuable addition to the reference libraries of students of aquatic oligochaetes and freshwater ecologists and pollution researchers even though their specific interests may involve organisms other than oligochaetes.—*Larry L. Eng.*

# INSTRUCTIONS TO AUTHORS

## EDITORIAL POLICY

The editorial staff will consider for publication original articles and notes dealing with the conservation of the fauna and flora of California and its adjacent ocean waters. Authors may submit two copies, each, of manuscript, tables, and figures for consideration at any time.

**MANUSCRIPTS:** Authors should refer to the *CBE Style Manual* (fourth edition) for general guidance in preparing their manuscripts. Some major points are given below.

1. *Typing*—All material submitted, including headings, footnotes, and references must be typewritten double-spaced on white bond paper. Papers shorter than 10 typewritten pages, including tables, should follow the format for notes.

2. *Citations.*—All citations should follow the name-and-year system. The "library style" will be followed in listing references.

3. *Abstracts*—Each paper will be introduced by a short, concise abstract. It should immediately follow the title and author's name and be indented at both margins to set it off from the body of the paper.

4. *Abbreviations and numerals*—Use approved abbreviations as listed in the *CBE Style Manual.* In all other cases spell out the entire word.

**TABLES:** Each table should be typewritten double-spaced throughout with the heading centered at the top. Number tables with arabic numerals and place them together in the manuscript following the references. Use only horizontal rules. See a recent issue of *California Fish and Game* for format.

**FIGURES:** Submit figures at least twice final size so they may be reduced for publication. Usable page size is $4\frac{5}{8}$ inches by $7\frac{3}{8}$ inches. All figures should be tailored to this proportion. Photographs should be submitted on glossy paper with strong contrasts. All figures should be identified with the author's name in the upper left corner and the figure number to the upper right corner. Markings on figures should be in blue pencil or grease pencil, as this color does not reproduce on copyfilm. Figure captions must be typed on a separate sheet headed by the title of the paper and the author's name.

**PROOF AND REPRINTS:** Galley proof will be sent to author's approximately 60 days before publication. Fifty reprints will be provided free of charge to authors. Additional copies may be ordered through the editor at the time the proof is submitted.