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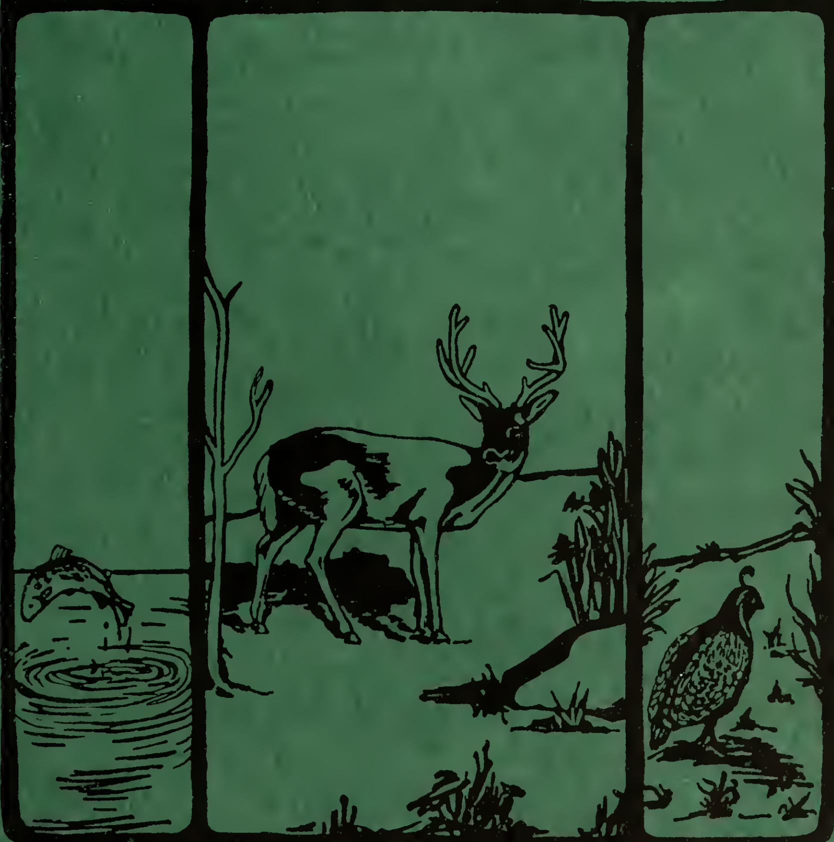

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CONTENTS

Page

Estimated Safe Copper and Zinc Levels for Chinook Salmon, *Oncorhynchus tshawtscha,* in the Upper Sacramento River California .... B. J. Finlayson and K. M. Verrue 68

Age and Growth of White Sturgeon Collected in the Sacramento-San Joaquin Estuary, California: 1965–1970 and 1973–1976 .... David W. Kohlhorst, Lee W. Miller, and James J. Orsi 83

Diets of Mountain Whitefish, *Prosopium williamsoni* (Girard), and Brook Trout, *Salvelinus fontinalis* (Mitchell), in the Little Walker River, Mono County, California .... John Paul Ellison 96

The Use of Road-killed Deer for Assessing Reproductive Potential and Winter Condition of the Devil's Garden Interstate Mule Deer Herd .... Hal Salwasser, Douglas J. Thayer, and D. Lewis Young 105

The Littoral Bottom Fauna of High Elevation Lakes in Kings Canyon National Park .... Timothy P. Taylor and Don C. Erman 112

Notes

A Blue Catfish from the Sacramento-San Joaquin Delta .... Thomas L. Taylor 120

First California Record: The Scalloped Hammerhead Shark, *Sphyrna lewini,* in Coastal Santa Barbara Waters .... Craig Fusaro and Shane Anderson 121

The Bigscale Goatfish, *Pseudupeneus grandisquamis* (Gill, 1863), Added to California's Marine Fauna ....John E. Fitch 123

Notes on the Establishment of the Rainwater Killifish, *Lucania parva,* in California .... Michael J. McCoid and James A. St. Amant 124

Book Reviews 126

Calif. Fish and Game 66(2): 68–82 1980

ESTIMATED SAFE ZINC AND COPPER LEVELS FOR CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA,* IN THE UPPER SACRAMENTO RIVER, CALIFORNIA [1]

B. J. FINLAYSON AND K. M. VERRUE
California Department of Fish and Game
Water Pollution Control Laboratory
2005 Nimbus Road
Rancho Cordova, California 95670

Long-term (83-d) and short-term (96-h) toxicity tests with combined copper and zinc solutions were conducted on chinook salmon, *Oncorhynchus tshawytscha,* eggs, alevins, and swim-up fry to determine tolerance levels to copper and zinc in the acid-mine waste from Spring Creek, a tributary to the Sacramento River. The ratio of copper-to-zinc in the waste can vary between 1:2 and 1:12. Eggs were just as tolerant or more tolerant than alevins and fry to combined concentrations of copper and zinc. The 83-d LC50 values (median lethal) for the period of eggs-to-fry to 1:3, 1:6, and 1:11 copper-to-zinc ratio stock solutions were 44 μg/l Cu and 160 μg/l Zn, 27 μg/l Cu and 206 μg/l Zn, and 17 μg/l Cu and 253 μg/l Zn, respectively, demonstrating that the toxicities of copper and zinc were "additive". The 96-h LC50 values for fry not previously exposed to the stock solutions were 37 μg/l Cu and 132 μg/l Zn, 29 μg/l Cu and 213 μg/l Zn, and 20 μg/l Cu and 279 μg/l Zn, for the same copper-to-zinc ratio stock solutions, respectively, demonstrating that an acclimation to these metals had occurred in the 83-d tests during embryonic and alevin development at the higher (1:3) copper-to-zinc ratio but not at the lower (1:6 and 1:11) copper-to-zinc ratios. Based on reduced growth of exposed fry for the period of eggs-to-fry, estimated "safe" levels of copper and zinc for chinook salmon would be below 11 and 83 μg/l, respectively.

INTRODUCTION

The acid-mine waste from the Spring Creek drainage (Figure 1) has caused numerous kills of anadromous and resident salmonid fishes in the upper Sacramento River between Keswick Reservoir and Cottonwood Creek, California (U.S. Fish and Wildlife Service 1959; Prokopovich 1965; Nordstrom 1977). Of the fishes affected by the waste, anadromous chinook salmon are of particular concern since they are both a recreationally and commercially valuable species, and the carrying capacity of the spawning areas in the upper Sacramento River below Keswick Dam fail to reach their anticipated levels. Since 1963, the waste has collected in Spring Creek Reservoir and been metered into Keswick Reservoir. The flow of the waste through the Spring Creek Diversion Dam is determined by the amount of "dilution" water originating from Shasta Lake. From 1963 through 1978 this water quality management program was based on dilution factors calculated by Lewis (1963) using waste copper concentrations as criteria. Finlayson and Ashuckian (1979) listed six theoretical reasons why these dilution factors had not provided for adequate protection of salmonid resources in the upper Sacramento River and further demonstrated that these factors could potentially allow very toxic concentrations of zinc to enter the Sacramento River. The factors did, however, provide borderline protection for steelhead trout, *Salmo gairdneri,* against acute copper toxicity.

[1] Accepted for publication September 1979.

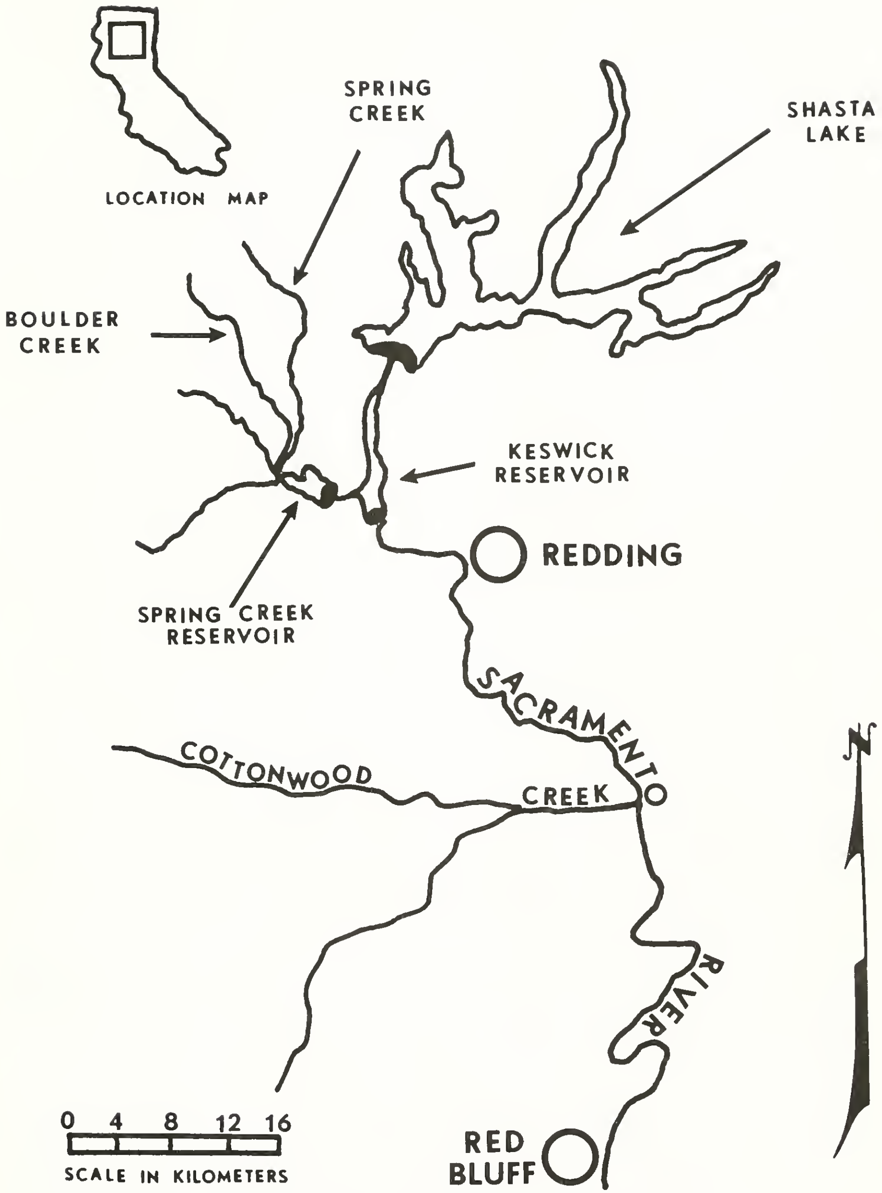

FIGURE 1. Location of Spring Creek drainage, upper Sacramento River basin, California

Finlayson and Ashuckian (1979) investigated the toxicity of the Spring Creek waste to steelhead trout eggs, alevins, and swim-up fry, and concluded that the toxicity of the waste was entirely due to its copper and zinc content and not to the other metals (aluminum and iron) present. Much information is available regarding the toxicities of zinc (Nehring and Goettl 1974; Sinley, Goettl, and Davies 1974; Lorz and McPherson 1977; Chapman 1978; Chapman and Stevens 1978; Lorz, Williams, and Fustish 1978), copper (Hazel and Meith 1970; McKim and Benoit 1971; Chapman and McCrady 1977; Lorz and McPherson 1977; Chapman 1978; Chapman and Stevens 1978; Lorz et al. 1978), and their combinations (Lloyd 1961; Sprague 1964; Sprague, Elson, and Saunders 1965; Sprague and Ramsey 1965; Thomsen, Hazel, and Meith 1970; Lorz et al. 1978) to salmonids. However, no one has investigated the combined toxicities of copper and zinc to chinook salmon eggs, alevins, or swim-up fry. It is the dissolved fractions of zinc (Sinley et al. 1974) and copper (Chapman and McCrady 1977) (Zn^{++} and Cu^{++} in acid waters; $ZnOH^{+}$ and $CuOH^{+}$ in soft waters), which are believed to produce toxic effects in fish (Davies et al. 1979).

Much of the copper contained in the Spring Creek waste now can be removed by several copper cementation plants located at the mine-adit openings (Nordstrom 1977). However, during periods of precipitation, the leachate from exposed tailings results in an increase in the ratio of copper to the other metals present. Hence, the copper-to-zinc ratios of the waste leaving the Spring Creek Diversion Dam fluctuate between 1:2 and 1:8 for wet and dry periods, respectively (D. Wilson, Calif. Dept. of Fish and Game, pers. commun.). Successful operation of the copper cementation plants could result in ratios as low as 1:12 during future dry periods (D. Wilson, pers. commun.). The other metals in the waste remain in the same ratio to each other throughout the year even though their concentrations decrease during storm periods and increase during dry periods (B. Finlayson, unpublished data, 1979).

Wilson (1978) developed new interim release schedules for the Spring Creek diversion dam to replace those of Lewis (1963). The new schedules use ratios of copper-to-zinc as criteria for releases and should eliminate the potential of toxic zinc concentrations in the upper Sacramento River. Recent investigations (Finlayson and Ashuckian 1979) have supported this new approach. However, additional toxicological information is needed before new Sacramento River Basin Plan copper and zinc objectives and permanent Spring Creek release schedules can be calculated and implemented by the State Regional Water Quality Control Board.

The objectives of this study were to gather accurate and relevant toxicological information on copper-to-zinc ratios that were not considered by Lewis (1963), to evaluate the new release schedules of Wilson (1978), and to complement the toxicity data on steelhead trout (Finlayson and Ashuckian 1979).

MATERIALS AND METHODS

We tested the toxicities of combined copper and zinc solutions rather than the acid-mine waste from Boulder Creek (Figure 1) which was done by Finlayson and Ashuckian (1979). This alternative was toxicologically valid because the toxicity of the waste had been demonstrated to be due entirely to its copper and zinc content. The combined copper and zinc stock solutions were prepared using reagent grade copper ($CuSO_4 \cdot 5H_2O$) and zinc ($ZnSO_4 \cdot 7H_2O$) sulfates in de-ionized water. All of the metals present in the Spring Creek acid-mine waste are in the form of sulfates (Nordstrom 1977).

Continual-flow acute and chronic toxicity tests using the methods of Peltier (1978) and Finlayson and Ashuckian (1979) were carried out at the

Department's Water Pollution Control Laboratory (WPCL) with freshly fertilized chinook salmon eggs and the resulting alevins and swim-up fry. All concentrations were tested in replicate. Water from the American River, a tributary to the Sacramento River, was sand-filtered and used for dilution. Since the American and Sacramento rivers are of similar pH and hardness, similar dissolved fractions of both metals would be expected in the Sacramento River and in our toxicity test water.

Three copper-to-zinc ratio (1:3, 1:6, and 1:11) stock solutions were used in both chronic (83-d) and acute (96-h) toxicity tests. The concentrations of zinc in the solutions were held constant at approximately 1525 mg/l and the copper concentrations were adjusted by adding copper to the appropriate ratio. The solutions were acidified to pH 1.8 with sulfuric acid (H_2SO_4) to keep the metallic ions in solution and to keep the metals from plating-out on the walls of the 20-l glass toxicant reservoirs. During the tests, the stock solutions were replenished every 7 to 14 d, and each new solution was analyzed for copper and zinc as a quality control measure (Table 1).

TABLE 1. Chemical Composition of Copper and Zinc Stock Solutions Used in Toxicity Tests.

	Copper-to-zinc ratios		
Metal	*1:3*	*1:6*	*1:11*
Copper (mg/l)	548 ± 21[a] n=8	266 ± 12 n=13	145 ± 10 n=15
Zinc (mg/l)	1503 ± 61 n=8	1543 ± 101 n=13	1543 ± 75 n=15

[a] Mean ± SD

The solutions were diluted in a geometric series of six concentrations (100, 56, 32, 18, and 10%, and control) and continually delivered to the developing eggs, alevins, and fry using the predilution systems and modified Mount and Brungs (1967) type proportional diluters designed and constructed by Finlayson and Ashuckian (1979). Immediately prior to entry into the proportional diluters, the concentrated stock solutions were prediluted to 0.042, 0.049, and 0.081% of original strength for the 83-d chronic toxicity tests and to 0.035, 0.053, and 0.052% of original strength for the 96-h acute test for the 1:3, 1:6, and 1:11 copper-to-zinc ratio solutions, respectively. These initial dilutions constituted the 100% concentrations used in the geometric series of dilutions.

The 83-d chronic toxicity tests began on 6 December 1978 with fertilized chinook salmon eggs obtained by dry spawning four adult female and two male fish at the Department's Nimbus Hatchery on the American River and ended on 27 February 1979 when the individuals were at the swim-up fry stage. At the end of the 83-d tests, the control fry had a mean weight of 400 mg, a mean total length of 36 mm, and had the yolk-sac absorbed to the diameter of 1 to 2 mm. The 96-h acute tests began on 5 March 1979 with the 90-d old unexposed swim-up fry of similar size and weight and ended on 9 March 1979. Continuous low-level illumination was provided by two, 40 W incandescent lamps during the 83-d tests. A continual 8-h light and 16-h dark photoperiod was provided during the 96-h tests by eight, 60 W fluorescent lights which were switched on and off with a rheostat.

Following fertilization, the eggs were allowed to water-harden in the different concentrations of the combined copper and zinc solutions. The control eggs were water-hardened in filtered American River water. Water-hardening lasted 3 h and took place in 4-l glass jars that previously had been acid-rinsed, followed by several rinses with de-ionized water. Following hardening, the eggs were volumetrically measured and floated into perforated, polyethylene egg baskets (50 eggs per basket; 3 baskets per replicate) contained inside of the 12-l plexiglass troughs used by Finlayson and Ashuckian (1979). Eggs not used in the chronic toxicity tests were water-hardened in filtered American River water, deposited in several square, 10-l, overflowing plexiglass aquaria, placed in the dark with a supply of filtered flowing water, and allowed to hatch and develop into swim-up fry. These unexposed swim-up fry were used in the acute toxicity tests, with 25 fry placed in each 12-l plexiglass trough (50 fry per concentration).

During the tests, water samples from the troughs were collected twice a week for analyses of both total and dissolved copper and zinc. Water samples (10 ml) were collected in 15-ml polycarbonate Nalgene® centrifuge tubes which were first rinsed twice in 1*N* nitric acid (HNO_3) followed with two rinses of de-ionized water and then followed by a sample rinse. Samples (10 ml) for dissolved metals were collected in a SESI® nylon syringe and filtered through a Gelman® type A-E 25-mm glass fiber filter held in a Nuclepore® 25-mm plastic valve. Before taking each sample, the syringe, filter, and valve were rinsed with 1*N* nitric acid and then with de-ionized water. All samples were preserved with 0.3 ml of 6*N* nitric acid and capped until analyzed. Copper concentrations $\geq$ 50 μg/l and all zinc concentrations were determined by air-acetylene flame atomic absorption analysis; copper concentrations $<$50 μg/l were determined by carbon-rod atomization atomic absorption analysis. Analytical precision (2σ) was determined from the modified Shewhart equation:

$$\sigma = \sqrt{\Sigma\ (\bar{x} - x)^2/N\text{-}1}$$

where the absolute value of $x = [A_1 - A_2]/[A_1 + A_2]$, and A_1 and A_2 are paired observations. Analytical precision for zinc was ± 4.4%, for copper concentrations $\geq$ 50 μg/l it was ± 3.5%, and for copper concentrations $<$ 50 μg/l it was ± 18%. Dissolved oxygen, pH, and temperature were measured in each test trough three times weekly, whereas water hardness was measured once every 3 wk. The hardness of American River water varies throughout the year between 19 and 26 mg/l $CaCO_3$ (California Department of Fish and Game, unpublished data, 1970–78).

Deaths were not recorded in the chronic tests until the eggs had become "eyed", approximately 3 wk after fertilization. The dead (opaque, white) eggs were recorded weekly and carefully suctioned away to avoid disturbing the other developing embryos. When hatching began 7 wk after fertilization, dead (absence of ventilation and movement) alevins and fry were recorded and removed three times weekly. Mortalities were calculated for the life-history periods of eggs-to-hatch (M_e), hatch-to-swim-up fry (M_a), and for the total 83-d exposures of eggs-to-swim-up fry (M_t). A sample of 20 fry or those remaining (whichever was less) was measured and weighed in each replicate at the end of the 83-d test to determine the effects of copper and zinc on fry growth. Mortalities were also calculated for the 90-d old unexposed swim-up fry (M_f)

for the 96-h exposures. Log-logit (metal concentrations vs. mortality estimates) analyses (Finley 1971) were used to calculate the $LC50_e$, $LC50_a$, $LC50_t$, and $LC50_f$ (50% lethal concentration) and the $LC10_e$, $LC10_a$, $LC10_t$, and $LC10_f$ (10% lethal concentration) by least square regression. The mortality estimates used in log-logit analyses were first normalized using Abbott's formula: $m = (1 - S_x/S_c) 100$ where m = normalized mortality, S_x = survival in concentration x, and S_c = survival of controls.

RESULTS AND DISCUSSION

The toxicity test concentrations had a pH range of 6.6 to 7.4 with the lowest and highest values corresponding to the highest and lowest solution concentrations, respectively. Water hardness of the test concentrations varied with time between 21 and 27 mg/l $CaCO_3$. Water temperatures during the toxicity tests varied with time between 8.5 and 11.0 C, and dissolved oxygen concentrations varied with the time between 8.5 and 12.2 mg/l.

Mortalities of the eggs (M_e), alevins (M_a), and for the total 83-d exposures (M_t) increased with increased total and dissolved copper and zinc concentrations in the 1:3 ratio (Appendix 1), 1:6 ratio (Appendix 2), and 1:11 ratio (Appendix 3) toxicity tests. For the period of eggs-to-fry (M_t), 100% mortality occurred in the highest concentrations while minimal mortality (means = 8.5 to 19.5%) occurred in the lowest concentrations tested. Mortalities of the controls from eggs-to-fry were also minimal (means = 5.5 to 8.6%). Dissolved copper concentrations in the controls were consistently <2 μg/l and dissolved zinc concentrations ranged from 2 to 5 μg/l. All copper-to-zinc ratio solution concentrations tested produced 83-d old fry which had lower mean weights and lengths than the control fry.

Mortalities of the unexposed 90-d old fry (M_f) increased with total and dissolved copper and zinc concentrations in the 1:3 ratio, 1:6 ratio, and 1:11 ratio tests (Appendix 4). Complete mortality occurred at the highest concentrations while minimal mortality (means =0.0 to 2.6%) occurred at the lowest concentrations tested. Mortalities of the control swim-up fry were also minimal (means = 0.0 to 5.3%). Dissolved copper and zinc concentrations in the control concentrations ranged from 1 to 2 μg/l and <5 to <7 μg/l, respectively.

The toxicity test data indicate that the swim-up fry at the end of the 83-d exposures (Table 2) were more tolerant to copper and zinc in the 1:3 copper-to-zinc ratio than the previously unexposed swim-up fry in the 96-h exposures (Table 3), almost as tolerant to copper and zinc in the 1:6 copper-to-zinc ratio, and less tolerant to copper and zinc in the 1:11 copper-to-zinc ratio. For example, the $LC50_t$ values of the 1:3, 1:6, and 1:11 copper-to-zinc ratio solutions during the 83-d exposures were 44 μg/l Cu and 160 μg/l Zn, 27 μg/l Cu and 206 μg/l Zn, and 17 μg/l Cu and 253 μg/l Zn, respectively, while the $LC50_f$ values during the 96-h exposures were 37 μg/l Cu and 132 μg/l Zn, 29 μg/l Cu and 213 μg/l Zn, and 20 μg/l Cu and 279 μg/l Zn, respectively.

The apparent acclimation to copper and zinc during the 83-d test in the higher (1:3) copper-to-zinc ratio, lack of this acclimation in the middle (1:6) ratio, and the greater toxicity of copper and zinc during the 83-d test in the lower (1:11) ratio may indicate that chinook salmon were able to acclimate to copper with relatively less amounts of zinc present (1:3 ratio) but that acclimating to zinc with relatively less amounts of copper present (1:11 ratio) was not possible. Chinook salmon have been reported to acclimate to copper during early life-history stages but copper acclimation has not been investigated in the presence of zinc (G. Chapman, Research Aquatic Biologist, U. S. Environmental Protection Agency, pers. commun.).

TABLE 2. Summary of Statistics and 95% Confidence Limits (In Parentheses) for Chinook Salmon Exposed for 83 Days to 1:3, 1:6, and 1:11 Copper-to-Zinc Stock Solutions.

	Eggs-to-hatch					
	$LC50_e$			*$LC10_e$*		
Metal	*1:3*	*1:6*	*1:11*	*1:3*	*1:6*	*1:11*
Dissolved zinc (μg/l)	174 (141–207)	280 (210–380)	477 (377–631)	145	224	396
Total zinc (μg/l)	207 (169–242)	326 (248–438)	524 (418–681)	175	254	437
Dissolved copper (μg/l)	48 (39–58)	37 (28–50)	31 (25–41)	40	29	26
Total copper (μg/l)	84 (69–99)	63 (48–85)	58 (46–78)	70	50	49
	Hatch-to-swim-up fry					
	$LC50_a$			*$LC10_a$*		
Metal	*1:3*	*1:6*	*1:11*	*1:3*	*1:6*	*1:11*
Dissolved zinc (μg/l)	182 (159–234)	205 (146–298)	253 (187–314)	119	156	208
Total zinc (μg/l)	214 (190–266)	243 (173–351)	283 (212–347)	146	187	234
Dissolved copper 'μg/l)	49 (43–63)	27 (20–38)	17 (13–20)	32	20	14
Total copper (μg/l)	89 (75–136)	45 (33–63)	32 (24–41)	56	37	27
	Total					
	$LC50_t$			*$LC10_t$*		
Metal	*1:3*	*1:6*	*1:11*	*1:3*	*1:6*	*1:11*
Dissolved zinc (μg/l)	160 (112–196)	206 (157–256)	253 (180–317)	131	165	200
Total zinc (μg/l)	192 (148–232)	245 (187–301)	283 (206–351)	170	197	226
Dissolved copper (μg/l)	44 (34–54)	27 (21–33)	17 (12–21)	38	21	13
Total copper (μg/l)	77 (59–94)	46 (36–56)	32 (22–39)	64	36	25

In toxicity test exposures of both 83 d and 96 h, it was apparent that the toxicities of copper and zinc were additive. The additive nature of copper and zinc was expressed by the fish becoming more tolerant of zinc concentrations as the copper concentrations decreased. This additive nature of copper and zinc toxicity is probably not of a completely additive concentration nature (i.e. ½ Cu LC50 plus ½ Zn LC50 producing 50% mortality), although we have no separate copper and zinc LC50 values to substantiate this suspicion. The 83-d $LC50_t$ values indicate that as the copper-to-zinc ratio decreased from 1:3 to 1:11, there was a 58% increase in zinc tolerance coupled with 61% reduction in copper tolerance. This is in comparison to the 96-h $LC50_t$ values which indicate there was a 111% increase in zinc tolerance coupled with a 46% reduction in copper tolerance between the same copper-to-zinc ratio solutions. Finlayson and Ashuckian (1979) found additive toxicity between copper and zinc to steelhead trout. Because there is substantial evidence that the toxicities of copper and zinc are additive, and by reducing the copper-to-zinc ratio from 1:3 to 1:11 will make the combined copper and zinc solutions 58% to 111% more tolerable to chinook salmon, the continued and efficient operation of the copper cementation plants in the Spring Creek drainage, which have the capability to decrease the copper-to-zinc ratio of the acid-mine waste, are of beneficial water quality value.

TABLE 3. Summary of Statistics and 95% Confidence Limits (In Parentheses) for Chinook Salmon Swim-up Fry Exposed for 96 Hours to 1:3, 1:6, and 1:11 Copper-to-Zinc Ratios of Stock Solutions.

	90-d swim-up fry					
	LC50$_f$			*LC10$_f$*		
Metal	*1:3*	*1:6*	*1:11*	*1:3*	*1:6*	*1:11*
Dissolved zinc (μg/l)	132 (103–160)	213 (181–245)	279 (243–321)	111	180	234
Total zinc (μg/l)	144 (112–173)	245 (209–282)	318 (274–373)	120	210	271
Dissolved copper (μg/l)	37 (25–48)	29 (25–35)	20 (18–24)	30	25	17
Total copper (μg/l)	48 (37–58)	40 (35–45)	31 (26–38)	40	33	26

The chinook salmon eggs in our tests were more tolerant to copper and zinc concentrations in the two lower (1:6 and 1:11) copper-to-zinc ratio solutions than were the resulting alevins and fry (Table 2). However, the alevins and fry were as tolerant to copper and zinc as the eggs in the higher (1:3) copper-to-zinc ratio solution. Finlayson and Ashuckian (1979) found steelhead trout eggs were more tolerant of copper and zinc than the resulting alevins and fry in two copper-to-zinc ratios (1:4 and 1:12), and Hazel and Meith (1970) found chinook salmon eggs were more tolerant of copper than the resulting alevins and fry. Hence, the eggs of both chinook salmon and steelhead trout are as tolerant or more tolerant to solutions containing copper and zinc than are the resulting alevins and fry.

Lethal levels of copper and zinc for our chinook salmon agree reasonably well with those of other researchers. Our LC50$_a$ and LC10$_a$ values varied from 17 to 49 μg/l Cu and 14 to 32 μg/l Cu and from 182 to 253 μg/l Zn and 119 to 208 μg/l Zn, respectively while Chapman (1978), in water hardness of 22–24 mg/l $CaCO_3$, found the separate copper and zinc 200-h LC50 and LC10 values for non-acclimated chinook alevins to be 20 and 15 μg/l Cu and >661 μg/l and 364 to 661 μg/l Zn, respectively. Hazel and Meith (1970) found about a 10% mortality to chinook salmon alevins and fry at 21 μg/l Cu. Our 96-h LC10$_f$ values for previously unexposed fry varied from 17 to 30 μg/l Cu and 111 to 234 μg/l Zn while Chapman (1978) found the separate copper and zinc 200-h LC10 values for non-acclimated fry at 14 μg/l Cu and 68 μg/l Zn. Chapman (1978) concluded that chinook salmon and steelhead trout alevins were more tolerant to copper and zinc than were swim-up fry. Additionally, he found that chinook salmon and steelhead trout tolerances to copper and zinc increased with development past the swim-up fry stage. Therefore, we must conclude that swim-up fry of chinook salmon and steelhead trout are probably the most sensitive life-history stage to copper and zinc, and hence, recommended "safe" levels based on this life-history stage should be protective for all developmental stages.

Based on our acute tests, estimated safe levels for copper and zinc at copper-to-zinc ratios of 1:3 to 1:11 for chinook salmon would be below 17 μ g/l and 111 μg/l, respectively. However, other criteria besides death affect the success of an organism. When compared to our control fish, exposed fry showed reduced growth (weight and length) at the end of the 83-d exposures in all concentrations of all copper-to-zinc ratio solutions. The lowest mean concentrations in the 83-d tests were 24 μg/l Cu and 88 μg/l Zn, 12 μg/l Cu and 86 μg/l Zn, and 11 μg/l Cu and 161 μg/l Zn for the 1:3, 1:6, and 1:11 copper-to-zinc ratio solutions, respectively. The lowest copper (11 μg/l) and zinc (86 μg/l) concentrations affecting a reduction of growth in chinook salmon fry were below the lowest copper (17 μg/l) and zinc (111 μg/l) concentrations at the $LC10_f$ values for previously unexposed chinook salmon swim-up fry. Since our response criteria to combined copper and zinc solutions consisted of growth from fertilized eggs to the most sensitive life-history stage (swim-up fry) for chinook salmon, the copper and zinc concentrations of 11 and 86 μg/l, respectively, should approximate the maximum acceptable toxicant concentrations (MATC) of Mount and Stephan (1967). MATC values are between the toxicant concentration having no effect and the toxicant concentration having a measurable effect on the organism. However, even lower copper concentrations have been reported to have an effect on anadromous salmonids. For example, Lorz and McPherson (1977) found that as little as 5 μg/l Cu (7% of Cu 96-h LC50), in water hardness of 68–78 mg/l $CaCo_3$, caused a reduction (below that of control fish) in the percentages of downstream yearling migrants of coho salmon, *Oncorhynchus kisutch*. Additionally, Lorz et al. (1978) found a greater effect on downstream migration when copper and zinc were present together at sublethal levels (10 μg/l Cu and 800 μg/l Zn) than when copper (10 μg/l) or zinc (800 μg/l) were present alone. We would recommend safe levels for chinook salmon in the Sacramento River below 11 μg/l Cu and 86 μg/l Zn until further information is obtained on the possible chronic effects of copper and zinc concentrations on smoltification and downstream migration.

Our toxicity data and those of Finlayson and Ashuckian (1979) are based on dissolved concentrations of copper and zinc. The term "dissolved" refers to copper and zinc concentrations which can pass through a 0.30 μm glass fiber filter. The filtering process removes 90% of the metal-containing particles and complexes which are greater than 0.30 μm in diameter and therefore, probably removes all suspended particulate matter containing copper and zinc. These particles and complexes are bound by adsorption onto particulate matter and complexed in large carbonate, hydroxide, and oxide colloids or precipitates, and are believed to be biologically unavailable. In natural waters relatively free of suspended particulate matter, the fractions of copper and zinc concentrations which compose these biologically unavailable complexes would be expected to increase with increased water pH and alkalinity. The relationship of these water quality parameters to copper (Chapman and McCrady 1977) and zinc (Sinley et al. 1974) toxicity has been expressed by fish becoming increasingly more tolerant of both metals with increased water pH and alkalinity. Since our toxicity data are based on dissolved concentrations of copper and zinc, they should better reflect the concentrations of these metals actually biologically available to cause fish toxicity.

There are two advantages with presenting copper and zinc toxicity levels in dissolved concentrations. First, it allows for a more accurate comparison of the toxicities of various metals to various organisms and secondly, it allows for the toxicity data to be applied to a variety of waters regardless of suspended particulate matter content and possibly water pH, alkalinity, and hardness. Other investigators (Sinley et al. 1974; Chapman 1978) have instead based their toxicity data on total metal concentrations and have listed the pH, hardness, and alkalinity (sometimes the suspended particulate matter content) of the water in which the data were obtained.

Finlayson and Ashuckian (1979) calculated that the old release schedules of Lewis (1963) would allow for theoretical maximum dissolved copper concentrations below Keswick Dam of 10 and 17 μg/l during periods May through December, and January through April, respectively. Likewise, these schedules allowed for maximum dissolved zinc concentration ranges of 20 to 910 μg/l, and 40 to 1600 μg/l for the same periods, respectively. Our present study indicates that safe levels of copper and zinc for chinook salmon are approximately 11 and 86 μg/l, respectively. Thus, the release schedules of Lewis (1963) provided borderline protection from copper toxicity and little, if any, protection from zinc toxicity. The new interim release schedules proposed by Wilson (1978) allow for maximum dissolved copper and zinc concentrations of 5 μg/l and 64 μg/l, respectively. Both the maximum copper and zinc criteria proposed by Wilson (1978) are below the levels determined by us to have a small adverse effect on the growth of chinook salmon fry.

In conclusion, this investigation has demonstrated that the chinook salmon eggs are as tolerant or more tolerant to combined concentrations of copper and zinc than alevins and fry, and that chinook salmon appear to be more easily acclimated to copper rather than to zinc during the period of eggs-to-fry. Additionally, this investigation has demonstrated that the toxicities of copper and zinc are additive to chinook salmon eggs, alevins, and fry. Finally, this investigation suggests safe copper and zinc levels below 11 μg/l and 86 μg/l for chinook salmon in the upper Sacramento River.

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APPENDIX 1—Zinc and Copper Concentrations in Toxicity Testing Troughs, Mortalities for Chinook Salmon Eggs Raised to Swim-up Fry Stage for 83 Days, and Weights and Lengths of Surviving Swim-up Fry at 83 Days in Five Concentrations and the Controls of the 1:3 Copper-to-Zinc Stock Solutions.

Replicate	Zn (μg/l)	Cu (μg/l)	Percent mortality: Eggs (M_e)	Alevins (M_a)	Total (M_t)	Wt (mg)	L (mm)
100-1	700±50[a] (751)	220±27 (310)	100.0	—	100.0	—	—
100-2	710±58 (760)	210±25 (310)	100.0	—	100.0	—	—
56-1	383±48 (430)	120±19 (220)	100.0	—	100.0	—	—
56-2	382±24 (421)	111±19 (182)	100.0	—	100.0	—	—
32-1	214±29 (240)	58±9 (110)	70.7	63.9	89.4	330	29
32-2	200±14 (242)	52±10 (92)	65.0	63.4	87.2	330	29
18-1	150±20 (178)	41±6 (70)	37.3	21.7	50.9	340	31
18-2	141±15 (173)	39±6 (67)	35.7	40.3	61.6	340	31
10-1	88±14 (111)	24±4 (45)	2.4	3.3	5.6	350	34
10-2	89±0 (112)	24±3 (40)	4.9	8.6	13.1	350	34
Control-1	4±3 (23)	2±2 (4)	2.4	3.3	5.7	400	37
Control-2	4±4 (22)	1±2 (3)	6.7	1.8	8.4	395	37

[a] Mean dissolved zinc and copper concentrations ± SD; mean total zinc and copper concentrations in parentheses.

APPENDIX 2—Zinc and Copper Concentrations in Toxicity Testing Troughs, Mortalities for Chinook Salmon Eggs Raised to Swim-up Fry Stage for 83 Days, and Weights and Lengths of Surving Swim-up Fry at 83 Days in Five Concentrations and the Controls of the 1:6 Copper-to-Zinc Stock Solution.

			Percent mortality				
Replicate	*Zn (µg/l)*	*Cu (µg/l)*	*Eggs (M_e)*	*Alevins (M_a)*	*Total (M_t)*	*Wt (mg)*	*L (mm)*
100-1	800 ± 82 [a] (900)	110 ± 15 (190)	100.0	—	100.0	—	—
100-2	820 ± 90 (900)	122 ± 17 (216)	100.0	—	100.0	—	—
56-1	480 ± 67 (530)	64 ± 6 (112)	91.9	100.0	100.0	—	—
56-2	447 ± 40 (510)	63 ± 13 (111)	88.2	86.7	98.4	300	27
32-1	263 ± 33 (302)	32 ± 5 (53)	12.3	30.7	39.2	300	32
32-2	250 ± 50 (300)	27 ± 6 (46)	9.3	29.9	36.4	300	32
18-1	147 ± 16 (180)	20 ± 14 (33)	3.2	17.4	20.0	330	34
18-2	150 ± 31 (180)	19 ± 4 (33)	9.0	13.1	20.9	330	34
10-1	86 ± 14 (106)	12 ± 2 (19)	2.4	2.5	4.8	360	35
10-2	91 ± 25 (112)	12 ± 3 (21)	9.4	3.4	12.2	360	35
Control-1	3 ± 3 (6)	1 ± 0 (2)	2.4	3.3	5.6	400	36
Control-1	5 ± 4 (10)	1 ± 0 (2)	3.9	1.6	5.5	390	36

[a] Mean dissolved zinc and copper concentrations ± SD; mean total zinc and copper concentrations in parentheses.

APPENDIX 3—Zinc and Copper Concentrations in Toxicity Testing Troughs, Mortalities for Chinook Salmon Eggs Raised to Swim-up Fry Stage for 83 Days, and Weights and Lengths of Surviving Swim-up Fry at 83 Days in Five Concentrations and the Controls of the 1:11 Copper-to-Zinc Stock Solution.

			Percent mortality				
Replicate	*Zn* *(μg/l)*	*Cu* *(μg/l)*	*Eggs* *(M_e)*	*Alevins* *(M_a)*	*Total* *(M_t)*	*Wt* *(mg)*	*L* *(mm)*
100-1	1240±77[a] (1340)	87±9 (143)	100.0	—	100.0	—	—
100-2	1250±121 (1340)	81±13 (149)	100.0	—	100.0	—	—
56-1	662±62 (701)	37±6 (80)	82.7	100.0	100.0	—	—
56-2	643±59 (702)	41±7 (78)	79.9	100.0	100.0	—	—
32-1	383±33 (442)	21±5 (42)	11.9	49.5	55.6	330	33
32-2	383±39 (426)	24±5 (49)	12.0	40.0	47.2	330	33
18-1	225±24 (224)	17±2 (31)	0.8	9.2	9.8	360	35
18-2	225±18 (268)	16±2 (30)	4.6	25.8	29.2	360	35
10-1	161±16 (184)	11±2 (20)	15.9	5.2	20.3	390	35
10-2	161±16 (190)	11±2 (20)	13.9	15.3	18.6	390	35
Control-1	2±1 (7)	1±0 (2)	5.9	4.5	10.0	400	36
Control-2	4±3 (5)	1±2 (2)	6.4	0.9	7.2	400	36

[a] Mean dissolved zinc and copper concentrations ± SD; mean total zinc and copper concentrations in controls.

APPENDIX 4—Zinc and Copper Concentrations and Mortalities for 90-Day Old Chinook Salmon Swim-up Fry Exposed for 96 Hours to Five Concentrations and the Controls of 1:3, 1:6, and 1:11 Copper-to-Zinc Stock Solutions.

	Copper-to-zinc ratios								
	1:3			*1:6*			*1:11*		
Replicate	*Zn (µg/l)*	*Cu (µg/l)*	*Percent mortility (M_t)*	*Zn (µg/l)*	*Cu (µg/l)*	*Percent mortality (M_t)*	*Zn (µg/l)*	*Cu (µg/l)*	*Percent mortality (M_t)*
100-1	532±6[a] (543)	150±14 (205)	100.0	741±27 (850)	120±0 (160)	100.0	813±61 (873)	50±7 (71)	100.0
100-2	513±21 (571)	180±14 (200)	100.0	796±29 (817)	131±21 (162)	100.0	806±35 (844)	65±3 (99)	100.0
56-1	302±22 (348)	84±8 (140)	100.0	430±23 (442)	60±5 (94)	100.0	425±7 (439)	35±5 (51)	95.0
56-2	298±28 (306)	73±8 (115)	100.0	439±19 (487)	63±10 (89)	100.0	420±9 (449)	30±5 (51)	93.3
32-1	168±7 (174)	56±1 (63)	85.0	243±0 (277)	31±11 (48)	73.7	243±13 (269)	18±4 (27)	68.4
32-2	156±13 (183)	47±9 (69)	80.0	248±11 (293)	36±6 (47)	72.7	232±12 (259)	17±3 (25)	68.4
18-1	113±10 (126)	34±1 (50)	57.2	151±6 (183)	22±2 (32)	31.2	145±14 (181)	10±3 (15)	5.3
18-2	118±9 (121)	34±1 (40)	25.0	160±18 (208)	22±1 (33)	5.0	160±9 (176)	12±3 (15)	11.8
10-1	75±3 (83)	18±3 (21)	5.3	89±3 (109)	11±1 (13)	0.0	134±34 (136)	7±1 (12)	0.0
10-2	78±11 (84)	24±4 (24)	0.0	92±0 (100)	12±1 (14)	0.0	107±6 (120)	7±1 (14)	5.0
Control-1	7±5 (10)	2±2 (4)	0.0	6±5 (8)	1±1 (1)	0.0	7±3 (7)	2±1 (2)	10.5
Control-2	6±3 (12)	2±1 (3)	0.0	5±3 (10)	2±1 (4)	0.0	5±4 (8)	2±1 (4)	0.0

[a] Mean dissolved zinc and copper concentrations ± SD; mean total zinc and copper concentrations in controls.

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AGE AND GROWTH OF WHITE STURGEON COLLECTED IN THE SACRAMENTO-SAN JOAQUIN ESTUARY, CALIFORNIA: 1965–1970 AND 1973–1976 [1]

DAVID W. KOHLHORST, LEE W. MILLER, JAMES J. ORSI
Bay-Delta Fishery Project
California Department of Fish and Game
4001 North Wilson Way
Stockton, California 95205

Ages of white sturgeon, *Acipenser transmontanus,* collected in the Sacramento-San Joaquin Estuary from 1965 to 1970 and from 1973 to 1976 were estimated from transverse sections of pectoral fin rays. Sturgeon were difficult to age and there was considerable disagreement between individuals interpreting ages. Estimates of male and female growth rates were not significantly different. A von Bertalanffy growth curve was calculated for ages 0–21 from the 1973–1976 collection. A length-weight relationship was estimated from 1965–1970 data. Estimated growth rate was similar in 1965–1970 and 1973–1976, but was lower than in 1954. It was not possible to determine if a recent decrease in growth rate was real or was due to different aging techniques. Possible causes of reduced growth are discussed.

INTRODUCTION

White sturgeon occur mainly in estuaries and rivers along the Pacific Coast of North America. Presently they support a small but important sport fishery in the Sacramento-San Joaquin Estuary and its tributaries. Sturgeon were common here in the mid-1800's but commercial exploitation severely reduced the population by 1900. Sturgeon fishing was prohibited from 1901 to 1910 and from 1917 to 1954, when sport fishing was again permitted. The sport fishery expanded with the discovery in 1964 that shrimp (*Crangon* spp. and *Palaemon macrodactylus)* were effective bait. Both catch and effort peaked in 1967 and have generally declined since (unpublished data).

Initiation of the sport fishery in 1954 stimulated investigations of sturgeon biology to provide information to manage the fishery. Pycha (1956) reported on sturgeon age, growth, size composition, migrations, and abundance. Chadwick (1959) and Miller (1972*a*, 1972*b*) estimated harvest rates and described migrations. Young (Schreiber 1962) and adult (McKechnie and Fenner 1971) sturgeon food habits also were described. Stevens and Miller (1970) and Kohlhorst (1976) determined time and location of spawning.

This report presents new information about white sturgeon age composition and growth from 1965–1970 and 1973–1976 and compares the recent growth rate to that estimated by Pycha (1956).

METHODS

Data were gathered during two collection periods: by the junior authors from spring 1965 to spring 1970 and by the senior author from spring 1973 to summer 1976. Samples from the two periods were analyzed separately since we wanted to compare growth rates between periods. In general, sampling was not systematic; we examined most available fish.

[1] Accepted for publication November 1979.

In any age group, some fish in our samples may have as much as one more season's growth than others, increasing the variability in length at each age. This problem was most significant in the 1965–1970 data. It was minimized in the 1973–1976 data because about two-thirds of the sample was collected from September to March after the growing season (June through October) was essentially complete.

Transverse sections of the first ray of the pectoral fin were used for age determination. Although pectoral fins were obtained from several sources, most samples were collected from the sport fishery, particularly commercial passenger fishing boats (CPFB's), and from sturgeon captured in trammel nets during tagging in fall 1974 (Table 1). All samples obtained from CPFB's in 1965–1970 and from creel censuses in both periods were $\geq$101.6 cm total length (TL), the minimum legal size for sturgeon. Fin rays from sturgeon of all sizes were collected by a Department of Fish and Game employee riding on CPFB's in 1975–1976.

TABLE 1. White Sturgeon Collection Methods in the Sacramento-San Joaquin Estuary.

Collection method	*Collection period*	*Number of sturgeon*
Sport angling		
Commercial passenger fishing boat	1965–70	579 [1]
	1975–76	502
Creel census	1967, 1969–70	48 [1]
	1973–75	346
Trammel net	1974	422
Gill net	1966	1
	1973–76	145
Surface trawl	1975–76	111
Beam trawl	1974–75	32
Otter trawl	1975	4
Fish screens at U. S. Bureau of Reclamation Tracy Pumping Plant	1965	4
Fyke trap	1970	1
	1973	2
Unknown	1969–70	6
Total	1965–70	639
	1973–76	1,564

[1] Only legal-sized fish (101.6 cm TL) were collected.

Methods of removing fin rays varied. Some fish were subsequently released alive; on those, the first ray was severed near its proximal end with a fine-toothed saw or heavy-duty wire cutter and then cut from the rest of the fin. The entire fin was removed from dead fish. Both fin rays and whole fins were thoroughly air-dried before sectioning.

Two 7.6-cm diameter diamond lapidary saw blades mounted 0.9 mm apart in 1965–1970 and 0.5 mm apart in 1973–1976 were used to section the rays. The water cooled saw operated at about 5000 rpm. Two to four transverse sections were cut between 1.3 and 2.5 cm from the proximal end of the ray. Age is most easily differentiated in this region and loss of early annuli is minimized (Sunde 1961). In 1965–1970 sections were polished with fine sandpaper and mounted on microscope slides with clear fingernail polish. In 1973–1976 the narrower spacing of the saw blades eliminated the need to sand the sections before mounting.

The sections were examined under a binocular dissecting microscope using transmitted light. Annuli were visible as narrow light or translucent bands (Figure 1). Periods of more rapid growth appeared dark or opaque.

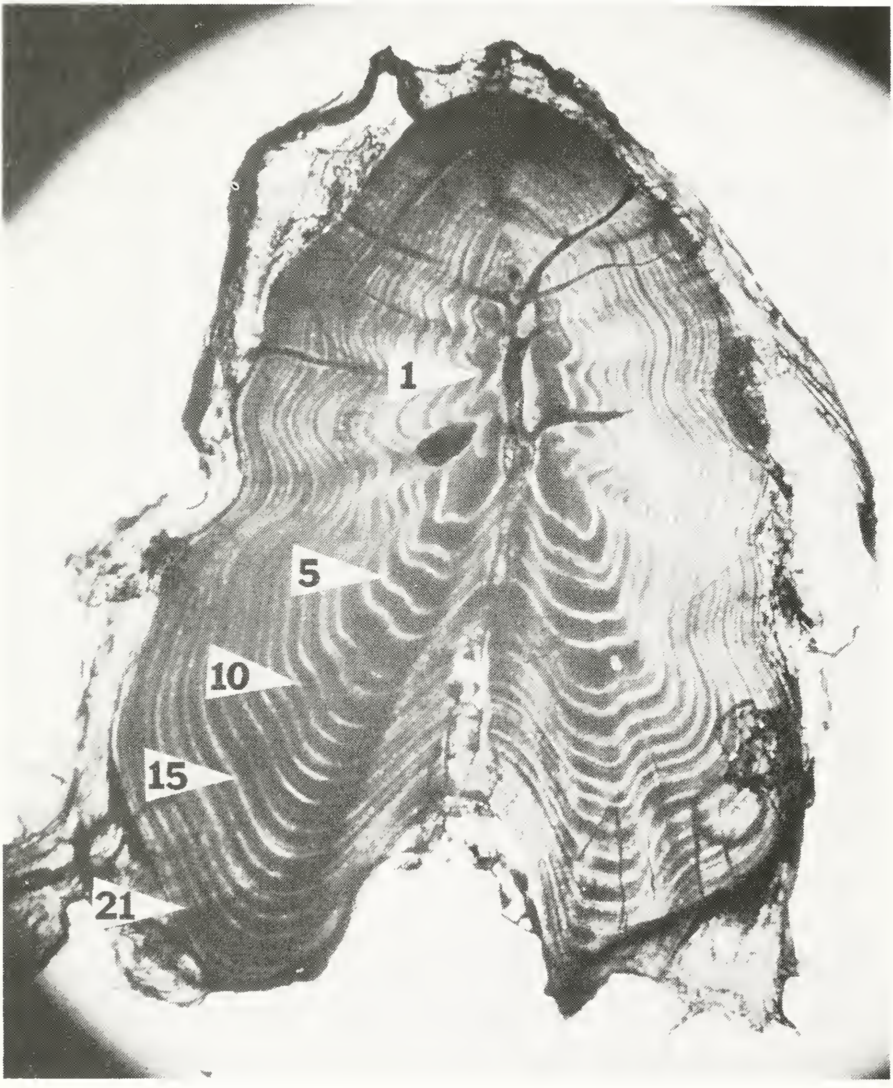

FIGURE 1. Cross-section of the first pectoral fin ray of a 21-yr-old white sturgeon collected in October 1974 from the Sacramento-San Joaquin Estuary. Five of the annuli are numbered for reference.

Sturgeon are difficult to age because they live long, annuli often are difficult to interpret, and known age fish are lacking for validation of aging technique. To assess the reliability of aging white sturgeon, five individuals familiar with fish aging techniques (but not necessarily with sturgeon aging) independently and without training or guidelines interpreted 40 fin rays randomly selected from the 1965–1970 collection. There were many disagreements (see Results).

We established two criteria in an attempt to increase consistency: (1) Only annuli that were distinct in the lobes of the rays and also in the dorsal and ventral portions were counted. Often, annular rings were very closely spaced in the lobes and did not appear in the other areas. Our criterion was intended to eliminate the possibility that some readers would interpret them as false annuli while other readers would interpret them as true annuli with little growth between. (2) A marginal annulus was assigned if one was not visible between 1 April, approximately the midpoint of the spawning season (Kohlhorst 1976), and 1 July. By 1 July that year's annulus was usually visible near the edge of the section and no additional annulus was assigned. This criterion was necessary because annuli were formed in spring but were not usually apparent until more rapid growth resumed.

After we defined these criteria, three new readers estimated ages of the same 40 randomly selected fish. Their performance was only slightly better than that of the first group of individuals, but for consistency we still adopted the criteria.

Subsequently, three trained readers independently examined all ray sections. If at least two age determinations agreed, that was accepted as the true age and was used in our age-growth analysis. If all three disagreed, the sample was omitted.

Length, to the nearest 2.5 cm in 1965–1970 and to the nearest centimetre in 1973–1976, and capture date were recorded when fins were collected. Sex was recorded when dissection was practical.

All lengths reported are total lengths (TL). However, only fork length (FL) was measured on 68 fish. These were converted to TL using the geometric mean functional relationship (Ricker 1973) $\text{TL} = 5.06 + 1.08\ \text{FL}$ ($r^2 = 0.98$, $n = 366$) that we obtained from sturgeon on which both TL and FL were measured.

In 1965–1970 age-length data from many of the youngest and oldest age groups were either biased by gear selectivity or unreliable due to small sample sizes. Therefore, growth was estimated only for ages 11–17. The data were fit to the linear equation:

$$l_t = a + bt$$

where: l_t = centimetres TL at age t

t = age in years

using the method of least squares.

Growth of sturgeon collected in 1973–1976 was adequately described by fitting all age-length data to the von Bertalanffy growth curve:

$$l_t = L_{\infty}[1\text{-}e^{-K(t-t_0)}]$$

where: l_t = centimetres TL at age t

L_{∞} = asymptotic TL in centimetres

K = constant determining the rate of decrease in growth

t = age in years

t_0 = hypothetical age at 0 length

using the least squares computer program BGC-2 (Tomlinson and Abramson 1961, Abramson 1971).

A separate sample of sturgeon collected in 1965–1970 was measured and weighed to the nearest 0.2 kg. The length-weight relationship was estimated by fitting the equation:

$$\log w = \log a + b(\log l)$$

where: w = kilogram weight
l = centimetre TL

using a geometric mean functional regression (Ricker 1973).

RESULTS

Evaluation of Aging Technique

Before we adopted specific aging criteria, we did not obtain complete agreement among the five technicians on the age of any of the 40 randomly selected fin ray samples. Agreement between pairs of readers 1, 3, 4, and 5 averaged 12.5 specimens (Table 2). Reader 2 averaged only 2.5 agreements with the other readers. Readers 1, 3, 4, and 5 disagreed mostly by 1 or 2 yr. Reader 2 often disagreed by 3 yr or more. Reader 2 generally assigned younger ages by ignoring annuli which he considered false.

TABLE 2. Variation Among Readers in Age Determination of 40 Randomly Selected Sturgeon Fin Rays Collected in the Sacramento-San Joaquin Estuary in 1965–70.

Readers compared	*Agreement*	*Disagreement (number of years)* 1	2	3	4	5	*Total disagreements*
1 & 2	3	2	6	9	10	10	37
1 & 3	13	12	6	4	3	2	27
1 & 4	11	17	7	2	2	1	29
1 & 5	10	16	8	2	2	2	30
2 & 3	5	10	5	9	7	4	35
2 & 4	1	5	7	12	8	7	39
2 & 5	1	3	7	12	4	13	39
3 & 4	15	14	7	4	0	0	25
3 & 5	12	14	9	2	1	2	28
4 & 5	14	16	7	1	2	0	26
Mean 1–5	8.5	10.9	6.9	5.7	3.9	4.1	31.5
Mean 1, 3, 4, 5 with each other	12.5	14.8	7.3	2.5	1.7	1.2	27.5
Mean of 2 with 1, 3, 4, 5	2.5	5.0	6.3	10.5	7.3	8.5	37.5

The specific criteria for identifying annuli did not have much effect on results (Table 3). Agreement between pairs of readers averaged 12.7 specimens. However, two of the three readers agreed on ages of 26 of the 40 sturgeon, meaning that ages could be assigned to 65% of these fish.

TABLE 3. Variation Among Trained Readers in Age Determination of 40 Randomly Selected Sturgeon Fin Rays Collected in the Sacramento-San Joaquin Estuary in 1965–70.

Readers compared	*Agreement*	*Disagreement (number of years)* 1	2	3	4	*Total disagreements*
1 & 2	6	22	9	2	1	34
1 & 3	16	12	11	0	1	24
2 & 3	16	16	6	2	0	24
Mean 1–3	12.7	16.7	8.7	1.3	0.7	27.3

In the 1965–1970 sample, 15–19 yr old sturgeon were the most troublesome group, two of three readers agreed on the age of only 56% of them (Table 4). Agreement in other age groups, from 0–4 yr to ≥20 yr was consistent, ranging from 65 to 67%.

TABLE 4. Effect of Age on the Rate of Age Agreement Between Two of Three Trained Readers for White Sturgeon Collected in the Sacramento-San Joaquin Estuary in 1965–70 and 1973–76.

			1965–1970	
Age	*Agree*	*Disagree*	*Total*	*% agreement*
0–4	2	1	3	67
5–9	56	30	86	65
10–14	282	152	434	65
15–19	58	46	104	56
≥20	8	4	12	67
Total	406	233	639	64
			1973–1976	
Age	*Agree*	*Disagree*	*Total*	*% agreement*
0–4	286	9	295	97
5–9	525	92	617	85
10–14	234	90	324	72
15–19	147	119	266	55
≥20	32	30	62	52
Total	1224	340	1564	78

In the 1973–1976 sample aging difficulty increased with age. At least two readers agreed on the age of 97% of 0–4-yr-old fish and agreement consistently decreased to 52% for fish ≥ 20 yr (Table 4).

Age-Length Frequency

We examined fin rays from 639 white sturgeon collected from 1965 to 1970 (Table 1) and assigned ages to 406 of them. They ranged from 2 to 27 yr and from 44 to 203 cm TL.

From 1973 to 1976, 1,564 white sturgeon were examined (Table 1). We assigned ages to 1,224 of these fish. They ranged from 0 to 24 yr and from 24 to 201 cm TL.

Age frequencies and length frequencies for combined 1965–1970 and 1973–1976 data both have two prominent modes. Two and 9-yr old fish dominated the collections, as did 50–54-cm and 100–104-cm length groups (Figure 2). Mean lengths of these modal ages, 54 cm and 103 cm, respectively, fall within the modal length groups, suggesting that age interpretation was reasonably consistent throughout the sample processing.

Growth Rate

Growth rates of the two sexes were compared to determine if they could be combined for an unbiased estimate of average growth. In making this comparison, only part of the available age range was used because: (1) sample sizes were small (≤4) at ages ≥18 in 1965–1970; (2) in both samples, sexed sturgeon were obtained primarily from the sport fishery which has a minimum legal TL of 101.6 cm, and data from sport caught fish are biased by selection for the fastest growing individuals among the partially recruited age groups. This bias is apparent in the length-age relationship for all ages (Figure 3).

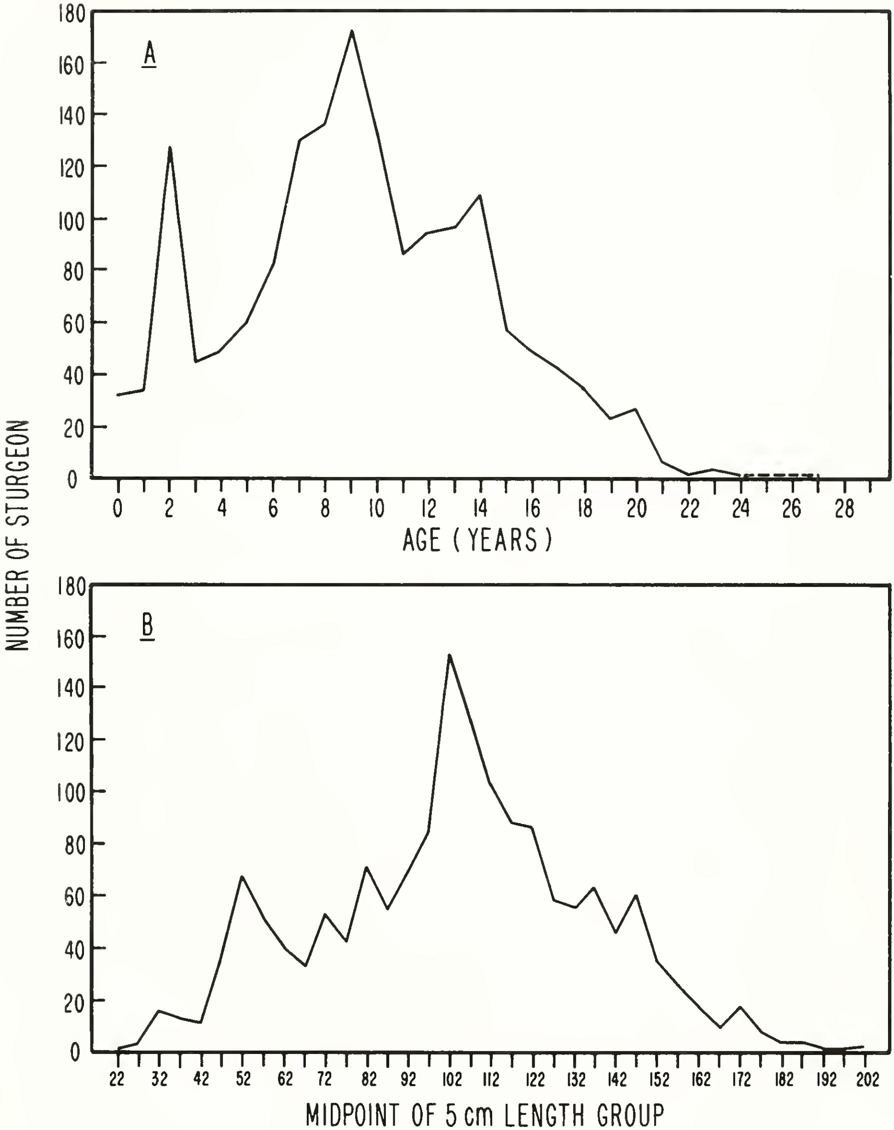

FIGURE 2. Age and length frequency distributions of white sturgeon collected in the Sacramento-San Joaquin Estuary in 1965–1970 and 1973–1976 combined. (A) Age distribution. (B) Length frequency grouped in 5-cm increments.

Growth rate was estimated separately for each sex for ages 11–17 in 1965–1970 and ages 10–20 in 1973–1976. In these age groups, linear regression coefficients for males and females were not significantly different in 1965–1970 ($t = 1.29$, $P = 0.20$) or 1973–1976 ($t = -0.34$, $P = 0.50$) (Figure 3). Therefore, in subsequent analyses we combined the data.

The following linear growth equation describes the 1965–1970 growth data from ages 11–17:

$$l_t = 44.86 + 6.212t$$

Length and age data from age 0–21 generated the following von Bertalanffy growth equation for the 1973–1976 data:

$$l_t = 261.2 \left[1 - e^{-0.04027(t + 3.638)}\right]$$

The von Bertalanffy curve agrees well with mean lengths calculated for each age; therefore, it appears to provide a good description of overall white sturgeon growth (Figure 4). The curve probably overestimates first year growth (35.6 cm) very slightly. Mean length of fish collected after one growing season (33.2 cm) is probably the best estimate. Subsequently growth estimates slowly declined, from 8.9 cm during the second growing season to 4.0 cm during the 22nd growing season. Length increased from 44.5 cm at age 1 to 164.4 cm at age 21 (Figure 4B).

Length-Weight Relationship

We determined both length and weight of 209 sturgeon collected in 1965–1970; the sex of 77 of these was known. Since the length-weight relationships for males and females were not significantly different ($t = 0.52$, $P > 0.50$), all data were combined to determine the functional relationship $\log W = 3.348 \log L - 5.927$ (Figure 5). Weight increased from 6.2 kg at 101.6 cm to 50.4 kg at 190 cm.

DISCUSSION

Estimates of sturgeon size varied considerably at each age. This finding is characteristic of sturgeon growth studies (Magnin 1964, Cuerrier 1966, Semakula and Larkin 1968). Aging inaccuracies are a factor, but size variation at each age may actually be large.

The validity of age determinations from sturgeon pectoral fin rays has been discussed by several authors, including Cuerrier (1951), Roussow (1957), and Sunde (1961). However, they did not determine consistency in age interpretation among several readers. In our analysis, two of three trained readers agreed on the age of 64% of the fish in the 1965–1970 sample and 78% in the 1973–1976 sample. In 1973–1976, agreement decreased with age, indicating increased difficulty in interpreting fin ray sections with age.

The growth rate calculated for age 11–17 sturgeon in 1965–1970 was similar to the rate for that age range in the 1973–1976 sample. The rates were not compared statistically because different methods were used to estimate growth in the two samples. A comparison over a wider age range was not possible because of weaknesses inherent in the 1965–1970 data, specifically: (1) Mean lengths from age 6 to at least age 10 are overestimated since essentially the entire sample consisted of fish larger than the minimum legal length (101.6 cm) in the sport fishery. Hence, the fastest growing individuals from these younger, partly recruited age groups were unavoidably selected. (2) The data for ages > 17 may not be representative because of small sample sizes.

We could not identify any important biases affecting the 1973–1976 data since sample sizes generally were adequate and fish were collected by a variety of methods. Hence, we believe that the 1973–1976 data adequately represent recent white sturgeon growth in the Sacramento-San Joaquin Estuary.

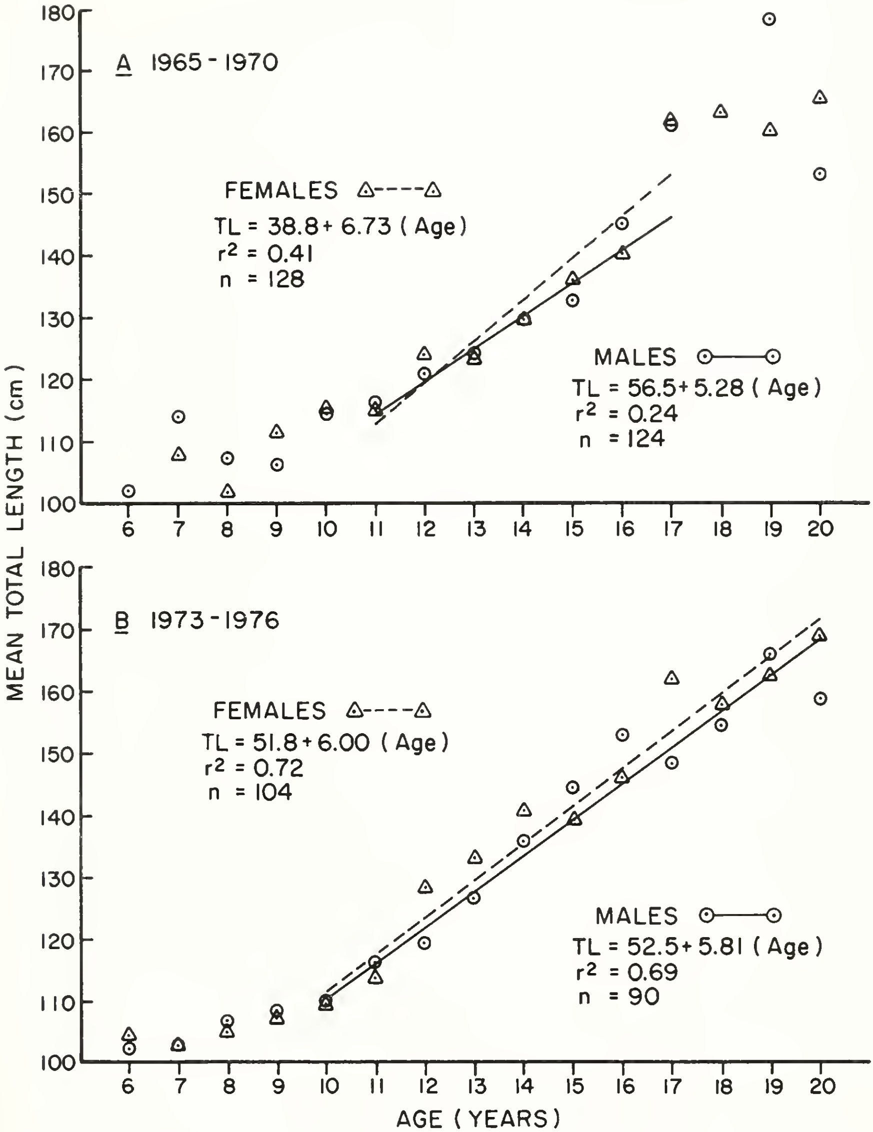

FIGURE 3. Growth rates of male and female white sturgeon from the Sacramento-San Joaquin Estuary. Lines are least squares linear regressions. (A) 1965–1970. (B) 1973–1976.

Assuming that Pycha (1956) used aging criteria similar to ours, it appears that white sturgeon growth has decreased since 1954 (Figure 6). However, growth here apparently is still more rapid than in the Fraser River, British Columbia (Semakula and Larkin 1968). Lower water temperatures and a shorter growing season in the Fraser River due to a 12° difference in latitude probably account for the difference.

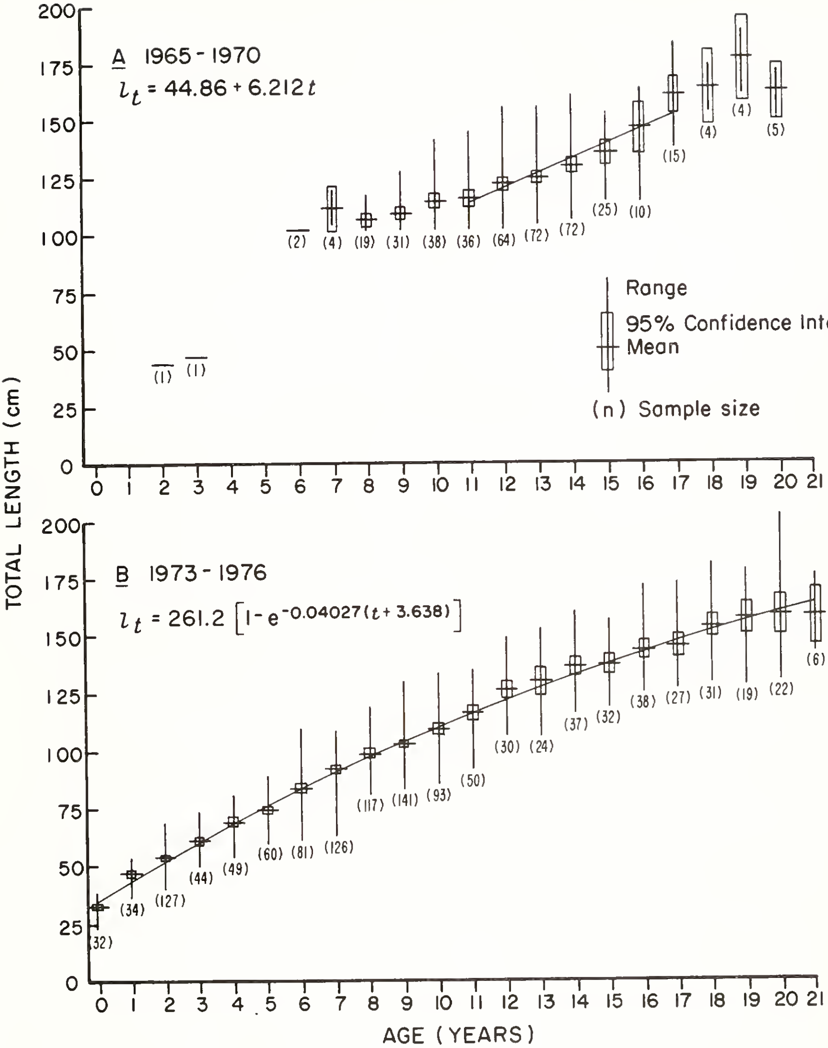

FIGURE 4. Growth curves fitted by the method of least squares for white sturgeon collected in the Sacramento-San Joaquin Estuary. Mean total lengths, confidence intervals, and length ranges are shown for comparison. Sample sizes are given in parentheses. (A) Linear growth between ages 11 and 17 of fish collected in 1965–1970. (B) Von Bertalanffy growth curve for age 0–21 fish collected in 1973–1976.

The apparent reduction in growth rate since 1954 has several possible explanations:

(1) *Genetic*—Presently, the fastest growing individuals are vulnerable to the sport fishery (which started in 1954) at a younger age and for a longer period than slower growing sturgeon. Hence, proportionately more slow growing fish remain in the population and cause an apparent reduction in population growth rate when sampled by nonselective methods.

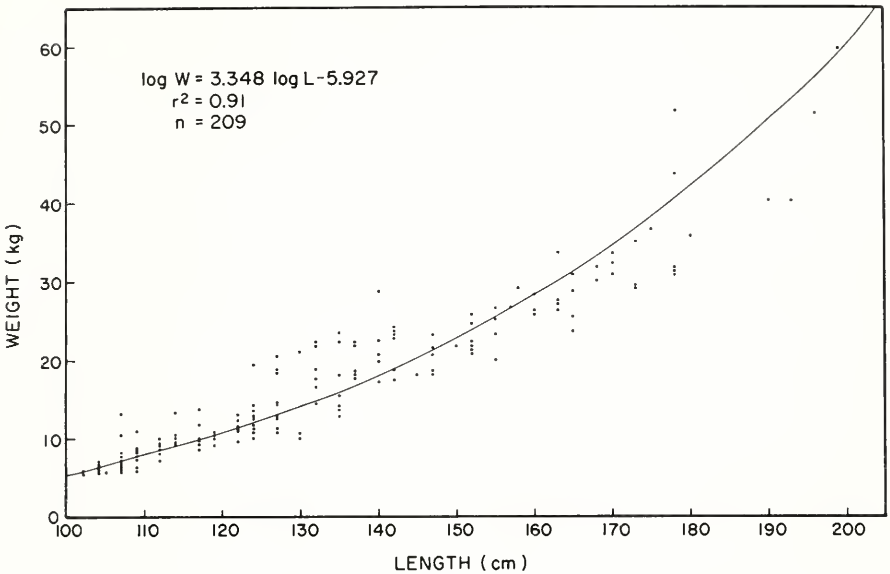

FIGURE 5. Length-weight relationship of white sturgeon collected in the Sacramento-San Joaquin Estuary from 1965 to 1970. The curve is a geometric mean functional regression.

(2) *Intraspecific competition for food*—There is evidence that sturgeon abundance increased between 1954 and 1967 (Miller 1972*a*), and that it declined between 1967 and 1974 (unpublished data). Increased abundance may decrease growth by intensifying intraspecific competition for a limited food supply. If food is limiting, effects of competition between 1954 and 1967 may still be apparent in our data since age-length relationships determined from a discrete sample reflect growth conditions over a number of previous years. Improved growth due to less competition more recently may not be detected for several years.

(3) *Decreased food supply*—White sturgeon feed primarily on benthic invertebrates in the San Francisco Bay area (McKechnie and Fenner 1971). One of these, the bay shrimp, is fished commercially and California Department of Fish and Game records indicate a substantial decrease in mean annual landings from 307,320 kg in the 1940's to 34,940 kg in the 1970's. Market demands and processing costs account for part of this change, but the magnitude of the reduction suggests that shrimp abundance actually decreased. Factors affecting shrimp abundance may have caused undocumented decreases in populations of other benthic organisms also.

(4) *Effects of environmental contaminants*—White sturgeon in the estuary accumulate polycholorinated biphenyls (PCB's) in their tissues. Means levels in muscle tissues of legal-sized fish collected in San Pablo and Suisun bays in 1975 were 2.0 ppm (SD = 2.5, n = 10) in males and 3.5 ppm (SD = 5.0, n = 12) in females. Concentrations in the gonads were much higher, 49.3 ppm (SD = 24.8, n = 8) in males and 23.7 ppm (SD = 27.8, n = 12) in females. Sublethal levels of PCB's inhibit growth in channel catfish, *Ictalurus punctatus* (Hansen, Wiekhorst, and Simon 1976) and might affect sturgeon in the same manner.

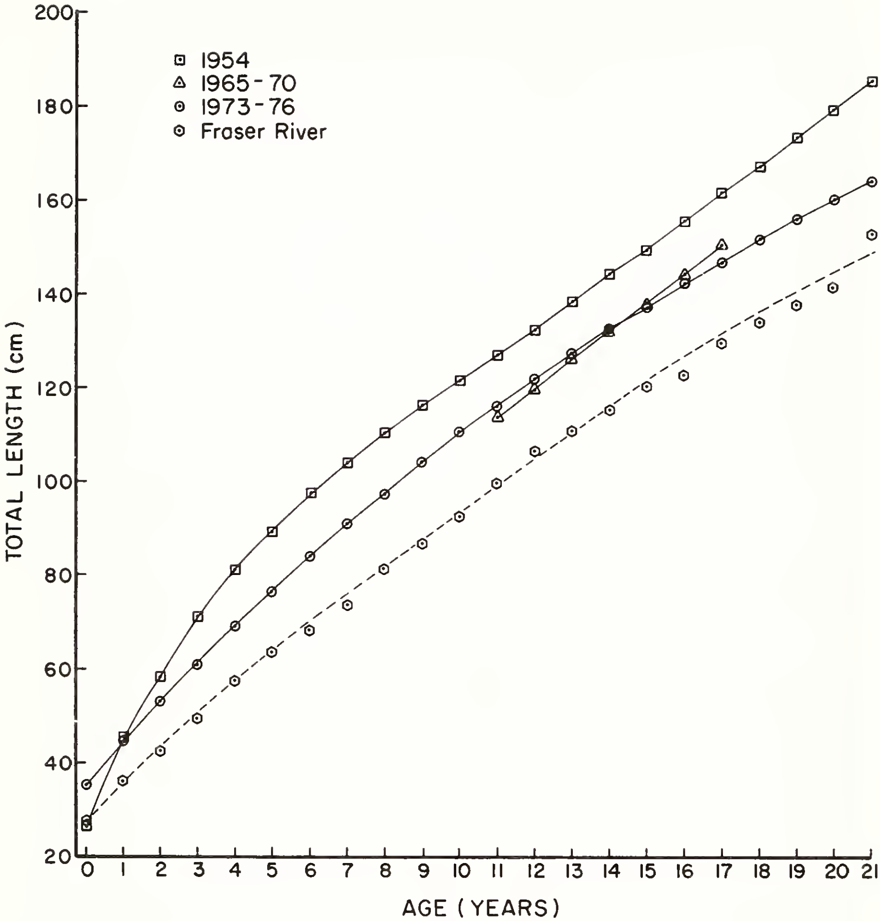

FIGURE 6. Growth of white sturgeon collected in the Sacramento-San Joaquin Estuary in 1954, 1965–1970, and 1973–1976, and in the Fraser River, British Columbia. Fraser River fish ages are adjusted to our method of age designation (age 0 is the youngest age class).

Facts are not available to evaluate the relative significance of the various potential causes of reduced growth.

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DIETS OF MOUNTAIN WHITEFISH, *PROSOPIUM WILLIAMSONI* (GIRARD), AND BROOK TROUT, *SALVELINUS FONTINALIS* (MITCHILL), IN THE LITTLE WALKER RIVER, MONO COUNTY, CALIFORNIA[1]

JOHN PAUL ELLISON[2]
Biology Department
California State Universiy, Long Beach
Long Beach, California 90840

Diets of brook trout, *Salvelinus fontinalis* (Mitchill), and mountain whitefish, *Prosopium williamsoni* (Girard), in July are described and compared to other studies. Diets were compared statistically and shown to be significantly different. Stomachs of brook trout contained insects of both terrestrial and aquatic origin, indicating a possible subsistence on the drift, whereas whitefish stomachs contained mostly immature aquatic insects, suggesting a bottom feeding habit. Differences between the diets of brook trout and whitefish are probably the result of differential feeding habits.

INTRODUCTION

Mountain whitefish, *Prosopium williamsoni* (Girard), a fresh water salmonid (Subfamily Coregoninae), range from the eastern slopes of the Rocky Mountains in the headwaters of the Saskatchewan and Missouri rivers to the Cascades and Columbia drainage in the northwest. It is also abundant in the Great Basin, with the Truckee River and the Lahontan Basin being the southernmost limit of its range (Eddy 1969). *P. williamsoni* occurs sympatrically with some species of endemic salmonids such as *Salmo clarki* and *Salmo gairdneri* (Sigler 1951; Eddy and Surber 1960).

Because the mountain whitefish is treated as a game fish in some states, including California, and also occurs sympatrically with other salmonids of interest to sport fishermen, it has been the subject of several studies. Brown (1952) investigated its reproduction and development, while McHugh (1940, 1941) described the food and growth of this species. Sigler (1951) studied the life history of whitefish and made recommendations for its management and McAfee (1966) provided a literature survey. More recent investigations have treated the seasonal migration (Pettit and Wallace 1975) and food habits (Pontius and Parker 1973) of mountain whitefish. There is no published literature available for the food habits of mountain whitefish in California.

Prosopium williamsoni has a poor reputation as a food species, and some biologists believe it is detrimental to populations of the more popular trout by feeding on trout eggs and young and offering direct competition for food (McHugh 1940). This paper compares the diet of mountain whitefish with the diet of brook trout, *Salvelinus fontinalis*, in July to determine the degree of similarity between their diets and possibly the extent of any competition. No attempt is made in this paper to comment on the supposed oophagus tendencies

[1] Accepted for publication July 1979
[2] Current address: California Department of Fish and Game, Post Office Box 47, Yountville, California 94599

of mountain whitefish as the fish used in this study were collected in July when few salmonid eggs are available to potential predators.

STUDY AREA

Fish used in this study were collected from the Little Walker River in Mono County, California. Located on the eastern slope of the Sierra Nevada Mountains, it is a tributary of the West Walker River, which flows east into Walker Lake. This drainage system is part of the Lahontan system; its geological morphology and history are discussed by Snyder (1917).

The Little Walker River drains an area of 163 km² and has a mean yearly discharge of 1.5 m³/sec (51 cfs). The mean discharge in the month of July for the years 1965 to 1972 was 3.4 m²/sec (118 cfs). Vegetation at the study site was primarily sage, with dense stands of pine and aspen in the immediate vicinity of the River.

The study section was 21 km northwest of Bridgeport, California. This section of the river was 5 to 9 m in maximum width, 0.3 to 1.5 m in maximum depth, 1 km long, and with an average gradient of 52 m/km. Elevation of this section was between 2,182 m and 2,555 m (U.S.G.S. topographic map). Bottom types ranged from rubble, with a current velocity in excess of 1 m/sec (35 cfs), to a sand and gravel bottom silted in areas, with a current velocity of about 0.2 m/sec (7 cfs). Latter mentioned bottom type was found in diversions created by beaver dams and accompanying snags.

Other native fish found in the Little Walker River include Lahontan cutthroat trout, *Salmo clarkii henshawi*; longnose dace, *Rhinichthys cataractae*; Lahontan redside, *Richardsonius egregius*; Piute sculpin, *Cottus beldingi*; mountain sucker, *Catostomus platyrhynchus*; and Tahoe sucker, *Catostomus tahoensis*. Introduced species are rainbow trout, *Salmo gairdneri*; brown trout, *Salmo trutta*; and brook trout, *Salvelinus fontinalis*.

MATERIALS AND METHODS

On 12 and 26 July 1973, 38 brook trout and 64 mountain whitefish were collected, using an electrofishing apparatus (Smith-Root Mark V Electroshocker). Previous to these dates fish were collected with hook and line in order to assess their distribution in the study section. Fish collected by hook and line were not used in the diet analysis because this collecting method resulted in the introduction of prey not usually found in the fishes' diets (viz., grasshoppers). All fish were collected between 1100 hours and 1800 hours. At the time of collection, weight to the nearest gram and standard length to the nearest millimetre were recorded and scale samples taken. As the survivability of the fish collected was not an imporatant factor, the electrofishing device was set to maximize fish attraction. Most fish collected by this method experienced extreme muscle contraction and usually died as a result. Fish not killed immediately with the electrofishing device were placed in a bucket and allowed to suffocate. No regurgitation of stomach contents was observed. Stomachs were removed by cutting the digestive tract at the esophagus and at the beginning of the intestine just posterior to the pyloric caecae. After removal, stomachs were individually wrapped in cheesecloth, numbered with a tag, and fixed in 10% formalin for 48 hours, and then rinsed and transferred to 70% isopropyl alcohol. If stomachs were not removed within an hour after capture, the fish were injected with 20% formalin into the body cavity to arrest the digestive process.

Organisms found in stomachs were examined with a variable power dissecting microscope and identified to the lowest taxon feasible using Usinger (1956), Ross (1965), and Borror and White (1970. Lengths (excluding anal ceri) and weights of each taxonomic group were measured using a dissecting microscope with an ocular micrometer disc and a Roller-Smith Precision Balance, respectively. All insects were weighed to the nearest 0.2 mg and their lengths were measured to the nearest 0.1 mm. The mean length of each taxon was calculated from the measurements of each entire individual in the group or an aliquot of 10 if there were more than 20 organisms present.

At the time of the first collection of fish, a reference collection of benthic, drift, and terrestrial insects was made. Insects were preserved in 70% isopropyl alcohol. Weights and lengths of preserved insects in the reference collection were used to determine reconstructed weights of insects found in stomachs of fish (Ricker 1937).

Data from the diet analysis were analyzed with an IBM 376 computer using an STSS (Nie, et al. 1970) program for discriminate analysis. The variables in the analysis were calculated by multiplying the number of each prey by its reconstructed weight.

RESULTS AND DISCUSSION

Diet Composition

Results in this paper are presented in two ways: (1) the type, number, and percent composition by number of principal prey species are listed because it is commonly used and permits comparison with other studies; and (2) diet composition, as represented by reconstructed weights of principal prey species, is also given. The stomachs of most fish were full or mostly full; only one whitefish had an empty stomach.

The data were not segregated on the basis of size or age class because it has been demonstrated that mountain whitefish of the size range sampled in my study do not show a significant difference in diet with an increase in size or age. Laakso (1950) found that fingerling whitefish use the same food as adults, but feed on smaller animals (probably the earlier instars of the same aquatic larvae). Sigler (1951) stated that there appears to be no great difference between the food habits of different sizes of mountain whitefish. Pontius and Parker (1973), in their investigation of the food habits of *P. williamsoni*, grouped the fish into the following size classes based on the size range and number of fish in their samples: I, less than 230 mm; II, 230 to 330 mm; and III, 330 mm or larger. They were able to show a quantitative difference in diets only between size classes II and III. Of the fish collected for my study, 92% fell within Pontius' and Parker's size class I and the remainder within size class II. Fish representing size class I were not adequately sampled in their study and fish greater than 330 mm were inadequately sampled in my study of the Little Walker River population.

When the data I obtained from the stomach analysis of whitefish from the Little Walker River (Table 1) were adjusted by removing fish representing Sigler's (1951) 0+ age class, there was no appreciable change in the order of abundance of the food groups. The only noticeable change was in the position of larval chironomids, which dropped from 15.4 to 10.9%. This result is consistent with previous studies. McHugh (1940) reported that the difference he found between diets of 0+ and older fish was due to larger proportion of larval dipterans (chiefly chironomid larvae) in the stomachs of smaller fish. Pontius and Parker (1973) noted that the difference in diets of larger whitefish was due to a consistently lower percentage of chronomids in the stomachs of older fish.

TABLE 1. Principal Prey in the July Diets of Brook Trout and Mountain Whitefish as Indicated by Number of Occurrence and Percent of Total.

		Brook Trout		*Whitefish*	
Order	*Family*	*Number*	*Percent*	*Number*	*Percent*
Ephemeroptera	Baetidae (*Baetis*) (N) [1]	40	3.0	1367	25.7
	Baetidae (*Ephemerella*) (N)	85	6.5	1139	21.4
	Heptageniidae (N)	9	0.7	562	10.5
	Baetidae (A)	77	5.9	185	3.5
Trichoptera	Lepidostomatidae (L)	283	21.6	47	0.9
	Brachycentridae (L)	73	5.6	141	2.6
	Rhyacophilidae (L)	23	1.8	128	2.4
Diptera	Chironomidae (L, P)	89	6.8	823	15.4
	Simulidae (L, P)	8	0.6	547	10.3
	Miscellaneous (A)	85	6.5	16	0.3
Coleoptera	Miscellaneous, nonaquatic (A)	50	3.8	4	0.1
Hymenoptera	Formicidae (A)	214	16.3	13	0.2
	Miscellaneous (A)	37	2.8	—	—
Plecoptera	Peltoperlidae (N)	25	1.9	48	0.9
Other prey	(N, L, P, A)	215	16.4	310	5.8

[1] Stage: N = nymph; L = larvae; P = pupae; A = adult

As for brook trout, Griffith (1974) found that the only difference in diet between age classes of fish was between fingerling (age class 0+) and older fish. None of the brook trout collected in my study were 0+ individuals.

In addition to insects and other animals, the stomachs of fish examined contained organic and inorganic debris. This debris was variously composed of sand, gravel, and pieces of terrestrial and aquatic vegetation that had been incorporated into pupal and larval cases of those caddisfly which were eaten. Also found were pieces of terrestrial vegetation the approximate size and shape of insect larvae and larval cases, which may have been mistaken by fish for food items. This material, which comprised an estimated 20 to 30% of the volume of the stomach contents, will be disregarded in this paper. Also disregarded are cases of trichopteran larvae and pupae removed before the insects were weighed.

Brook Trout

Organisms found in the stomachs of brook trout collected from the Little Walker River in July were largely terrestrial and aquatic insects. The single most important prey species, as determined by reconstructed weight (Table 2), were larval brachycentrids. The second most important food item were salmonid fry (probably whitefish), followed in descending order of importance by terrestrial adult coleopterans, formicids, lumbricids, larval lepidostomatid trichopterans, nymphal baetids (*Ephemerella* spp.), adult heptageniids, terrestrial adult hymenopterans other than formicids, and terrestrial and aquatic adult dipterans. The use of reconstructed weight instead of simple occurrence by number elevated in relative importance those food organisms which would otherwise have been considered an insignificant portion of the diet (e.g., salmonid fry).

TABLE 2. Principal Prey in the July Diets of Brook Trout and Mountain Whitefish as Indicated by Reconstructed Weight of Prey (Gram) and Percent of Total.

		Brook Trout		*Whitefish*	
Order	*Family*	*Gram*	*Percent*	*Gram*	*Percent*
Ephemeroptera	Baetidae (*Baetis*) (N)[1]	0.07	0.5	3.00	9.4
	Baetidae (*Ephemerella*) (N)	0.75	5.1	7.52	23.7
	Heptageniidae (A)	0.71	4.8	7.14	22.5
	Baetidae (A)	0.24	1.6	0.37	1.2
Trichoptera	Lepidostomatidae (L)	1.02	6.9	0.21	0.7
	Brachycentridae (L)	2.48	16.7	8.38	26.4
	Hydropsychiidae (L)	0.04	0.3	0.55	1.7
	Rhyacophilidae (L)	0.09	0.6	1.32	4.2
	Miscellaneous (P)	0.27	1.8	0.41	1.3
Diptera	Simuliidae (L, P)	0.01	0.1	0.49	1.5
	Miscellaneous (A)	0.46	3.1	0.06	0.2
Coleoptera	Miscellaneous, nonaquatic (A)	1.50	10.1	0.02	0.1
Hymenoptera	Formicidae (A)	1.22	8.2	0.01	0.0
	Miscellaneous (A)	0.55	3.7	—	—
Opisthopora	Lumbricidae	1.17	7.9	0.06	0.2
Osteichthyes	Miscellaneous (eggs)	—	—	0.76	2.4
	Miscellaneous (fry)	2.00	13.5	—	—
Other prey	(N, L, P, A)	2.27	15.3	1.48	4.7

[1] Stage: N = nymph; L = larvae; P = pupae; A = adult

Griffith (1974) found that brook trout fed largely on Ephemeroptera, Coleoptera, Diptera, Trichoptera, and Plecoptera. He reported that these aquatic insects comprised 97% of the number of organisms in the drift and 92% of the number of organisms eaten by the trout. Insects of terrestrial origin were poorly represented in the drift of the Idaho streams he studied. Aquatic insects made up about 72% of the number of organisms eaten by brook trout in the Little Walker River (Table 1). This difference may be expected as trout in streams and rivers largely feed off the drift (Jenkins, Feldmuth and Elliott 1970, Griffith 1974), and the terrestrial component of the drift from the Little Walker River is greater than that found by Griffith at his study site in Idaho.

Whitefish

Mountain whitefish collected in July from the Little Walker River were found to be feeding largely on immature aquatic insects. The following food groups, listed in descending order of importance as determined by reconstructed weight (Table 2), comprised 86% of the stomach contents: larval brachycentrid trichopterans, nymphal baetids (Ephemerella spp.), nymphal heptageniids, nymphal baetids (Baetis spp.), and larval rhyacophilids. Terrestrial organisms were almost entirely absent from the diet of whitefish and made up only 1.9% of the reconstructed weight of the organisms in the stomachs. The immature ephemeropterans and trichopterans accounted for 91.1% of the whitefish diet.

Laakso (1950), using a volumetric method, found whitefish, *Prosopium williamsoni cismontanus,* of the Gallatin and Yellowstone rivers in Montana to have differing summer diets. Whitefish from the Yellowstone River had a high percentage of ephemeropterans and plecopterans nymphs in their diet. The Ephemeroptera were largely represented by nymphs of the family Baetidae, and Trichoptera were almost entirely of the family Brachycentridae. Whitefish from the Gallatin River had a summer diet composed principally of plecopteran nymphs, annelid worms, and simuliid larvae. Laakso describes *P. williamsoni* as essentially being a benthic feeder that will utilize surface organisms during summer and spring to supplement its diet. Mountain whitefish of the Little Walker River had a diet roughly comparable to the summer diet of whitefish in the Yellowstone River. Both groups of fish utilize immature Ephemeroptera to a large extent (53.4%, by volume, in Yellowstone River whitefish, and 55.6%, by reconstructed weight, in Little Walker River whitefish). As the diet of any benthic-feeding fish is directly related to the composition of the benthic community in its habitat, no valid comparison can be made of allopatric populations of such fish without also comparing the quantitative aspects of the benthos. Because such data are not available in this instance, no further comparison will be made of these populations.

McHugh (1940) also described *P. williamsoni* as a basically bottom-feeding fish with the most important food being aquatic insect larvae. In spite of its usual bottom-feeding behavior, McHugh found that mountain whitefish taken from waters poor in aquatic insect fauna had a large percentage of terrestrial insects in their stomachs. Those whitefish he collected from rivers showed a high percentage of immature Ephemeroptera, Trichoptera, and chironomid larvae and pupae in their diets. A large proportion of the fish McHugh examined were collected in summer.

Sigler (1951) listed insect orders found in mountain whitefish from the Logan River, Utah, in descending order of importance by volume as Trichoptera, Diptera, Ephemeroptera, and Plecoptera. However, he made no mention of the exact date of collection of the fish. His data serve to illustrate the relative importance of the larval dipterans (mostly chironomids). He, too, indicated that the mountain whitefish is a bottom feeder.

Mountain whitefish collected during the summer by Pontius and Parker (1973) from the Snake River in Wyoming fed on large numbers of larval Trichoptera and chironomids. The authors stated that it was impossible to determine to what extent the fish fed on the bottom or drift by comparing stomach contents to bottom and drift samples. However, they did suspect that *P. williamsoni* was primarily a bottom-feeder, due to the high incidence of benthic forms in the stomachs and the whitefish's subterminal mouth, which suggested that it is adapted for this type of feeding.

High numbers of benthic insects found in the stomachs of whitefish from the Little Walker River tended to support the findings of other studies that *P. williamsoni* is primarily a bottom-feeder. However, some whitefish were captured with a baited hook suspended in the water column, suggesting that they occasionally feed in the drift. Results of the stomach analysis showed that whitefish in the Little Walker River feed more extensively on immature ephemeropterans in summer and depend less on chironomid larvae and pupae during this period than whitefish in other rivers. This may simply have been an indication of the relative abundance or availability of these two food items. The incidence of plecopteran nymphs in the diet of these whitefish was not as high as encountered in other studies. The relatively high importance of Trichoptera, particularly the family Brachycentridae, was consistent with other populations of whitefish.

Comparison of Diets

Four major aquatic food groups (Ephemeroptera, Trichoptera, Diptera, and Plecoptera) as determined by reconstructed weight account for a little over one-third (37.7%) of the brook trout's summer diet, with mostly terrestrial prey species making up the remainder of the diet (Figure 1). These same food groups (Table 1) made up nearly the entire diet of whitefish in July (94.6%).

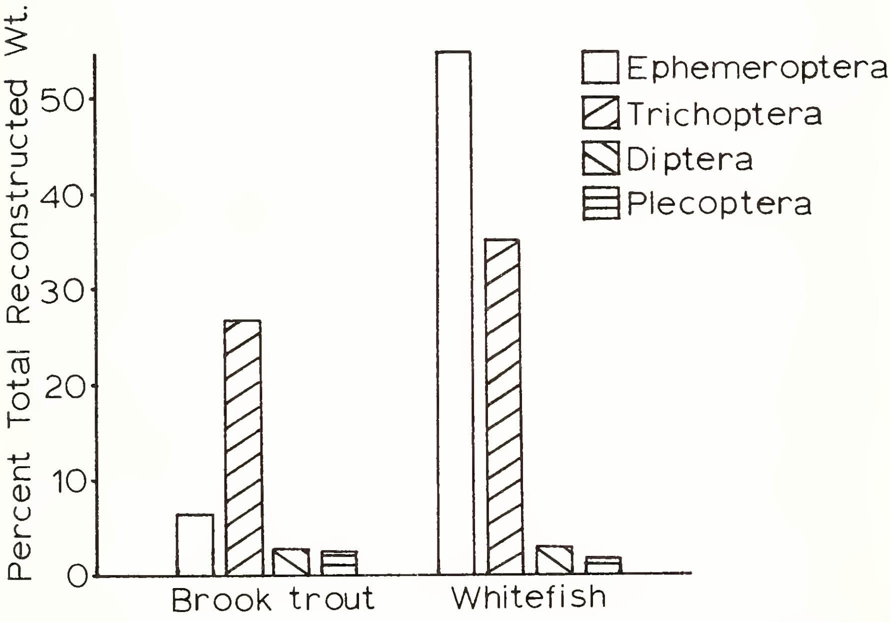

FIGURE 1. Relative abundance of benthic insect food groups in the diets of mountain whitefish and brook trout from the Little Walker River in July 1973.

Larval Trichoptera, particularly of the family Brachycentridae, were the one group of food organisms of high relative importance to both whitefish and brook trout. Larval brachycentrids were among the largest aquatic insect larvae available in the Little Walker River and may have provided the fish the greatest amount of caloric and nutritional value per unit of energy expended in their capture of the prey organisms present. The trichopterans' large size and cumbersome larval case would have made them an obvious and vulnerable portion of the benthos or drift. Griffith (1974) determined that brook trout selected immature Trichoptera and Ephemeroptera, as indicated by positive electivity indices (Ivlev 1961). Pontius and Parker (1973) found that mountain whitefish actively select larval Trichoptera.

It was probably in the selection of larval Trichoptera that the greatest degree of competition occurred between brook trout and whitefish during the summer in the Little Walker River. It may have been possible that this competition was not as direct as indicated by the results. Whitefish may have been largely selecting larval Trichoptera from the benthos and brook trout taking them from the drift. This is not to suggest that either brook trout or whitefish were strictly limiting their feeding to any one portion of the environment. Another factor to be considered is that the cropping of any benthic form will ultimately affect its abundance in the drift and vice versa. However, it did appear that whitefish were largely benthic in their feeding habits, whereas brook trout utilized drift organisms to a large extent.

I used discriminate analysis to analyze the data from my study to determine if brook trout and whitefish have statistically different diets. Discriminate function analysis is a multivariate tool which forms linear combinations of discriminating variables that maximize separation between groups (Sokal and Rohlf 1969). A feature of the computer program I used is the derivation of an F value based on the within group variance. An F of 13.15 with degrees of freedom of 22 and 77 was determined for the diets of brook trout and whitefish, yielding a significant difference in their diets at the 99.99% level of confidence.

Those food groups which contributed most to the difference between the diets of the two species were immature Ephemeroptera, adult Hymenoptera, adult Diptera, and adult nonaquatic Coleoptera. It was primarily the fishes' differential utilization of these food groups which allowed the necessary partitioning of the environment for the coexistence of these two species with respect to diet.

SUMMARY

1. Mountain whitefish and brook trout were collected from the Little Walker River, Mono County, California, and their stomach contents analyzed. A reference collection of insects and aquatic invertebrates was used as an aid in the classification and determination of the reconstructed weights of the prey species. Diets of whitefish and brook trout in July were qualitatively and statistically compared and the results contrasted with other studies.

2. In July brook trout fed on both terrestrial and aquatic insects. The brook trout's diet was composed largely of larval brachycentrids, terrestrial adult coleopterans, formicids, lumbricids, larval lepidostomatids, nymphal baetids (*Ephemerella* spp.), adult heptageniid ephemeropterans, terrestrial adult hymenopterans other than formicids, and terrestrial and aquatic adult dipterans.

3. Brook trout in the Little Walker River were similar in their utilization of drift fauna to populations of brook trout in other states.

4. In July whitefish fed mostly on immature aquatic insects, especially larval brachycentrids, nymphal baetids (*Ephemerella* spp.), larval heptageniid ephemeropterans, larval baetid ephemeropterans (*Baetis* spp.), and larval rhyacophilids.

5. Whitefish from the Little Walker River had summer diets similar to whitefish populations investigated by others. They utilized benthic fauna and ate immature aquatic insects, predominately.

6. Brook trout and whitefish in July have diets which are significantly different. I attribute this difference to the predominantly benthic-feeding habits of whitefish as opposed to the predominantly drift-feeding habits of brook trout.

Based on this study mountain whitefish did not offer brook trout serious competition for food during July in the Little Walker River.

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THE USE OF ROAD-KILLED DEER FOR ASSESSING REPRODUCTIVE POTENTIAL AND WINTER CONDITION OF THE DEVIL'S GARDEN INTERSTATE MULE DEER HERD [1]

HAL SALWASSER
Department of Forestry and Conservation
University of California, Berkeley [2]
and
DOUGLAS J. THAYER
California Department of Fish and Game
P.O. Box 1623, Alturas, CA 96101
and
D. LEWIS YOUNG
Modoc National Forest, U.S. Forest Service [3]

This paper illustrates some inventory uses of highway-killed deer and describes a simple method for gathering biological data from these deer. Data on reproductive potentials, herd age structure, and winter fat reserves are evaluated to show some ecological conditions of the herd. The Devil's Garden Interstate herd has declined in size since 1964 due to poor fawn survival. Fawn production at birth is high. We postulate that winter depletion of fat reserves could retard fetal growth. This condition, related to fall and spring nutrition, may be an important factor in high neo-natal fawn mortality in the herd. Road-killed deer can serve the biologist/manager as an important inventory tool in assessing some aspects of deer herd ecology.

INTRODUCTION

Recent recruitment declines in many western mule deer, *Odocoileus hemionus,* herds have resulted in dwindling herds and reduced hunter success. The problem is acute on the Devil's Garden Interstate herd of northeastern California and south central Oregon. A 40% drop in recruitment since 1964 has led to a 60% herd reduction (Salwasser 1976, 1979). The reported buck harvest has declined by 80% over the period. Local speculation regarding the factors causing poor recruitment include too few bucks for total breeding, an abundance of "barren does," and excessive coyote predation on fawns. Obviously, the only way to reverse current recruitment trends is to alter the ecological factors actually responsible. To examine some possible factors, biologists from the Interstate Deer Herd Technical Committee initiated an investigation of winter deer condition and reproductive potentials through the use of road-killed deer. The sampling period was October 1974 to April 1975. Evaluation of diets was also included in the investigation but is not included in this report. This paper discusses the acquisition of information on age structure, reproductive potential, and carcass condition through necropsy of road-killed deer, the analysis of such data, and the ecological and management implications of the findings.

Literature concerning the use of data from road-killed deer is limited. The

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[1] Assistance to this investigation was provided by Federal Aid in Wildlife Restoration projects W-51-R "Big Game Studies" and W-52-R "Wildlife Investigations Laboratory."

[2] Current address, U.S. Forest Service, Tahoe National Forest, Nevada City, CA 95959.

[3] Current address, U.S. Forest Service, Dakotas Planning Team, Pulver Hall, Dickinson, ND 58601.

Kansas Forestry, Fish, and Game Commission has used road-killed deer to gather reproductive data for both mule deer and white-tailed deer, *O. virginianus,* for several years (Peabody and Hlavachick 1970). Their largest sample of mule deer in recent years included 13 does.

South Dakota biologists used 17 road-killed does to gather reproductive data for both mule deer and white-tailed deer as part of a study to determine mortality of fawns in the Black Hills (Rice 1977).

In Colorado, Gill (1971) used road-killed deer as one part of the estimate of total mortality in the Middle Park mule deer herd. Goodwin and Ward (1976) reported the sex ratios of road-killed mule deer were similar to those ratios observed on the adjacent winter range along part of Interstate 80 in Wyoming.

The North Dakota State Game and Fish Department examined road-killed does to obtain fetus counts during the spring of 1978 in an attempt to obtain reproductive data after a severe winter, but the sample size obtained was small (J. McKenzie, North Dakota State Fish and Game Department, pers. commun.). In past years, the Colorado Division of Wildlife has utilized road-killed deer to gather various data, but none have been published (A. Anderson, Colorado Division of Wildlife, pers. commun.).

METHODS

Our field method for necropsy of road-killed deer was designed with several criteria in mind. First, road kills are found in a variety of conditions, ranging from severely dismembered to essentially whole carcasses. The data we collected were obtainable from most carcasses regardless of condition. Second, eight biologists participated in data collection, so the methods had to be standardized to reduce human judgment errors. Third, the biologists collected data as a part-time addition to regular duties; therefore, the necropsy method had to be simple and time efficient.

Each cooperating biologist was equipped with sampling kits (one per deer) which included:

1—quart (or litre) plastic ice cream carton for rumen contents
2—20 cm x 25 cm (8 in. x 10 in.) plastic food storage bags
1—150-ml glass jar (6 oz baby food jar) for gonads and eyeballs
2— "sale tag" labels
1—large plastic bag 46 cm x 61 cm (18 in. x 24 in.) for fetuses
1—data card

An accessory kit was also provided to cooperators:

1—gallon 10% formalin for preservation of all samples
1—metric tape measure
1—small metric rule
1—permanent ink marker
1—box extra plastic food storage bags
extra labels

Each carcass was processed as follows:

1. Check for external parasite load or abnormalities, reported qualitatively.
2. Measure hindfoot length (Hall 1962) with cloth tape.
3. Remove jaw for later aging.
4. Remove eyeballs, preserve in formalin in glass jar.

5. Open body cavity (Cowan and Karstad 1971).
6. Remove handful of solid rumen contents and preserve in equal amount of formalin in bag in carton.
7. Measure rib fat at thickest depth on sternum with small metric rule.
8. Estimate percent of kidney surface area covered by fat, record highest value of either kidney.
9. Remove and preserve ovaries (testes if male) in glass jar.
10. Remove and preserve fetuses (or entire reproductive tract, if small) in large plastic bag.
11. Check for any internal abnormalities.

All data were recorded on a standard data form. Specimen containers, labels, and the data form were pre-labeled to avoid errors of omission. Specimens were forwarded to the senior author for further evaluations. Ages up to 2 years old were assigned by tooth eruption and replacement (Robinette et al, 1957); ages of older deer were based on annular ring counts on the first incisor. Ovaries were sectioned and corpora lutea counted using the criteria established by Teer, Thomas, and Walker (1965). Fetuses were sexed and weighed to the nearest gram. The left hindfoot was measured to the nearest millimetre.

While not all data are reported in this paper, the method described provides information on age structure, parasite conditions, skeletal size, diets, fat reserves, reproductive potentials, fetal growth and conception dates, and gross abnormalities. Bled carcass weights, a desirable parameter to measure under special collections, should not be measured unless most carcasses are whole.

Data collection required about 15 minutes per carcass after cooperating biologists were trained on two or three carcasses. All desired data and samples were obtained from each deer, except badly mutilated ones. Additional tasks, such as detailed parasite checks and quantitative kidney fat measurements, can be incorporated according to time, supplies, and training. A detailed presentation of the necropsy method and data analysis procedures is available upon request from the senior author.

RESULTS AND DISCUSSION

Data were collected from 43 road-killed deer. Fat reserve information was obtained from all carcasses, and reproductive performance was ascertained from 30 female deer taken on California Highway 139 through the Interstate winter range. Female sample age structure reflects recent poor recruitment and indicates a declining population (Table 1). Nearly two-thirds of the doe sample was composed of 3-year-old and older animals. Interestingly, fawn road-kills showed an even ratio of bucks to does.

TABLE 1. Age Structure of Winter Road-Killed Deer in the Devil's Garden Interstate Mule Deer Herd, October 1974–April 1975.

Age	*Male sample*	*Female sample*
Fawn	6	7
Yearling	1	3
2 year	0	4
3 year	0	10
4 + year	1	11
TOTAL	8	35

The road-kill sample reflects true population age and sex structure. The composition of the winter road-kill sample, 7 bucks (BB): 100 does (DD): 46 fawns (FF), is essentially identical to the fall composition count on the herd, 6BB: 100DD: 48FF. From our data, although an admittedly small sample, there appears to be little sex or age differential in vulnerability to highway mortality. Additional yearly comparisons or larger samples are needed, however, before making stronger conclusions on such vulnerability.

Ovulation and fetal rates (Table 2) show that potential fawn production is not a factor in low recruitment. Fetal rates for a herd are a function of: i) percent prime breeding age does, ii) doe condition at rut, iii) sufficient bucks to breed all does, and iv) abortive diseases.

TABLE 2. Reproductive Performance of Winter Road-Killed Does from the Devil's Garden Interstate Mule Deer Herd, October 1974–April 1975.

Age class	*Sample*	*Ovulation rate*	*Fetal rate*	*Percent pregnant*	*Fertility %*	*Twin rate %*	*Male: female*
Fawn	7	0.00	0.00	0	–	–	–
Yearling	3	1.33	1.00	100	75	0	0 : 3
2 year	4	2.00	1.75	100	88	75	6 : 1
3 year	6	2.00	1.67	100	83	67	3 : 7
4+ year	10	2.00	1.90	100	95	90	14 : 5
Yearling+	23	1.91	1.70	100	89	70	23 : 16
2 year+	20	2.00	1.80	100	90	80	23 : 13

The high fetal rate for Interstate does (1.7 fetuses per yearling and older doe), 100% pregnancy, and high fertility indicate no problem with the first three factors. Recent low post-harvest buck ratios (6BB : 100DD) are still biologically sufficient for reproductive success. Furthermore, fetal ages showed a 25-day breeding period from early November to early December with a peak during the last 2 weeks in November. Low buck ratios are not resulting in extended breeding periods or conception on the second or third estrus cycle. We saw no evidence of abortion, resorption, or fetal abnormalities. However, none of our samples were from late gestation, and abortion cannot be ruled out by these data.

Chattin (1948) found a 1.75 fetal rate in 2-year-old and older Interstate does during 1946–1947. The current 1.80 rate in the same age group indicates little change in this potential. The slight increase may be due to small sample variation, or it may be a function of a higher percentage of 3-year-old and older does presently in the herd. Interstate fetal rates are lower than those reported from the highly productive Sublett herd in Utah during the mid-1950's; Julander, Robinette, and Jones (1961) found fetal rates of 1.96 in mature does compared with our 1.80, and 1.56 in yearlings, compared with our 1.00. Interstate fetal rates are, however, higher than for many wild herds (Robinette and Gashwiler 1950, Hudson 1959, Julander et al. 1961; Nellis 1968; Browning, Schulenberg, and Brunetti, 1973; Salwasser, Holl, and Ashcraft 1978).

The influence of nutrition on fetal rates and fawn survival has long been understood by deer biologists. Robinette et al. (1973) reported significant increases in fawn production and survival when they improved the nutritional plane of their penned mule deer. Verme (1969) found significant survival differences in white-tailed deer fawns born to does on differing nutritional planes.

Verme (1967) also documented the phenomenon of compensatory breeding, which explains why does on low quality diets and with poor fawn survival still show high fawn production potentials. Doe condition at rut is influenced by both summer and fall habitat quality and the number of fawns nursing the doe during that period. If fawns suffer high neo-natal mortality, as has been shown to occur in the wild (Trainer 1975, Smith and LeCount 1976, Salwasser et al. 1978) the doe is able to use all available nutrition to rebuild her own tissue reserves. Hence, does not nursing fawns are able to show high ovulation and fertility rates on what is actually a poor nutritional plane for total reproductive success. Ransom (1967) has shown the extreme of compensatory breeding; on the northern fringe of white-tailed deer distribution, does skip a year in breeding if they are successful in raising a fawn. It appears that compensatory breeding may be responsible for the relatively high fetal rates in the Interstate herd.

The Interstate herd's fetal sex ratio shows a slight preponderance (59%) of males. Verme (1965) observed a higher male fawn ratio from does on poor diets. Robinette et al. (1973), however, did not find a significant difference in sex ratios as a result of doe diets. Our sample is probably too small to make meaningful conclusions as to the nutritional implications of Interstate fetal sex ratios. The sex ratio of road-killed fawns indicates that by the following winter the ratio is likely to be 50 : 50.

Evaluation of carcass fat showed the Interstate deer entered winter with moderate energy reserves (Table 3). Fawns carried the lowest fat stores going into winter, with 3 mm along the sternum and a 20% covering of kidney surfaces. By late February they had depleted their reserves. Mature does retained some fat reserves until early April. Winter conditions in 1975 were quite stressful to the herd. There was no fall "greenup" that year. Consequently, the herd was forced to subsist on dry grass, sagebrush, and juniper through a long cold winter. Green forage did not appear on the ranges until mid-April, some 6 to 8 weeks after fawns had exhausted their fat reserves and 2 to 3 weeks after adults had depleted their reserves. Late winter fawn mortality and reduced fetal growth would be expected outcomes of the 1975 interaction between individual deer condition, habitat quality, and winter weather.

TABLE 3. Fat Reserve Trends in Road-Killed Mule Deer from the Devil's Garden Interstate Mule Deer Herd, October 1974–April 1975

	Fawn			*Yearling*			*2 Year*			*3+ Year*		
Period	*n*	*Rib*[1] *(mm)*	*Kidney*[2] *(%)*	*n*	*Rib (mm)*	*Kidney (%)*	*n*	*Rib (mm)*	*Kidney (%)*	*n*	*Rib (mm)*	*Kidney (%)*
17 Oct— 24 Dec	3	3	20 (5–25)[3]	3	13	75 (75–80)	1	6	50	4	11	85 (75–100)
1 Feb— 7 Feb	–	–	–	–	–	–	–	–	–	2	9	70 (50–90)
24 Feb— 20 Mar	9	0	5 (0–10)	3	2	15 (0–25)	1	3	5	14	4	35 (0–100)
30 Mar— 13 Apr	4	0	3 (0–10)	2	1	5 (0–10)	2	3	5 (0–10)	4	1	10 (0–25)

[1] Rib fat measured at thickest depth on sternum.
[2] Percent of kidney surface area covered by fat.
[3] Range of values in parenthesis.

SUMMARY AND CONCLUSIONS

Road-killed deer can be a valuable addition to the manager's inventory arsenal. A sample of 43 deer yielded reproductive data on 23 breeding females, an adequate sample for most management purposes. Other data can be obtained on herd age structure and deer condition with a minimum of manpower, time, and supplies. This information can be used to indicate animal and herd response to habitat conditions. When integrated with other inventories, such as herd composition counts, it can give valuable clues to which factors are or are not responsible for observed population trends.

The age structure of the Interstate sample indicates the results of ever-declining recruitment: a population dominated by older age classes. Herd size will continue to decline because there are fewer females in young age classes to replace older deer as they succumb to natural factors. Yet, fawn production remains relatively high because most females in the herd are in the prime reproductive ages of 3 years and older. Even at the low buck ratio of 6 per 100 does at rut, all reproductive age does were pregnant, and they conceived during the optimum breeding period. These facts show conclusively that fawn production is not responsible for poor recruitment in the herd. Factors contributing to fawn mortality are the problem.

Other work on mule deer in California has indicated that spring nutrition, summer nutrition, and summer cover are probably the most important factors in neo-natal fawn survival (Salwasser 1976, 1979; Salwasser et al. 1978; Holl, Salwasser, and Browning 1979). The carcass condition analysis performed on these road-killed deer further indicates that current fall habitats may not provide sufficient nutrition to prepare the herd for a stressful winter. Fawns in 1975 depleted their energy reserves with 4 weeks of winter remaining; adults by winter's end. It is likely that fetal growth would be impaired under such conditions. Indeed, Verme (1977) has recently shown that the small size of fawns born after such circumstances is correlated with high fawn mortality.

Correction of the recent trends in recruitment must focus on spring, summer, and fall habitats. Conceivably, improvement of the fawning and summer habitats (which the Interstate herd uses from 4 weeks prior to fawning to the start of the fall migration) and of fall migration ranges will significantly alter the nutrition and cover problems that are causing high fawn mortality and early winter depletion of fat reserves. On the Interstate ranges, this will require a commitment by managers to use fire, logging, and livestock grazing to create and maintain seral brushfields on forest soils.

Road-killed deer can be used to further monitor deer herd trends and responses to management actions. This study indicates a sample of 40 to 50 deer is sufficient to gather valuable information for assessing the success or failure of deer management.

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THE LITTORAL BOTTOM FAUNA OF HIGH ELEVATION LAKES IN KINGS CANYON NATIONAL PARK [1]

TIMOTHY P. TAYLOR and DON C. ERMAN
Department of Forestry and Resource Management
University of California,
Berkeley, CA 94720

Benthic macroinvertebrates were collected with skin diver-operated coring tubes from the littoral zone of 11 high elevation lakes in Kings Canyon National Park. Macroinvertebrate density averaged 5418 individuals/m^2, was fairly uniform (SD = 1716/m^2), and was positively correlated with human use around the lakes. Chironomidae, Oligochaeta, or *Pisidium* were the most common invertebrate organisms found.

INTRODUCTION

The high mountain lakes of California's Sierra Nevada are major attractions to hikers in wilderness areas of national parks. Many of these alpine lakes now contain introduced trout (Christensen 1977), for which benthic macroinvertebrates are an important dietary component (Elliott and Jenkins 1972). But their attractiveness as well as the general increased human use of remote areas has led to so many people visiting and camping at the lakes that managers of wilderness areas are concerned about deteriorating natural features. In Kings Canyon National Park heavy visitor use of remote high elevation lakes has prompted the Park Service to restrict use and to sponsor research on the possible impacts of people on these lakes. It was our broad objective to evaluate the effects of people on a series of high elevation lakes in Kings Canyon National Park. Over three summers, studies were conducted on 11 lakes close to the John Muir Trail in a heavily used part of Kings Canyon N. P. (lat 118°25′N, long 36°48′W; elevation 3161–3350 m; Figure 1). In 1975 and 1976 data on basic limnology were obtained (Silverman and Erman 1979; Taylor and Erman, in press). These data suggested a pattern among the lakes that pointed to an impact by people. Lakes with greatest use had more rooted aquatic plants and less dissolved nitrate than lakes with low human use. We hypothesized that conditions in the sediment may have been the key factors in reflecting past use levels, and so we returned to the lakes for an intensive, short term sampling of bottom features in all lakes in August 1977. The effects of past use on benthic plants and other features are reported elsewhere (Taylor and Erman, in press). The purposes of the study reported here were to obtain information on the composition and abundance of benthic invertebrates of these little studied lakes and to determine if invertebrates were responding to different levels of human use around the lakes.

METHODS

In the last week of August 1977, 11 oligotrophic lakes (all Kearsarge Lakes—Upper, Middle, Main, and East; Bullfrog and Charlotte lakes; Upper and Lower Rae lakes; Dragon Lake, and 2 of the 7 major Sixty lakes—Upper and

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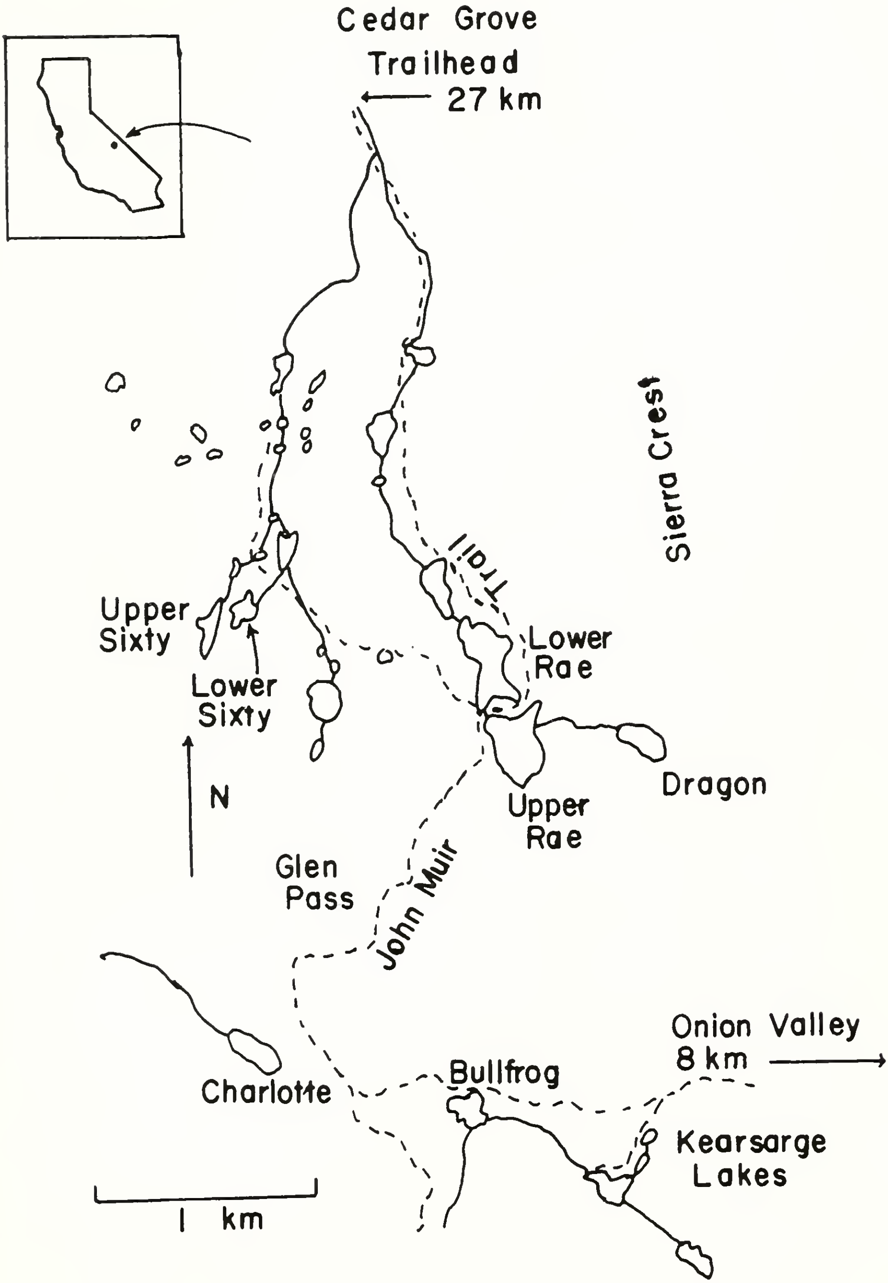

FIGURE 1. Location of study lakes, major streams, and main trails in Kings Canyon National Park.

Lower), representing the range of lake sizes and levels of visitor use characteristic of the area, were sampled by skin divers. These are the same lakes for which previous data on limnological conditions were collected with the exception of Dragon Lake, which was added in 1977; morphological features were not obtained. The late August date was chosen so that bottom plants would be at peak annual growth and any seasonal differences among the lakes would be minimized by a short sampling period. All of the lakes contained trout but no data on their relative abundance was obtained.

We allocated the total amount of diving effort to each lake based on the proportion of bottom area shallower than 6 m (lake morphology was surveyed in 1975–76). This depth was the limit for free diving. Within this zone divers sampled benthic plants at 2 m and 4 m (Taylor and Erman, in press) and bottom fauna at the mid point of the zone, 3 m. Points around the shore were spaced evenly, and a pair of samples were taken 4 m apart on the 3 m contour at each point. In Bullfrog Lake, where as many as 22 pairs were required, sampling was reduced to only 10 pairs because of the rigor of diving at these elevations.

Samples were obtained by pushing a 2.8-cm diameter by 15-cm coring tube into the bottom, capping it, and extracting it. Cores from mud and sand bottoms were about 12 cm in length, but cores from coarser bottoms were as short as 3 cm. Gravel or rock substrates could not be sampled by core. Uneven sample numbers (Table 1) reflect a missed sample because of these conditions. We did not have a comparable method for quantitatively sampling gravel or rock. The cores were preserved in 5% formalin and mixed thoroughly; a small amount (1–2 g) of the core was set aside for other analysis, and silt was washed from the remainder through a 0.21-mm mesh screen. All macroinvertebrates were removed, identified as far as possible (Edmondson 1959; Mason 1968; Brinkhurst and Jamieson 1971; Burch 1972), and the data used to compute a Shannon diversity index (Shannon and Weaver 1949) for each lake:

$$H' = \Sigma \frac{n_i}{N} \log_e \frac{n_i}{N}$$

where n_i is the number of individuals of species i, and N is total individuals of all species.

TABLE 1. Physical Features and Human Impact Index Values of the Study Lakes.[1]

	Mean depth (m)	*Volume ($m^3 \times 10^3$)*	*Surface area (ha)*	*Human impact index*	*Elevation (m)*
Upper Kearsarge	3.1	38	1.2	57	3324
East Kearsarge	4.2	196	4.6	23	3383
Middle Kearsarge	4.3	65	1.5	68	3322
Main Kearsarge	8.7	664	7.5	98	3322
Bullfrog	6.0	595	8.7	106	3231
Charlotte	4.8	465	9.6	179	3161
Upper Rae	14.0	3,421	24.5	86	3200
Dragon	N.A.[2]	N.A.	N.A.	32	3383
Lower Rae	6.3	1,424	22.5	244	3200
Lower Sixty	5.5	317	5.7	36	3250
Upper Sixty	8.2	457	5.5	27	3250

[1] In part from Taylor and Erman, in press.
[2] Data not available. Dragon Lake was not surveyed in previous work.

On the remaining subsample, organic content was determined by combustion of dry samples (Black et al. 1965). The effect of formalin on the organic content was negligible when checked against blanks of unpreserved soil.

Relative levels of human impact upon the study lakes were determined from data compiled by the Park Service. Investigators identified campsites around the lakes and ranked each campsite from 1 to 5 (5 = greatest impact) based on impacts on vegetation, leaf litter, duff, soil; on campsite area and development; and on human trails in the area. The sum of all rankings around a lake gave a composite score for each lake (human impact index, Taylor and Erman, in press; Table 1).

RESULTS AND DISCUSSION

Chironomids, oligochaetes, and *Pisidium* (fingernail clams) were the dominant benthic organisms found in the lakes (Table 2). Upper and Lower Rae lakes and the three upper Kearsarge lakes were dominated by oligochaetes, but in the lower lakes of the Kearsarge basin, Main Kearsarge and Bullfrog, *Pisidium* became progressively more important. Upper and Lower Sixty and Charlotte lakes were dominated by chironomids. These three taxa are also dominant in the Convict Creek basin lakes (Reimers, Maciolek, and Pister 1955) and are dominant in many other oligotrophic lakes (Fillion 1967; Sarkka 1972; Pennak 1977). However, Lower Rae, Lower Sixty, and Upper Sixty had no *Pisidium*, and, surprisingly, we found no chironomids in Dragon Lake. However, the distribution of these organisms is patchy, and our relatively light sampling effort at some lakes may have missed some groups.

Chironomid density averaged 1437 individuals/m ^{2} in our study lakes; oligochaetes, 2135/m ^{2} and *Pisidium,* 1567/m ^{2}. The chironomid density was about the same as densities found in 3 2440-m elevation, northern Sierra lakes (Needham and Sumner 1941; Calhoun 1944; Friehofer 1952) and 10 southern Sierra lakes at 2311–3377 m elevations (Reimers, Maciolek, and Pister 1955). By contrast, we found much higher densities of oligochaetes (primarily tubificids of which *Limnodrilus hoffmeisteri* was most common) and *Pisidium* than other investigators reported from northern and southern Sierra lakes.

Precise comparisons with other studies are difficult because of differences in sampling techniques. Apparently corers collect more individuals per unit area than Ekman grabs (Paterson and Fernando 1971), and the other studies cited used an Ekman grab. However, small corers may underestimate some taxa (Kajak 1963). In addition, many small organisms slip through screen openings larger than 0.2 mm (Jónasson 1958). We used a 0.21-mm mesh screen; most studies in the past used even larger mesh openings.

The total invertebrate density ranged from 2599/m^2 in Lower Rae Lake to 7308/m^2 in Dragon Lake and Bullfrog Lake (Table 2). Mean density of all lakes was 5418/m^2 and variation was moderate (SD = 1716/m^2). Oligotrophic mountain lakes in the Sierra and elsewhere generally have densities less than 2500/m^2 (Needham and Sumner 1941; Calhoun 1944; Friehofer 1952; Erman 1969; Sarkka 1972), although densities up to about 4700/m^2 were found in lakes of the nearby Convict Creek basin (Reimers et al. 1955). By contrast, the littoral zone of eutrophic Lake Esrom in Denmark had 10 810 individuals/m^2 (Jónasson 1969).

Elsewhere in North America chironomids from the profundal zone have been used to classify trophic lake types (Saether 1975). Orthocladiinae characterize oligotrophic lakes, while the genus *Chironomus* characterizes eutrophic lakes. These types occur together in the littoral zone of the study lakes (Table 2);

however, samples from the littoral zone may reflect only local conditions rather than conditions in the lake as a whole (Erman 1969; Saether 1975). These differences in species composition do not reflect any obvious trend in response to the human impact index.

The low number of samples from several lakes (Middle, Kearsarge, Upper Rae, Dragon, and Upper Sixty) and the small core size restrict any strong conclusions; nevertheless we observed an apparent correlation between invertebrate density (based on log transformations to correct for clumped distributions, Elliott 1971) and the human impact index (Figure 2). Lower Rae was an exception; it had the lowest density but the highest human impact index. We are uncertain why this Lake was so different. If Lower Rae is excluded, the positive correlation is significant ($r = 0.64$, $P < 0.05$). In a related study we found a highly significant positive correlation between the human impact index and the frequency of occurence of benthic plants in these lakes (Taylor and Erman, in press), but invertebrate density and benthic plant frequency were not significantly correlated. Physical and chemical factors (organic carbon, nitrate nitrogen, total iron, substrate type, lake dimensions, and lake flushing rate) also were not significantly correlated with invertebrate density. Diversity indices calculated for the study lakes ranged from 0.61 in Dragon Lake to 3.29 in Charlotte Lake (Table 2), but diversity was not significantly correlated with any of the above factors.

Bullfrog Lake is interesting because it has a high human impact index (Table 1), a high frequency of bottom plants (Taylor and Erman, in press), and a high macroinvertebrate density (Table 2). This Lake once had obvious overuse from campers and grazing stock and was closed to use over a decade earlier (D. Parsons, National Park Service, pers. commun.). Nevertheless, upstream and nearby use and perhaps slow recovery continue to place Bullfrog Lake in the class of lakes showing effects of human use.

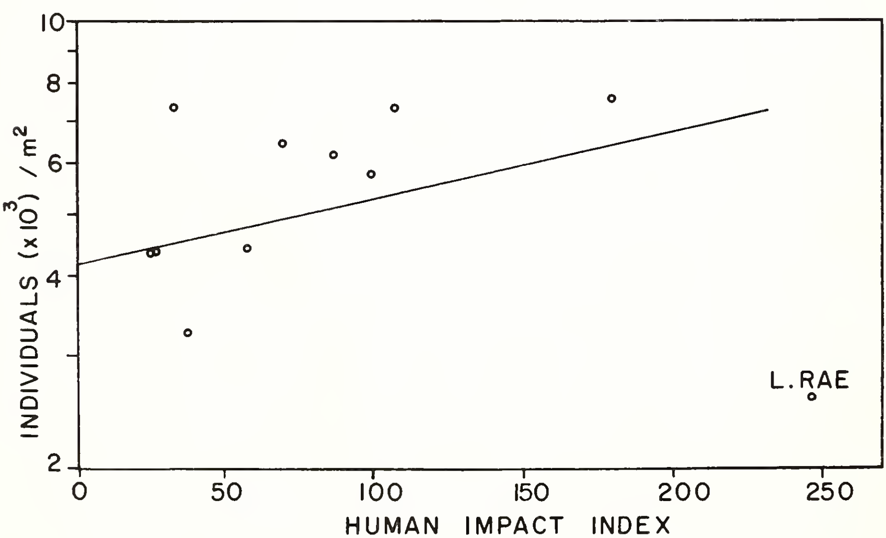

FIGURE 2. The correlation of macroinvertebrate density to human use around lakes in Kings Canyon National Park, California.

TABLE 2. Benthic Macroinvertebrates (Individuals/m^2) from the Littoral Zone of High Elevation Lakes in Kings Canyon National Park, August 1977.

	Upper Kearsarge	*East Kearsarge*	*Middle Kearsarge*	*Main Kearsarge*	*Bullfrog*	*Charlotte*	*Upper Rae*	*Dragon*	*Lower Rae*	*Lower Sixty*	*Upper Sixty*
Number of cores	8	12	4	14	20	14	5	4	15	11	3
Chironomidae											
Chironomini											
Chironomus (Dicrotendipes)	203		406	348	81				433	148	
Glyptotendipes					81						
Polypedilum									108		
Calopsectrini											
Micropsectra		271				116	325			591	
Cladotanytarsus							325			148	1083
Stempellina										148	
Tanypodinae											
Pentaneurini				116	162	348				886	
Procladius										1181	
Orthocladiinae	406				1056	3480	974		217		2165
Total Chironomidae	609	271	406	464	1380	3944	1624	0	758	3102	3248
Oligochaeta											
Tubificidae											
Species a	406	406	1624	116			974				
Species b *(Peloscolex?)*	203	1489	406	812	893	116	1299				541
Species c	406	812	1218		81	348					
Limnodrilus hoffmeisteri	1624		2030	1040	650		650	406	1516		
Enchytraeidae											
Achaeta	203		406	580				406	217		
Species a					325	696	325		108	148	
Total Oligochaeta	2842	2707	5684	2548	1949	1160	3248	812	1841	148	541
Nemata	406			232	650	1160					541
Pisidium (Mollusca)	609	1353	406	2552	3248	1276	1299	6496			
Hirudinea (Leech)					81						
Total individuals	4466	4331	6496	5796	7308	7540	6171	7308	2599	3250	4330
Diversity index	2.79	2.08	2.48	2.35	2.82	3.29	3.12	.61	2.03	2.30	1.75

We could detect no local effects on total number of invertebrates or individual taxa close to areas of most camping. But further studies that concentrate samples at locations near traditional camping areas would be useful to see if localized effects of people have occurred. Our data on benthic plants indicated that increased human use was producing lake-wide stimulation of plant growth in these relatively small, rapidly circulating lakes (Taylor and Erman in press). We hypothesized that stimulation was from input of plant nutrients from the greater human activity. Possibly invertebrates are also benefiting from a lake-wide increase in organic and inorganic nutrients, although the organic carbon in sediment samples was not correlated with invertebrate density. An increase in benthic standing crop is typical of enrichment.

The benthic amphipod *Hyalella azteca* was absent from all samples, although in a previous study this species was the predominant animal in plankton tows from Rae and Sixty lakes (Silverman and Erman 1979). Its absence is probably due to hand sampling, which may disturb the amphipod, and the small corer, which may bias the samples (Kajak 1963). *Hyalella azteca* (= *H. knickerbockeri*) was introduced into the Rae Lakes, along with benthic alga *Nitella*, in 1919 (Coleman 1925) as fish forage.

In summary, we present information on abundance and composition of littoral bottom fauna from 11 high elevation lakes. Macroinvertebrates tend to follow the same pattern we observed for benthic plants; they are more abundant in the lakes with historically high levels of human use. Concern is justified about use levels changing the characteristics of these remote alpine lakes. Stricter limits on use were instituted while the whole project was in progress, but follow up studies should be conducted to evaluate recovery.

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NOTES

A BLUE CATFISH FROM THE SACRAMENTO-SAN JOAQUIN DELTA

A blue catfish, *Ictalurus furcatus* (LeSueur), was captured in the San Joaquin River near Mossdale, CA (lat 37° 48′N, long 121° 18′W) on 6 December 1978. The fish was captured in a hoop net operated to catch white catfish for tagging. This is the first reported catch of a blue catfish in public waters of northern California.

FIGURE 1. Blue catfish, *Ictalurus furcatus,* 535 mm TL taken in the San Joaquin River near Mossdale, San Joaquin County, California, 6 December 1978. *Photograph by Ron Cole and the author, January 1979.*

Identification of the specimen was confirmed by W. I. Follet, California Academy of Sciences, San Francisco. It was a female, 436 mm SL, 535 mm TL, that weighed 1.7 kg. Identification of the specimen was based on the following characteristics: distal margin of the anal fin nearly straight, anal fin base length into standard length 3.3 times, two-thirds of the lobe of the adipose fin free of the body, eyes located low on the head, tail deeply forked, pronounced hump between head and dorsal fin, and fins darker than body. Anal fin ray count was 29, which differs from the expected anal fin ray count of 30–36 for blue catfish (Trautman 1957, Cross 1967).

The specimen was deposited with the California Academy of Sciences, Department of Ichthyology (Catalog Number CAS42576).

The native range of the blue catfish is in large river systems from Ohio and Minnesota southward into Mexico (Pelzman 1971). They were first introduced by the California Department of Fish and Game on 23 October 1969 into Lake Jennings, San Diego County (Richardson et al. 1970). They have since been introduced into Lake Mathews, Sutherlund Reservoir, El Capitan Reservoir, and the Santee Lake chain, San Diego County (Moyle 1976). Blue catfish have been authorized for introduction into northern California (Pelzman 1971), but have not yet been introduced by the Department of Fish and Game. The most probable source of my specimen is one of the 18 licensed fish breeders authorized to raise blue catfish in the Sacramento and San Joaquin valleys. My specimen is similar in size to blue catfish held at a fish farm in central Stanislaus County, about 24 km east southeast of the capture location. Fish held in this pond may have entered the Stanislaus River, a tributary of the San Joaquin, through an agricultural drain canal.

ACKNOWLEDGMENTS

I would like to thank W. I. Follet for verifying the identification of the specimen. Special thanks is also extended to Ron Cole for his assistance in photographing the specimen. This work was performed as part of Dingell-Johnson Project California F-9-R, "Sturgeon, Striped Bass, and Resident Fishes Study," supported by Federal Aid to Fish Restoration funds.

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—Thomas L. Taylor, California Department of Fish and Game, 4001 North Wilson Way, Stockton, California 95205. *Accepted for publication August 1979.*

FIRST CALIFORNIA RECORD: THE SCALLOPED HAMMERHEAD SHARK, *SPHYRNA LEWINI,* IN COASTAL SANTA BARBARA WATERS

A female scalloped hammerhead shark was caught about 100 m outside the edge of a kelp bed (about 2 km offshore) immediately east of the Ellwood Pier, some 21 km west of Santa Barbara, California. It was captured by Michael Kearney, a sport fisherman from Santa Barbara, on 28 August 1977. Surface water temperature on that day was 20°C. Kearney had been fishing for thresher sharks, *Alopius vulpinus,* with freshly caught jack mackerel, *Trachurus symmetricus,* on steel leader suspended from surface buoys to a depth of 6 m. Upon retrieving the gear, he found the hammerhead shark, snagged in the orbital lobe of the right hammer.

We examined the shark (Figure 1) and took the following measurements: 262 cm total length, 72 cm from tip of snout to first dorsal, 145 cm from front base of first dorsal to base of caudal, and 66 cm from eye to eye. It had a maximum girth of 89 cm and its second dorsal was 6.4 cm high, with the unattached posterior portion 14 cm long. The specimen was disembowelled and weighed in several pieces for an estimated total weight of 80 kg.

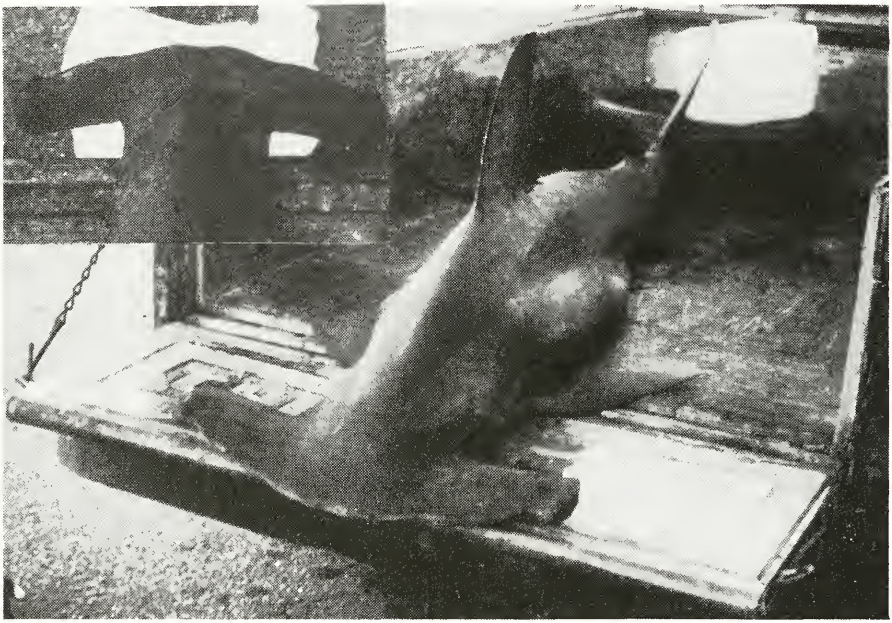

FIGURE 1 Femal scalloped hammerhead shark, *Sphyrna lewini,* taken about 21 km west of Santa Barbara, California in August 1977. Insert: Frontal lobes. *Photograph by Shane Anderson, August 1977.*

The shark was not gravid. The stomach contained mostly digested remains of five fishes, four of which were tentatively identified as Pacific bonito, *Sarda chiliensis.* The abdominal cavity contents and gills were free of parasites.

On the same day, another female hammerhead shark was caught by a sport fishing party from Santa Barbara Harbor. Jerry Sylvia reported that he and two other fishermen were trolling at the surface with fresh mackerel fillet (species unknown) about 1.5 km off the Harbor when they caught the shark. This specimen was estimated to weigh 80 kg without the head and viscera. We were unable to examine it and no other measurements were available. A comparison of photographs and teeth of this specimen to that of the other showed them to be the same species.

Species of hammerhead sharks similar in appearance to *Sphyrna lewini* are the smooth hammerhead, *S. zygaena,* and great hammerhead, *S. mokarran. S. lewini* can be distinguished from the former by having four, rather than one or three, lobes on the anterior margin of the head, and from the latter by having a second dorsal fin with a free rear margin twice as long as the fin is high.

Since hammerhead shark species are known to school, it may be that these two sharks and possibly more, traveled northward for some distance as a group.

There is no other published record of *S. lewini* from California. One earlier report from southern California was erroneous (Kato, Springer, and Wagner 1967). The previous northernmost published record was Isla San Marcos in the

Gulf of California, Mexico (Gilbert 1967), although the Los Angeles County Museum (LACM) collection has material from San Felipe, Baja California (C. Swift, pers. commun.). Therefore, this record represents a northern range extension of 500–600 km.

The final disposition of the two specimens is unknown, but representative teeth from both sharks were kept by the authors.

ACKNOWLEDGMENTS

We wish to thank M. Kearney and J. Sylvia for bringing these sharks to our attention. We thank M. Love [University of California, Santa Barbara (UCSB)] for identifying the gut contents of the shark we examined, M. Moser (UCSB) for his examination of the abdominal cavity contents and gills for parasites, and S. Kato (National Marine Fisheries Service, Tiburon, California) for his helpful comments. We also thank C. Swift (LACM) and R. Rosenblatt (Scripps Institution of Oceanography) for checking their respective collections for records of *S. lewini.*

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—*Craig Fusaro, Marine Science Institute, University of California, Santa Barbara, Santa Barbara, California 93106, and Shane Anderson, Department of Biology, University of California, Santa Barbara, Santa Barbara, California 93106.*
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THE BIGSCALE GOATFISH, *PSEUDUPENEUS GRANDISQUAMIS* (Gill, 1863), ADDED TO CALIFORNIA'S MARINE FAUNA

On 27 February 1979, biologist Mike Curtis, Southern California Edison Co. (SCE), removed a small goatfish from the cooling water trash screens of the company's Nuclear Generating Station at San Onofre, California. Initially, it was presumed to be a Mexican goatfish, *Mulloidichthys dentatus* (Gill, 1862), a species that had been reported from California 60 yr earlier (Higgins 1919), based upon several small individuals that had been trawled off Encinitas and Long Beach. Critical examination, however, revealed it to be a bigscale goatfish, *P. grandisquamis,* not known previously from north of San Juanico Bay, Baja California (lat 26°15'N, long 112°28'W). Hubbs, Follett, and Dempster (1979) noted this species in their recently published checklist, but did not give any details concerning the fish or its capture.

Although Thomson and McKibbin (1976) reported that *P. grandisquamis* attains a length of "about 12 in." (305 mm), the largest for which I could find a published record was a 220 mm total length (TL) individual from the Galapagos Islands mentioned by Hildebrand (1946). The San Onofre goatfish was 173 mm SL, 218 mm TL, and weighed 130 g.

The easiest way to distinguish these two eastern Pacific goatfishes is to count scales, or where scales are missing, scale pockets. *P. grandisquamis* has 3 scale rows in the dorsal fin interspace and 29 to 32 pored scales in the lateral line, compared with 6 and 37 to 41, respectively, for *M. dentatus.*

The San Onofre goatfish has been deposited in the ichthyological collection of the Natural History Museum of Los Angeles County (LACM 31847-1).

ACKNOWLEDGMENTS

Special thanks are extended to Mike Curtis (SCE), Robert J. Lavenberg and Jerry Neumann (LACM), and Richard Rosenblatt (Scripps Institution of Oceanography) for assistance rendered.

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—*John E. Fitch, 2657 Averill Ave., San Pedro, CA 90731. Accepted for publication November 1979.*

NOTES ON THE ESTABLISHMENT OF THE RAINWATER KILLIFISH, *LUCANIA PARVA,* IN CALIFORNIA

The rainwater killifish is a small cyprinodontid having a native range from the coastal regions of Massachusetts south to northeastern Mexico, including the Gulf of Mexico. Additionally, the species occurs in two major river systems in inland Texas and New Mexico. However, the rainwater killifish has been reported (Hubbs and Miller 1965) as having established populations in Utah, Oregon, and various localities in California.

Recently, there has been a surge of interest in the spread of exotic fauna and Moyle (1976) has stated the status of exotics in California should be documented. The purpose of this paper is to report yet another population of *L. parva.* On 22 April 1976, the senior author and Dr. Thomas Fritts were monitoring an introduced population of the African clawed frog, *Xenopus laevis,* near Vail Lake, Riverside County, California. Routine seining and dip-netting were used to sample the frog population and to collect and identify possible prey items. During these identification procedures, an unusual fish was taken and was subsequently identified as *L. parva.*

A total of 34 specimens was collected from Arroyo Seco Creek, a tributary of Vail Lake; 32 specimens (20 females and 12 males) were used for the analysis presented below. The males ranged in size from 24 mm to 34 mm ($^{15}/_{16}$ in. to $1^{11}/_{32}$ in.) total length ($\bar{x} = 29.42$ mm) and the females from 24 mm to 36 mm ($^{15}/_{16}$ in. to $1^{13}/_{16}$ in.) total length ($\bar{x} = 29.95$ mm). The specimens are deposited with California Fish and Game (Region 5), Texas Cooperative Wildlife Collection (TCWC 2499.1), and Los Angeles County Museum of Natural History (LACM 38462-1).

During the course of the African clawed frog study, Vail Lake and all tributaries were routinely surveyed. Arroyo Seco Creek was the only locality where *L. parva* was encountered. At this site, *L. parva* was restricted to a small outflow of an impoundment of Arroyo Seco Creek. *Lucania parva* was taken in running water, while the mosquitofish, *Gambusia affinis,* was taken in both running and still waters.

Hubbs and Miller analyzed a number of characters to find which could be used to determine parent localities for the introduced populations. They concluded that the number of supraorbital pores (SOP), the preopercular pores (POP), and gill rakers on the first arch (GR) are the characters best used for parental population determination. Comparisons were made of our counts of SOP (male: range 6–7; $\bar{x} = 6.916$; female: range 7, $\bar{x} = 7$), POP (male: range 7, $\bar{x} = 7$; female: range 7–8, $\bar{x} = 7.05$), and GR (male: range 6–10, $\bar{x} = 7.916$; female: range 6–9, $\bar{x} = 7.75$) with those given in Hubbs and Miller. These counts most closely resemble those given for the Florida/Gulf Coast populations by Hubbs and Miller.

Vail Lake is an artificial impoundment and the fishes (with the exception of one species of those encountered) are not native. During the course of the study, *Micropterus coosae,* redeye bass; *Pomoxis nigromaculatus,* black crappie; *Lepomis cyanellus,* green sunfish; *G. affinis,* mosquitofish; and *Gila orcutti,* arroyo chub; were encountered. It seems likely that the population of *L. parva* was introduced with the game fishes during stocking.

Lucania parva was also collected by St. Amant in Irvine Lake, Orange County in 1963 as reported by Hubbs and Miller (1965). This introduction is probably the result of shipments of game fishes made in the 1940's from the Dexter Federal Fish Hatchery along the Pecos River, New Mexico. Additional collections of *L. parva* in Lake Irvine were made in 1964 (Hubbs and Miller 1965).

ACKNOWLEDGMENTS

The authors thank James Dixon and John McEachran for reviewing an earlier draft of the manuscript. We also thank R. R. Miller and Camm Swift in confirming identifications. The senior author thanks Thomas Fritts for his patience.

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—Michael J. McCoid. Department of Herpetology, Natural History Museum, San Diego, CA 92112 and James A. St. Amant. Inland Fisheries, California Department of Fish and Game, 350 Golden Shore, Long Beach, CA 90802. Mr. McCoid's current address: Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, TX 77843. *Accepted for publication October 1979.*

BOOK REVIEWS

Pacific Coast Subtidal Marine Invertebrates: A Fishwatchers' Guide

By Daniel W. Gotshall and Laurence L. Laurent. Sea Challengers Los Osos, California 1979; 107 P.; illustrated; $12.50/hardback; $9.50/softback.

If a criterion by which books are judged is the proximity of the final product to the authors' goals, then *Pacific Coast Subtidal Marine Invertebrates* must be rated very highly. In their introduction, Gotshall and Laurent state their purpose is "to enable the sport diver and others to identify most of the larger invertebrates in the area covered by the Guide". In this, they have succeeded admirably. Using the same style and format as Gotshall's popular *Inshore Fishes of the Pacific Coast,* this second book in the Fishwatchers' Guide series covers 161 of the invertebrates commonly encountered by divers from Alaska to Baja California.

Each species is represented by an excellent, and in some instances outstanding, photograph and a brief text that includes identifying characteristics, size, range, and a few natural history notes. Other aids to identification are included. I was particularly intrigued by the artificial key to the invertebrates and spent some time trying, in vain, to confound it. This key and accompanying drawings function to direct the user to the correct group of organisms. The photographs and descriptions serve to pin down the identification.

Two or three of the photographs are not of the same high standards as their cohorts and a few spelling errors occur. However, most of these latter have been noted in an errata sheet and any lack in the photographs would not be as noticeable in lesser company.

In general, I enthusiastically commend this book to anyone with a desire to stick their heads below the sea surface. The uninitiated will be educated and old hands will view fine portraits of old friends.
—John J. Grant

Pacfic Salmon

By R. J. Childerhose and Marj Trim; University of Washington Press, Seattle, WA; 1979; 166 pp; illustrated; $25.95.

My preliminary evaluation, after first thumbing through *Pacific Salmon,* was that it was an attractive coffee table book, but probably without much substance. Wrong. To its intended general public audience, it could be titled *All You Wanted to Know About British Columbia Salmon.*

This book is divided into four major sections: history, biology, environment, and enhancement. Through this format the author, science writer R. J. Childerhose, has done an excellent job of summarizing what is known about the five northeast Pacific salmon: chinook, coho, sockeye, pink, and chum. He addresses just about every facet of salmon biology and management, from estuarine life to fish marking to the 200-mile limit. The subjects are treated with enough detail for understanding, but not so much that the reader gets bogged down.

A highlight of *Pacific Salmon* is the excellent color photography of salmon, fishermen, rivers, lakes, hatcheries, habitat, etc., in British Columbia by Marj Trim.

As I indicated previously, the book emphasizes British Columbia stocks, with occasional mention of conditions or studies in Oregon, Washington, and Alaska. California populations are dismissed with the statements that ". . .[the] great Sacramento [River] runs were decimated by new fishing methods" and that because of this and hydraulic gold mining, "in a few years the salmon runs of the Sacramento River were gone." These, plus the absence of California from the species distribution maps, incorrectly lead the reader to believe that salmon are gone from the Golden State. My only other complaint is the lack of even a modest reference section which could introduce the interested reader to the scientific literature.

Pacific Salmon presents the results of the white man's ecological arrogance with cautious optimism for the future of today's stocks. It closes with a quotation from 1855 of Chief Seathl of the Duwamish tribe, in part:

> "What is man without the beasts? If all the beasts were gone, man would die from great loneliness of spirit, for whatever happens to the beast also happens to the man. All things are connected. Whatever befalls the earth befalls the sons of the earth."

—Dave Hoopaugh

Field Guide to the Fish of Puget Sound and the Northwest Coast

By David Somerton and Craig Murray; University of Washington Press, Seattle, WA; 1976; 70 pp.; $4.95, paperback (printed on water-resistant stock).

This booklet has been described by the publishers as a "long awaited guide to the fishes of Puget Sound and the Northwest waters, from northern California to Alaska, [which] will be welcomed by amateur naturalists, scuba divers, and sports fishermen alike." I am afraid that we are still waiting!

In the preface the authors state the purpose of their effort was to produce a field guide "which used features for identification that were easily recognized under a variety of viewing conditions, and which could be taken underwater as well as used on land or in a boat." The authors did not intend to include all Puget Solund fishes but cover 99 species which they "feel will be at least occasionally seen in Puget Sound or the Strait of Juan de Fuca." Twenty groupings of fishes are considered—i.e., (a) salmon, trout, char; (b) rockfish; (c) cartilaginous fish, etc., and the species for each group are then delineated. Depth range and relative abundance (for Puget Sound) is indicated for each species.

The authors do state, "don't be discouraged when unable to identify many fish—it takes time." A certain knowledge is initially assumed as only a brief explanation or characterization of the larger groupings is given. I am confused by the authors' varying use of the singular and plural in indicating family groups—i.e., rockfish and seaperch vs. flounders and sculpins. They might have followed the American Fisheries Society's "List of Common and Scientific Names of Fishes" for standardization.

The first group of fishes discussed is the salmonids. Eight species are considered (five salmon, two trout, and one char) and the authors point out that these fishes are more often encountered by the angler than the diver. A key is given here, the only one contained, to aid the angler in identifying his fish. It might have been preferable to place the herring and smelt (two species considered) after the salmonids rather than relegating them a rather cryptic space midway through the text between the clingfish and sand lance.

The second group, rockfishes, includes 11 of 24 species recorded in Puget Sound. This genus is difficult even to the trained biologist and I wonder about identifications made from diagrammatic drawings without the aid of a key. Distinguishing characters are given but the task still remains difficult. The use of red snapper as a secondary common name for the yelloweye rockfish is unfortunate. This appellation has been applied to all of the reddish rockfishes as well as a number of brownish and greenish forms. It is confusing and should be avoided.

Sixteen of 36 sculpins are included and again several of the species would be difficult to identify without more complete information.

The greenlings, family Hexagrammidae, are characterized by having several lateral lines. This is correct only for members of the genus *Hexagrammos;* the lingcod and painted greenling have only one lateral line.

The booklet concludes with a list of "common fishes" which "represents most of the fishes likely to be encountered in Puget Sound and along the Washington coast." The inclusion of rosy rockfish is based upon historic literature records which cannot be substantiated and should be changed to rosethorn rockfish. Vermilion rockfish is incorrectly spelled. Although the list is not intended to be complete, several species are not included which should be: northern anchovy, graveldiver, and Pacific pompano, among others.

The booklet is printed on water-resistant stock and will serve as a handy addition in the fisherman's tackle box or the diver's gear bag, the audience which will find it most useful. It will be of limited value to the marine biologist.—*Robert N. Lea*

The Abalone Book

By Peter C. Howorth; Naturegraph Publishers, Inc., CA; 1979; 77 p.; illustrated; $3.50.

The Abalone Book by Peter C. Howorth is an interesting and educational little text covering most aspects of the abalone from pre-historical usage to contemporary gastronomical preparation. The book appears to be intended for the sport-diving and shore-picking public who are descending on the abalone populations in ever increasing numbers. Of particular interest to these will be the eight pages of color photographs portraying west coast species. Howorth, in cautioning pickers to be concerned over such matters as picking technique, legal size, and bag limits, serves to reinforce vital conservation practices. Indeed, the entire book has a concerned tone with the author demonstrating a good understanding of the problems confronting the abalone resource.

In a clear, concise style, Howorth presents sections on abalone evolution, historic and pre-historic usage, life history, species descriptions, and current status. The final section describes the preparation of abalone for food and includes some excellent recipes.

A minor error in a figure identification does not mar the overall presentation of an interesting and well-illustrated text that will allow the average abalone hunter to better understand his prey and better care for it once captured.—*John J. Grant*

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