

## Physiological Responses of Three Species of Fishes to Various Salinities

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The effects of varying salinity on parameters such as growth, food consumption, food conversion efficiency, and respiration were determined for three species of fish inhabiting the Salton Sea, California. *Bairdiella (Bairdiella icistia)*, orangemouth corvina (*Cynoscion xanthulus*), and sargo (*Anisotremus davidsoni*), were subjected to salinities ranging between 29 and 45‰. The optimal range of salinity was between 33-37‰ for all three species. Growth, food consumption, food assimilation, and respiration were adversely affected at the extreme salinities of 29 and 45‰. The results indicate that the fish inhabiting the Salton Sea will experience difficulty in maintaining populations of the current size when the salinity reaches 40‰.

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Les auteurs ont mesuré les effets de diverses salinités sur des paramètres tels que croissance, consommation et efficacité de conversion des aliments et respiration chez trois espèces de poissons de la mer Salton, Californie. Ils ont exposé *Bairdiella icistia*, *Cynoscion xanthulus* et *Anisotremus davidsoni* à des salinités variant de 29 à 45‰. La gamme optimale de salinité se situe entre 33 et 37‰ pour les trois espèces. Les extrêmes de salinité de 29 et 45‰ ont un effet adverse sur la croissance, la consommation et l'assimilation d'aliments et la respiration. Il semble bien, d'après ces résultats, que les populations de poissons de la mer Salton pourront difficilement se maintenir à leurs niveaux actuels quand la salinité atteindra 40‰.

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THE Salton Sea is the largest inland body of water in California. It presently supports a sports fishery of considerable importance and is utilized heavily by the 8 million residents in the Los Angeles area. The success of fish species introductions into the Salton Sea have usually been limited. However, the introduction of bairdiella (*Bairdiella icistia*), orangemouth corvina (*Cynoscion xanthulus*), and sargo (*Anisotremus davidsoni*), proved successful and have provided a substantial sports fishery. Since the introduction of these three species, the Salton Sea has become progressively more saline because of the lack of a freshening water supply. Salt importation to the Basin has increased from an average of 3.95 million tons per year from 1945 to 1962 to 5.59 million tons per year since 1962. Presently, the salinity of the Salton Sea is 37‰, and it has been predicted that by the year 1975 it will increase to approximately 40‰ (Walker 1961; United States Geological Survey 1969). If this prediction becomes a reality, there will be an obvious physiological stress placed on the fish inhabiting the Salton Sea.

In seeking to define the tolerable limits to fish of salinity change in the Salton Sea, we believe that such limits should be defined in terms of the production of the fish populations involved. Assuming that the reproduction and activity of the fish populations are not influenced (these questions are being investigated by others), the problem of the influence of increasing salinity on the production of any fish population can be reduced to direct effects on the growth of the fish and effects on their food organisms.

The importance of energy relations to individual organisms, to the success of populations, and to the stability of communities, has been generally accepted by biologists. Ivlev (1961) has suggested quantitative approaches to the study of growth in fishes, and Winberg (1956) and Fry (1957) have contributed much valuable information on the bioenergetics and growth of fishes. Warren and Davis (1967) and Davis and Warren (1968) have further defined terms of Ivlev's bioenergetic model for use in measuring the possible fates of energy consumed.

The data presented in this paper are the results of efforts to quantify the effects of various salinities on the growth, respiration, and assimilation capacities

of bairdiella, sargo, and corvina under laboratory conditions.

### Methods and Materials

Growth, assimilation, and respiration of each species were studied at the five salinities of 29, 33, 37, 41, and 45‰, in the spring and summer of 1969. The California Department of Fish and Game facilities at Salton City, California, were utilized.

The juvenile sargo, bairdiella, and yearling corvina used in our experiments were collected with beach seines from the Salton Sea and were transported to the laboratory, where they were held for one week in 250-gallon tanks. The fish were selectively sorted for uniform size (Table 1) and for apparently good physical condition. After sorting, the fish were placed in aquaria for salinity acclimation. During the period of acclimation and also during the experiments, the fish were fed commercially frozen bait shrimp and squid. Salton Sea water used in the experiments was filtered through glass wool and charcoal to remove detritus and other suspended material. Throughout the experimental periods, the salinity of the Salton Sea was 37‰. Lower salinity waters (29‰ and 33‰) were prepared by diluting with distilled water and higher salinities (41‰ and 45‰) by evaporation followed by dilution with distilled water. A conductivity bridge was used to measure salinity. The pH and dissolved oxygen content of the water were continually monitored and did not fall in a range where they could be considered a stress factor.

Feeding experiments were conducted in 75 translucent plexiglass aquaria, each having a capacity of 10 liters. This material was used to reduce any behavioral problems such as those inherent in growth experiments conducted in clear aquaria in which fish are held next to one another and fed different rations. Moreover, unfiltered sea water is turbid and it was believed there would be fewer behavioral problems if the visual environment in the aquaria more closely simulated that in the Salton Sea. Evaporation was a problem even though all aquaria had translucent plastic covers. For this reason, salinities were checked daily and adjusted by the addition of distilled water. The aquaria were arranged in five sets of 15 each. Water was recirculated in each set through the use of a headbox, where aeration, filtration of particulate material, and heating occurred. Approximately 20% of the water in the system was freshened each day by introduction of new water in the headbox. Air-conditioners maintained the air temperature at  $21 \pm 2$  C. The water was heated to  $25 \pm 0.5$  C, and day length was held at 15 hr.

### GROWTH AND FOOD CONSUMPTION

The growth rate-consumption rate experiments were conducted with juvenile sargo and bairdiella ranging in length from 8 to 10 cm (Table 1). Forty-five fish were gradually acclimated to each of the five test salinities over a 2-week period. The salinity was changed by increments of 1‰ per day until the desired salinity was achieved. Thereafter, the fish were held at the experimental salinity for the remainder of the 2-week period.

TABLE 1. The species and weights of experimental fish used in the Salton Sea investigations.

Test	Salinity (‰)	Species	Test Weight (g)	
			Mean	Range
Growth	29	Sargo	1.50	1.06-1.88
		"	1.55	1.35-1.84
		"	1.59	1.22-2.01
		"	1.59	1.12-1.99
		"	1.60	1.37-2.07
	33	Bairdiella	4.89	4.15-5.34
		"	4.85	4.26-5.83
		"	4.89	4.09-5.63
		"	5.13	4.28-5.91
		"	5.00	4.13-5.92
Assimilation	29	Corvina	16.67	7.70-29.67
		"	15.53	3.27-32.98
		"	16.00	6.23-26.13
Respirometry	29	Corvina	10.08	8.90-11.45
		"	13.72	3.54-24.65
		"	17.31	2.95-32.98
		"	16.30	3.70-23.89
		"	14.73	8.12-23.75

Excess food was available to the fish during the acclimation period. Fifteen fish were selected from the original 45 acclimated to each salinity. These 15 were divided into five groups of three fish each. The groups were individually fed rations of 1, 2, 4, 6, and 10% of their wet body weight. The change in weight of the fish during the test period was calculated on a dry-weight basis. Each value obtained was divided by the mean dry weight of the fish for the time interval involved (14 days) and the quotient was then divided by the number of days of actual feeding in the interval (10 days). Growth rates were expressed in terms of milligrams of growth per gram of biomass per day.

#### RESPIRATION

Respiration studies were conducted using yearling corvina acclimated to the five test salinities. The respirometers used were circular 2-liter black plexiglass containers through which water could be continuously passed. Water was cycled between the respirometer and a headbox where aeration and temperature control was accomplished. Following introduction and acclimation of the individual fish, an initial water sample was withdrawn. The water source to the test chamber was then sealed off and the animal was allowed to respire in the dark, unfed, for periods of time ranging from 15 min to 1 hr. At the conclusion of the test period, a final water sample was withdrawn. The water samples were analyzed for dissolved oxygen using the Azide Modification of the Winkler method (American Public Health Association 1960). Values were expressed in terms of total oxygen consumed ( $\text{mg O}_2/\text{hr}$ ) and oxygen consumption rate ( $\text{mg O}_2/\text{g/hr}$ ).

#### ASSIMILATION

Yearling corvina were acclimated to 29, 37, and 45‰ salinities. After acclimation, a 48-hr period of food deprivation was followed by feeding rations of known weight and caloric value. The fish were held for 48 hr to allow for digestion and assimilation. Then, the resultant fecal material was collected from the aquaria, filtered, and frozen along with a 30-ml aliquot of the filtrate for analysis of organic matter. A wet combustion method was employed using dichromate as the oxidizing agent (Brocksen et al. 1972). The percentage of food assimilated by the fish held at the various salinities was calculated by dividing the milligrams of oxygen required to oxidize the fecal material and other organic material in the sample by the milligrams of oxygen required to oxidize the same amount of food fed.

### Results and Interpretation

#### FOOD CONSUMPTION AND GROWTH OF SARGO AND BAIRDIELLA

The results of growth rate-consumption rate experiments conducted with juvenile bairdiella at 29, 33, 37, 41, and 45‰ indicate that at the lower feed-

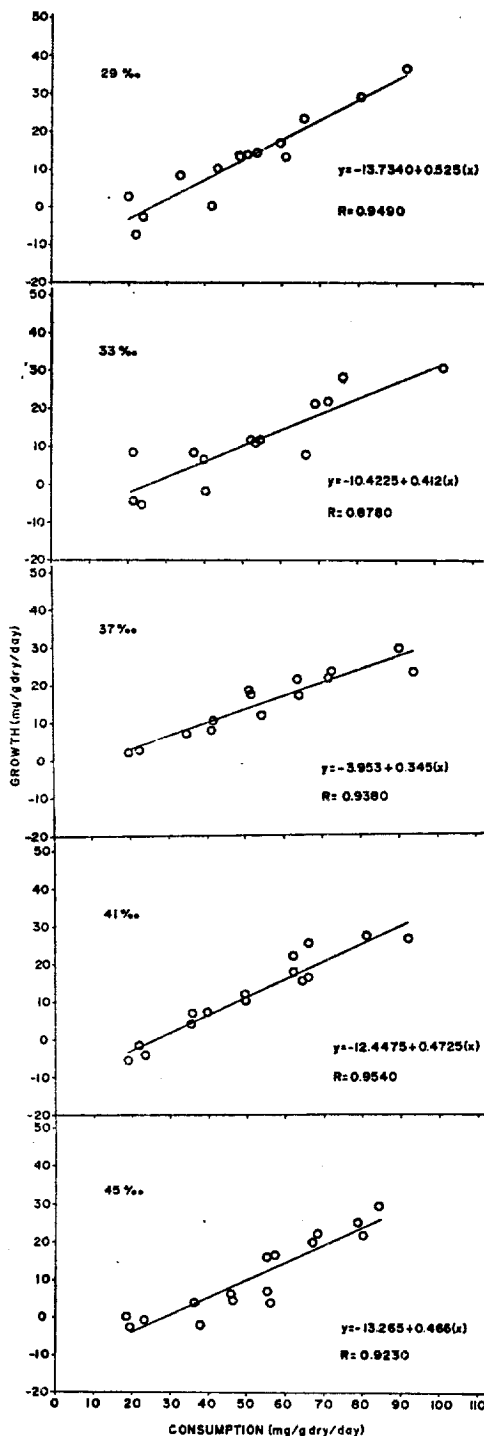


FIG. 1. Relation between consumption rate and growth rate for juvenile bairdiella held at five salinities.

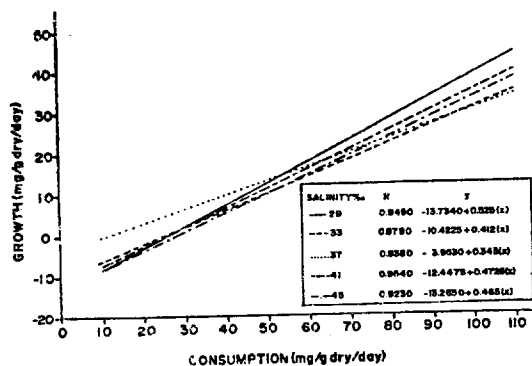


FIG. 2. The influence of salinity on growth rate-consumption rate relationships of juvenile bairdiella.

ing levels the salinity at which the bairdiella is most efficient is 37‰ (Fig. 1, 2). The favorability of the 37‰ salinity is particularly evident at the maintenance level of energy intake where, on a dry-weight basis, 11.16 mg of food per gram dry weight of fish per day (mg/g dry per day) was required to maintain this species in a no-gain, no-loss state (Fig. 1). At a salinity of 41‰, the maintenance requirement increased by 136% to 26.37 mg/g dry per day (Fig. 1) and at the highest salinity tested, 45‰, 28.52 mg/g dry per day was required for maintenance (Fig. 1). The latter figure represents an increase of 156% above the energy required to maintain the fish at the 37‰ salinity. While the bairdiella had a relatively high efficiency ratio at the three lowest feeding levels (1, 2, and 4% of the body weight) at 37‰ they did not utilize their food as efficiently at the highest feeding levels of 6 and 10% of their body weight (Fig. 2). This may be a result of experimental error in collecting uneaten food rations at the higher feeding levels. During these experiments, it was discovered that the possibility of passage of food between individual containers existed and this situation was then corrected while the experiment was in progress. Table 2 gives the maintenance rations at the various salinities for both the bairdiella and the sargo.

The results of the growth experiments with juvenile sargo were quite different from those of the bairdiella (Fig. 3, 4). The most favorable salinity for food utilization appeared to be 33‰ for the sargo (Fig. 3, 4). Sargo held at a salinity of 45‰ were the least efficient, indicating a rather severe stress (Fig. 4). The sargo held at 37‰ were inefficient in utilizing their food for growth (Fig. 3, 4). The sargo being an ocean species has evolved to grow and reproduce in salinities approximating 35‰. The stress indicated by a 2‰ difference is not in proportion to that caused by the other salinities. Considering the osmoregulatory processes involved in maintaining a

TABLE 2. Food (mg/g dry/wt/day) required to maintain bairdiella and sargo in a no-gain, no-loss state (maintenance) at five salinities, and the correlation coefficients derived from the growth rate-consumption rate experiments.

Salinity (%)	Maintenance		Correlation coefficient	
	Bairdiella	Sargo	Bairdiella	Sargo
29	26.16	75.83	0.949	0.918
33	25.29	63.48	0.878	0.971
37	11.16	77.34	0.938	0.895
41	26.37	75.66	0.954	0.798
45	28.52	78.71	0.923	0.970

rather constant internal environment, one would expect the growth at 33‰ and 37‰ to be nearly the same. The energy required for maintenance of this internal environment would not be expected to be significantly different between 33‰ and 37‰.

The most striking feature of the curves in Fig. 4 is the increase in the amount of energy required to simply maintain the fish. The maintenance ration increased from 63.5 mg/g dry per day at a salinity of 33‰ to 78.7 mg/g dry per day at a salinity of 45‰ (Fig. 4, Table 2). The difference represents an increase of nearly 25% in the amount of energy required to meet the maintenance requirements.

The major difference between the results of the experiments involving the sargo and the bairdiella is the comparative location of the growth curve at 37‰ for the sargo. The shifting of the growth-rate curves to the right is certainly an effect of the stress placed on the fishes by exposure to the different salinities. This is substantiated by an examination of the results of food assimilation and respiration experiments.

#### ASSIMILATION

The amount of food assimilated by the juvenile corvina from a given ration was highest at the salinity of 37‰ and lowest at the extreme salinities of 29‰ and 45‰ (Table 3). Determinations were not made at other salinities or with other species. We recognize that there can be differences in the amounts of food assimilated from a given food ration between species (Brocksen et al. 1972), but because of logistic problems and time limitations, the number of experiments reported here were limited. We believe that because the three species of fish under consideration are carnivores, the results are valid for comparative purposes. It appears that in relation to the maintenance requirements of the fish, a portion of the increase in food requirements above and below

the 33‰ and 37‰ salinities is probably a result of the decreased food assimilation at the extreme salinities.

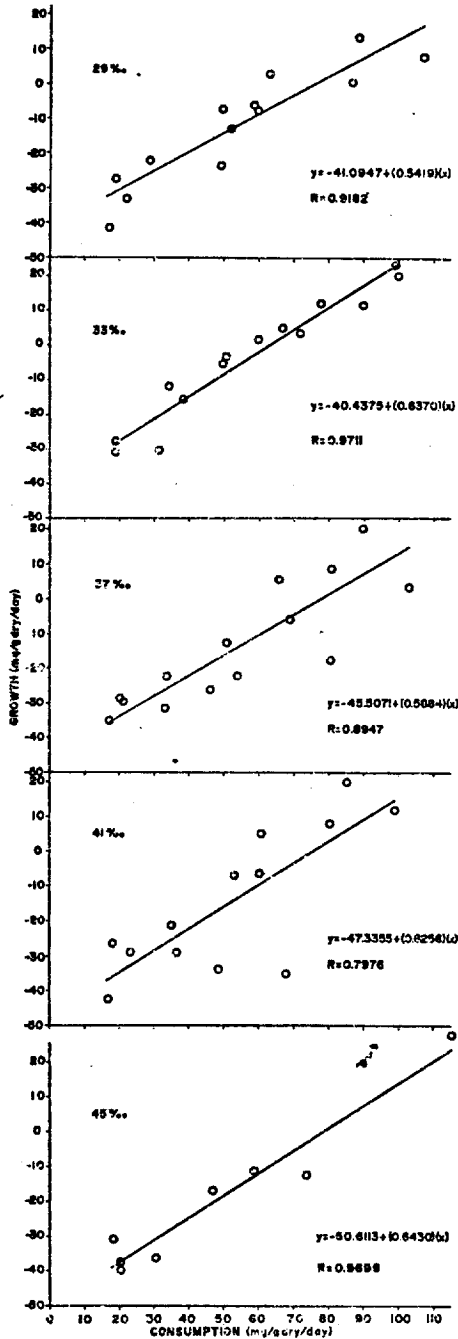


FIG. 3. Relation between consumption rate and growth rate for juvenile sargo held at five salinities.

RESPIRATION

Total respiration is the amount of oxygen consumed by the fish per given unit of time (here expressed per hour) and was measured using yearling corvina of different weights at various salinities (Fig. 5). Oxygen uptake was markedly higher by the fish held at 29‰ and 45‰ than by those fish held at the intermediate salinities. When the oxygen uptake values are divided by the weight of the fish and plotted against the fish weight, the result is respiration rate (Fig. 6). The higher rates of respiration are exhibited at the extreme salinities of 29‰ and 45‰ and the lower rates at the intermediate salinities.

Respiration values obtained in these experiments were not equivalent to the standard metabolism of the fish, but rather are routine metabolism (Fry 1947), because the fish were simply held in darkened containers and activity was not controlled. Control over activity during respiration measurements is desirable when synthesizing energy budgets (Warren and Davis 1967). There is, however, interest in routine metabolism. The convergence of the points at

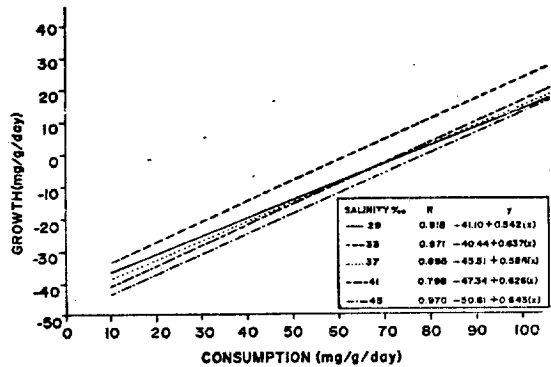


FIG. 4. Influence of salinity on growth rate-consumption rate relationships of juvenile sargo.

TABLE 3. Assimilation efficiencies for Corvina held at 25 C in three different salinities.

Salinity (%)	Percent Assimilation	
	Range <sup>a</sup>	Mean
29	63-69	66.25
37	70-75	72.00
45	59-60	59.33

<sup>a</sup>Number of determinations in each case was five.

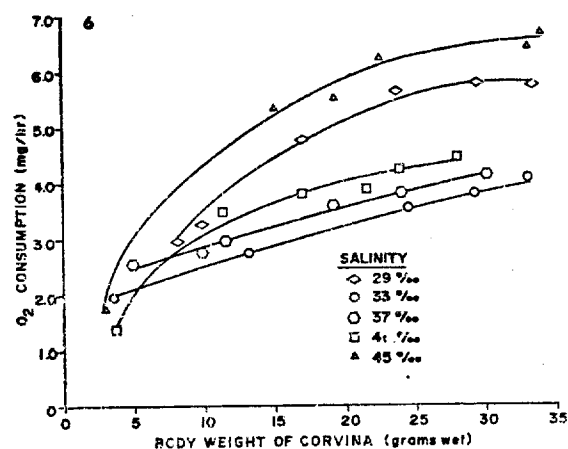
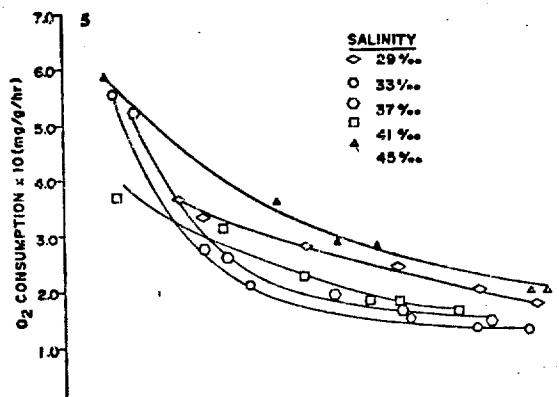


FIG. 5. Respiration rate of the orangemouth corvina at five different salinities.

FIG. 6. Total oxygen consumption of the orangemouth corvina at five different salinities.

the left in Fig. 5 and 6 indicate that the smaller corvina have a different response to the extreme salinities than do the corvina of greater weight. The small corvina are either not as physiologically influenced by the extreme salinities or their activity is markedly suppressed. Only activity control would help to explain the convergence of the respiratory curves with the small fish. It is for this reason that standard metabolism is preferred over routine metabolism as a measure of stress.

### Discussion

We did not attempt to investigate all of the energy demanding physiological processes involved in budgeting the energy of a fish. Changes in salinity experienced by the fish could cause changes in specific dynamic action (Averett MS 1969), but this is

difficult to measure. Costs of activity and behavior, too, are difficult to measure and are most often estimated as residuals after growth and the other energy-demanding processes are accounted for. In routine investigations of effects of water quality, it is perhaps not necessary to measure either specific dynamic action or activity.

Our ultimate goal for management of fishes of the Salton Sea is knowledge of the effects of increased salinity on their production rates. Since production is most often defined as the product of growth rate and biomass, it is obvious that any decrease in growth rate without a simultaneous increase in biomass will result in a decrease in production. It has been demonstrated by the relations shown in Fig. 1-4 and the data in Table 3, that decreases in growth rate due, in part, to increases in respiratory costs and a decrease in assimilation efficiencies can be expected at salinities above 40‰ and below 32‰. This is especially true with *bairdiella* at the lower feeding levels. Production is a complex event involving food supply, density of fish, and competition for food (Brocksen et al. 1968, 1970; Brocksen and Warren MS 1972). Without growth, there is no production, and certainly no reproduction, and it is because of this that we believe it is the best single measure for determining the influence of water-quality changes on fish (Averett and Brocksen 1970). The measurements of growth in this study were not made without difficulties, and there are definite seasonal differences which must be taken into consideration. Ideally, growth experiments for each species of fish should be conducted during the four seasons of the year. During the time periods involved in this study, fishes of a similar weight and age were used. In addition, a food ration of uniform quality was used. Because of these procedures, comparative information of sufficient value to define the physiological stress caused by salinities ranging between 29-30‰ and 40-45‰ was derived. Those salinities causing the least stress for the species studied can be defined on this basis as being between 33‰ and 37‰. This range takes into consideration only growth and the processes involved with energy utilization, but not reproduction. It is unfortunate that information on growth, assimilation, and respiration are not available for all three species of fish. This was, in part, owing to availability of fish and, in part, owing to limited facilities. Yet, the corroborative results of the growth data of the *bairdiella* and the sargo (Fig. 1-4), combined with the assimilation and respiration data derived using the corvina, exhibits some rather basic responses to the stress of salinity. Without all of the aforementioned data for any one species, it is impossible to construct a meaningful energy budget. There is danger in the extrapolation of any

laboratory-derived data to existing wild populations, but the basic principles and relations can often warn us of potential or impending stresses such wild populations may experience. Elucidation and understanding of such causal factors is essential before any sound management programs can be initiated.

If, then, there is a resultant increase in the maintenance requirements of the fishes at salinities other than those in the range of 33–37‰, one wonders if the food base is adequate to meet these needs in the Salton Sea. The pile worm, *Neanthes succinea*, forms the basis of the rather simple food chain existing presently in the Sea (Carpelan and Linsley 1961). This organism must be able to afford the increase in energy requirements to the fish in question if they are to grow and reproduce. If the physiological stress placed on the fishes is being experienced by the pile worm, it is questionable whether or not the worm can provide the increased energy needs or, in fact, absorb the increased pressure and maintain a population of any consequence. We believe, as with the fish, that the measurement of growth and its related processes point the way towards the most meaningful evaluation of the influence of increasing salinities on the pile worm.

Irrespective of the dynamics of the pile worm populations, the bairdiella, sargo, and corvina inhabiting the Salton Sea are presently undergoing salinity stress. We believe the solution to this problem lies in the retardation of increasing salinity in the Salton Sea, for even the most rapid physiological adaptation cannot be visualized for the increasing salinities predicted in the near future.

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AMERICAN PUBLIC HEALTH ASSOCIATION. 1960. Standard methods for the examination of water and waste water. 11th ed. APHA Inc., New York, N.Y. 626 p.  
 AVERETT, R. C. MS 1969. Influence of temperature on energy and material utilization by juvenile Coho

- salmon. Ph.D. Thesis. Oregon State Univ., Corvallis, Oregon, 74 p.  
 AVERETT, R. C., AND R. W. BROCKSEN. 1970. Measuring the influence of water-quality changes on fish. Proc. Amer. Water Quality Ass. 00: 217–227.  
 BROCKSEN, R. W., J. BUGGE, AND R. E. COLE. 1972. A simplified method of determining assimilated energy by fishes. J. Fish Biol. (In press)  
 BROCKSEN, R. W., G. E. DAVIS, AND C. E. WARREN. 1968. Competition, food consumption, and production of sculpins and trout in laboratory stream communities. J. Wildlife Manage. 32: 51–75.  
 1970. The analysis of trophic processes on the basis of density-dependent functions, p. 468–498. In J. E. Steele [ed.] Marine food chains. Univ. Calif. Press, Berkeley, Calif.  
 BROCKSEN, R. W., AND C. E. WARREN. MS 1972. Density dependence of trophic processes in laboratory stream communities.  
 CARPELAN, L. H., AND R. H. LINSLEY. 1961. The pile worm, *Neanthes succinea* (Frey and Leukart), In B. W. Walker [ed.] The ecology of the Salton Sea, California, in Relation to the Sport Fishery. Calif. Dep. Fish Game Fish Bull. 113: 198 p.  
 DAVIS, G. E., AND C. E. WARREN. 1968. Estimation of food consumption rates, p. 204–225. In W. E. Ricker [ed.] Methods for assessment of fish production in fresh waters. (IBP Handbook No. 3.) Blackwell, Oxford, England.  
 FRY, F. E. J. 1947. Effects of the environment on animal activity. Univ. Toronto Stud. Biol. Ser. 55: 62 p.  
 1957. The aquatic respiration of fish, p. 1–63. In M. E. Brown [ed.] The physiology of fishes. Vol. 1. Academic Press, New York, N.Y.  
 IVLEV, V. S. 1961. On the utilization of food by plankton-eating fishes. Tr. Sevastopol' Biol. Sta. Im. A. D. Kovalenskogo Akad. Nauk. SSSR. 14: 188–201. (Transl. from Russian by Fish. Res. Board Can. Transl. Ser. No. 447)  
 UNITED STATES GEOLOGICAL SURVEY. 1969. Report on hydrological conditions of the Salton Sea. 256 p.  
 WALKER, B. W., ed. 1961. The ecology of the Salton Sea, California, in relation to the sport fishery. Calif. Dep. Fish Game Fish Bull. 113: 198 p.  
 WARREN, C. E., AND G. E. DAVIS. 1967. Laboratory studies on the feeding, bioenergetics, and growth of fish, p. 175–214. In S. Gerking [ed.] The biological basis of freshwater fish production. Blackwell, Oxford, England.  
 WINBERG, G. G. 1956. Rate of metabolism and food requirements of fishes. Nauch. Tr. Beloruss. Gosudarst. Univ. imeni V.I. Lenina Minsk. 253 p. (Transl. from Russian by Fish. Res. Board Can. Transl. Ser. No. 194)