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CALIFORNIA FISH AND GAME

Editorial Staff

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CONTRIBUTION OF CUTTHROAT TROUT IN HEADWATER STREAMS TO THE SEA-RUN POPULATION [1]

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This study was designed to assess the contribution of populations of cutthroat trout in headwater areas of three creeks to anadromous cutthroat populations.

Cutthroat living upstream of permanent barriers to anadromous fish migration in Snow and Andrews creeks are resident fish which do not migrate to saltwater. In Salmon Creek, anadromous cutthroat penetrate farther into a watershed than either steelhead trout or coho salmon and rear sympatrically with resident cutthroat populations. Consequently, some fish present in these headwater areas will migrate to saltwater.

Cutthroat present in streams with indefinite or intermittent migration barriers (e.g., Salmon Creek) may be anadromous. In this study, outmigrant cutthroat marked in the Salmon Creek study area are probably the progeny of anadromus cutthroat, not migrants from a resident population. A method to identify resident and anadromous cutthroat juveniles must be developed in order to more clearly define the distribution of anadromous cutthroat trout populations.

INTRODUCTION

Coast cutthroat trout, *Salmo clarki clarki,* range from northern California to southeastern Alaska (Hart 1973). Within a watershed there may exist sympatric and allopatric populations of resident and anadromous cutthroat (DeWitt 1954; Royal 1972; Scott and Crossman 1973; Moring and Lantz 1975; and Jones 1979). Hartman and Gill (1968) found cutthroat generally occupying smaller tributary and headwater streams, especially when steelhead trout, *S. gairdneri,* were present in the system. Lowry (1965) found age 0+ cutthroat abundant in small tributaries within a stream system. Royal (1972), Edie (1975), and Jones (1979) speculated that resident cutthroat populations may contribute to sea-run populations. Moring and Lantz (1975) reported a substantial downstream migration of cutthroat juveniles from an area upstream of two "barrier" falls; however, the destination of these migrants was undetermined and the nature of the barrier was poorly defined. Cedarholm and Tagart (Univ. of Wash., research biologists, pers. commun.) reported anadromous cutthroat adults captured upstream of what they had previously considered to be an anadromous migration barrier. This study was initiated to assess the contribution of cutthroat trout inhabiting headwater areas of three separate streams to the sea-run cutthroat population and to contribute to the knowledge of the life history of coastal cutthroat, which has been inadequately studied.

STUDY AREAS

Snow Creek, its main tributary Andrews Creek, and Salmon Creek are located on the northeastern portion of the Olympic Peninsula and drain into the Strait

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of Juan de Fuca (Figure 1). The Washington Department of Game operates permanent fish traps near the mouths of Snow and Salmon creeks. The traps are designed to trap all migrating salmonids longer than 300 mm fork length (FL) year-round and greater than 50 mm FL from March through August. Study areas were located upstream of 20-m single-step falls in Snow Creek, a steep bedrock chute with a 6-m drop at an angle of 60° or greater in Andrews Creek, and upstream from a series of log jams, boulder jams, and cascades in Salmon Creek. The difference in streambed elevation between the up and downstream sides of the jams in Salmon Creek was 2–4 m. Preliminary sampling of each study section failed to find steelhead and coho, *Oncorhynchus kisutch,* implying a lack of penetration by anadromous fish.

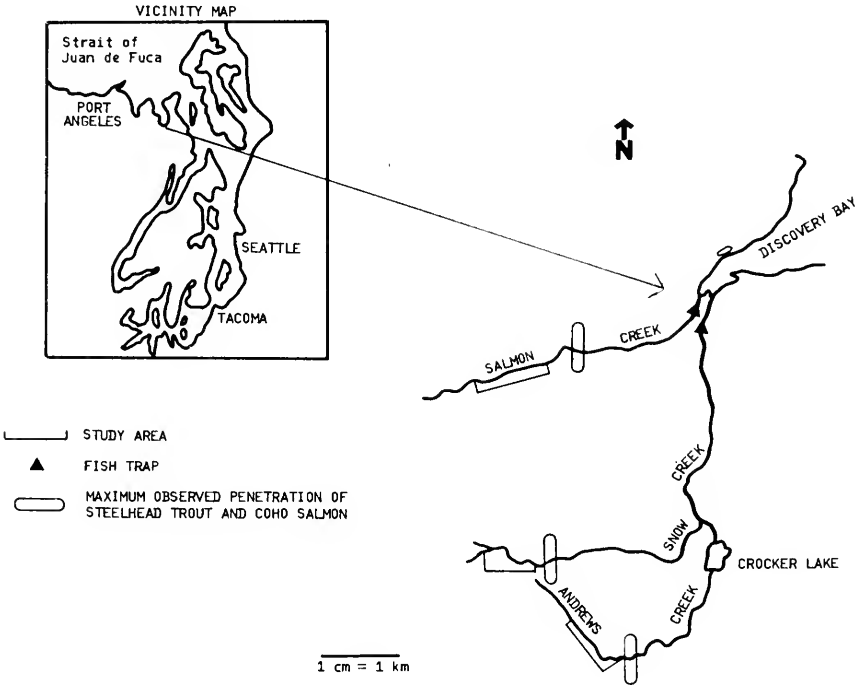

FIGURE 1. Location of study areas in Snow, Andrews, and Salmon creeks.

Anadromous cutthroat trout in Snow and Salmon creeks are the late-entry variety (Johnston and Mercer 1976). Adult cutthroat upstream migration peaks during January through April. Smolt migration peaks during May but occurs March through July.

METHODS

Cutthroat from the study areas were collected using a battery powered backpack electrofisher. All fish were measured to the nearest millimetre fork length, fin clipped, and released.

Cutthroat trout juvenile outmigrants captured in Snow and Salmon creeks' traps were measured to the nearest millimetre fork length and examined for marks. A subsample was weighed to the nearest 0.1 g wet weight. Condition index, K, was calculated by the formula:

$$K = \frac{10^5 \text{ wet weight}}{\text{Length}^3}$$

In 1978 all outmigrants trapped at Snow Creek were given a left maxillary clip and all outmigrants trapped at Salmon Creek were given a right maxillary clip. In 1979 a freeze brand was applied to the left side of all outmigrants trapped at Snow Creek and to the right side of all outmigrants trapped at Salmon Creek.

Cutthroat captured as upstream migrants were measured to the nearest millimetre fork length, weighed to the nearest gram wet weight, examined for marks, and tagged with a numbered monel-metal mandible tag. The sex and degree of maturity of the fish were determined by external examination. The same procedure was employed for downstream migrating adults.

Scale samples were collected from a subsample of cutthroat captured in the Salmon Creek study area, and a subsample of all cutthroat captured as outmigrants at the Snow and Salmon creek traps.

Electrofishing surveys were conducted in Snow Creek in the 100 m immediately downstream from the anadromous barrier during September 1978, to determine if marked cutthroat from the study area had descended the falls. Electrofishing surveys were also conducted downstream from the Snow and Salmon creeks traps to tidewater during September 1978, to determine if any cutthroat outmigrants had remained in freshwater.

RESULTS

More than 2,500 cutthroat ranging in size from 33 to 207 mm FL were marked in the three study streams over a 1-yr period (Table 1). Age analysis of fish in the Salmon Creek study area indicated fish up to 4 yr old were present (Figure 2). While electrofishing during April and May 1978, sexually mature male and female cutthroat were collected from the Salmon Creek study area. No adult anadromous cutthroat were found in any study area.

TABLE 1. Number of Cutthroat Trout Marked, Length Range, and Type of Mark for Fish Marked in Study Areas in Snow, Andrews and Salmon Creeks.

Stream	*Date*	*Number marked*	*Length range (mm)*	*Mark*
Snow Creek system				
Snow Creek	September 1977	788	51-207	Left pelvic
Andrews Creek	November 1977	193	40-186	Right pelvic
Total		981	40-207	
Salmon Creek	September,			
	October 1977	810	40-182	Right pelvic
	April, May 1978	172	51-200	Right pelvic
	September 1978	614	33-186	Right pelvic
Total		1,596	33–200	
Total (all systems)		2,577	33-207	

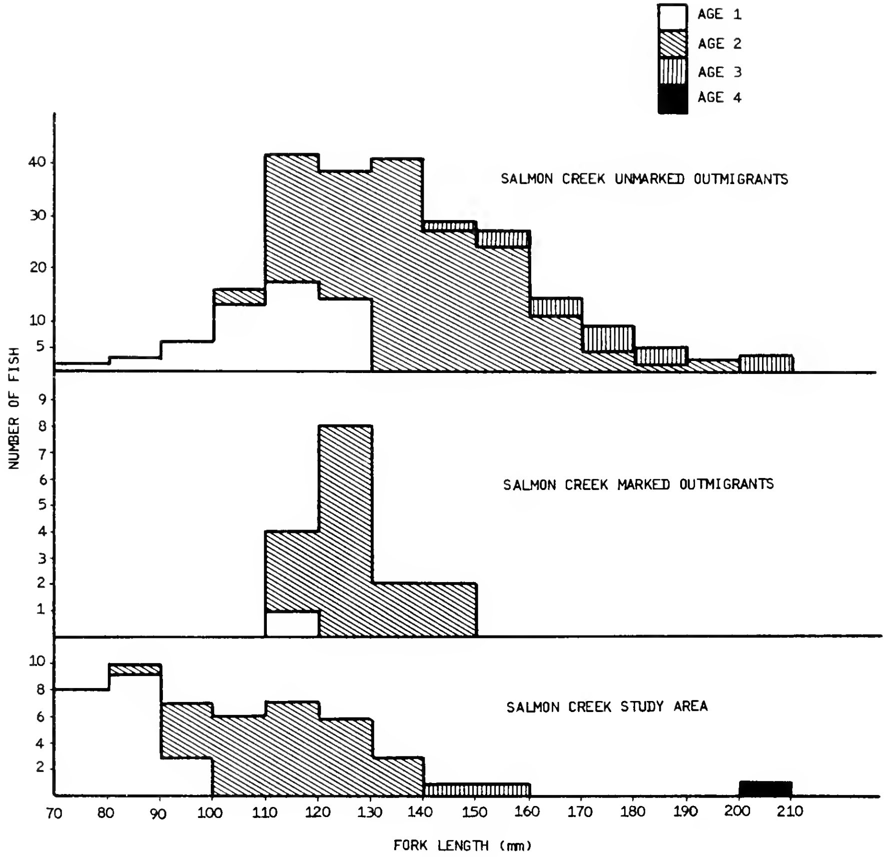

FIGURE 2. Ages of cutthroat trout from Salmon Creek, April and May 1978.

No cutthroat marked in either the Snow or Andrews creeks study areas were captured at the Snow Creek trap. Total cutthroat outmigration for Snow Creek was small (Table 2). One cutthroat (153 mm FL) marked in the Snow Creek study area was found immediately downstream of the falls.

TABLE 2. Numbers, Length, Weight, and Condition Indices (K) for Outmigrant Cutthroat Trout Captured in the Snow Creek and Salmon Creek Downstream Traps, 1978 and 1979.

				Fork Length (mm)			*Wet Weight (g)*			
Location	*Year*	*Group*	*Total out-migration*	*N*	*Mean*	*Range*	*N*	*Mean*	*Range*	*Mean K*
Snow Creek	1978	Unmarked	25	25	178	121–298	16	64.3	19.4–194.8	0.8172
	1979	Unmarked	37	37	166	128–251	36	47.2	20.8–136.0	0.9143
Salmon Creek	1978	Marked	54	54	130	112–153	40	20.8	14.1– 30.2	0.9463
		Unmarked	653	653	134	76–257	425	23.8	3.9–146.8	0.9757
	1979	Marked	14	14	143	106–162	14	25.8	12.6– 41.0	0.8942
		Unmarked	226	226	143	76–223	196	28.5	7.3–102.1	0.9235

Cutthroat marked in the Salmon Creek study area were captured during spring smolt outmigration at the Salmon Creek trap. Marked cutthroat outmigrants were physically and behaviorally similar to unmarked outmigrants; their length, weight, condition (K), ages, and migration timing were all similar (Table 2, Figures 2 and 3).

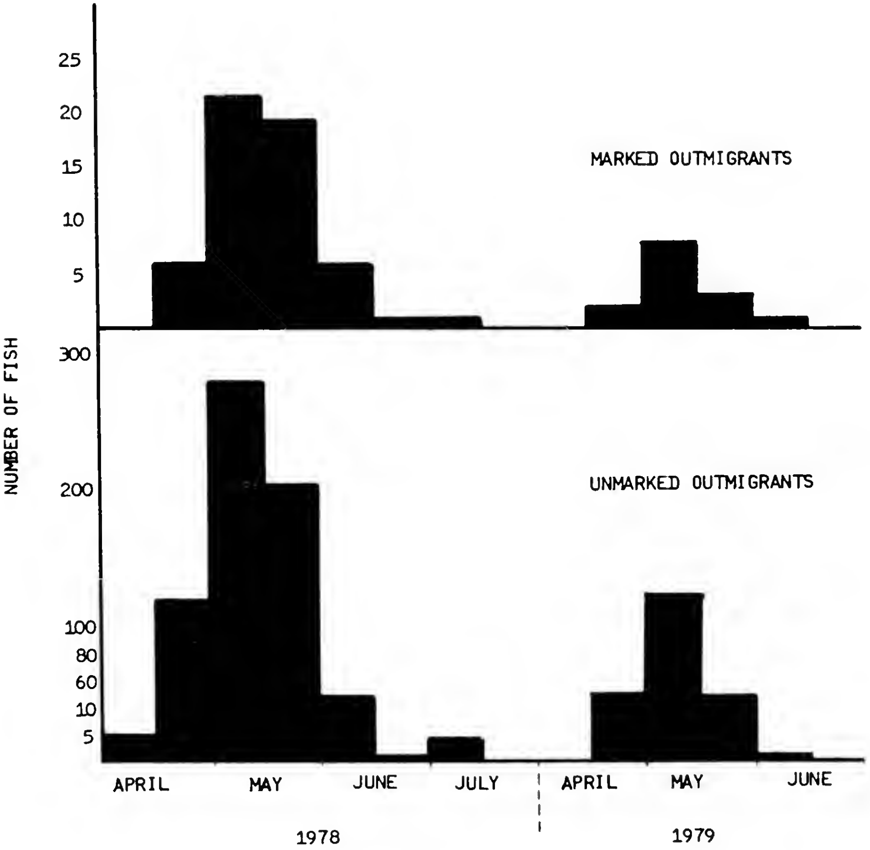

FIGURE 3. Timing of capture at downstream migrant trap for outmigrating cutthroat trout in Salmon Creek, 1978 and 1979.

There was no apparent residualism of study area cutthroat outmigrants in Salmon Creek as none of the study area outmigrants were captured during surveys downstream from the trap. Three sea-run cutthroat originally marked in the Salmon Creek study area were recaptured on their migration from saltwater to Salmon Creek. One of these fish was later recaptured, spawned out, on its return migration to saltwater. All Salmon Creek outmigrant groups demonstrated similar saltwater survival rates of 2 to 7% (Table 3).

TABLE 3. Survival from Smolting to First Return to Freshwater for Cutthroat Trout Outmigrations from Snow and Salmon Creeks.

Origin	*Year*	*Group*	*Total outmigration*	*First return to upstream trap*			
				1978–79	*1979–80*	*Total*	*Percent*
Snow Creek	1978	Unmarked	25	5	0	5	20
	1979	Unmarked	37	N/A	4	4	11
Salmon Creek....................	1978	Marked	54	1	1	2	4
		Unmarked	653	21	4	25	4
		All Salmon Ck.	707	22	5	27	4
	1979	Marked	14	N/A	1	1	7
		Unmarked	226	N/A	5	5	2
		All Salmon Ck.	240	N/A	6	6	3

DISCUSSION

Andrew and Geen (1960) report on the survival rates of various species of trout and salmon smolts passing over the spillways of 18 to 90 m high dams. Survival rates ranged from 36–98%. The Washington Department of Fisheries regularly stocks coho salmon in streams where the resulting smolts have passed successfully over barriers of greater heights than those on Snow and Andrews creeks (T. Flint, Wash. Dept. of Fisheries biologist, pers. commun.).If there was a migration of cutthroat from the Snow Creek study area, it was expected that enough of the fish would have survived the passage over the falls and instream predation and have arrived at the trap. Outmigration of smolts from Andrews Creek is complicated by the presence of Crocker Lake downstream from the barrier. A trap operated on the inlet to the lake during the spring of 1977 trapped over 200 migrating juvenile cutthroat, one of which passed through the lake and was captured in the trap on the outlet stream. Whether the other fish were anadromous and eaten by predators or were adfluvial and remained in the lake is not known. In any case, no cutthroat marked in the study areas of Snow and Andrews creeks migrated to saltwater. Brannon (1967), Northcote, Williscroft, and Tsuyki (1970), and Raleigh and Chapman (1971) have discussed the influence of inheritance on salmonid migration patterns with the basic movement pattern being an inherited characteristic. Studies by Miller (1957), Diana and Lane (1978), and Lestelle (1978) indicate the home range for resident populations of cutthroat is small. In populations of fish which exist upstream of an impassable barrier, any fish passing over that barrier is lost to the population. Unless the fish spawns prior to its downstream migration, the migratory urge is "lethal," as far as the population is concerned. Fish which leave the headwater areas of Snow and Andrews creeks are probably random drifters, few in number, and make no contribution to the anadromous population.

Outmigrant cutthroat which had been marked in the study area of Salmon Creek are probably the progeny of anadromous cutthroat, not migrants from a resident cutthroat population. Marked and unmarked outmigrants were similar in many ways (size, age, migration timing, marine survival rates). In 1978 and 1979, preseason estimates, obtained by electrofishing, of the number of cutthroat smolts present in the presumed anadromous zone of Salmon Creek failed to indicate the magnitude of the cutthroat outmigration. A large portion of the unmarked cutthroat likely migrated from reaches of Salmon Creek upstream of the assumed anadromous barrier, but outside of the study area of this experiment. Although population estimates were not conducted in the Salmon Creek study area, evidence from experiments being conducted in Penny Creek (Washington State Game Department 1979), a stream inhabited by resident cutthroat trout, indicates a rather stable population biomass and stable numerical populations of age one and older fish. The stability in numbers of age 1 fish present in October and age 2 and older fish present the following April suggests that if there is migration from a resident population, it should be stable from year to year since the numerical decline is stable. Instead, the number of marked outmigrants declined from 1978 to 1979. A more probable explanation of the migration of marked cutthroat from the study area to saltwater is that during the spawning migrations of 1975–1976 and 1976–1977, adult anadromous cutthroat were able to negotiate what we had considered to be a migration barrier. Cedarholm, Martin, and Osborne (Univ. of Washington, research biologist, pers. commun.) have all observed anadromous cutthroat in reaches of streams thought to be inaccessible to them.

The evidence implies that the "barrier" in Salmon Creek is intermittent or non-existent and cutthroat migrating from the study area to saltwater were the progeny of anadromous parents. Because no adult anadromous cutthroat were captured in the study area of Salmon Creek, it cannot be proven that sea-run fish actually spawned in the study area during the study period. Marine survival rates measured for Salmon Creek cutthroat are substantially lower than the 20 to 40% reported by Giger (1972) for an unfished population and 17% reported by Jones (1978) for a population considered to be overexploited. It is very difficult to detect anadromous cutthroat adults in small streams (J. Johnson, Wash. Dept. of Game biologist, pers. commun.). This difficulty, plus the poor return rates which resulted in small numbers of adults in the stream, made it very unlikely that any anadromous adults would be located during surveys in the study area, even if they were present.

The existence of sympatric spawning populations of resident and anadromous cutthroat may lead to some interbreeding; it is not known what effect this would have on the migratory patterns of the offspring. Interbreeding may allow the genes which determine migration patterns to remain in the population and be expressed in the progeny upstream of a newly-created migration barrier. Unless anadromous spawners re-invade the area or the fish spawn prior to migration, the genetic basis for migration will be removed from the population as each migrant passes over the barrier. The final result will be the evolution of a resident population of cutthroat trout.

In the absence of a permanent migration barrier, it should be assumed anadromous cutthroat could be present in a stream. Currently, there is no way to separate juvenile resident and anadromous cutthroat stocks from each other. There is a good deal of concern being voiced by research personnel in Washington (Johnston 1979) as to the depressed state of sea-run cutthroat stocks, especially in those areas of Puget Sound and the Strait of Juan de Fuca most accessible to anglers. To determine the status of sea-run cutthroat stocks, a method must be developed to differentiate them from resident cutthroat stocks.

Measurements of otolith nuclei (Rybock, Horton, and Koski 1975; and Tippetts 1979) have been used to differentiate resident from anadromous stocks of rainbow trout and may do the same for cutthroat.

SUMMARY

Cutthroat trout residing upstream of permanent migration barriers in Snow and Andrews creeks were non-anadromous. Cutthroat residing upstream of apparent migration barriers in Salmon Creek appeared to be progeny of anadromous stock, i.e., the "barrier" probably did not stop migration of adult sea-run cutthroat. Cutthroat present in streams with indefinite or intermittent migration barriers may be anadromous. It is apparent that to assess the status of sea-run cutthroat populations, a method of discriminating between juvenile anadromous and resident cutthroat must be developed.

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LITERATURE CITED

Andrews, F.J., and G.H. Geen. 1960. Sockeye and pink salmon production in relation to proposed dams in the Fraser River system. Int. Pac. Salmon Fish Comm. Bulletin 11, 259 pp.

Brannon, E.L. 1967. Genetic control of migrating behavior of newly emerged sockeye salmon fry. Int. Pac. Salmon Fish. Comm., Prog. Rept. 16, 31 pp.

DeWitt, J. W., Jr. 1954. A survey of the coast cutthroat trout, *Salmon clarki clarki* Richardson, in California. Calif. Fish and Game. 40(3): 329-335.

Diana, J.S., and E.D. Lane. 1978. The movement and distribution of Paiute cutthroat trout, *Salmo clarki seleniris,* in Cottonwood Creek, California. Trans. Amer. Fish. Soc. 107(3):444-448.

Edie, B.G. 1975. A census of juvenile salmonids of the Clearwater River basin, Jefferson County, Washington, in relation to logging. M.S. Thesis, Univ. of Wash., Seattle. 86 pp.

Giger, R.D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Oregon State Game Comm. Federal Aid to Fish Restoration. Project F-72-R. Final Report. 61 pp.

Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Bd. Can. Bull. 180:740

Hartman, G.F., and C.A. Gill. 1968. Distribution of juvenile steelhead and cutthroat trout (*Salmo gairdneri* and *S. clarki clarki*) within streams in southwestern British Columbia. Can., Fish. Res. Bd., J., 25(1):33–48.

Johnston, J.M. 1979. Sea-run cutthroat; Stillaquamish River creel census (1978) and harvest limit recommendations. Wash. Dept. of Game Progress Report. 26 pp.

Johnston, J.M., and S.P. Mercer. 1976. Sea-run cutthroat in saltwater pens: broodstock development and extended juvenile rearing. Wash. State Game Dept. Federal Aid to Fish Restoration, Progress Report AFS-57-1. 92 pp.

Jones, D.E. 1978. Life history of sea-run cutthroat trout. Alaska Dept. Fish and Game. Anadromous Fish Studies, Completion Rept, 1971–1977. Project AFS-42. 18(AFS-42-5-B):78-105.

———. 1979. Development of techniques for enhancement and management of anadromous cutthroat trout in southeast Alaska. Alaska Dept. Fish & Game. Anadromous Fish Studies, Annual Performance Rept., 1977–1978. Project AFS-42. (AFS-42-6-B):69-119.

Lestelle, L.C. 1978. The effects of forest debris removal on a population of resident cutthroat trout in a small headwater stream. M.S. Thesis, Univ. of Wash., Seattle. 86 pp.

Lowry, G.R. 1965. Movement of cutthroat trout, *Salmo clarki clarki* (Richardson), in three Oregon coastal streams. Amer. Fish. Soc., Trans. 94(4):334-338.

Miller, R.B. 1957. Permanence and size of home territory in stream-dwelling cutthroat trout. Can. Fish. Res. Bd., J., 14:687-691.

Moring, J.R., and R.L. Lantz. 1975. The Alsea Watershed study: effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon, Part 1-Biological Studies. Federal Aid to Fish Restoration. Project AFS-58. Final Report. 66 pp.

Northcote, T.G., S.N. Williscroft, and H. Tsuyki. 1970. Meristic and lactate dehydrogenase genotype differences in stream populations of rainbow trout below and above a waterfall. Can. Fish. Res. Bd., J., 27:1987-1995.

Raleigh, R.F., and D.W. Chapman. 1971. Genetic control in lakeward migrations of cutthroat trout fry. Amer. Fish. Soc., Trans. 100(1):33-40.

Royal, L.A. 1972. An examination of the anadromous trout program of the Washington State Game Department. Wash. State Game Dept. Final Report. AFS-49. 176 pp.

Rybock, J.T., H.F. Horton, and K V. Koski. 1974. Use of otoliths to separate juvenile steelhead trout from juvenile rainbow trout. Fish. Bull., 73(3):654-659.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can. Bull. 184:966 pp.

Tippetts, W.E. 1979. Evidence of successful reproduction of steelhead rainbow trout, *Salmo gairdneri gairdneri*, in the Ventura River, California. Calif. Fish Game, 65(3):177-179.

Washington State Game Department. 1980. Penny Creek coho planting study. Pages 70-84 *in*: G. Garrison, ed. Steelhead program progress report, December 31, 1979.

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BENTHIC INVERTEBRATES OF THE EARTHEN COACHELLA CANAL, CALIFORNIA [1]

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At least 19 taxa of invertebrates inhabited the Coachella Canal, California, in October–November 1980. Dominants were Asiatic clam, *Corbicula fluminea*; a hydropsychid caddisfly, *Smicridea utico*; oligochaetes, *Aelosoma* sp. and *Chaetogaster* sp.; and chironomid dipterans. Mean densities were from 158 to 3,678 individuals/m^2, and biomass was 2.02 to 7.63 g dry wt/m^2 in mid-channel and near-shore habitats, respectively. Invertebrate distributions reflected substrate size and stability, and the presence of organic matter. Concrete structures supported populations of *S. utico* and lepidopteran larvae, *Parargyractis confusalis*, of 25,000 and 1,500/m^2, respectively, far greater than densities of any invertebrate on natural substrates.

INTRODUCTION

Macroinvertebrates of North American canals are poorly known despite the fact that such systems support substantial fish populations (St. Amant *et al.* 1974) that may depend on such animals for food. The U.S. Bureau of Reclamation has conducted investigations of the biota of the Delta-Mendota canal in western California (e.g., Prokopovich 1968, Eng 1975), although these data received limited distribution. Outside the United States, work has been done on life cycles of euryhaline and marine invertebrates of the Baltic Canal (Schutz 1969), and molluscs have been studied in the Worchester-Birmingham Canal (Young 1975), and in irrigation canals of Lombardy (Bianchi *et al.* 1978).

Increasing demands for water transport efficiency in the arid American Southwest has resulted in proposals to line existing earthen canal systems with concrete. Conversion from earth to concrete substrate is an immediate environmental alteration. The biological effects of such alterations are not assessable because of a lack of information. This report provides baseline data on relative species abundance, biomass, and community structure of invertebrates in the earthen Coachella Canal, southeastern California, during autumn.

METHODS AND MATERIALS

The Coachella Canal (Figure 1) delivers Colorado River water for agricultural irrigation in the Imperial, Coachella, and Indio valleys. The canal has a capacity of 70.8 m^3/sec at the turnout from the All American Canal; this is reduced by withdrawals to 36.8 m^3/sec 137.8 km downflow. Depths range from 1–5 m (mid-channel) and open-reach width is approximately 20 m. The region consists of "Colorado Desert" (Jaeger 1957), is mostly below sea level, and lies entirely within the endorheic Salton Sea basin. In order to reduce water loss through seepage and to increase transport efficiency, the southernmost (upstream) 78.5 km of canal were re-aligned into a concrete structure in mid-November 1980.

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[1] Accepted for publication November 1981.

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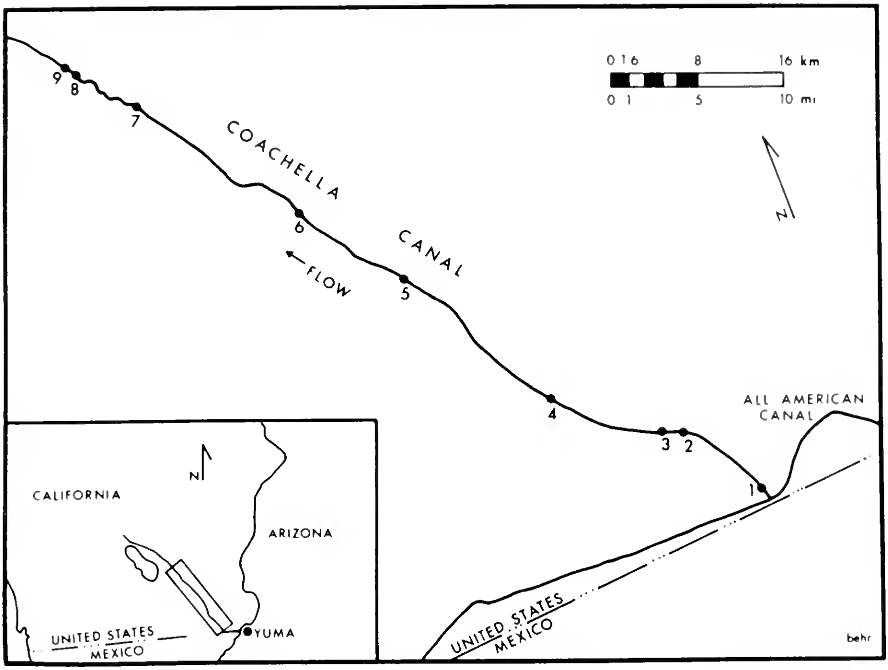

FIGURE 1. Earthen Coachella Canal and southern California location map (inset). Sampling stations denoted by closed circles.

Nine sampling stations on the earthen canal (Figure 1, Table 1) were sampled by Ekman dredge (0.023 m^2) on 23–24 October 1980. Quantitative samples were collected along both banks and at mid-channel in depths of <1 to 3 m. Samples were retained on a 420 μm-mesh sieve and preserved in 10% formalin. Estimates of current velocity and qualitative observations of substrate type and aquatic vegetation were made at each station. Additional observations were made adjacent to stations 2, 3, and 7 during 10–13 November, when the earthen canal was dewatered. Qualitative studies included substrates and vegetation; densities of biota associated with concrete structures were estimated within a 0.01 m^2 quadrat.

Laboratory processing included removal of course particles from samples and examination at magnification of 7X for removal, enumeration, and identification of organisms. Wet weights of invertebrates (en masse except clams) were recorded to the nearest milligram after blotting to remove excess water. Weights of individual Asiatic clams were recorded after removal from valves (clams >4 mm shell length), or following decalcification in 0.1 N HCL (clams <4 mm). Dry weights were estimated to be 0.1 times wet weight (Winberg 1971).

RESULTS AND DISCUSSION

General Characteristics

Substrate was predominately fine to medium sand with sparse, pea-sized gravel (Table 1); silt or clay was in near-shore habitats where emergent vegetation reduced current velocity. Concrete structures at check drops, siphons, and bridge crossings provided spatially limited, solid substrate. Water velocity was relatively uniform (0.3 to 0.7 m/sec) in open reaches, but slower near banks and immediately upstream from constrictions. Rooted aquatic vegetation was in water <1.0 m deep, and areal coverage was <5.0%. Emergent macrophytes were common reed, *Phragmites australis,* and cat-tail, *Typha domingensis;* occasional beds of sago pondweed, *Potamogeton pectinatus,* and milfoil, *Myriophyllum spicatum,* were present. Water velocity was lower within and near vegetation, and substrates in such areas contained particulate organic material not present in areas of greater current. Attached filamentous algae, *Cladophora glomerata,* was only on side-walls and aprons of concrete structures.

TABLE 1. Characteristics of Sampling Stations on the Coachella Canal[1]

	Substrate characteristics		
Station	*East*	*Mid-channel*	*West*
1	Clayey sand, pebble	Sand	CPOM[2], detritus, sand and subm. vegetation
2	Sand, CPOM, pebble	Sandy clay	Sand, CPOM, detritus
3	Sand	Clay	Sand
4	Sand, detritus	Clayey sand	Sand
5	Pebbles, sand	Clay	Pebbles, sand
6	Sand, FPOM[2]	Clayey sand	Sand
7	Pebble, sand, clay	Clayey sand	Pebble, sand
8	Sandy clay	Sand	Silt, detritus, vegetation
9	Sand	Sand	Sand

[1] East and west depths less than 1 m, mid-channel depths 2–3 m; current velocities 0.3–0.7 m/sec at all stations except 8W, which was slack.

[2] CPOM = coarse particulate organic matter, FPOM = fine particulate organic matter.

Macroinvertebrates

Seventeen taxa of aquatic invertebrates were collected on 23–24 October (Table 2). Asiatic clam, *C. fluminea*; oligochaetes, *Aelosoma* sp. and *Chaetogaster* sp.; chironomid midges; and a hydropsychid caddisfly, *S. utico* collectively comprised >90% of numbers taken (Table 3). Two species of odonates (*Erpetogomphus compositus, Gomphus intricatus*) were collected on 10–13 November. Biomass was predominated by *C. fluminea,* with *S. utico* a distant second (Table 3). Near-shore habitat supported the largest populations and biomasses, with more than 20 times as many individuals and nearly four times the biomass as in mid-channel. More than twice as many taxa (17) were near-shore as in mid-channel (7). Proportions of total individuals within each predominant taxon was, however, about the same for near-shore and mid-channel samples (Table 3).

TABLE 2. Mean (±1 Standard Error) Number per Square Meter of Macroinvertebrates Collected at East Bank, Mid-Channel, and West Bank Sites in the Earthen Coachella Canal, 23–24 October 1980.

Invertebrate	*Site*		
	East	*Mid-channel*	*West*
Ephemeroptera			
Baetis sp.	5±5	0	0
Baetiae, undet. genus	14±10	5±5	0
Odonata			
Hetaerina americana	0	0	14±14
Hyponeura lugens	5±5	0	22±19
Trichoptera			
Smicridea utico	693±265	19±10	182±90
Nectopysche sp.	43±13	5±3	96±50
Lepidoptera			
Parargyractis confusalis	0	0	7±5
Diptera			
Chironomidae	804±318	48±38	447±325
Chrysops sp.	0	0	14±14
Non-insecta			
Turbellaria	5±5	0	5±5
Nematoda	0	0	112±94
Oligochaeta (*Aelosoma* sp., *Chaetogaster* sp.)	627±553	5±4	658±454
Ostracoda	0	0	6±6
Hydracarina	67±31	0	24±15
Physidae, undet. genus	5±5	0	6±6
Corbicula fluminea	1033±645	76±33	2457±1733
Number of samples	9	9	9
Overall mean	3305 ± 1133	158 ± 56	4050 ± 2636
Total number of taxa	12	7	15

TABLE 3. Mean (±1 Standard Error) Number and Biomass (mg dry wt) per Square Meter, and Percentage (in Parentheses) of Total of Predominant Macroinvertebrates Collected at Bank Sites (East and West Combined) Compared with Mid-Channel Sites in the Earthen Coachella Canal, 23–24 October 1980.

Invertebrate		*Site*	
		Bank	*Mid-channel*
Trichoptera			
Smicridea utico	Number	440 ± 150(12)	19 ± 10(12)
	Biomass	63 ± 15(<1)	2 ± 1(<1)
Diptera			
Chironomidae	Number	625 ± 252(17)	45 ± 38(28)
	Biomass	13 ± 5(<1)	1 ± 1(<1)
Non-insecta			
Oligochaeta (*Aelosoma* sp., *Chaetogaster* sp.)	Number	642 ± 346(17)	5 ± 5(3)
	Biomass	45 ± 24(<1)	<1 ± 0.3(<1)
Corbicula fluminea	Number	1745 ± 912(47)	74 ± 33(47)
	Biomass	7460 ± 4440(98)	2010± 1100(99+)
Other Taxa	Number	226 ± 93(6)	15 ± 8(9)
	Biomass	44 ± 18(<1)	1 ± 1(<1)
Overall Mean	Number	3678 ± 1394	158 ± 56
	Biomass	7625 ± 4205	2015 ± 1101
Total Number of Taxa		17	7
Number of Samples		18	9

Distribution of total organisms and biomass among stations (Table 4) appeared related to substrate (Table 1) since highest numbers and biomass were in habitats containing particulate organics. Greatest density occurred at Station 1 (west bank) where juvenile clams (shell <4 mm) predominated. Greatest biomass was at Station 8 (west bank) where large clams (shells >1–2 cm) averaged 1,277/m^2 in three replicate samples. Station 8 (west bank) had the lowest water velocity and silt/organic substrate, and supported two distinct size-classes of clams, the smaller with mean individual dry weight of 0.01 mg, and the larger with dry weights of 10-550 mg.

TABLE 4. Total Number per Square Meter and Biomass (mg dry wt in parentheses) of Macroinvertebrates Collected at 27 Sites (East Bank, Mid-Channel, and West Bank at Each of Nine Stations) in the Earthen Coachella Canal, 23–24 October 1980.

	Site					
Station	*East Bank*		*Mid-Channel*		*West Bank*	
1	4692	(185)	0	(0)	24,282	(487)
2	9643	(586)	430	(10)	1205	(51)
3	43	(1)	0	(0)	215	(2)
4	6974	(6117)	0	(0)	0	(0)
5	4649	(234)	344	(7)	1077	(63)
6	1506	(23,724)	0	(0)	344	(4)
7	1765	(104)	258	(8191)	732	(66)
8	86	(1)	172	(3014)	7306	(66,103)
9	387	(38,319)	215	(6893)	1291	(49)
Mean (±1 Standard Error) per Station	3305	(7677)	158	(2013)	4050	(7425)
	±1133	±4619	±56	±1101	±2636	±7335

Oligochaetes were abundant near both shores at Stations 1, 2, and 8, and chironomids near shore at most stations. Caddisfly larvae were most abundant at Stations 1, 2, 5, and 7, along the east bank where gravel substrates were present (Table 1). Mean individual dry weights of these organisms were far less than that of clams, which largely explains the predominance of clam biomass.

The remaining taxa comprised a small numerical and biomass proportion of the fauna and had no obvious distributional patterns relative to substrate; they were notably more abundant near shore than in mid-channel (Table 3).

Concrete surfaces exposed upon de-watering were densely populated by lepidopteran larvae, *P. confusalis,* and hydropsychid caddisflies, *S. utico.* The lepidopteran was unexpected since it was rare in quantitative samples (Table 2), yet densities were estimated at 1,500/m^2. These organisms are scrapers and shredders (Merritt and Cummins 1978), and must have been associated with microalgae films on concrete surfaces. The caddisfly, which feeds on drifting materials caught in specially-constructed nets, was even more abundant; estimated densities were at least 25,000/m^2 and biomass was nearly 2,500 mg/m^2.

Compared with most lotic systems the invertebrate fauna of the earthen Coachella Canal was depauperate in terms of taxa represented and numbers of individuals. For example, Merritt and Cummins (1978) reported densities of chironomids >50,000/m^2 as not unusual in lotic habitats, yet <2,300/m^2 were in quantitative canal samples. The unfavorable environment afforded by shifting sand bottom undoubtedly explains part of the scarcity of organisms (Hynes 1970). Additional taxa could have been associated with beds of aquatic macrophytes; however, qualitative sampling upon de-watering added only two taxa (the odonates) not previously collected. Seasons and organism life histories have significant influences on organism abundance and biomass (Rosenberg 1979) since population numbers are high (mean individual weights are small) early in the life of a given cohort. In these contexts data presented here must be considered point estimates that may have little relation to mean annual standing crops.

Predominant organisms in the canal were either filter feeders (Asiatic clam, many chironomids, the dominant caddisfly), or sediment-detritus ingesters (Oligochaeta), while others include predators (Turbellaria, Hydracarina, *Hetaerina, Hyponeura*) and collector-gatherers (Baetidae, *Nectopsyche, Chrysops*). Organisms which rely on a scraping-type habitat (e.g., the snail) were nearly absent, or were highly localized in distribution (*P. confusalis*). This suggests that during autumn production of attached microalgae was low on natural substrates (sand), and local stands on stable substrates such as concrete were inadequate to support large populations of dependent invertebrates.

It is notable that mayflies, typically in high population densities, were poorly represented in the canal fauna, and that aquatic beetles, which inhabit an exceedingly broad spectrum of habitats, were not found. Seasonal effects may be important, or possibly the shifting sand substrate largely excluded these taxa. Certainly the most successful organisms were those which lived within substrates, or which were associated with locally stable substrates (*S. utico*).

Since biomass in the canal was predominated by filter-feeding organisms (*C. fluminea* and *S. utico*), which rely upon zooplankton, phytoplankton, and fine organic detritus as food, it is relevant to ask where these foods are derived. Three potential sources seem likely: i) in water from the All American Canal; ii) aeolian particulate materials; and iii) autochthonous production by plants and animals. If the first were the case, one would anticipate greater densities and biomass of filter feeders upstream near the source of water. This did not occur (Table 4). A choice cannot be made between the other alternatives, but a combination of those two food sources seems likely.

CONCLUSIONS

The earthen Coachella Canal supported a depauperate invertebrate fauna. Based upon our observations of stable concrete structures, we expect that *Cladophora* and other periphyton will be highly productive on these substrates in the new canal section and will support high secondary production of associated grazers and filter-feeders. Burrowers will be habitat-limited until substrate accumulates through blow-in from the surrounding dune fields. Water clarity should be enhanced by the virtual elimination of bank erosion and this should have a positive effect on primary and secondary production. This new canal will lack cover such as bank holes and vegetation which provide habitat diversity. Too, concrete canals can be effectively cleaned and this disturbance could substantially reduce the system's productivity.

LITERATURE CITED

Bianchi, I., A. Freddi, A. Girod, and M. Marian. 1978. Faunistic considerations and population dynamics of mollusks living in irrigation canals in Lombardy. Boll. Pesca Piscic. Idrobiol., 30(2) : 177–206.

Eng, L. L. 1975. Biological studies of the Delta-Mendota Canal, Central Valley Project, California, II. Final Report, U.S. Bureau of Reclamation, Sacramento, CA. 178 p.

Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press, Toronto, Ontario. 555 p.

Jaeger, E. C. 1957. The North American deserts. Stanford University Press, Stanford, CA. 308 p.

Merritt, R. W., and K. W. Cummins. 1978. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co., Dubuque, IA. 441 p.

Prokopovich, N. P. 1968. Organic life in the Delta-Mendota Canal, Central Valley Project, California. Progress Report, U.S. Bureau of Reclamation, Sacramento, CA. 126 p.

Rosenberg, D. M. (ed.). 1979. Freshwater benthic invertebrate life histories: current research and future needs. Can., Fish. Res. Bd., J. 36(3) : 289–345.

Schutz, L. 1969. Ecological investigations on the benthic fauna in the Baltic Canal, III. Autecology of vagile and hemisessile species on piles overgrown with vegetation and animals: macrofauna. Int. Rev. Gesamten Hydrobiol., 54(4) : 553–592.

St. Amant, J., R. Hulquist, C. Marshall, and A. Pickard. 1974. Fisheries section including information on fishery resources of the Coachella Canal study area. *in* Calif. Department of Fish and Game. Inventory of the fish and wildlife resources, recreational consumptive use, and habitat in and adjacent to the upper 49 miles and ponded areas of the Coachella Canal. Report to the U.S. Bureau of Reclamation.

Winberg, G. G. 1971. Methods for the estimation of production of aquatic animals. Academic Press, New York, NY 175 p.

Young, M. R. 1975. The life cycles of six species of freshwater molluscs in the Worchester-Birmingham Canal. Malacol. Soc. London., Proc. 41(6) : 533–548.

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OSTEOPHAGIA AND ANTLER BREAKAGE AMONG ROOSEVELT ELK

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Quantified observations of bone and antler chewing by Roosevelt elk, *Cervus elaphus roosevelti,* were made on Gold Bluffs Beach, Prairie Creek Redwoods State Park, Humboldt County, California during 1973. Bulls were observed chewing bones and antlers in June and July, and cows during June through August. Seventeen elk antlers were measured and sampled for calcium and phosphorus content. Significant correlations were found between antler size and both phosphorus content and the calcium:phosphorus ratio. It was suggested osteophagia was in response to calcium and phosphorus deficiencies in forage plants, and that such inadequacies were related to antler breakage in bulls. Differences in the mineral intake between dominant and subordinate individuals were related to elk dominance hierarchies, and are discussed in terms of their adaptive significance.

INTRODUCTION

The consumption of bones and antlers by free-ranging ungulates may be widespread. Osteophagia has been reported for several cervids (Murie 1935, Flerov 1952, Banfield 1954, Harper *et al.* 1967, Dansie 1968, Prior 1968, Krausman and Bissonette 1977), and the consumption of bird eggs (Palmer 1926) as well as other occasional carnivory by ungulates (Severinghaus 1967, Skoog 1968, Wormell 1969, Stone and Palmater 1970) may be similar to osteophagia.

The reason generally offered to explain bone and antler chewing is supplementation of a calcium or phosphorus deficient diet. However, with the exception of Langman (1978), little quantitative information exists on the minerals obtained by osteophagia, or the frequency with which this behavior occurs. This paper provides a quantified description of osteophagia for Roosevelt elk, *Cervus elaphus roosevelti,* and examines the relationship between osteophagia and antler breakage among bulls.

STUDY AREA AND METHODS

This study was conducted on the Gold Bluffs Beach portion of Prairie Creek Redwoods State Park, Humboldt County, California. The study area is comprised largely of coastal prairie separated from nearby redwood, *Sequoia sepervirens,* forest by precipitous sandstone cliffs. Red alder, *Alnus rubra,* groves surround numerous creeks in the 4-km^2 area. The climate is mild, but rainfall commonly exceeds 200 cm per year. More complete descriptions of the Gold Bluffs Beach climate and vegetation are available elsewhere (Harper *et al.* 1967, Franklin, Mossman and Dole 1975, Bowyer 1976). Elk were observed for over 700h between 12 November 1972 and 28 November 1973. Behavioral data were recorded using an all-occurrences log (Altmann 1974).

The circumference of the main beam for each of 17 antlers was measured directly above the corona. The total length of each antler was measured along the main beam from the corona to the tip of the last tine (royal or sur-royal), and the number of tines recorded. An index of antler size was obtained by

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multiplying antler length by antler circumference and dividing by 1000. This measurement was used rather than antler weight or density because some antlers were attached to the skulls of museum specimens. Samples for chemical analysis were obtained by drilling a small hole through the main antler beam at the mid-point of its length. Plant and soil samples for chemical analyses were collected at random from Gold Bluffs Beach in July 1973. Chemical analyses were performed by the Department of Soils, Water, and Engineering of the University of Arizona. Antler and plant samples were subjected to a perchloric acid digestion for calcium and phosphorus determinations (Horwitz 1975). For the soil sample, calcium was determined by the soluable plus exchangeable method, while phosphorus was determined using the saturated carbon dioxide extraction method (Horwitz 1975).

RESULTS AND DISCUSSION

Bulls were observed chewing bones or antlers on six occasions in June and July, and a cow did so once during August. Osteophagia was observed among 50% of 10 bulls and 5% of 20 cows which comprised the Gold Bluffs Beach herd. Other researchers observed Roosevelt elk cows chewing bones on eight occasions in June and July (Severy, Kitchen, and Mandel, Humboldt State Univ., pers. commun.) and once during December (Harper *et al.* 1967). A yearling male was observed chewing bone in late April (Mandel, Humboldt State Univ., pers. commun.). It appeared all bones and antlers chewed were from elk. Those bones recognized included a scapula, rib, vertebra, lower jaw, and cannon bone. Bones and antlers were never completely consumed by elk. Three bones and an antler examined after elk had chewed them all showed areas where small splinters and chips had been broken away and, presumably, ingested. Elk chewed bones and antlers with their premolars and molars and often turned the object in their mouth while chewing. A cow once temporarily lodged a vertebra in her mouth. The mean length of time elk engaged in osteophagia was 10 min (SD = 5.8 min, range = 5–20 min, N = 7).

Agonistic encounters between bulls over the possession of bones and cast antlers were observed on five occasions during June, and accounted for 16% of observed bull aggression during that month. Aggression over bones or antlers was not observed in other months.

Following the 1972 rut, 5 of 10 bulls sustained breaks of the main antler beam. Severe antler breakage occurred among bulls with small or medium sized antlers, but was not observed in large-antlered males. However, after the 1973 mating season, there were no breaks of the main beam; antler breakage was restricted to tines. Although the sample was small, a highly significant difference occurred in the number of bulls with breaks of the main antler beam between 1972 and 1973 ($X^2 = 6.66$, $P < 0.01$, 1 d.f.). Logsden (cited in McCullough 1969) noted that elk from this area showed little or no antler breakage in 1964. Variability among years in which antlers were broken and the occurrence of osteophagia by bulls just prior to velvet shedding in August, raise the possibility that calcium and phosphorus obtained by this behavior may be related to antler size and strength.

Significant positive correlations were found between antler length and antler basal circumference ($r^2 = 0.43$, $P < 0.01$, 16 d.f.) and between the number of antler tines and antler length ($r^2 = 0.99$, $P < 0.001$, 16 d.f.) (Table 1). The correlation between antler basal circumference and the number of antler tines was not significant ($r^2 = 0.01$, $P > 0.99$, 16 d.f.). Since most of the variation in the number of antler tines was explained by antler length, and number of tines was significantly correlated with the composite variable antler size ($r^2 = 0.39$, $P < 0.05$, 16 d.f.), number of tines was eliminated from further analyses.

TABLE 1. Measurements and Mineral Composition of 17 Roosevelt Elk Antlers

	Mean	*SD*	*Range*
Length (cm)	96.5	11.2	77.6–121.2
Basal circumference (cm)	21.1	2.4	16.5–25.4
Tines (no.)	5.4	0.9	4–7
Calcium content (%)	19.01	3.02	16.63–30.19
Phosphorus content (%)	7.00	0.87	5.51–8.95
Calcium: phosphorus ratio	2.7:1	0.4:1	2.3:1–3.3:1

A significant positive correlation was found between antler size and phosphorus content ($r^2 = 0.26$, $P < 0.05$, 16 d.f.), but there was no correlation between antler size and calcium content ($r^2 = 0.01$, $P > 0.99$, 16 d.f.).

The ratio between calcium and phosphorus, rather than the amount of phosphorus *per se*, may be the critical factor in determining antler size and strength. Unfortunately, no optimum calcium:phosphorus ratio has been established for elk antlers. The four largest elk antlers (length $\overline{X} = 110.7$ cm, SD = 4.5 cm, range = 100.5–121.2 cm; circumference $\overline{X} = 24.5$, SD = 4.3 cm, range = 23.5–25.4 cm; number of tines $\overline{X} = 6.5$, SD = 0.5, range = 6–7) were assumed to be the strongest since main beam breakage did not occur among large-antlered bulls. These four antlers approximated a calcium:phosphorus ratio of 2.5:1. This value was assumed to be favorable for antler growth and strength, and all other ratios were expressed relative to it. When antler size was regressed against the absolute value of the difference of the calcium:phosphorus ratio of 2.5:1, the inverse correlation was significant ($r^2 = 0.26$, $P < 0.05$, 16 d.f.), but explained no more of the variation than did phosphorus content alone. However, antlers from which the mineral samples were obtained came from specimens collected from 1957–1973, and some variation may have resulted from differences in mineral availability between years.

Calcium and phosphorus contents of soil from a prairie area on Gold Bluffs Beach were <0.001% and 0.103%, respectively. Prairie wedge grass, *Sphenopholis obtusata*, had a calcium content of 0.729% and a phosphorus content of 0.103%. The calcium content of red alder leaves was 0.598% and its phosphorus content was 0.174% . The calcium:phosphorus ratio for prairie wedge grass and red alder was 7.1:1 and 2.9:1, respectively. The phosphorus content of prairie wedge grass was identical to the amount of this mineral available in the soil, suggesting the possibility of low phosphorus availability in some forage species.

Care should be exercised in interpreting these data. The true digestibility of phosphorus is quite high in domestic ruminants while a considerably smaller portion of calcium is assimilated (Church 1971). For instance, a broad range of calcium:phosphorus values (1:1 to 7:1) are adequate for growth in domestic cattle and these rations all result in approximately a 2:1 ratio being deposited in bones (Maynard and Loosli 1969). Data relating mineral intake to the final chemical composition of elk antlers are unavailable. Nonetheless, the possibility exists that phosphorus or the proper calcium:phosphorus ratio may be related to antler size and strength, and that elk may supplement their diet by chewing bones and antlers. Calcium:phosphorus deficiencies in livestock typically are corrected by feeding bone meal (Maynard and Loosli 1969).

McCullough (1969) presented the only other information concerning the mineral composition of Roosevelt elk antlers. He found a mean calcium:phosphorus ratio of 1.9:1 for 5 antler samples collected from Prairie Creek Redwoods State Park in 1964. Similarly, the mean ratio for 10 tule elk, *C. e. nannodes*, antlers from Owens Valley, California was 1.9:1 and 5 antlers from the Tupman Reserve in California yielded a mean ratio of 2.0:1 (McCullough 1969). McCullough (1969) suggested that tule elk antlers were predisposed to breakage by low phosphorus levels available in forage, and noted that those elk herds with the highest proportion of phosphorus to calcium in their antlers seemed less prone to antler breakage. The significant correlation between antler size and phosphorus content for Roosevelt elk supports this hypothesis. Moreover, phosphorus is often in limited supply on western ranges (Stoddart, Smith and Box 1975).

An inadequate supply of either calcium or phosphorus in an animal's diet may limit the nutritive value of both minerals (Maynard and Loosli 1969). It is unclear whether phosphorus or the calcium:phosphorus ratio is more important in determining antler size and strength.

Roosevelt elk bulls exhibited a linear dominance hierarchy (Bowyer 1976). High-ranking males of *Cervos elaphus* typically have larger antlers than subordinates, and antler size may be important in the establishment of dominance and ultimately influence breeding success (McCullough 1969, Lincoln 1972, Topinski 1974, Bowyer 1976, Clutton-Brock *et al.* 1979). All agonistic interactions between bulls over possession of bones and cast antlers resulted in subordinates relinquishing these objects or being driven away from them. Minerals obtained by this behavior may be important in antler size and strength and perhaps reproductive success.

Ruminants have high calcium requirements during lactation and phosphorus is needed for the proper growth of young (Maynard and Loosli 1969, Church 1971). Elk cows were nursing calves during June and July when bone and antler chewing was most common, suggesting osteophagia may supplement minerals needed for lactation.

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Literature Cited

Altmann, J. 1974. Observational study of behaviour: sampling methods. Behaviour, 49: 227–267.

Banfield, A.W.F. 1954. Preliminary investigation of the barren ground caribou. Canadian Wildl. Serv., Wildl. Mgmt. Bull., Ser. 1 nos. 10A & 10B. 79 & 112 p.

Bowyer, R.T. 1976. Social behavior of Roosevelt elk during rut. Unpubl. M.S. thesis, Humboldt State Univ., Arcata, 122 p.

Church, D.C. 1971. Digestive physiology and nutrition of ruminants. Nutrition, Vol. 2. D.C. Church and Oregon State Univ. Book Stores, Inc., Corvallis, 801 p.

Clutton-Brock, T.H., S.D. Albon, R.M. Gibson, and F. E. Guiness. 1979. The logical stag: adaptive aspects of fighting in red deer (*Cervus elaphus* L.). Anim. Behav., 27: 211–225.

Dansie, W. 1968. Muntjac pecularities. Deer J. Brit. Deer Soc., 1: 181.

Flerov, C.C. 1952. Musk deer and deer. Fauna of USSR, Mammals. Vol. 1 (New Series). Acad. Sci. USSR. Moscow and Leningrad. Transl., 1960. Natl. Sci. Foundation, and the Smithsonian Inst. Washington, D.C. 275 p.

Franklin, W.L., A.S. Mossman, and M. Dole. 1975. Social organization and home range of Roosevelt elk. J. Mamm., 56: 102–118.

Harper, J.A., J.H. Harn, W.W. Bentley, and C.F. Yocom. 1967. The status and ecology of the Roosevelt elk in California. Wildl. Monogr., 16: 1–49.

Horwitz, W. 1975. Official methods of analysis of the Association of Official Analytical Chemists. 12th Edition, 1094 p.

Krausman, P.R., and J.A. Bissonette. 1977. Bone chewing behavior of desert mule deer. Southwest Nat., 22: 149–150.

Langman, V.A. 1978. Giraffe pica behavior and pathology as indicators of nutritional stress. J. Wildl. Manage., 42: 141–147.

Lincoln, G.A. 1972. The role of antlers in the behavior of red deer. J. Exp. Zool. 182: 233–250.

Maynard, L.A., and J.K. Loosli. 1969. Animal nutrition. McGraw-Hill, New York, 613 p.

McCullough, D.R. 1969. The tule elk: its history, ecology, and behavior. Univ. Calif. Publ. Zool., 88: 1–209.

Murie, O.J. 1935. Alaskan-Yukon caribou. N. Amer. Fauna No. 54, U.S. Dept. Agric., 93 p.

Palmer, L.J. 1926. Progress of reindeer grazing investigations in Alaska. U.S. Dept. Agric. Bull., 1423, 37 p.

Prior, R. 1968. The roe deer of Cranborne Chase, an ecological survey. Oxford Univ. Press, London, 224 p.

Severinghaus, C.W. 1967. Fishy deer. New York State Conservationist, 22: 40.

Skoog, R. 1968. Ecology of the caribou (*Rangifer tarandus granti*) in Alaska. Unpubl. dissertation. Univ. California, Berkeley, 699 p.

Stoddart, L.A., A.D. Smith, and T.W. Box. 1975. Range management. McGraw-Hill, New York, 480 p.

Stone, W.B., and J.R. Palmateer. 1970. A bird ingested by a white-tailed deer. New York Fish and Game J., 17: 3.

Topinski, P. 1974. The role of antlers in establishment of the red deer herd hierarchy. Acta Theriol., 19: 509–514.

Wormell, P. 1969. Red deer (*Cervus elaphus*) as a predator on Manx Shearwater (*Procellaria puffins*). Deer J. Brit. Deer Soc., 1: 289.

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CONCURRENT MEASUREMENT OF INTERTIDAL ENVIRONMENTAL VARIABLES AND EMBRYO SURVIVAL FOR THE CALIFORNIA GRUNION, *LEURESTHES TENUIS,* AND ATLANTIC SILVERSIDE, *MENIDIA MENIDIA* (PISCES: ATHERINIDAE) [1]

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Concurrent daily measurements of environmental variables and embryo survival were made for two atherinid fishes: the California grunion, *Leuresthes tenuis,* observed at Blacks Beach, La Jolla, California; and the Atlantic silverside, *Menidia menidia,* observed at the Point of Pines, Edisto Island, South Carolina. Measurements were made during April 1980.

Both species spawned in the upper intertidal zone on high tides. *L. tenuis* eggs were deposited approximately 4 cm below the beach surface during nighttime. Subsequent sand deposition buried embryos to a depth of approximately 8 cm where they were protected from thermal and desiccation stresses. Daily survival of incubating embryos averaged 97%. *M. menidia* utilized three spawning substrates: (i) abandoned crab burrows, (ii) detrital mats, and (iii) the stems and primary leaves of cordgrass, *Spartina alterniflora.* These substrates provided embryos with varying degrees of protection from thermal and desiccation stresses. Daily survival of embryos located 15 cm deep in abandoned crab burrows averaged 88%. Survival was less, 76%, at the entrance. Daily survival averaged 94% at the surface of detrital mats and at the axis of stems and primary leaves of cordgrass. Survival was lower at other locations on these substrates.

INTRODUCTION

The California grunion, *Leuresthes tenuis,* and the Atlantic silverside, *Menidia menidia,* are rhythmic spawners that deposit their eggs in the upper intertidal zone (Thompson and Thompson 1919, Middaugh 1981). The California grunion spawns in a sand substrate at the approximate time of new and full moons during February through August (Clark 1925, Walker 1952). Spawning runs occur at night and are timed just after the highest high tides during each semilunar period; subsequent high tides and wave action result in deposition of sand over the incubating embryos (Thompson and Thompson 1919, Moffatt and Thomson 1978). Approximately 2 weeks after deposition, developed embryos are washed out of the sand by the next series of high tides of the same or greater height (Shepard and LaFond 1940). The buried embryos are protected from thermal stress and remain relatively moist even though they usually are not inundated for a week or more during incubation (Thompson and Thompson 1919, Walker 1949).

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In contrast, the Atlantic silverside deposits eggs on several intertidal substrates including: (1) abandoned crab burrows along eroding intertidal scarps; (ii) detrital mats; and (iii) the primary leaves and stems of cordgrass plants, *Spartina alterniflora.* Spawning runs occur during daytime high tides. Eggs are deposited at intertidal elevations where they are usually inundated daily during high tide (Middaugh, Scott and Dean 1981). As with *L. tenuis,* maximum intensity spawning runs of *M. menidia* occur every 2 weeks at the approximate time of new and full moons. A high tide-sunrise cue has been suggested as the synchronizer for spawning in *M. menidia* (Middaugh 1981).

Similarities in the reproductive periodicity of these atherinids, and differences in the substrates utilized for egg deposition, prompted a study of intertidal environmental variables and embryo survival of *L. tenuis* and *M. menidia.* During April 1980, daily observations of *L. tenuis* were made at Blacks Beach, La Jolla, California and similar observations of *M. menidia* were made at the Point of Pines, North Edisto River estuary in South Carolina.

MATERIALS AND METHODS

Study Sites

Blacks Beach, La Jolla, California (lat. 32°52′37″, long. 117°15′0″) is located at the base of 50-m high cliffs, about 1 km northwest of the Scripps Institution of Oceanography pier. During the highest-high tides in April 1980, only a narrow section of beach, approximately 2.5 m above mean low water (MLW), was available as a spawning substrate for *L. tenuis.* The Point of Pines, North Edisto River estuary (lat. 32°35′12″, long 80°13′48″) is located on the northeastern end of Edisto Island, South Carolina. Three substrates utilized for spawning by *M. menidia,* abandoned crab burrows, detrital mats, and cordgrass, *S. alterniflora,* all occur along a 100-m section of shoreline at an elevation of approximately 1.8 m above MLW.

Environmental Measurements

Measurements of sand deposition and erosion were made at Blacks Beach. A wooden stake marked at 1-cm intervals was driven into the substrate at the location where females were observed depositing eggs on the nighttime high tide of 17 April 1980. Daily measurements were taken between 1100 and 1300 Pacific Standard Time (PST) to establish the pattern of sand deposition and erosion from 18 to 30 April.

Substrate temperatures were measured at the surface of the beach (0 to 2 cm deep) and at the estimated depth of incubating embryos each day between 1100 and 1300 PST. Two replicate measurements were made at 3 to 5 minute intervals with a YSI telethermometer (mention of trade names does not imply endorsement by the U.S. Environmental Protection Agency or the University of San Diego) and Model 401 probe.

Percentage moisture (g water/kg sand) at the beach surface and depth of incubating embryos was determined by taking a 2.5 cm diameter core, extruding the sample from the coring tube and quickily placing 2.0 cm sections in air tight plastic bags. Samples were taken to the laboratory, weighed, dried for 24 hours at 90° C and reweighed.

A Bailey Instruments Model BAT-4 Laboratory Thermometer with a MT-29/1 microprobe was used to measure substrate temperatures at the following locations on spawning substrates of *M. menidia:* (i) abandoned crab burrows at the lip of the entrance and on the wall 15 cm below the entrance; (ii) detrital mats on the surface and 4 cm below the surface; (iii) *Spartina alterniflora,* at the axis of the stem and primary leaves and 4 cm above it.

Percentage moisture (g water/kg atmosphere) was measured at the locations outlined above (except 4 cm below the surface of detrital mats) with an Atkins Model 90023-30 Digital Psychrometer. Replicate measurements of temperature and moisture were made at 3- to 5-min intervals between 1100 and 1300 Eastern Standard Time (EST).

Where appropriate, paired comparison t-tests were used to test for differences in environmental variables and embryo survival at each location on respective spawning substrates (Sokal and Rohlf 1969).

Embryo Survival

One or two pods of *L. tenuis* embryos were collected daily from 18 to 28 April and microscopically classified as viable or nonviable.

Groups of *M. menidia* embryos were collected from each substrate location from 22 to 28 April. The first 30 embryos from each substrate location, observed with a dissecting microscope, were also classified as viable or nonviable. For the first few days, eggs of each species were classified as viable or nonviable on the basis of similar developmental stages for all individuals. Later, the absence or presence of a heart beat was used to determine viability.

RESULTS

Sand Deposition

There was an overall trend of sand deposition from 18 to 28 April at the intertidal elevation where *L. tenuis* eggs were deposited on the night of 17 April. We estimated that eggs were deposited approximately 4 cm below the beach surface by females (Figure 1). The nighttime high tide on 28 April caused moderate erosion (measured on 29 April); many embryos were presumably washed out of the substrate. Measurements taken on 30 April indicated that a total washout occurred on the nighttime high tide of 29 April when erosion reduced the substrate elevation to approximately 11 cm below the developing embryos (Figure 1). An extensive search between 1100–1300 PST on 29 and 30 April failed to yield embryos from the spawning area of 17 April.

Substrate Temperatures

Substrate temperatures where *L. tenuis* embryos developed were less extreme than on the surface (Figure 2*a*). The maximum temperature at the surface was 40° C; at the depth of embryos, 31° C. During the 12-day incubation period, temperatures at the depth of embryos were significantly lower ($P \leq 0.001$) than at the surface.

Temperatures in abandoned crab burrows utilized as a spawning substrate by *M. menidia* were very uniform (Figure 2*b*). The temperature varied only 6°C at the burrow entrance during embryo development; and 7°C at 15 cm depth. During the 7-day incubation period temperatures were significantly lower ($P \leq 0.05$) at the 15 cm depth than at the burrow entrance. Temperatures were less uniform in detrital mats (Figure 2*c*). The range at the surface was 16°C, maximum temperature 40°C. At 4 cm depth, the temperature range was 13°C and maximum temperature, 34°C. Surface temperatures and those at 4 cm depth in detrital mats were significantly different ($P \leq 0.01$). The harshest environment for embryos was 4 cm above the axis of stems and primary leaves of *S. alterniflora,* where a maximum temperature of 41°C was measured (Figure 2*d*). Temperatures measured at the axis of the stem and primary leaves, and 4 cm high on *S. alterniflora* leaves were not significantly different ($P \geq 0.05$); however, the maximum temperature for the former location was only 36°C.

Figure 1. Egg deposition and subsequent deposition and erosion of sand from Blacks Beach, California. Arrow indicates beach surface on 18 April, 1980.

Percentage Moisture

The moisture content of the sand where *L. tenuis* embryos developed ranged from 1 to 19% (Figure 2*e*). There was no significant difference ($P \leq 0.05$) in the moisture content at the surface (0 to 2 cm deep) and the depth at which embryos developed.

Atmospheric moisture was uniformly high and similar ($P \leq 0.05$) at the entrance and at 15 cm depth in abandoned crab burrows where *M. menidia* embryos occurred (Figure 2*f*). At the surface of detrital mats, moisture was similar to that measured in abandoned crab burrows (Figure 2*g*). No measurements were made at 4 cm depth in detrital mats; however, embryos were always moist at this location and there was no evidence of desiccation. Embryos developing at 4 cm above the axis of stems and primary leaves of *S. alterniflora* were exposed to significantly lower atmospheric moisture ($P \leq 0.001$) than those lower on the plant (Figure 2*h*).

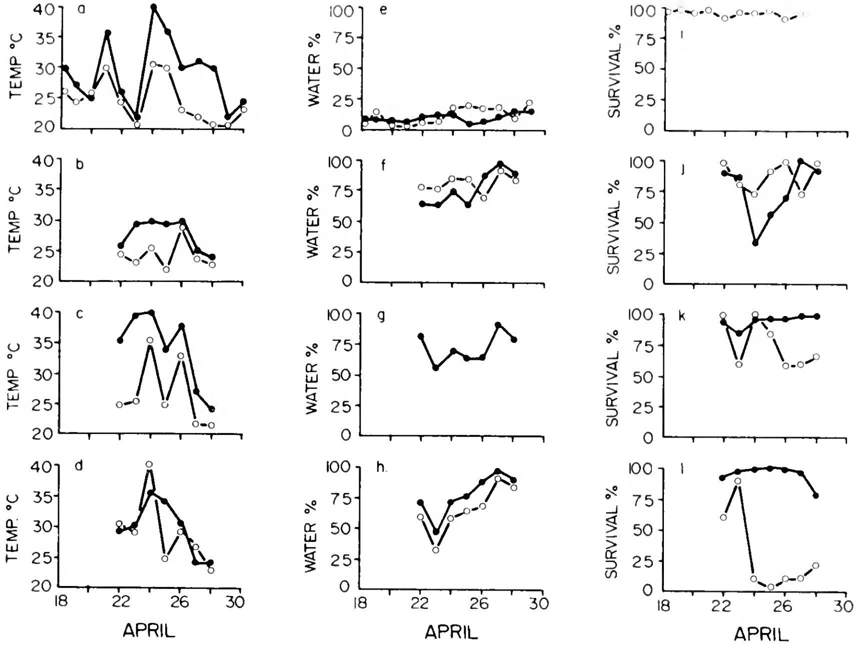

Figure 2. Concurrent daily comparison of environmental variables and embryo survival for the California grunion, *Leuresthes tenuis,* and Atlantic silverside, *Menidia menidia. L. tenuis:* a) beach surface ●—●, depth of embryos ○—○; *M. menidia:* b) burrow entrance, ●—●, 15 cm deep ○—○, c) detritus surface ●—●, 4 cm deep, ○—○, d) primary leaves ●—●, 4 cm high ○—○; *L. tenuis:* e) beach surface ●—●, depth of embryos ○—○; *M. menidia:* f) burrow entrance ●—●, 15 cm deep ○—○, g) detritus surface ●—●, h) primary leaves ●—●, 4 cm high ○—○. *L. tenuis. i) buried embryos ○—○; M. menidia: j) burrow entrance ●—●, 15 cm deep ○—○, k) detritus surface ●—●, 4 cm deep ○—○, l) primary leaves ●—●, 4 cm high ○—○.*

Embryo Survival

L. tenuis embryos showed excellent survival during the 12-day incubation period, daily $\bar{X} = 97\%$ (Figure 2*i*). Although wide daily variations occurred, there was no significant difference ($P \leq 0.05$) in the number of surviving *M. menidia* embryos taken from the entrance or 15 cm depth in abandoned crab burrows (Figure 2*j*). During the 7-day incubation period, survival at the entrance to burrows averaged 76%; at the 15 cm depth, 88%. The number of surviving embryos on the surface of detrital mats was significantly greater ($P \leq 0.05$) than 4 cm deep (Figure 2*k*), even though temperatures were more rigorous at the surface of the mat (Figure 2*c*). Finally, embryos deposited at the base of primary leaves of cordgrass showed significantly better survival ($P \leq 0.01$) than those 4 cm high (Figure 2*l*). Very poor survival in daily samples taken from 24 to 28 April probably resulted from extremely high temperatures on 24 April (Figure 2*d*).

DISCUSSION

The California grunion spawns from February through August, with peak intensity runs from April to June (Walker 1949, 1952). Shepard and LaFond (1940) observed that spawning during April to June ensured against the influence of seasonal cut or fill of the spawning substrate since the primary influence on sand movement during the period was tidal. Earlier in the year, October to February, a combination of physical factors resulted in net loss of sand, whereas later, during July to September, there was net accretion of sand on the beach adjacent to the Scripps Pier. Timing of spawning runs to coincide with the highest high tides or a decreasing tidal series on nights following the highest high tides resulted in deposition of sand over embryos developing in a high-energy environment.

During the present study, *L. tenuis* spawned in the sand of Blacks Beach during the nighttime high tide of 17 April, part of the decreasing tidal series. Subsequent sand deposition buried the embryos to a maximum depth of approximately 8 cm prior to washout (Figure 1). Deposition of sand provided protection from thermal and desiccation stresses and predation. Walker (1949) reported that shore birds, including marbled godwits, *Limosa fedosa,* and Hudsonian curlews, *Numenius phaeopus hudsonicus,* actively probed the sand in search of *L. tenuis* embryos. California gulls, *Larus californicus,* were observed feeding on embryos left at the surface by godwits and curlews. It is likely that birds would find pods of embryos buried to a depth of 7 to 15 cm (Thompson and Thompson 1919 and this study) more difficult to locate than ones 3 to 4 cm deep, the approximate depth of pods immediately after deposition by females. Recently, Moffatt and Thomson (1978) reported that *L. tenuis* egg pods were buried to a depth of 30 cm. At this depth predation would be highly unlikely. Moreover, ambient temperatures and the percentage moisture probably would be more uniform, and less rigorous, than measured in our study.

In contrast, *M. menidia* spawns in a relatively low-energy estuarine environment. Spawning runs occur during daytime high tides in the upper intertidal zone. Although *M. menidia* occasionally spawns aerially at the water's edge, release of eggs and milt usually occurs underwater. Precise timing of spawning to coincide with high tide, when tidal currents are low, probably helped to ensure egg fertilization since eggs and milt would remain in close proximity for a longer period during slack high tide than at times when current velocities are stronger (Middaugh 1981). Recently, Middaugh and Takita (manuscript in preparation) learned that 10-min old *M. menidia* sperm were capable of fertilizing 95% of freshly stripped eggs, but aging of sperm for 20 min reduced the fertilization rate to only 26%.

L. tenuis embryos monitored during this study showed excellent survival. Substrate temperatures where embryos developed ranged from 19° to 32° C, $\bar{X} = 25°$ C. Thompson and Thompson (1919) measured temperatures from 16 to 27° C at a depth of 7 to 15 cm below the surface; concurrent surface temperatures ranged from 15 to 36° C. Our data and those of Thompson and Thompson (1919) are within the thermal limits for *L. tenuis* determined in laboratory studies. Hubbs (1965) reported successful fertilization at temperatures between 12 and 32.5° C; however, hatching occurred only between 14.8 and 26.8° C.

Similarly, Ehrlich and Farris (1971) observed that *L. tenuis* embryos hatched when maintained at 14.0 to 28.5° C. Optimum hatching, close to 100%, occurred between 16.0 and 27.0° C, but dropped off rapidly outside this range. Moffatt (1977) reported a thermal tolerance limit of 18 to 30° C for embryonic development and 50% hatching in *L. tenuis.* Infrequent hatching was noted for embryos maintained at 14° C. Hatched prolarvae showed decreased total length and weight when incubated at temperatures above 25° C. Hubbs (1965) pointed out that embryos incubated at temperatures above 19° C would be able to hatch on the next series of highest tides (approximately 10 to 14 days after they were fertilized). During our study, these high tides occurred 11 and 12 days after eggs were fertilized, i.e., on the nights of 28 and 29 April. No embryo pods were found, despite extensive digging, during daytime (1100–1300 PST) on 29 and 30 April.

Thompson and Thompson (1919) and Walker (1952) reported that *L. tenuis* embryos remained relatively moist even though they had not been covered by high tides for several days. In our study, interstitial water ranged from 1 to 19% (10 to 190 g/kg sand). Sand at the depth of incubating embryos was damp; no desiccation was evident.

Temperatures encountered by developing *M. menidia* embryos were, in general, within their thermal tolerance range. Critical thermal maxima (CTM) tests (Hutchinson 1961) conducted with newly fertilized embryos (0- to 1-cell stage) indicated at least 96% survival up to 38° C, 66% at 39° C, and no survival at 40° C. In tests with embryos in the closure of blastopore stage (19-h post-fertilization at 25° C) and in the onset of circulation stage (48-h post-fertilization at 25° C), the CTM was 42° C (Middaugh, unpubl. data).

M. menidia embryos developing in abandoned crab burrows and detrital mats retained their spherical shape; there was no evidence of extreme desiccation. However, those located 4 cm above the juncture of stems and primary leaves of *S. alterniflora* did suffer desiccation and, apparently, the effects of thermal stress. On 24 April, embroys located 4 cm high on *Spartina* had been distorted to a half sphere by desiccation; one side was dimpled. The cumulative effects of thermal stress, a temperature of 41° C was measured on 24 April, and desiccation resulted in very low survival of embroys sampled on 24 April and subsequent days.

In summary, reproductive tactics of *Leuresthes tenuis* and *Menidia menidia* are remarkably similar. Both species spawn intertidally, generally from March through July. The fortnightly (lunar) spawning periodicity observed in *L. tenuis* (Walker 1949, 1952) apparently has evolved because of the availability of a relatively stable spawning substrate during the highest high tides and decreasing tidal series shortly after new and full moons (Thompson and Thompson 1919). Additionally, deposition and erosion of spawning substrates during April to June is influenced primarily by tidal forces; there is not a long term trend of cut and fill that occurs during other times of the year (Shepard and LaFond 1940).

Menidia menidia also shows a fortnightly periodicity for maximum intensity spawning runs (Middaugh 1981). However, the coincidence of a high tide at the time of sunrise every 2 weeks, at the approximate time of new and full moons, apparently cues the observed periodicity. Deposition of eggs in abandoned crab burrows, detrital mats, or on *Spartina alterniflora* probably occurs because these substrates provide protection from thermal stress, desiccation, and predation.

LITERATURE CITED

Clark, F.N. 1925. The life history of *Leuresthes tenuis,* an atherinid fish with tide controlled spawning habits. Calif. Fish and Game Comm. Bull., 10:1–51.

Ehrlich, K.F., and D.A. Farris. 1971. Some influences of temperature on the development of the grunion, *Leuresthes tenuis* (Ayres). Calif. Fish Game, 57(1):58–68.

Hubbs, C. 1965. Developmental temperature tolerance and rates of four southern California fishes, *Fundulus parvipinnis, Atherinops affinis, Leuresthes tenuis,* and *Hypsoblennuis sp.* Calif. Fish Game, 51(2):113–122.

Hutchinson, V.H. 1961. Critical thermal maxima in salamanders. Physiol. Zool., 2:92–125.

Middaugh, D.P. 1981. Reproductive ecology and spawning periodicity of the Atlantic silverside, *Menidia menidia* (Pisces:Atherinidae). Copeia, 4:766–776.

Middaugh, D.P., G.I. Scott, and J.M. Dean. 1981. Reproductive behavior of the Atlantic silverside. *Menidia menidia* (Pisces:Atherinidae). Environmental Biology of Fishes, 6(3/4):269–276.

Moffatt, N.M. 1977. Thermal effects on the survival and development of embryonic grunions *Leuresthes sardina* and *L. tenuis* Ph.D. Dissertation. University of Arizona, Tucson. 88 p.

Moffatt, N.M., and D.A. Thomson. 1978. Tidal influence on the evolution of egg size in grunions (*Leuresthes,* Atherinidae). Environmental Biology of Fishes, 3(3):267–273.

Shepard, F.P., and E.C. LaFond. 1940. Sand movements along the Scripps Institution Pier. Am. J. Sci., 238:272–285.

Sokal, R.R., and J.F. Rohlf. 1969. Biometry. W.H. Freeman and Co., San Francisco. 776 p.

Thompson, D.A., and J.B. Thompson. 1919. The spawning of the grunion. Calif. Fish Game Comm. Bull., 3:1–29.

Walker, B.W. 1949. Periodicity of spawning by the grunion, *Leuresthes tenuis,* an Atherine fish. Dissertation. Univ. of Calif., Los Angeles. 166 p.

———. 1952. A guide to the grunion. Calif. Fish Game, 38(3):409–420.

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AGE, GROWTH, REPRODUCTIVE CHARACTERISTICS, AND SEASONAL DEPTH DISTRIBUTION OF THE SPOTFIN SURFPERCH, *Hyperprosopon anale* [1]

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Life history information, based on an analysis of museum material, on the age, growth, reproductive characteristics, and seasonal depth distribution of the spotfin surfperch is presented. Females attain mean standard lengths (SL) of 103 mm at age one, 116 mm at age two, and 121 mm at age three. Males grow more slowly. All females produce their first brood at age one. Brood size varies from 4 to 20. Brood size, size of young, and brood wet weight all increase significantly with length of female. The regression of brood size on age is significant; moreover, when used with length, age contributes to the prediction of brood size by multiple regression. Spotfin surfperch occur in offshore waters (depths of 15–64 m) during most of the year but in summer months females migrate inshore and give birth in shallow waters.

INTRODUCTION

Life history variation within the family Embiotocidae is extensive and involves differences in longevity, growth, and reproductive characteristics; however, information on several species is very sparse. To fill one such void for an uncommon species, the spotfin surfperch, we analyzed several large museum samples. DeMartini (1969) summarized information on food habits and feeding morphology of the surfperches. The delicate pharyngeal plates, numerous sharp teeth, and mouth structure of the spotfin surfperch correlate well with the limited information on their diet of small fishes, zooplankton, and benthic crustaceans (Cailliet *et al.* 1977). This species is now known to range from Blanca Bay, Baja California to Seal Rock, Oregon (Miller and Lea 1972). Other published information includes systematic status (Tarp 1952) and distributional records (Gilbert 1915; Roedel 1953; Isaacson and Poole 1965; Miller, Gotshall, and Nitsos 1965; Wydoski 1969). The purpose of this paper is to report life history information on the age, growth, reproductive characteristics, and seasonal depth distribution of this species.

METHODS

All of the fish examined were from museum collections from several locations and years. A large sample, including 92 gravid females (beach seined by W.I. Follett and party at San Simeon on 21 July 1948) was loaned by the California Academy of Sciences (CAS 25471). Other series, beach seined by B. W. Walker and party at San Simeon on 27 June 1949 (W49-161) and on 20 July 1950 (W50-145), were loaned by the Department of Biology, University of California, Los Angeles. An additional 73 specimens trawled in Monterey Bay on 6 August

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1971 were borrowed from California State University, San Francisco; and 18 specimens trawled near the Farallone Islands on 24 February 1971 were borrowed from the Natural History Museum, Los Angeles County (LACM 32654-1). Four Elkhorn Slough specimens were obtained from the teaching collection at the University of California, Davis. All of the specimens examined had been preserved in formalin and transferred to alcohol.

Age and growth rates were estimated from annuli on unregenerated scales. Scales from the left pectoral region were read independently by two observers on a modified microfiche projector (27.5 X); disputed scales were read by a third person. Annuli were considered to be false if they were incomplete or comparable in size to the regenerated portions of adjacent scales, and counts were accepted only if they were the same on two or more scales. Growth rates were estimated by back-calculation (Tesch 1971). To facilitate comparison with other studies, linear equations for converting standard length (SL) to fork length (FL) and total length (TL) were fitted:

$$\mathrm{FL\ mm} = 5.20 + 1.10\ \mathrm{SL\ mm},\ r = 0.99,\ N = 48$$

$$\mathrm{TL\ mm} = 10.20 + 1.13\ \mathrm{SL\ mm},\ r = 0.99,\ N = 48.$$

The fecundity of 46 near-term females was determined by counting embryos. Using stratified sampling, females were selected to cover the range of sizes available; however, females were excluded if their genital aperture indicated that they might have aborted young. Females and their young were measured to the nearest millimetre standard length. The preserved wet weight of the entire brood was determined to the nearest 0.01 g.

RESULTS

Age and Growth

Females attained mean lengths of 103, 116, and 121 mm SL at ages one, two, and three, respectively. The largest female examined was 128 mm SL. The mean SL at age, as determined from the age composition of samples collected during the birthing season and by back-calculation, was obtained (Table 1). Back-calculation appears to greatly underestimate the length at age of near-term females. Most of the 1-year-old females from the San Simeon 1948 collection had not formed an annulus by 21 July. The summer collections we examined contained only nine adult males. One-year-old males were 81 mm SL and 2-year-old males were 83 mm SL. Based on these limited data, it appears that males may grow more slowly and perhaps do not live as long as females.

Brood Characteristics

The number of young in intact broods ranged from 4 to 14 in the samples we examined. All females of age one or older collected during the summer months (June–August) carried young or were spent. The smallest 1-year-old female was 81 mm SL and had a brood of four. Wydoski (1969) reported an unusually large female (161 mm SL; 4 yr) with a brood of 20; however, he did not indicate whether or not this brood was intact. Simple regression analysis of brood size on female SL (Figure 1) indicates that larger females produce larger broods ($y = -13.8 + 0.21x$, $r = 0.873$, $N = 46$, $P < 0.01$). Age does contribute significantly to prediction of brood size by multiple regression when used with SL. The multiple regression coefficients were both positive and significant (slope of age: 1.85, $P < 0.001$; slope of SL: 0.15, $P < 0.001$). The age-specific regression of brood size was significant ($y = 3.0 + 4.1x$, $r = 0.79$, $N = 46$, $P < 0.01$). Mean brood sizes at ages one, two, and three were 7.1, 11.4, and 14, respectively (Table 2); only one female of age three had an intact brood. The brood wet weight (g) increased with female SL (Figure 2; San Simeon 1948: $y = -30.5 + 0.33x$, $r = 0.714$, $N = 29$, $P < 0.01$) and accounted for as much as 26% of total female weight.

TABLE 1. Mean Standard Length (mm) at Age of Female Spotfin Surfperch.

Location	*4 Year*	*Age*	*N*	*Mean SL (± 1 SD)*		
OBSERVED LENGTH AT AGE				1	2	3
San Simeon	1948	1	91	104.3(3.40)		
		2	1		122	
	1949	1	3	94.3(2.52)		
		2	16		120.4(3.37)	
		3	2			127.5(0.71)
	1950	1	6	97.3(2.50)		
		2	1		115	
		3	1			125
Monterey Bay	1971	1	7	95.3(2.43)		
		2	13		110.2(1.69)	
		3	7			118.4(1.90)
Weighted Mean		1	107	103.0		
		2	31		116.0	
		3	10			120.9
Growth Increment				103.0	13.0	4.9
BACK-CALCULATED LENGTH AT AGE				1	2	3
San Simeon	1948	1	8	85.4(9.35)		
		2	1	101.3		
San Simeon	1949	1	0			
		2	16	107.9(3.20)		
		3	2	97.5(4.17)	121.5(0.57)	
Monterey Bay	1971	1	6	76.4(4.72)		
		2	13	89.5(13.05)	97.6(1.49)	
		3	5	78.8(5.52)	91.3(5.27)	104.0(4.29)
Weighted Mean				92.6	98.4	104.0
Growth Increment				92.6	5.8	5.6

TABLE 2. Age-Specific Brood Size of Spotfin Surfperch.

	Age		
	1	*2*	*3*
Sample Means	7.1	11.4	14
SD	1.51	1.74	—
N	36	9	1

The size of young produced seems to increase with female size; however, since parturition occurs earlier in older than in younger females in some embiotocids these trends may not be valid at parturition (Carlisle, Schott, and Abramson 1960). Mean embryo weight (g) increased significantly with female SL (San Simeon 1948: $y = -2.95 + 0.33\ SL$, $r = 0.64$, $N = 29$, $P < 0.01$). Embryo length (Figure 3) also increased with female SL (San Simeon 1948: $y = -25.4 + 0.51x$, $r = 0.633$, $N = 29$, $P < 0.01$). Near-term embryos collected at San Simeon averaged 27% of the SL of their female parents in June 1948 and 26% in July 1949 (range 18–34%).

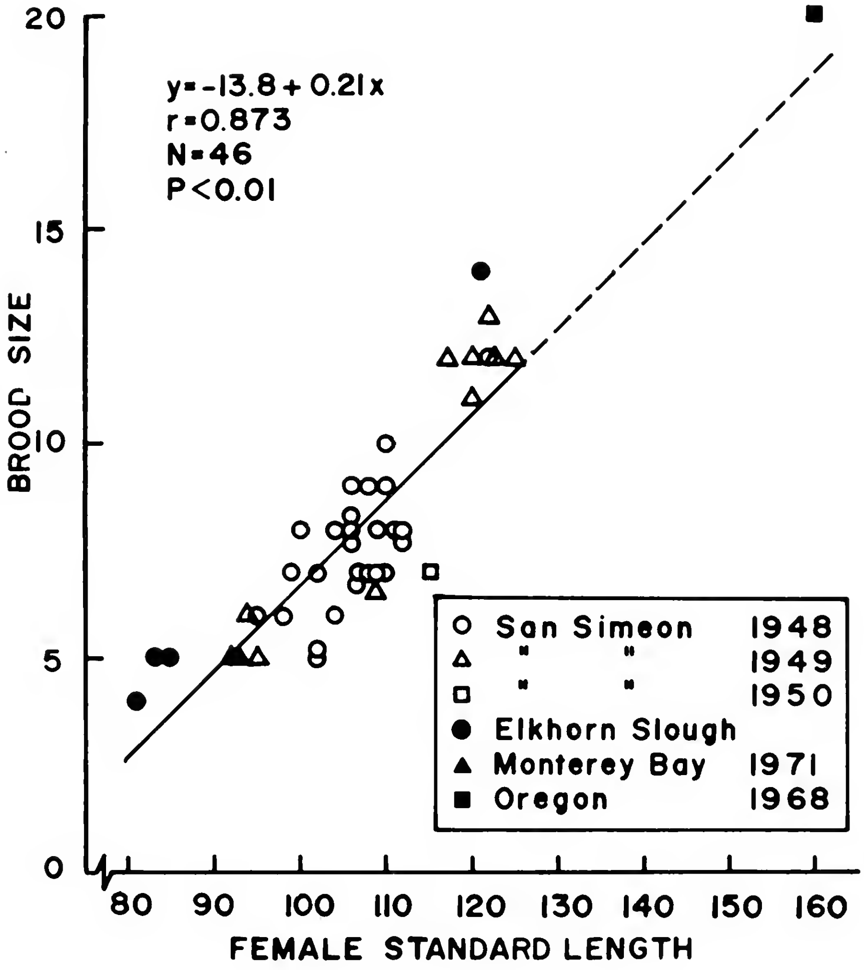

FIGURE 1. The regression of brood size on standard length (mm) of female spotfin surfperch. The Oregon specimen (Wydoski 1969) was not included in the regression.

Seasonal Depth Distribution

A review of depth distribution data for spotfin surfperch suggests that they occupy offshore waters (15–64 m) during most of the year, but in summer months schools composed mostly of females move inshore where the young are born between June and August. Trawl surveys in Monterey Bay indicate that spotfin surfperch are locally abundant during all seasons at survey depths of 15 to 35 m (Kukowski 1973; G. M. Cailliet, Moss Landing Marine Laboratories, pers. commun.); however, catch-per-unit-effort appears to decline between 18 and 30 m. Future studies should document sex-specific differences in distribution and growth rates.

Recent work (Dorn, Johnson, and Darby 1979) comparing the swimming abilities of pregnant and nonpregnant rainbow surfperch, *Hypsurus caryi,* indicates that near-term females are unable to achieve the sustained or burst swimming speeds typical of the species; therefore, they must be at a great disadvantage when trying to avoid predators. This is probably true for all near-term surfperches, and females of many species move inshore or take refuge in turbid bays, eelgrass beds, or other complex habitats where they and their young can better avoid predation. The young can grow more rapidly in a warm, productive habitat. This tendency helps to explain the skewed adult sex ratios seen in many inshore collections of embiotocids; however, the slower growth of male spotfin surfperch suggests that they, like some other male embiotocids, also suffer higher mortality than females (Warner and Harlan 1982). Thus the skewed adult sex ratios observed in spotfin surfperch collections are related to sex-specific differences in distribution and/or mortality.

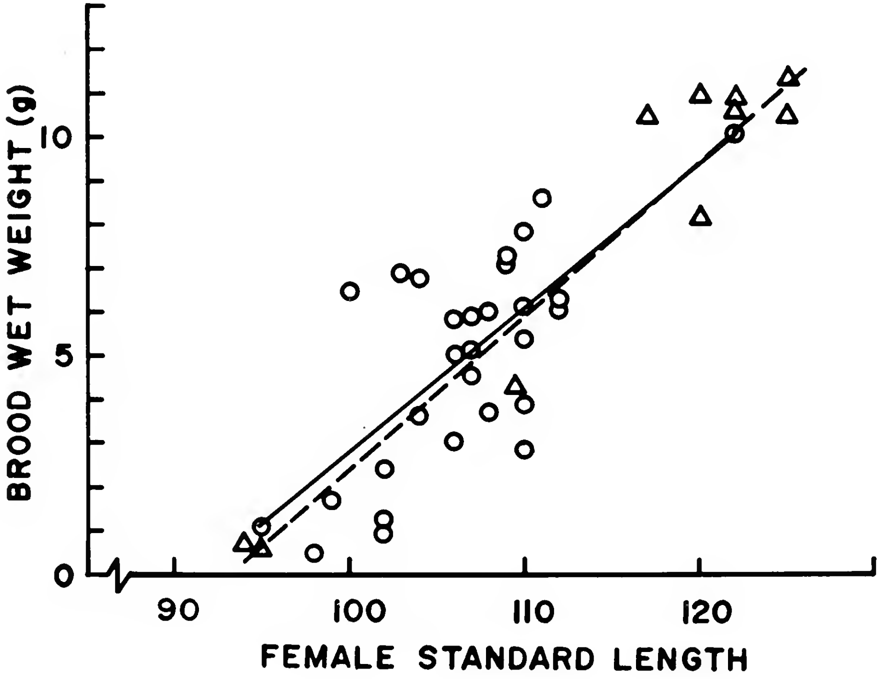

FIGURE 2. The regressions of preserved brood wet weight (g) on female standard length (mm) in two samples of near-term embryos: open circles, solid line, San Simeon 1948 ($y = -30.5 + 0.33x$, $r = 0.714$, $N = 29$, $P < 0.01$); open triangles, dashed line, San Simeon 1949 ($y = -32.7 + 0.35x$, $R = 0.971$, $N = 10$, $P < 0.01$).

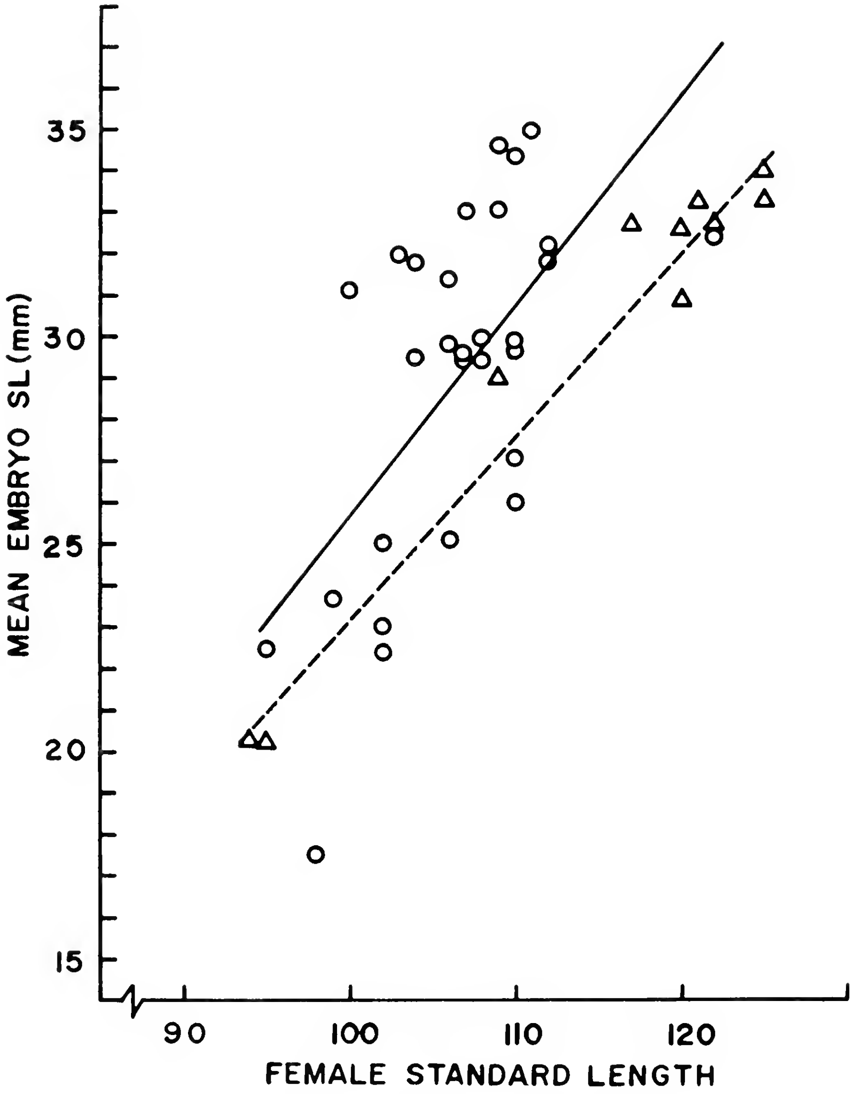

FIGURE 3. The regressions of mean embryo standard length (mm) on female standard length (mm) in two samples of near-term embryos: open circles, solid line, San Simeon 1948 ($y = -25.4 + 0.51x$, $r = 0.633$, $N = 29$, $P < 0.01$); open triangles, dashed line, San Simeon 1949 ($y = -20.8 + 0.44x$, $r = 0.978$, $N = 10$, $P < 0.01$).

DISCUSSION

The life history of the spotfin surfperch is best understood in comparison to what is known of other embiotocids. Miller and Lea (1972) indicated that spotfin surfperch attain a maximum size of 152 mm TL; however, a much larger female (199 mm TL) was reported by Wydoski (1969). Such large individuals are apparently quite rare, and spotfin surfperch are among the smallest embiotocids (Miller and Lea 1972). Generally none of the small species studied, including spotfin surfperch, delay first reproduction beyond age one (Hubbs 1921, Wilson and Millerman 1969, Hayase and Tanaka 1980). However, under some circumstances resulting in poor growth, tule perch, *Hysterocarpus traski,* and shiner surfperch, *Cymatogaster aggregata,* may not produce their first brood at age one (Gordon 1965, Baltz 1980). The increasing trends in age- and length-specific reproductive characteristics, including brood size, size of young, and brood wet weight, found in the spotfin surfperch are typical of most embiotocids. Only the pink surfperch, *Zalembius rosaceus,* does not show a significant increase in brood size with female length (Baltz, unpubl. data) and has a mean brood size of 3.5 (Goldberg and Ticknor 1977). However, the lack of an increasing length-fecundity trend in pink surfperch may be an artifact of capture in deep water since fecund females tend to abort their young. Other small embiotocids have brood sizes comparable to spotfin surfperch (Abe 1969, Wilson and Millerman 1969, Hayase and Tanaka 1980); but tule perch, kelp surfperch, *Brachyistius frenatus,* (Baltz, unpubl. data), dwarf surfperch, *Micrometrus minimus,* and reef surfperch, *M. aurora,* (Hubbs 1921) and one Japanese species, *Ditrema viridis,* (Abe 1969, Hayase and Tanaka 1980) greatly exceed the spotfin surfperch in length-specific fecundity.

Other members of the genus *Hyperprosopon* differ greatly from spotfin surfperch in life history traits. Both the silver surfperch, *H. ellipticum,* and the walleye surfperch, *H. argenteum,* are considerably larger species, maximum length 267 and 305 mm TL, respectively (Miller and Lea 1972). They are also longer lived and may delay first reproduction. Silver surfperch produce their first brood at age two and live for 5 years (Wydoski and Bennett 1973). Walleye surfperch populations near the southern end of their range may attain 170 mm SL, live for 4 or 5 years, and produce their first brood at age one (E.E. DeMartini, Marine Science Institute, U.C. Santa Barbara, pers. commun.); however, females in central California and Oregon attain a larger size (226 mm SL), have higher fecundity and may delay reproduction for one or more years (Baltz, unpubl. data). Based upon the morphological distinctiveness of the spotfin surfperch from other members of the genus, Hubbs, Follett, and Dempster (1979) use the scientific name *Hypocritichthys analis* rather than *Hyperprosopon anale* (W. I. Follett, California Academy of Sciences, pers. commun.). Both life history and morphological variation within the genus deserves further attention.

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LITERATURE CITED

Abe, Y. 1969. Systematics and biology of the two species of embiotocid fishes referred to the genus *Ditrema* in Japan. Japanese Ichthyology, 15(3):105–121.

Baltz, D. M. 1980. Age-specific reproductive tactics and reproductive effort in the tule perch (*Hysterocarpus traski*). Ph. D. dissertation, University of California, Davis. 85 p.

Cailliet, G. M., B. Antrim, D. Ambrose, S. Pace, and M. Stevenson. 1977. Species composition, abundance and ecological studies of fishes, larval fishes, and zooplankton in Elkhorn Slough. Pages 216–386 *in* Nybakken, J., G. Cailleit, and W. Broenkow, eds. Ecological and Hydrographic Studies of Elkhorn Slough, Moss Landing Harbor and Nearshore Coastal Waters. Moss Landing Marine Laboratories, 464 p.

Carlisle, J. G., J. W. Schott, and N. J. Abramson. 1960. The barred surfperch (*Amphisticus argenteus* Agassiz) in southern California. Calif. Dept. Fish and Game, Fish Bull. (109):1–79.

DeMartini, E.E. 1969. A correlative study of the ecology and comparative feeding mechanism morphology of the Embiotocidae (Surf-fishes) as evidence of the family's adaptive radiation into available ecological niches. Wasmann J. of Biol., 27(2):177–247.

Dorn, P., L. Johnson, and C. Darby. 1979. The swimming performance of nine species of common California inshore fishes. Am. Fish. Soc., Trans., 108:366–372.

Gilbert, C. H. 1915. Fishes collected by the United States steamer "Albatross" in southern California in 1904. Proc. U. S. Nat. Mus., 48:305–380.

Gordon, C. D. 1965. Aspects of the life history of *Cymatogaster aggregata*. Thesis, Univ. British Columbia. 90 p.

Goldberg, S. R. and W. C. Ticknor, Jr. 1977. Reproductive cycle of the pink surfperch, *Zalembius rosaceus* (Embiotocidae). Fishery Bull., 75(4):882–884.

Hayase, S. and S. Tanaka. 1980. Growth and reproduction of three species of embiotocid fishes in the *Zostera marina* belt of Odawa Bay. Bull. Japanese Soc. Sci. Fisheries, 46(9): 1089–1096.

Hubbs, C. L. 1921. The ecology and life history of *Amphigonopterus aurora* and other viviparous perches of California. Biol. Bull., 40(4):181–209.

Hubbs, C. L., W. I. Follett, and L. J. Dempster. 1979. List of the fishes of California. Occas. Papers Calif. Acad. Sci., 133. 51 p.

Isaacson, P.A., and R.L. Poole. 1965. New northern records for the spotfin surfperch, *Hyperprosopon anale*. Calif. Fish Game, 51(1):57.

Kukowski, G. E. 1973. Results of the Sea Grant fishes sampling program for the 1971–1972 season. Moss Landing Mar. Lab. Tech. Publ. 73–6, 48 p.

Miller, D.J., D. Gotshall, and R. Nitsos. 1965. A field guide to some common ocean sport fishes of California. Calif. Dept. Fish and Game, Marine Resour. Oper., Sacramento. 87 p.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dept. Fish and Game, Fish Bull., (157):1–235.

Roedel, P.M. 1953. Common ocean fishes of the California coast. Calif. Dept. Fish and Game, Fish Bull., (91):1–184.

Tarp, F.H. 1952. A revision of the family Embiotocidae (the surfperches). Calif. Dept. Fish and Game, Fish Bull., (88):1–99.

Tesch, F. W. 1971. Age and growth. Pages 98–130 *in* W. E. Ricker, ed. Methods for assessment of fish production in fresh waters. IBP Handbook No. 3, Blackwell Scientific Pub., Oxford, England.

Warner, R. R., and R. K. Harlan. Sperm competition and sperm storage as determinants of sexual dimorphism in the dwarf surfperch, *Micrometrus minimus*. Evolution, 36:44–55.

Wilson, D. C., and R. E. Millerman. 1969. Relationships of female age and size in the shiner perch, *Cymatogaster aggregata*. Canada, Fish. Res. Bd., J., 26(9):2339–2344.

Wydoski, R.S. 1969. Occurrence of the spotfin surfperch in Oregon waters. Calif. Fish Game, 55(4):335.

Wydoski, R. S., and D. E. Bennett. 1973. Contributions to the life history of the silver surfperch *Hyperprosopon ellipticum* from the Oregon coast. Calif. Fish Game, 59(3):178–190.

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HAZARDS TO GEESE FROM EXPOSURE TO ZINC PHOSPHIDE RODENTICIDE BAITS [1]

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Enclosure studies were conducted on Canada Geese, *Branta canadensis moffitti,* and White-fronted Geese, *Anser albifrons,* to evaluate bait acceptance and mortality of these species from field exposure to 1% zinc phosphide-treated rodent baits applied at 1, 3, and 10 times the normal application rate of 6.7kg/ha over hay cover crops. Over alta fescue, *Festuca arundinacea,* Canada Geese died at all toxicant levels, but significant weight loss suggested that geese were forced to take bait due to a lack of sufficient quantity of forage. Over alfalfa, *Medicago sativa,* Canada Geese for the most part refused the bait and all survived 4 days of exposure in good condition. White-fronted Geese over a minimal growth of alfalfa consumed sublethal amounts of bait at all treatment levels but survived exposure in good condition.

INTRODUCTION

Zinc phosphide-treated oat groat bait (1%) is commonly used to control populations of voles *Microtus* sp. in western hayfields and certain perennial crops. In the Klamath and Tule Lake basins, on the California-Oregon border, large populations of geese frequently graze baited fields and may become exposed to lethal quantities of bait. During operational baiting programs goose mortality has been attributed to this rodenticide (Mohr 1959, Keith and O'Neill 1964); however, these reports suggest exaggerated or unusual exposures of zinc phosphide bait to geese.

The toxicity of zinc phosphide baits to geese has been demonstrated under laboratory conditions (Anon. 1962). In these tests, Snow Geese, *Chen hyperborea,* and White-fronted Geese died after being force-fed 200–300 kernels of 1% zinc phosphide oat groat bait. Free-feeding studies, however, indicate that zinc phosphide-treated baits are repellent and may act as an emetic to certain species of birds (Siegfried 1968, Hines and Dimmick 1970).

We report here on an evaluation of the potential hazards to two species of geese from exposure to normal and exaggerated application rates of zinc phosphide rodenticide bait under conditions closely simulating those that exist during operational hayfield baiting programs.

METHODS

All field testing was conducted at the Tule Lake National Wildlife Refuge, Tulelake, California. Sixteen Canada and 16 White-fronted Geese were tested in two trials per species of 8 geese each. All geese were wild-trapped adults held in captivity for at least 1 month before testing and fed a ration of domestic goose or rabbit pellets and water *ad libitum.* Canada Geese were exposed to zinc phosphide baits over two types of hay cover: an alta fescue and alfalfa immedi-

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ately after the first hay cutting in July 1976. After cutting, both the fescue and the alfalfa were about 8 cm high. In both White-fronted Goose trials, the birds were exposed to zinc phosphide bait in alfalfa at the beginning of the growing season (April 1977), when alfalfa averaged 2.5 cm high.

For each trial two geese were randomly assigned to each of four (2.4 × 9.8 × 1.2 m) portable enclosures assembled on site from 18 (2.4 × 1.2 m) panels. The panels were constructed of 1.9-cm PVC pipe and 2.5-cm poultry netting and fastened together with 7-cm worm screw-type hose clamps. The enclosures, readily moved by two people, provided 23.5 m^2 of grazing area for each pair of geese.

Geese were acclimated to the enclosures for at least 3 days while their general condition and weight were monitored. During this period the only food provided to Canada Geese in both trials was the hay cover available on enclosure sites. Enclosures were moved daily to provide a new source of forage. Water was provided *ad libitum.* During pretreatment acclimation, White-fronted Geese were maintained in a similar manner except that in the first trial, 100 g and 200 g of alfalfa pellets were offered per day in each of two enclosures, respectively, to assess the need of supplemental feeding over the sparse alfalfa growth.

We formulated the zinc phosphide bait with 1% technical grade (94%) zinc phosphide on oat groats (hulled oats) using 1% lecithin/mineral oil (1:1) as a binder-adhesive and 0.2% Monastral Green B pigment (E. I. DuPont Nemours & Co.) as a coloring agent (reference to trade names or commercial suppliers does not imply endorsement by the U.S. Government). An inert flourescent particle manufactured by Metronics Associates, Palo Alto, California (Tracerite, 0.1%) was used in the bait to determine the relative amount of bait consumed by geese. Previous trials on domestic ducks indicated that these particles were voided within 24 h.

One of three toxicant levels—1, 3, and 10 times (1X, 3X, and 10X) the normal application rate of 6.7 kg/ha (the equivalent of 16, 48, and 160g, respectively, per enclosure site)—was assigned and applied to each site by broadcasting bait with a hand seeder. The fourth enclosure in each series was used as an untreated control (OX).

In the second trial with White-fronted Geese the 3X treatment level was replaced with a 48-g equivalent of twelve 4-g bait spots placed at 1.5-m intervals within the enclosure. Enclosures were moved daily over newly applied bait for 4 consecutive days to provide a constant exposure factor and source of forage. All geese were observed from 3 to 7 days following the last day of bait exposure.

Twenty-four hours after each bait application, body weight and physical condition of geese were observed and the amount of bait remaining in the enclosure was noted. A composite sample of goose droppings was collected from each enclosure site to determine the presence and relative amounts of Tracerite. Each composite goose dropping sample was hand-mixed and a portion of the sample diluted with an equal amount of distilled water. Using a disposable pipette, we transferred each diluted specimen to a glass slide and examined it thoroughly; at least two dilutions were examined to verify the presence or absence of Tracerite. Tracerite levels were ranked by average number of particles per field into five categories.

Geese found dead during trials were weighed, frozen, and shipped to the Denver Wildlife Research Center for gross pathology and residue analysis. Specimens of gizzard and liver were analyzed for zinc phosphide in the form of phosphine (PH_3) by the gas-liquid chromatography method (Okuno, Wilson, and White 1975).

Canada Geese surviving field trials were transported to and held in captivity at the San Joaquin Experimental Range, Madera County, California. Geese were held 7 days for observation on a ration of goose pellets and water. Following the observation period we attempted acute oral LD_{50} determinations for 1% formulated zinc phosphide bait and with technical grade zinc phosphide using a method described by Thompson (1947) and Weil (1952). The technical zinc phosphide was encapsulated in gelatin and introduced into the stomach by means of a plastic tube. Geese were fasted 4 h before dosing, placed in individual cages where they were initially observed for 30 min after dosing, and then observed briefly each day for 7 days after dosing. Two geese were dosed at each of four levels; 8, 12, 18, and 28 mg/kg with technical grade zinc phosphide. Tests with formulated baits were similar except that freshly prepared 1% zinc phosphide bait was administered by stomach tubing. Dosage levels were calculated by grams of bait and administered in equivalent dosages of 12, 18, 28, 42, and 62 mg/kg to each of two geese. Because of the limited number of geese available, most of the geese surviving the formulated bait test were later used in the technical material test 60 days later.

RESULTS

Test 1: Canada Geese

During the pretreatment acclimation before Trial 1, the eight geese feeding on alta fescue stuble lost a mean of 7.3% of their initial body weight (range 0 to 12.5%). However, all geese were healthy and vigorous at the end of the 3-day period and testing was completed without supplemental feeding. During the 4-day exposure period, test geese continued to lose weight and, based on Tracerite analysis, consumed lethal and sublethal amounts of zinc phosphide-treated bait at all toxicant levels (Table 1). Evidence of regurgitation was found in the 3X enclosure 24 h after the first bait application and one of the geese died. Both 10X geese died 24 h following the second bait application and it appeared that most of the bait had been consumed. Following the fourth and last bait application one of the geese in the 1X enclosure died although no tracerite was found in the droppings that day or the previous day. Zinc phosphide residues of 27 ppm and higher were found in the gizzards of all geese found dead (Table 1), but no detectable residues were found in the livers. Gross pathology indicated that all geese were in varying degrees of emaciation and some congestion in the heart and lungs was noted.

During 3 days of acclimation geese feeding on an alfalfa stubble (Trial 2) lost a mean of 1.9% of their initial body weight (range 0 to 6.3%) and testing commenced without supplemental feeding. Geese lost a mean of 3.8% (0.1 kg) of their body weight during the 4-day testing period (Table 2). However, the largest loss was with geese in the control group (0.3 kg) and not the treatment groups. Tracerite analysis revealed that geese refused the bait under this test regime except in one instance.

Table 1. Weight Maintenance, Bait Acceptance, and Treatment Effects of Canada Geese Exposed to 1% Zinc Phosphide Bait Over 8-cm High Alta Fescue (Trial 1).

Treatment level		*Day 0*	*Day 1*	*Day 2*	*Day 3*	*Day 4*	*Mean wt loss (kg)*	*Deaths/ 2 geese*	*Gizzard residues PH_3 (ppm)*
OX (0 kg/ha)	Avg. wt. (kg)	3.6	3.5	3.5	3.6	3.3	0.3	0	—
	Treatment effects	—	—	—	—	—			
	Tracer level [1]	—	0	0	0	0			
1X (6.7 kg/ha)	Avg. wt. (kg)	3.2	3.2	3.1	3.1	2.8	0.4	1	27.0
	Treatment effects	—	none	none	none	death [2]			
	Tracer level	—	+	++	0	0			
3X (20.1 kg/ha)	Avg. wt. (kg)	2.9	2.8	2.8	2.7	2.6	0.3	1	27.0
	Treatment effects	—	death [2,4]	none	diarrhea	none			
	Tracer level [1]	—	++	++++	+	0			
10X (67 kg/ha)	Avg. wt. (kg)	2.9	2.9	2.6	—	—	0.3	2	47.0/ 48.0
	Treatment effects	—	none	death [3]	—	—			
	Tracer level [1]	—	+	++	—	—			
							$\bar{X} = 0.32$		

[1] Tracer level:
0 = no particles found
+ = < 1 particle/field
++ = 1–10 particles/field
++++ = > 20 particles/field

[2] = One death occurred within 24 hours of exposure day.

[3] = Two deaths occurred within 24 hours of exposure day.

[4] = Evidence of regurgitation.

TABLE 2. Weight Maintenance, Bait Acceptance, and Treatment Effects of Canada Geese Exposed to 1% Zinc Phosphide Bait Over 8-cm High Alfalfa (Trial 2).

Treatment level		*Day 0*	*Day 1*	*Day 2*	*Day 3*	*Day 4*	*Mean wt loss (kg)*	*Deaths/ 2 geese*
OX	Avg. wt. (kg)	3.5	3.5	3.4	3.3	3.2	0.3	
(0 kg/ha)	Treatment effects	—	—	—	—	—		0
	Tracer level [1]	—	0	0	0	0		
1X	Avg. wt. (kg)	3.1	3.1	3.1	3.2	2.9	0.2	
(6.7 kg/ha)	Treatment effects	—	none	none	none	none		0
	Tracer level [1]	—	0	0	0	0		
3X	Avg. wt. (kg)	3.5	3.6	3.7	3.6	3.5	0	
(20.1 kg/ha)	Treatment effects	—	none	none	none	none		0
	Tracer level [1]	—	0	+ + +	0	0		
10X	Avg. wt. (kg)	3.7	3.9	3.9	3.8	3.7	0	
(67 kg/ha)	Treatment effects	—	none	none	none	none		0
	Tracer level [1]	—	0	0	0	0		
							$\overline{X} = 0.12$	

[1] Tracer level:
0 = no tracer found
+ + + = 11–20 particles/field

Canada geese surviving both trials showed no effect of treatment during the 7-day post-treatment observation period, and all were healthy and vigorous before the force feeding trials with formulated 1% zinc phosphide bait. Geese survived dosages of grain bait at 1.2 g/kg and 1.8 g/kg or the equivalent of 12 and 18 mg/kg of zinc phosphide. The first death occurred at 2.8 g/kg, or the equivalent of 520 kernels of grain. One of two geese dosed at 2.8 g/kg and 4.2 g/kg died, and both geese died at the 6.2 g/kg dosage. The LD_{50} for formulated bait was calculated with 95% confidence limits at 33.09 (Range = 18.62–58.69) mg/kg. Regurgitation of treated grain was noted at all dosage levels, but became increasingly apparent at the higher levels. All deaths occurred within 18 h after dosing.

Geese fed by stomach tube with technical zinc phosphide died at a minimum dose of 8 mg/kg. One of two geese dosed at 8, 12, and 18 mg/kg died, and both geese dosed at 28 mg/kg died. The acute oral LD_{50} and 95% confidence limits were calculated at 12.00 (Range = 2.94–48.89) mg/kg. Regurgitation was not observed during this test. Deaths occurred within 24 h of dosing except at the 8 mg/kg dose which occurred between 48 and 72 h after dosing.

Test II: White-fronted Geese

After 4 days of acclimation to enclosures, White-fronted Geese showed no improved performance with supplemental feeding; thus supplemental feeding was eliminated during the testing period. All geese maintained their initial body weight during the 4-day testing period. Tracerite analysis indicated that geese at all treatment levels initially consumed sublethal quantities of bait, but consumption appeared to decrease after the first 2 days of exposure (Table 3). All geese survived 4 consecutive days of exposure without weight loss or unusual effects except diarrhea, as noted in the 3X and 10X enclosures on day 2 (Table 3). The second trial with eight White-fronted Geese was a repetition of the first and geese reacted to spot bait and broadcasted treatments in a similar manner. Tracerite analysis indicated that bait was consumed in the 1X enclosure only on day 4 and in the spot bait enclosure on days 1 and 4. In the 10X enclosure sublethal quantities of bait were consumed in decreasing amounts on all 4 days (Table 3). Again, diarrhea was noted in all treatment enclosures, but no other adverse effects were observed.

DISCUSSION

Bait acceptance and mortality varied with differences in cover crops, amounts of standing forage, and bait application rates. Over fescue stubble Canada Geese consumed bait in large enough quantities to cause mortality at all toxicant levels. Timing and number of mortalities per enclosure generally corresponded to the application rate. Continued weight losses before and during treatment suggest that geese were forced to take the grain bait due to lack of sufficient diet on the fescue stubble. In contrast, Canada Geese with an ample diet of alfalfa appeared to refuse bait except in one instance. Some weight loss during this trial did not appear to be treatment related.

White-fronted Geese, although about half the size of the large Canadas, were supplied with about one-third the amount of standing alfalfa forage. Under these conditions the White-fronted Geese appeared to accept sublethal quantities of bait at all treatment levels, but did not consume sufficient quantities to cause

Table 3. **Weight Maintenance, Bait Acceptance, and Treatment Effects of Two Trials with White-fronted Geese Exposed to 1% Zinc Phosphide Bait Over 2.5-cm High Alfalfa.**

Treatment level		*Day 0 Trial*		*Day 1 Trial*		*Day 2 Trial*		*Day 3 Trial*		*Day 4 Trial*		*Deaths/ 4 geese*
		(1)	*(2)*	*(1)*	*(2)*	*(1)*	*(2)*	*(1)*	*(2)*	*(1)*	*(2)*	
OX (0 kg/ha)	Avg. wt. (kg)	1.8	1.9	1.8	1.9	1.8	1.9	1.9	1.9	1.9	1.9	0
	Treatment effects	—	—	—	—	—	—	—	—	—	—	
	Tracer level [1]	—	—	0	0	0	0	0	0	0	0	
1X (6.7 kg/ha)	Avg. wt. (kg)	1.9	1.9	1.9	2.0	2.0	1.9	2.0	1.9	2.0	1.9	0
	Treatment effects	—	—	none	yes [3]	none	none	none	none	none	none	
	Tracer level [1]	—	—	+	0	+	0	0	0	0	+	
3X [2] (20.1 kg/ha)	Avg. wt. (kg)	2.0	1.8	2.1	1.9	2.0	1.9	1.9	1.9	2.0	1.9	0
	Treatment effects	—	—	none	yes [3]	yes [3]	none	none	none	none	none	
	Tracer level [1]	—	—	++++	+	++++	0	+	0	+	++	
10X (67 kg/ha)	Avg. wt. (kg)	1.9	1.7	1.9	1.8	1.9	1.8	1.9	1.8	1.9	1.7	0
	Treatment effects	—	—	none	none	yes [3]	yes [3]	none	none	none	none	
	Tracer level [1]	—	—	++	+++	++	++	+	+	0	+	

[1] Tracer level:
0 = no particles found
+ = <1 particle/field
++ = 1–10 particles/field
+++ = 11–20 particles/field
++++ = >20 particles/field

[2] Spot bait treatment used in Trial 2.

[3] Diarrhea.

mortality even at 10 times the normal application rate. After consuming sublethal quantities of bait, White-fronted Geese appeared to develop an aversion to it after 2 days of exposure. Subacute doses of toxicant did not appear to have visible adverse effects, except for diarrhea, on either species. Apparently diarrhea was the result of ingesting sublethal amounts of the toxicant and was usually associated with the presence of tracerite in the feces. This symptom of zinc phosphide poisoning was observed with domestic fowl and had been attributed to excessive amounts of bile being excreted (Robertson, Campbell, and Graves 1945).

Tests of technical material and formulated bait force-fed to geese indicated that these baits are highly toxic and would present a potential hazard to geese exposed to them. The difference in toxicity between that calculated for technical material and that for formulated baits is not completely known but may be associated with the volume of grain necessary to achieve lethal doses resulting in regurgitation of a portion of the amount of treated grain administered. For this reason we believe the LD_{50} of 12.00 mg/kg for the technical material on the Canada Goose to be more accurate. The LD_{50} for White-fronted Geese is reported to be 7.5 mg/kg and for the Snow Goose, 8.8 mg/kg (Anon. 1962). These indicators of toxicity suggest that all species of geese tested are equally susceptible to poisoning on a per weight basis. However, the minimum lethal dose in kernels of 1% treated grain bait was estimated for White-fronted Geese to be between 200–300 kernels (Anon. 1962), whereas our study with similar procedures indicates that the minimum lethal dose for the larger Canada Geese was about 520 kernels of bait. Further studies with 1% formulated bait (Anon. 1962) indicated that White-fronted Geese died when fed between 50–100 kernels of treated bait for up to 5 days. The high gizzard residues in geese found dead in our study suggest that all died of acute poisoning, although high subacute doses and emaciation may have contributed to mortality.

Our studies suggest that geese under these testing regimes developed an aversion to zinc phosphide-treated bait following ingestion of sublethal quantities. In free-feeding studies with other avian species, Bobwhite Quail, *Colinus virginianus,* (Hines and Dimmick 1970), Crowned Guinea Fowl, *Numida melagris,* and Laughing Doves, *Stigmatopelia senegalensis,* (Siegfried 1968) initially avoided zinc phosphide-treated bait except under extreme food deprivation. Geese, especially White-fronted Geese, did not appear to be as discriminating as seed-eating birds in avoiding treated bait. In part, this may be due to bait being inadvertently ingested while geese grazed on alfalfa.

Zinc phosphide is considered to be a strong emetic (Schitoskey 1975). We were able to document only one instance of regurgitation during field trials, although, based on force-fed trials, we believe it occurred more frequently. In studies with Laced-necked Doves, *Streptopela chinensis,* L. F. Pank (Supervisory Wildlife Biologist, U.S. Fish and Wildlife Service, pers. commun.) conducted both free- and force-feeding tests with zinc phosphide-treated oat groats. Caged doves consistently regurgitated free- and force-fed bait but no other adverse effects were noted. We speculate that the emetic action of zinc phosphide may have initially prevented geese from ingesting lethal quantities of bait and may have been responsible for bait aversion developing later in the test. Regardless of cause and effect, aversion combined with the emetic properties of zinc phosphide may have contributed to the survival of geese exposed to treated bait.

Possibly the most important factor contributing to survival of geese was the availability of a preferred food source. The presence and amount of green forage (alfalfa) appeared to correspond inversely to the amount of treated bait consumed. Two documented cases of significant mortality to geese are reported from the Tulelake and Klamath Basins and illustrate the definite hazards to geese when bait is improperly exposed during periods of relative food scarcity. In 1958 a confirmed loss of 3,676 geese was attributed primarily to 1% zinc phosphide bait used to control voles during one of the worse vole irruptions ever reported (Mohr 1959). During February and March alone, about 68,000 kg of bait were applied, primarily to dormant alfalfa fields, at rates greater than 22 kg/ha. Mechanical broadcasting at excessive application rates was blamed for the mortality, but the limited forage available after a major vole irruption may have been an equally important contributing factor. In late October 1963 a loss of 455 geese was attributed to 1% zinc phosphide-treated bait applied to a barley field in late July and August at the recommended rate of 7 to 9 kg/ha (Keith and O'Neill 1964). Subsequent burning of the field in October exposed residual bait and barley to geese. These documented kills indicate that geese will accept lethal quantities of zinc phosphide-treated bait when it is exposed on essentially bare ground during stress periods.

The overall conclusion from the present study is that zinc phosphide-treated oat groats pose a relatively low hazard to geese if applied over alfalfa at recommended rates during periods when sufficient foods are available; however, the initial acceptance of zinc phosphide-treated bait by geese mandates that reasonable care should be taken to (i) minimize the short- and long-term exposure of bait, especially in fields where geese are not apt to discriminate between bait and residual grain (barley stubble or Alta fescue), and (ii) coordinate bait application with field management regimes insofar as possible until safer rodent control measures are developed.

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LITERATURE CITED

Anon. 1962. Economic poisons (pesticides) investigations. Calif. Dep. Fish Game, Wildl. Invest. Lab. Job Compl. Rep., Pittman-Robertson Wildl. Restoration Proj. No. W-52-B-6. 10 p.

Hines, T., and R. W. Dimmick. 1970. The acceptance by Bobwhite Quail of rodent baits dyed and treated with zinc phosphide. Proc. Annu. Conf. Southeast Assoc. Game Fish Comm., 24:201–205.

Keith, J. O. and E. J. O'Neill. 1964. Investigations of a goose mortality resulting from the use of zinc phosphide as a rodenticide. Unpubl. U.S. Fish Wildl. Serv. Rep. Klamath Basin Refuge. 7 p. (Mimeo)

Mohr, J. 1959. The Oregon meadow mouse irruption of 1957–1958: Influences of the poisoning program on wildlife. Fed. Coop. Ext. Serv. p. 27–34.

Okuno, I., R. A. Wilson, and R. W. White. 1975. Determination of zinc phosphide in range vegetation by gas chromatography. Bull. Environ. Contam. Toxicol., 13(4):392–396.

Robertson, A., J. G. Campbell, and D. Graves. 1945. Experimental zinc phosphide poisoning in fowls. J. Comp. Pathol. Ther., 55:290–300.

Schitoskey, F. 1975. Primary and secondary hazards of three rodenticides to kit fox. J. Wildl. Manage., 39(2):416–418.

Siegfried, W. R. 1968. The reactions of certain birds to rodent baits treated with zinc phosphide. Ostrich, 39(3):197–198.

Thompson, W. R. 1947. Use of moving average and interpolation to estimate median—effective dose. Bacteriol. Rev., 11(2):115–145.

Weil, C. S. 1952. Tables for convenient calculation of median-effective dose (LD_{50} or ED_{50}) and instructions in their use. Biometrics, 8(3):249–263.

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OVA FERTILITY RELATIVE TO TEMPERATURE AND TO THE TIME OF GAMETE MIXING IN THE RED ABALONE, *HALIOTIS RUFESCENS*[1]

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Five test temperatures (9°C, 12°C, 15°C, 18°C and 21°C) were selected along with gamete mixing delays up to 8 h to compare ova fertility in the red abalone, *Haliotis rufescens.* At extreme test temperatures (9°C and 21°C) fertilization success was poor even at short gamete mixing delay intervals. Optimum fertilization success at the time of spawning and for extended gamete mixing delay intervals was at 15°C. Overall, fertilization rate was inversely related to the gamete mixing time delay period.

Comparisons of sperm and ova viability loss, at 15°C, revealed that sperm lost its viability well in advance of ova.

INTRODUCTION

Induced spawning techniques for the red abalone, *Haliotis rufescens,* have been largely perfected by using either heavily ultraviolet irradiated seawater (Kikuchi and Uki 1974*a*) or hydrogen peroxide (Morse *et al.* 1977). However, spawnings may lack synchrony and other factors may intercede causing both a delay in gamete mixing and a loss in gamete viability.

Inoue (1969) and Kikuchi and Uki (1974*b*) reported on the duration of fertility of spawned gametes relative to temperature for Japanese haliotid species. However, such data are lacking for North American haliotids.

The objectives of this paper are (i) to determine gamete viability loss through time relative to spawning onset and gamete mixing, (ii) to determine the relationship of temperature to the aforementioned objective, and (iii) to compare the viability duration of ova and sperm. Such information is considered valuable to the developing abalone mariculture industry in California.

MATERIALS AND METHODS

Adult red abalone came either directly from a wild population or from laboratory cultivate (F_1) stocks. These stocks were maintained and conditioned at the Department's Marine Culture Laboratory (Ebert, Haseltine, and Kelly 1974) where all research was performed. Parent stock was conditioned in ambient temperature (approximately 11-15 C), 15 μm filtered, continuous flowing seawater, with a natural photoperiod. Holding tanks were cleaned and supplied weekly with an excess of fresh giant kelp, *Macrocystis* sp.

Testing was conducted in a lucite plastic water table measuring 2.4 m by 0.5 m by 0.3 m deep. Seven styrofoam containers, each measuring 28.0 cm by 21.0 cm by 26.0 cm deep, were positioned on the holding table to accomodate the culture containers. The latter consisted of 10.2 cm inside diameter PVC pipe sections, 11.4 cm high and screened at the base with 90 μm NITEX® to retain ova and larvae. The containers were placed on plastic grate shelves situtated to

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give each culture container a water volume of 0.5 litre (Figure 1). Filtered seawater (3 μm) was supplied continuously to the seven cultures at a rate of about 200 ml/min. Five test temperatures were used: 9 C, 12 C, 15 C, 18 C and 21 C.

FIGURE 1. Experimental apparatus for holding spawned gametes at test temperatures.

Mature parent stock was selected based on gonadal bulk and color. One male-female pair was used for each test run. Each member of a pair was held separately in a 15-l plastic container.

Spawning was induced by using heavily ultraviolet irradiated seawater (Kikuchi and Uki 1974*a*). We used a REFCO® water purifier, Model RL-10 (REFCO Purification Systems Inc, San Leandro, Calif.) and 3 μm filtered seawater. Water flow from the purifier to each of the parent abalones was maintained at about 150 ml/min. Only synchronous spawners or those that spawned within 30 min of one another were used.

At spawning, about 1,000 ova were pipetted into each of the seven culture containers at the predetermined test temperature, ± 0.5 C. Sperm was collected at spawning, concentrated in a 1 litre beaker (400,000/ml), unaerated, and immersed in a water bath at the test temperature. A 50-ml sperm suspension was added to one culture with ova at spawning and served as a control. Thereafter, 50 ml of sperm suspension was added hourly to successive ova cultures.

Tests to compare sperm and ova viability were conducted similarly; however, they were conducted only at 15 C. Also, one male-female pair was spawned synchronously, followed 3 h and 6 h later by separate male-only spawnings. Ova were distributed in three containers. Sperm from each male was mixed with one of the ova samples at the time of spawning. This gave fresh sperm with 0 h, 3 h and 6 h old ova.

Ova fertilization success was determined microscopically using 100X magnification. Four replicate samples of 30 ova each were used for each determination. Successful fertilization was defined as normal cell cleavage at least to the morula stage. Fertilization was deemed unsuccessful if cleavage did not occur or if cleavage planes were aberrant. Fertilization success means and ranges were calculated.

RESULTS

Thirty-six test runs were conducted from November 1979 through September 1980. Of these, 16 were usable and the remainder rejected. Rejection causes included (i) asynchronous spawning, (ii) one or both sexes failed to spawn, (iii) failure to observe spawning onset, and (iv) insufficient observations following spawning.

Acceptable test runs included six at 15 C, three at 9 C and 21 C, and two at 12 C and 18 C. Four of the 15 C test runs compared ova and sperm viability loss.

Spawning induction time for male abalones exposed to the ultraviolet-irradiated seawater took from 2 h 25 min to 4 h, and averaged 3 h 1 min. Concomitant temperature rise averaged 4.1 C and ranged from 1.0–6.7 C. Spawning induction for female abalones took from 2 h 45 min to 4 h 30 min and averaged 3 h 8 min. Concomitant temperature rise averaged 4.3 C and ranged from 1.3–6.2 C (Table 1).

At both temperature extremes (9 C and 21 C) replicate test runs disclosed rather wide variations. For instance at 9 C and 0 h post spawning, fertilization success ranged from 13% to 97% and averaged 54%; at 21 C and 0 h post spawning, fertilization success ranged from 20% to 85% and averaged 65%. Gamete viability duration was markedly affected by the 21 C temperature and no fertilizations were observed after 1 h. At 9 C fertilization success sharply declined after 1 h post spawning, however some fertilization did occur after 5 h.

The intermediate test temperatures (12 C, 15 C, and 18 C) yielded more uniform results between replicate tests, and significantly better fertilization success at longer time delays in gamete mixing, than did the test temperature extremes. However, variations were apparent at extended gamete mixing delay periods. For example, duplicate test runs at 15 C after a 4 h gamete mixing delay yielded 39% and 92% fertilization success.

Tests to compare sperm and ova viability loss revealed that sperm lost its viability well in advance of ova. For example, 6 h old ova inoculated with a 6 h old sperm suspension resulted in 3% fertilization success. But, 6 h old ova inoculated with a freshly spawned sperm suspension resulted in 72% fertilization success (Figure 2).

TABLE 1. Temperature Rise And Time To Spawning For Sixteen Test Runs Using The Heavily Ultraviolet Irradiated Seawater Spawning Induction Technique.

Test run	*Temperature, C*			*Time to spawning, hr:min*	
	Initial	*At spawning*			
Temp. (C)	*male and female*	*male*	*female*	*male*	*female*
9	12.0	19.0	19.0	2:25	2:45
9	12.0	18.0	18.0	3:00	3:00
9	14.2	19.0	19.0	3:00	3:00
12	11.1	17.0	17.0	2:51	3:20
12	14.0	18.3	18.0	3:00	3:00
15	14.0	18.5	18.5	2:30	3:00
15	14.0	18.5	18.8	2:45	2:45
15[1]	14.0	19.1	19.1	3:30	3:30
15[1]	16.0	19.0	—	2:30	—
15[1]	16.0	19.0	—	2:30	—
15[1]	16.0	19.0	—	—	—
18	12.8	19.5	19.0	4:00	4:30
18	12.5	18.0	18.4	3:00	3:00
21	14.5	17.6	18.0	3:36	3:53
21	17.0	18.0	18.3	3:30	3:30
21	16.0	18.0	18.0	3:10	3:15

[1] Test runs that compared ova and sperm viability loss.

DISCUSSION

Approximately one-half of the test runs were unusable; however, this high rejection rate was generally not attributable to the spawning induction method. In effect, six test runs were rejected because of human factors. For example, insufficient observations after spawning in the sampling time interval resulted from a change in our sampling plan following initial test runs. Also, later in the study period ripe stock became scarce and we had to select from marginally ripe abalones. This resulted in one or both sexes failing to spawn, insufficient spawn or clumpy ova, and accounted for nearly 50% of the rejections.

Although wide variation in fertilization success occurred among replicate samples at test temperature extremes, and at extended gamete mixing delay periods, an inverse relationship was apparent between the fertilization rate and the time of gamete mixing post-spawning. This concurs with the observations of Kikuchi and Uki (1974*b*). However, these investigators used just one pair of abalones, *H. discus hannai.* Possibly some of the variations in fertilization success between our replicate tests were related to genetic differences among the parent stocks. Also, we did not acclimate parent stocks to a uniform temperature prior to spawning induction and the ambient seawater temperature varied nearly 5 C during the study period. This could have imposed additional physiological stress on the gametes depending upon the magnitude of the differential between ambient seawater and the test temperature.

The tests to compare ova and sperm viability loss revealed that sperm viability

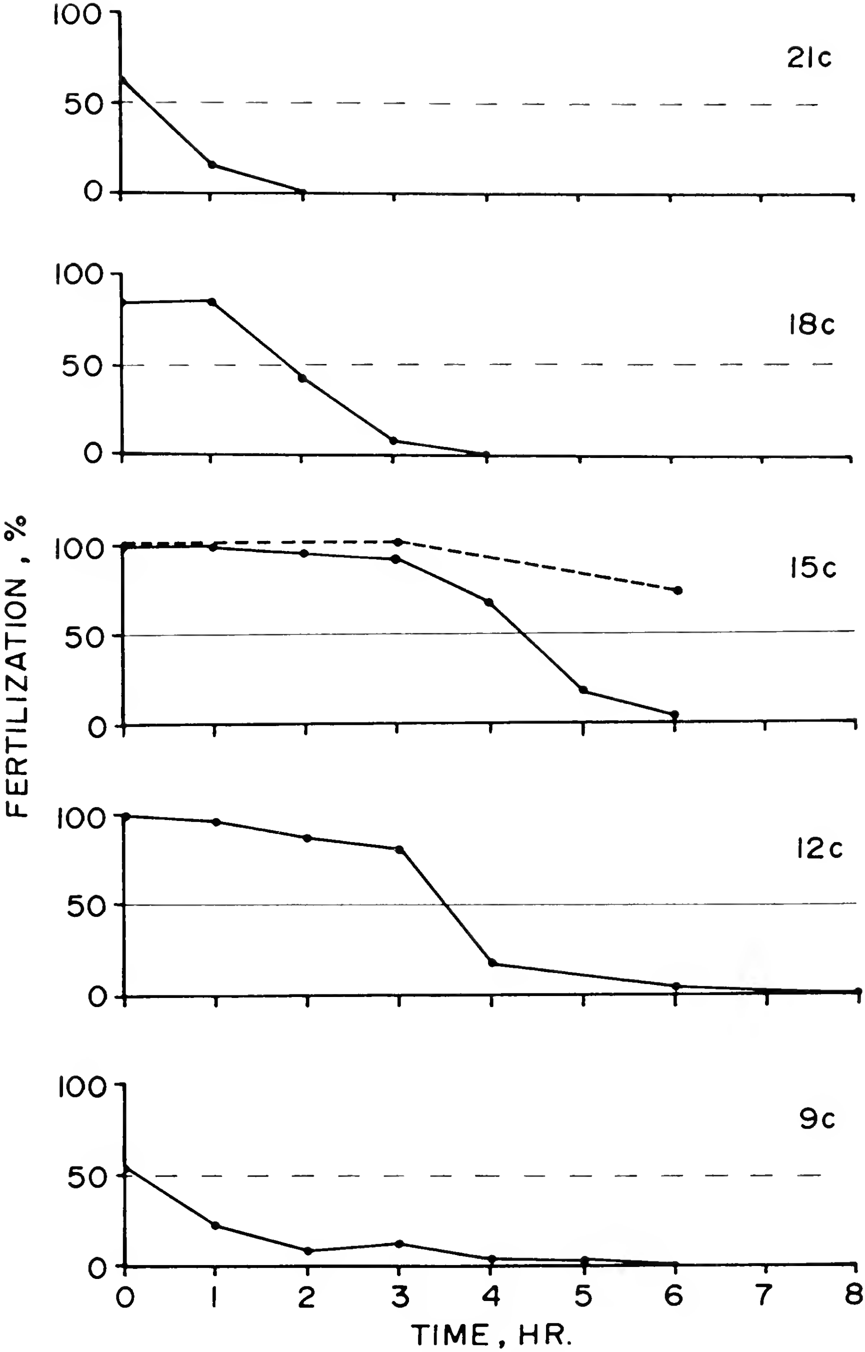

FIGURE 2. Abalone fertilization success (mean %) as a function of temperature and time post-spawning. The dashed line (15 C graph) indicates the fertilization success obtained when newly spawned sperm was added to O h, 3 h and 6 h old ova.

diminished quicker than ova viability. Possibly sperm viability duration can be extended by maintaining them at a reduced density, at a lower temperature, with aeration or some combination of these.

Fifteen C apparently is an optimal temperature for fertilization success at spawning and for gamete mixing delays. We have also found this temperature is optimum for rearing larval and juvenile stage red abalone.

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LITERATURE CITED

Ebert, E. E., A. W. Haseltine and R. O. Kelly. 1974. Sea water system design and operations of the Marine Culture Laboratory, Granite Canyon. Calif. Fish Game, 60 (1):4–14.

Inoue, M. 1969. Mass production and transplantation of abalone. Bull. Kanagawa Fish. Exp. Sta. 131:295–307.

Kikuchi, S. and N. Uki. 1974*a*. Technical study on artificial spawning of abalone, genus *Haliotis* II. Effect of irradiated sea water with ultraviolet rays on inducing spawning. Bull. Tohoku Reg. Fish Res. Lab. 33:79–86.

———. 1974*b*. Technical study on artificial spawning of abalone, genus *Haliotis*. IV. Duration of fertility related to temperature. Bull. Tohoku Reg. Fish. Res. Lab. 34:73–75.

Morse, D.E., H. Duncan, N. Hooker, and A. Morse. 1977. Hydrogen peroxide induces spawning in molluscs with activation of prostaglandin endoperoxide synthetase. Science, 196:298–300.

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NOTES

FIRST CALIFORNIAN RECORD OF THE AMARILLO SNAPPER, *LUTJANUS ARGENTIVENTRIS*

On 21 April, 1977, an amarillo snapper, *Lutjanus argentiventris (Peters),* was caught by a sportfisherman, George Uman, just inside Oceanside Harbor, San Diego County, California, in approximately 1.8 m of water. When received by California Department of Fish and Game personnel, the fish had been eviscerated but was in otherwise excellent condition. The rose-colored front and yellowish posterior portion of the body were still quite distinct and the joined, blue spots just beneath the eye formed a brilliant blue stripe. The fish was 410 mm long and weighed 950 g. Examination of its otoliths revealed six good hyaline (winter) zones and the beginning of an opaque margin (summer growth).

Based upon this specimen, *L. argentiventris* appeared in a checklist of California fishes by Hubbs, Follett, and Dempster (1979) and a list of fishes from the United States and Canada by Robins *et al.* (1980); neither publication gave details of its capture.

One of the most recent publications on reef fishes of the tropical eastern Pacific (Gulf of California) reported that *L. argentiventris* is "the commonest snapper in the Gulf, ranging from Puerto Peñasco to Peru and extending north outside the Gulf to Bahia Magdalena" (Thomson, Findley, and Kerstitch 1979). Fitch's (1952) records from Santa Maria Lagoon, located slightly upcoast from the entrance to Magdalena Bay, do not constitute more northerly captures for the species. The Oceanside fish, however, does represent a northward extension of the range on the outer coast by approximately 1040 km.

Only one other member of family Lutjanidae, *Lutjanus colorado,* has been captured off California (Lehtonen 1979). Therefore it was deemed desirable to offer a few counts and measurements from Mr. Uman's fish (deposited in the fish collection of the Natural History Museum of Los Angeles County—LACM 36943-1) to aid in distinguishing the two species. The following measurements were recorded: standard length 325 mm; head length 119 mm; orbit width 23 mm; snout to pectoral fin insertion 120 mm; snout to pelvic fin insertion 138 mm; snout to dorsal fin insertion 135 mm; snout to anal fin insertion 240 mm; dorsal insertion to pelvic insertion 115 mm; length of pectoral fin 100 mm. Counts were: dorsal X, 14; anal III, 8; pored scales in the lateral line, 39. The vomerine patch of teeth was anchor-shaped with a long posterior extension.

I wish to thank J. Fitch for his guidance, research assistance and editorial help, and H. Frey for suggestions and editorial assistance. C. Avants typed the manuscript from my rather rough draft. I especially wish to thank G. Uman for calling his catch to my attention and for his willingness to part with it for its scientific value.

Literature Cited

Fitch, J. E. 1952. Distributional notes on some Pacific Coast marine fishes. Calif. Fish Game, 38(4):557–564.

Hubbs, C. L., W. I. Follett, and L. J. Dempster. 1979. List of the fishes of California. Calif. Acad. Sci., Occas. Pap., 133:1–51.

Lehtonen, P. B. 1979. Colorado snapper, *Lutjanus colorado,* taken near Morro Bay adds new family (Lutjanidae) to California's marine fish fauna. Calif. Fish Game, 65(2):120–122.

Robins, C. R. (Chairman), R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W.B. Scott. 1980. A list of the common and scientific names of fishes from the United States and Canada (fourth edition). Am. Fish. Soc., Spec. Publ. 12, 174 p.

Thomson, D. A., L. T. Findley, and A. N. Kerstitch. 1979. Reef fishes of the Sea of Cortez. John Wiley & Sons, New York, XVII + 302 p.

—James E. Phelan, California Department of Fish and Game, Marine Resources Region. Accepted for publication June 1982. (After a long illness Jim passed away on 24 Nov. 1982.)

EVIDENCE OF BIRTH OF A SEA OTTER ON LAND IN CENTRAL CALIFORNIA

There has been considerable speculation and some circumstantial evidence suggesting that sea otters, *Enhydra lutris,* in the wild, may give birth on land or in the water. Scammon (1874) states that otter pups ". . . are brought forth upon the kelp . . .". Fisher (1940), referring to the California population, states that parturition takes place in kelp beds. Barabash-Nikiforov (1947), at Mednyi Island, U.S.S.R., observed two sea otters on shore with newborn pups and afterbirth nearby and, therefore concluded that birth takes place on land. Kenyon (1969), in Alaska, determined the orientation of 43 near-term fetuses and found about an equal number of them cephalically or caudally oriented. He suggests that caudal presentation would be adaptive for aquatic birth, and concluded that parturition in sea otters normally takes place on land. Sandegren, Chu, and Vandevere (1973), in California, observed a sea otter in the water with a newborn pup, a bloody ano-genital area and an umbilical cord protruding from the vagina. They subsequently observed the passage of blood and afterbirth into the water and concluded, probably correctly, that the pup had been born in the water. Differences observed in northern versus southern populations were attributed to differences in haulout behavior; northern populations haulout frequently and "California otters are rarely seen ashore" (Sandegren *et al.* 1973).

The following observations were made in my studies of haulout patterns of sea otters. I used a 50 x 80 Questar telescope at a distance of approximately 150 m. Observations were continuous until light conditions precluded seeing the otters. Times are Pacific Standard. Conditions for viewing were excellent with high overcast and calm winds and seas.

On 25 May 1981 at 0831 h an otter with a very small pup was sighted hauled-out on an intertidal reef located approximately 1 km south of Breaker Point, San Luis Obispo Co., California. The female's head, shoulders, and sides were dry, indicating that she had been out of the water for more than a few minutes. She was vigorously grooming a very small pup that was completely wet, showed no signs of life and had small patches of membranous material and blood adhering to its pelage. About 5 cm of the umbilical cord was still attached to the pup's abdomen and 10 to 20 cm of the cord could be seen protruding from the vagina of the female. The female's chest was wet, where the pup lay, as were the flippers and ano-genital area. Based on these observations I estimated that the pup had been born within a few minutes of being sighted.

After approximately 2 minutes of grooming by the female the pup began to show signs of life by weakly moving its flippers and head. At 0846 h a membranous bag (about 10 cm in diameter) filled with fluid protruded from the vagina.

At this point the female, lying supinely, stopped grooming the pup, rolled forward and bit the sack which ruptured and released the fluid. She immediately resumed grooming the pup and continued uninterrupted for 98 min. In the total observation period (432 min) the female groomed the pup 70% of the time, rested for 26% and self-groomed for only 4% of the period. After the continuous 98 min pup-grooming session, grooming bouts were shorter, ranging from one to 45 min. Self-grooming bouts were short (3–8 min) and infrequent. Rest periods were short (21–31 min), but were more frequent.

At 0944 h, 73 min after observations began, the placenta and associated tissues were passed in less than 3 sec. The female paid no attention to the afterbirth which was quickly dragged away and consumed by an attending western gull, *Larus occidentalis.* In the remainder of the observation period, no further material passed from the female and the vulva appeared clean.

By 0930 h the pup was dry and fluffy and could move all four legs and weakly shake its head. Several times the pup was in a position where nursing could have occurred; it nuzzled the female's fur, but I saw no suckling. When the female was self-grooming, and occasionally during rest periods, the pup was placed on the algae covered rocks, but 83% of its time was spent on the female's chest and abdomen.

These observations reveal some interesting aspects of the behavior of parturient sea otters in California. The mother spends much of the time grooming the neonate. This probably has several functions, i.e. cleaning, stimulating circulation and breathing of the newborn, and possibly establishing and reinforcing the maternal bond. Birth sometimes occurs on land. In this instance there were no nearby large expanses of giant kelp, *Macrocystis pyrifera.* The dominant kelp is bull kelp, *Nereocystis lutkeana,* which in this area does not form a dense surface canopy until July. In such areas pupping on land may occur, and in areas where beds of kelp persist throughout the year, aquatic births (as reported by Sandegren *et al.* 1973) may be common. Therefore, environmental differences and individual variation are probably more important in determining the place of parturition in sea otters than are behavioral differences between populations.

LITERATURE CITED

Barabash-Nikiforov, I. I. 1947. Kalan (The sea otter, in Russian, translated by Dr. A. Birron and Z. S. Cole, 1962) Israel Program for Scientific Translations, Jerusalem. 227 pp.

Fisher, E. M. 1940, Early life of a sea otter pup. J. Mammal., 21(2):132–137.

Kenyon, K. W. 1969. The sea otter in the Eastern Pacific Ocean. N. Amer. Fauna. 68. U.S. Gov. Printing Off. Washington, D.C. 352 pp.

Sandegren, F. E., E. W. Chu, and J. E. Vandevere. 1973. Maternal behavior in the California sea otter. J. Mammal., 54(3):668–679.

Scammon, C. M. 1874. The marine mammals of the northwestern coast of North America. John H. Carmany, San Francisco. 319 pp.

— *Ronald J. Jameson, U.S. Fish and Wildlife Service, P.O. Box 67, San Simeon, CA. 93452.* *Accepted for publication October 1981.*

AGE AND GROWTH AND LENGTH-WEIGHT RELATIONSHIP FOR FLATHEAD CATFISH, *PYLODICTIS OLIVARIS,* FROM COACHELLA CANAL, SOUTHEASTERN CALIFORNIA

Flathead catfish were introduced in 1962 into Martinez Lake, Arizona, on the lower Colorado River (Anonymous 1980). They quickly spread into canals of the Imperial Valley, California (Bottroff, St. Amant, and Parker 1969), and upstream in the river to Parker Dam (Minckley 1973). To date, nothing has been published on age and growth or length-weight relationship of the species from this area. Flathead catfish are native to the Río Grande-Mississippi River complex of central North America (Glodek 1980).

METHODS AND MATERIALS

Three sections of the Coachella Canal (T11S, R15E, and T15, R19E, San Bernardino Meridian) were blocked by 2.5-cm-mesh nets prior to a water outage (Minckley 1981). When water levels receded, sections were further isolated by earthen dikes. A concrete box siphon that comprised one study section was breached and water was pumped from the structure to allow access and sampling. Emulsifiable rotenone was applied to all sections at greater than 2.5 mg/liter active ingredients and affected fishes were collected by nets and seines.

Fish were measured to the nearest centimetre from the tip of the lower jaw to the tip of the caudel fin and weighed in pounds (later converted to metric system) in the field. Fish less than 15 cm long were preserved in 10% formalin for analysis in the laboratory. No adjustments were made for possible changes in length or weight following preservation.

Pectoral spines were disarticulated and excised, dried after removal of soft tissues in dilute potassium hydroxide, and sectioned with a jeweler's saw following procedures of Turner (1977). Thin sections were polished on emery paper and examined under alcohol and reflected light with a binocular microscope. Spine diameters at the point of sectioning were measured to the nearest 0.1 mm by Vernier calipers; anterior radius and anterior radius to each annulus were recorded to the nearest 0.01 mm by ocular micrometer.

Back calculation of lengths at consecutive annuli was by the equation:

$$L' = C + S'/S(L - C),$$

where L' is fish length when annulus "x" was formed, L is the length at capture, S' is the anterior spine radius at the n^{th} annulus, S is total anterior spine radius, and C is the intercept value from least squares linear regression of fish length and spine diameter at the point of sectioning. Size-frequency distribution clearly segregated fish of Age Group 0, and this was verified by examination of spines from 10 young-of-the-year fish of varying lengths.

RESULTS AND DISCUSSION

Flathead catfish comprised about 1.0% (94 specimens) of about 9,000 fishes taken in sampling from the Coachella Canal (Minckley 1981). Other abundant fishes included channel catfish, *Ictalurus punctatus;* bluegill, *Lepomis macrochirus;* largemouth bass, *Micropterus salmoides;* threadfin shad, *Dorosoma petenense;* red shiner, *Notropis lutrensis;* and carp, *Cyprinus carpio.* All are included, when of appropriate size, in the diet of flathead catfish in the lower Colorado River (Minckley 1982). Fishes were abundant, with 0.55 to 1.08 individuals $/m^2$ recovered. Biomass also was high, with 49.4 and 102.0 g/m^2 in the two samples from the open canal, and 593.9 g/m^2 in the siphon (25% of the latter were flathead catfish; Minckley 1981).

Spine diameter at the point of sectioning correlated highly (r = 0.98) with length of flathead catfish, with the regression described by the formula $Y = 13.6 + 137X$. Calculated lengths at each annulus (Table 1) compared favorably with age groups indicated by length-frequency distribution (Figure 1), and with lengths at capture of the next youngest year classes. Since no indications of annuli were near spine edges of any age group, the fish would presumably have grown prior to annulus formation in January (the coolest month in the region; Jaeger 1957) to approximate calculated lengths at annuli. Length-weight relationship is described by the formula $\mathrm{Log}\ W = -5.2500 + 3.1441\ \mathrm{Log}\ L$.

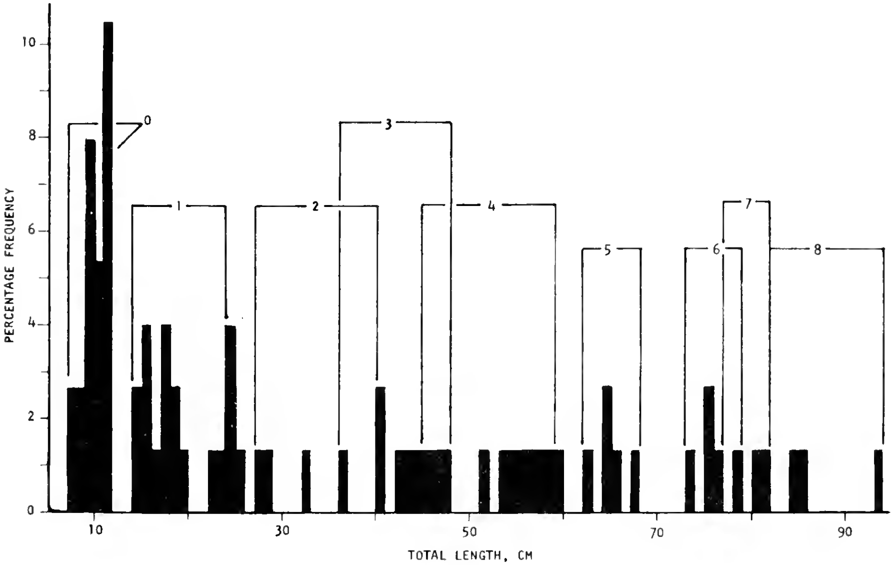

FIGURE 1. Size frequency distribution of 75 flathead catfish from the Coachella Canal, California. Numbered brackets indicate ranges in total length at capture for fish aged by examination of pectoral spines. Some lack of correspondence with Table 1 results from additional fish being included here.

Growth rates of flathead catfish from the Coachella Canal were comparable to, or exceeded, those in reservoirs and rivers within their native range (Table 2). Their length-weight relationship is, expectedly, more like riverine populations than those in reservoirs.

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Table 1. Computed Lengths at Consecutive Annuli for 66 Flathead Catfish From the Coachella Canal, Southeastern California (means ± one standard error)

Age Group	Number Fish	TL at Capture	TL Range at Capture	*Average Calculated Total Lengths (mm)* 1	2	3	4	5	6	7	8
0	22	95	70–114	–	–	–	–	–	–	–	–
		±14.1									
I	10	205	148–241	120	–	–	–	–	–	–	–
		±29.4		±24.3							
II	3	331	279–395	101	237	–	–	–	–	–	–
		±58.7		±37.4	±45.0						
III	6	425	360–470	107	235	389	–	–	–	–	–
		±43.3		±22.4	±48.9	±44.5					
IV	10	532	445–590	143	247	370	482	–	–	–	–
		±50.6		±45.4	±60.2	±70.3	±61.3				
V	5	642	620–670	148	253	410	508	577	–	–	–
		±18.2		±38.1	±36.2	±93.1	±51.3	±30.5			
VI	4	754	730–780	112	207	264	508	620	693	–	–
		±21.4		±12.8	±12.8	±52.0	±128.0	±75.8	±55.8		
VII	2	783	770–795	127	230	352	404	509	619	721	
		±17.7		±19.8	±52.0	±28.9	±16.3	±25.5	±10.6	±15.6	
VIII	4	864	810–930	123	269	428	532	605	682	742	800
		±51.5		±37.8	±124.6	±60.3	±59.2	±36.1	±51.8	±45.5	±36.1
Total	66	–	–	123	240	382	487	578	665	732	800
				±16.5	±19.5	±31.7	±49.5	±49.2	±39.9	±14.8	±36.1
Average Annual Increment		–	–	123	117	143	105	91	87	67	68

Table 2. Comparative Data on Age and Growth, and Length-Weight Relationship of Flathead Catfish

Location	*Reference*	*Mean Total Lengths (mm) at consecutive annuli*								
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*No.*
21 Oklahoma Lakes	McCoy 1953	117	246	386	508	594	658	734	824	723
Upper Grand Lake, OK	Jenkins 1954	86	175	387	411	465	544	625	–	61
Lower Grand Lake, OK	Jenkins 1954	64	127	185	259	340	386	455	442	59
Kansas River, KS	Cross and Hastings 1956	210	254	387	622	648	819	850	1,022	39
Neosho River, KS	Minckley and Deacon 1959	97	226	320	391	437	–	–	–	79
Blue River, KS	Minckley and Deacon 1959	142	262	366	483	630	701	773	–	74
Lake Carl Blackwell, OK	Turner 1977	58	117	198	309	446	549	623	678	146
Coachella Canal, CA	1980	123	240	382	487	578	665	732	800	66

		Length-weight relationships
21 Oklahoma Lakes	McCoy 1953	$\log W = -4.9738 + 3.2550 \log L$
Upper and lower Grand lake, OK	Jenkins 1954	$\log W = -4.9170 + 3.2331 \log L$
Blue and Neosho rivers, KS	Minckley and Deacon 1959	$\log W = -5.3873 + 3.0990 \log L$
Coachella Canal, CA	1980	$\log W = -5.2500 + 3.1441 \log L$

LITERATURE CITED

Anon. 1980. Special report on distribution and abundance of fishes of the lower Colorado River. Final Rept. U.S. Bureau Reclamation, Boulder City, Nev., Contr. No. 9-07-03-X0066, U. S. Fish Wildl. Serv., Phoenix, Ariz. ii + 157 p.

Bottroff, L., J. A. St. Amant, and W. Parker. 1969. Addition of *Pylodictis olivaris* to the California fauna. Calif. Fish Game, 55(1):90.

Cross, F. B., and C. E. Hastings. 1956. Ages and sizes of thirty-nine flathead catfish. Kans. Acad. Sci., Trans. 59(1):85–86.

Glodeck, G. S. 1980. *Pylodictis olivaris* (Rafinesque), flathead catfish. p. 472, *in* D. S. Lee, *et al.,* eds. Atlas of North American Freshwater Fishes. N. C. State Mus. Nat. Hist., Raleigh, N. C. x + 854 p.

Jaeger, E. C. 1957. The North American Deserts. Stanford Univ. Press, Stanford, Calif. x + 308 p.

Jenkins, R. M. 1954. Growth of the flathead catfish, *Pylodictis olivaris,* in Grand Lake, Oklahoma. Okla. Acad. Sci., Proc., 33(1): 11–20.

McCoy, H. A. 1953. The rate of growth of flathead catfish in twenty-one Oklahoma lakes. Okla. Acad. Sci., Proc., 34(1): 47–52.

Minckley, W. L. 1973. Fishes of Arizona. Ariz. Game Fish Dept., Phoenix, Ariz. xvi + 293 p.

———. 1981. Fishery inventory of the Coachella Canal, southeastern California. Final Rept. U. S. Bureau Reclamation, Boulder City, Nev., Purch. Ord. No. 1-01-30-04780, Ariz. State Univ., Tempe, Ariz. ii + 25 p.

———. 1982. Trophic interrelationships among introduced fishes of the lower Colorado River, southwestern United States. Calif. Fish Game, 68(2): 78–89.

Minckley, W. L. and J. E. Deacon. 1959. Biology of the flathead catfish in Kansas. Amer. Fish. Soc., Trans., 88(4): 344–355.

Turner, P. R. 1977. Age determination and growth of flathead catfish. Unpubl. Dissertation. Okla. State Univ., Stillwater, Okla. 146 p.

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