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ABUNDANCE AND DISTRIBUTION OF THE ICHTHYOPLANKTON IN THE SALTON SEA, CALIFORNIA IN RELATION TO WATER QUALITY

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ABSTRACT

The relative distribution and abundance of ichthyoplankton in the Salton Sea was determined by sampling 11 sites monthly during 1987 and semimonthly in 1988 and 1989. During the years of the survey, the total dissolved solid (TDS) level fluctuated from 38 ppt in 1987 to 44 ppt in 1989. Although early developmental stages of eggs continued to exist in the plankton as the TDS levels continued to increase, each successive year the number of ichthyoplankton declined as the result of a significant decline in both the late egg and early larval stages for Cynoscion xanthulus and Anisotremus davidsoni. The exception to this was Bairdiella icistia with significantly more late larvae occurring in samples with each progressive year.

In the 1950's, several fish species were introduced into the Salton Sea, the largest inland body of water in California (Whitney 1961). Three of these species (Orangemouth Corvina, Cynoscion xanthulus; Bairdiella, Bairdiella icistia; and Sargo, Anisotremus davidsonii) have formed reproductive populations that provide one of the highest quality fisheries in the State (Black 1988). Since 1925, the diversion of Colorado River water into the Imperial Valley for agriculture has raised the level of the Salton Sea from 83 m below sea level to a current elevation of 75 m below sea level. It is 53 km long, 23 km wide and approximately 14 m deep. The water level of the Sea is currently stable, however, the salinity is constantly increasing. About 5 million tons per year of salt is carried into the Sea from its tributaries, but no salt is removed because the Sea has no outlets. The Salton Sea has an ionic composition different from that of ocean water (Carpelan 1961, Young 1970) and its overall salinity is now 43 ppt. Although Brocksen and Cole (1972), Lasker et al. (1972), and May (975a, b) found that 40 ppt salinity exceeds the upper tolerance limits of Salton Sea fish during embryonic and larval development, recruitment is still occurring at salinity levels above 40 ppt. The development of Salton Sea solar and geothermal energy resources, as well as recently mandated water conservation and water transfers necessitates an assessment of the reproductive success of the Salton Sea sportfishery.

MATERIALS AND METHODS

Since the Salton Sea is a large inland body of water (53 km long and 23 km wide), 11 sampling sites were designated to determine the relative distribution of ichthyoplankton in the Sea (Fig. 1). Ten sites have both nearshore and offshore stations. Nearshore stations have an approximate depth of two meters, while the offshore stations have a depth of approximately eight meters. Since the Sea has a gradual sloping contour, the nearshore stations often were as much as 4.8 km from the offshore stations. All stations were sampled with a 333 micron Nitex, conical, plankton net equipped with a TSK rotary flowmeter. The tows were two minutes in duration over an approximate distance of 100 meters. Stations deeper than three meters were sampled using the oblique and surface ichthyoplankton net tows while stations three meters or less were sampled with surface tows. Stations were sampled in a random fashion both in terms of time of sampling and sequence of sampling. Monthly sampling occurred in 1987 with semimonthly sampling taking place in 1988 and 1989. Samples were preserved in 5% formalin, buffered with a saturated sodium borate solution (Smith and Richardson 1977). All samples were 100% sorted for eggs and larvae, with 1000 eggs from each sample staged into easily recognized embryological events modified from information on the embryology of Bairdiella icistia (May 1975a) and adapted to fit all three species (Table 1). Taxonomic identification of the late stage eggs was accomplished through the development of an algorithm utilizing distinguishing pigmentation patterns in Stage V, VI, and VII eggs (Jordan et. al. 1992). All larvae were identified to species. Water quality parameters (DO, pH, temperature, depth, electrical conductivity) were measured using a Sonde water quality analyzer (HydroLab Corp., Austin, Tx) to ascertain whether water quality parameters determined the abundances and distribution of the ichthyoplankton.

Figure 1. Salton Sea sampling stations.

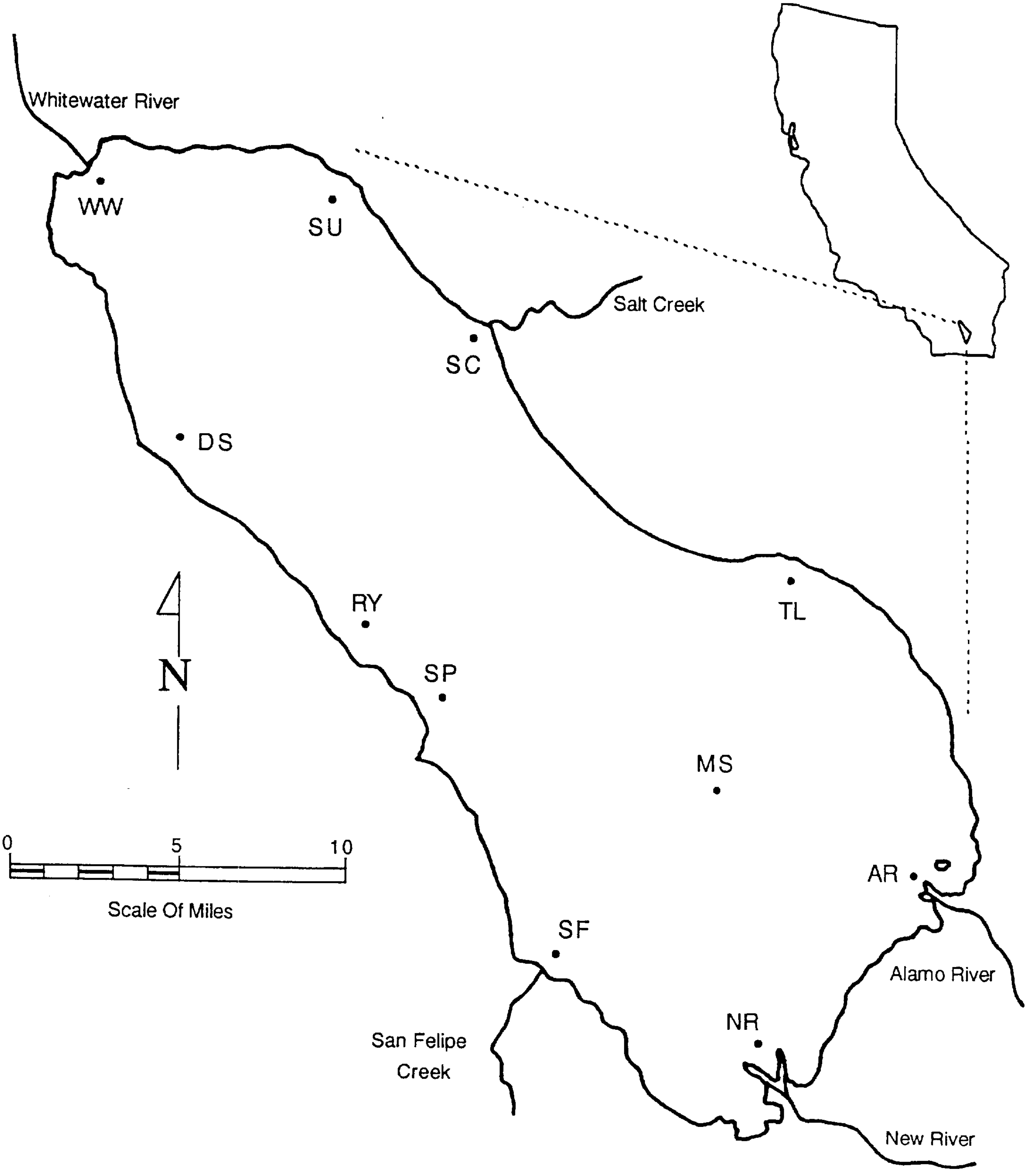


Table 1. Ahlstrom's numerical designation of developmental stages.

Ahlstrom Stage	Sub-Stage	Description
I	a	Unfertilized egg
	b	Blastodisc
II	a	2 blastomeres
	b	4 blastomeres
	c	8 blastomeres
	d	Morula
	e	Blastula, periblast very apparent
III	a	Early gastrula, germ ring encircles as much as 1/3 yolk, embryonic shield rudimentary
	b	Mid gastrula, embryonic shield expands, germ ring encircles as much as 2/3 of yolk
IV		Late gastrula, primitive streak forms
V		Blastopore closes, optic vesicle and Kupffer's vesicle form
IV	a	Somites begin to form; scattered melanophores appear, a few extending posterior along notochord
	b	Lens and otic vesicles form. Tip of tail reaches oil droplet
VII		Tail has moved beyond oil droplet and lifted off yolk; finfold apparent
		Hatching

RESULTS

Abundance

Five developmental categories:

EE = Early Eggs (Stage II and damaged eggs)

ME = Middle Eggs (Stage III and IV)

LE = Late Eggs (Stages V, VI, and VII and abnormal eggs)

EL = Early Larvae (yolk sac and preflexion larvae and abnormal larvae)

LL = Late Larvae (Flexion and post flerxion larvae)

These categories were utilized to analyze the mean number of individuals by age per plankton tow for each of the three years (Table 2).

The majority of the ichthyoplankton in the night tows were early egg stages (EE: 55% in 1987; 86% in 1988; and 83% in 1989) suggesting that the sportfish species in the Salton Sea do tend to spawn nocturnally. The relative abundance of EE stages in the night samples increased in 1988 and 1989, indicating a drop in the relative abundance of older developmental stages (LE and EL). The total night-tow abundance also dropped significantly in 1989. In the day samples, most of the plankton were LE or EL, and there was a significant drop in abundance of these stages across years ($p = .04$ and .001, respectively). A Chi-squared analysis was performed on the relative abundance of different age groups in the day versus the night which confirmed the heterogeneity of relative abundances across years within the day/night category.

Although more stations were sampled in 1989, the mean number of each stage collected per tow was not significantly increased. During the sampling period in 1987, one sample was taken from each of the designated stations per month. However,

Table 2. Mean count per tow by age group across years.

Year	EE	ME	LE	EL	LL	Total
Night plankton tows						
1987	77042	1630.3	24695	36253	154.51	139775
	55.12%	1/17%	17.67%	25.94%	0.11%	
1988	189986	6417	18778	3660	1625.1	220466
	86.27%	2.91%	8.52%	1.66%	0.74%	
1989	5643	852.65	8837.5	1918.3	119.46	68160
	82.79%	1.25%	12.97%	2.81%	0.18%	
Day plankton tows						
1987	53081	4979.3	143819	44142	18641	246208
	21.56%	2.02%	58.41%	17.93%	0.08%	
1988	12290	881.78	40635	13854	238.92	67900
	18.10%	1.30%	59.85%	20.40%	0.35%	
1989	5747.7	725.03	5860.3	4969.5	81.245	17384
	33.06%	4.17%	33.71%	28.59%	0.47%	

sampling intensity was increased during the most productive time of the year in 1989 to two sampling events per month at each designated station. An analysis of variance was performed after equating the sampling effort across the three years, the total numbers obtained drop dramatically from 1987 to 1989 by nearly a factor of four. There was no significant change across years for either EE or ME individuals. The effect was mainly caused by a massive reduction in the abundance of LE ($p = .04$) and EL ($p = .0001$).

Abundance by Species

Egg stages earlier than Stage VI cannot be identified to species (Jordan et al. 1992), so the EE and ME categories dropped out of this analysis. An analysis of variance was performed on the mean numbers for each station for each month/year combination by species and developmental stage. Figures 2-4 depict mean number per tow for each species by developmental stage. A summary of the significance levels is given:

	Late Eggs	Early Larvae	Late Larvae
Anisotremus	$p = 0.16$ NS	$p < 0.001$ **	$p < 0.001$ **
Bairdiella	$p = 0.001$ **	$p < 0.001$ **	$p = 0.006$ **
Cynoscion	$p = 0.007$ **	$p = 0.06$ NS	$p = 0.03$ *

The relatively lower significance of Cynoscion results is mainly a result of a much smaller population. The significant effect for late larvae for Bairdiella is in the opposite direction, with more individuals in this class in later years. For both Anisotremus and for Cynoscion, the late eggs, early larvae and late larvae are in the direction of significantly fewer individuals in successive years.

Figure 2. Mean number per tow of late egg, early larvae, and late larvae by year for _Anisotremus_ _davidsoni_

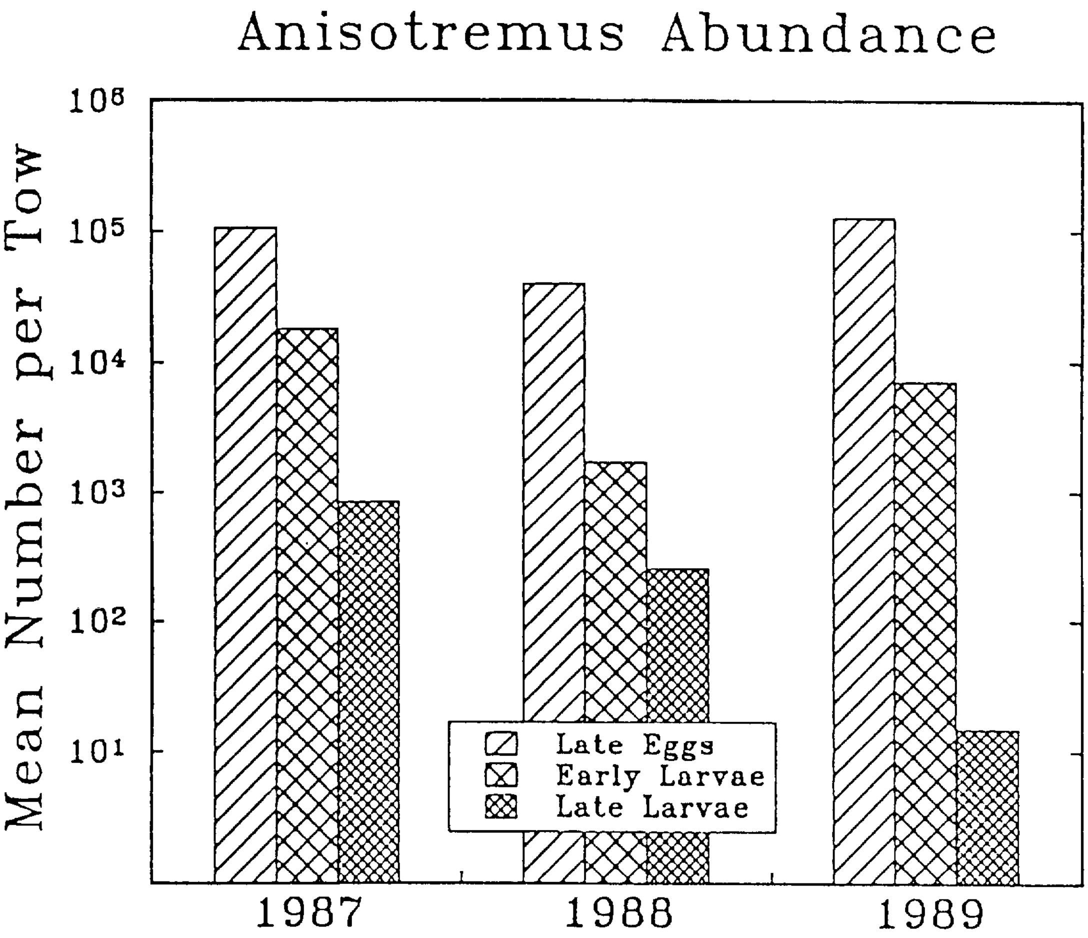


Figure 3. Mean number per tow of late egg, early larvae, and late larvae by year for Bairdiella icistia

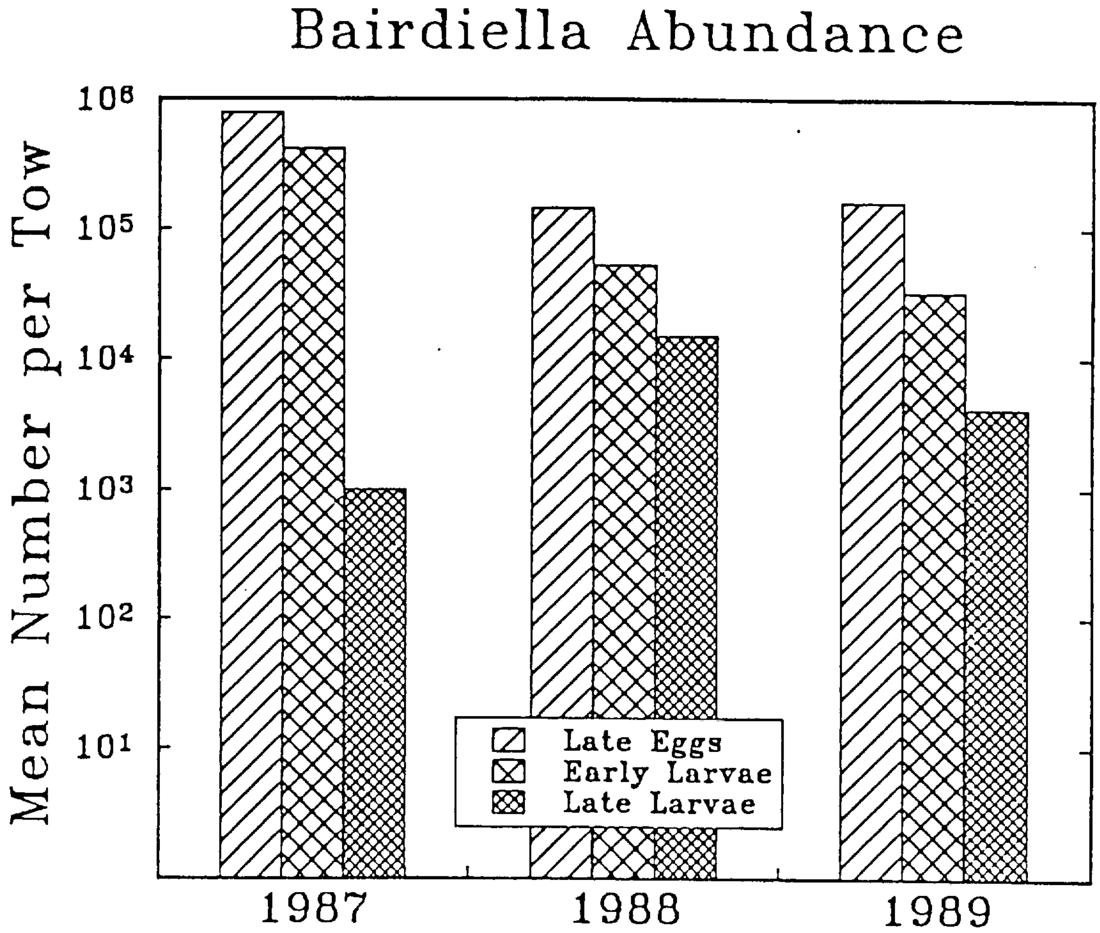
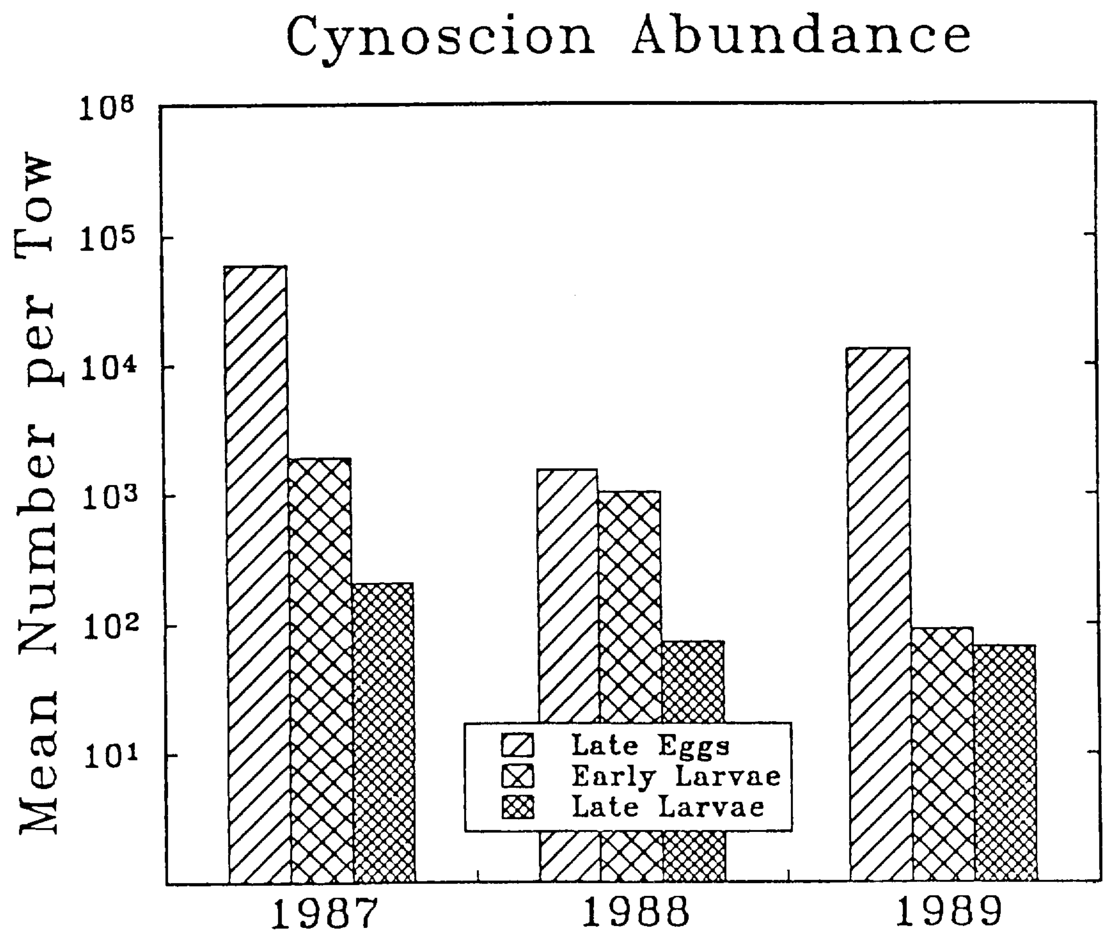


Figure 4. Mean number per tow of late egg, early larvae, and late larvae by year for Cynoscion xanthulus



Distribution

The proportional distribution of identifiable eggs is displayed by year and by species (Figs. 5-13). Data previously collected by Occidental College (Jordan et. al. 1992) indicate that to reach an identifiable egg stage (Stage VI) for Anisotremus at 22°C requires 20 hours from fertilization, Bairdiella at 27°C requires 14 hours from fertilization and Cynoscion at 26°C requires 13 hours. The distributional figures consequently reflect eggs which have had a prolonged period over which dispersal may have occurred. Egg abundance is much more heterogeneously distributed than larval abundance. The most productive stations are not consistent from year to year. There is more consistency across species within years than within species across years. In 1987, the predominance of late eggs and larvae are found on the western side of the Salton Sea with more late eggs found at the San Felipe Creek (SF) station. The pattern moves to the north and east in 1988, and back to San Felipe and the Middle of the Sea (MS) station in 1989.

The predominance of larval Cynoscion near the freshwater inlets (San Felipe Creek, the New River and the Alamo River) in 1988 and 1989 with similar distribution for Bairdiella in these same years should also be noted.

Water Quality Parameters

The Hydrolab data (pH, DO, temperature, electgrical conductivity) were analyzed by comparing mean values for each physical parameter by comparing stations near major river outflow (outflow stations include Alamo River, New River, and Whitewater River) to non-outflow stations (including San Felipe Creek and Salt Creek which provide periodic flow into the Sea and other stations not directly adjacent to a tributary). Comparisons of

Figure 5. Proportional distribution of identifiable eggs for

Anisotremus davidsonii, 1987

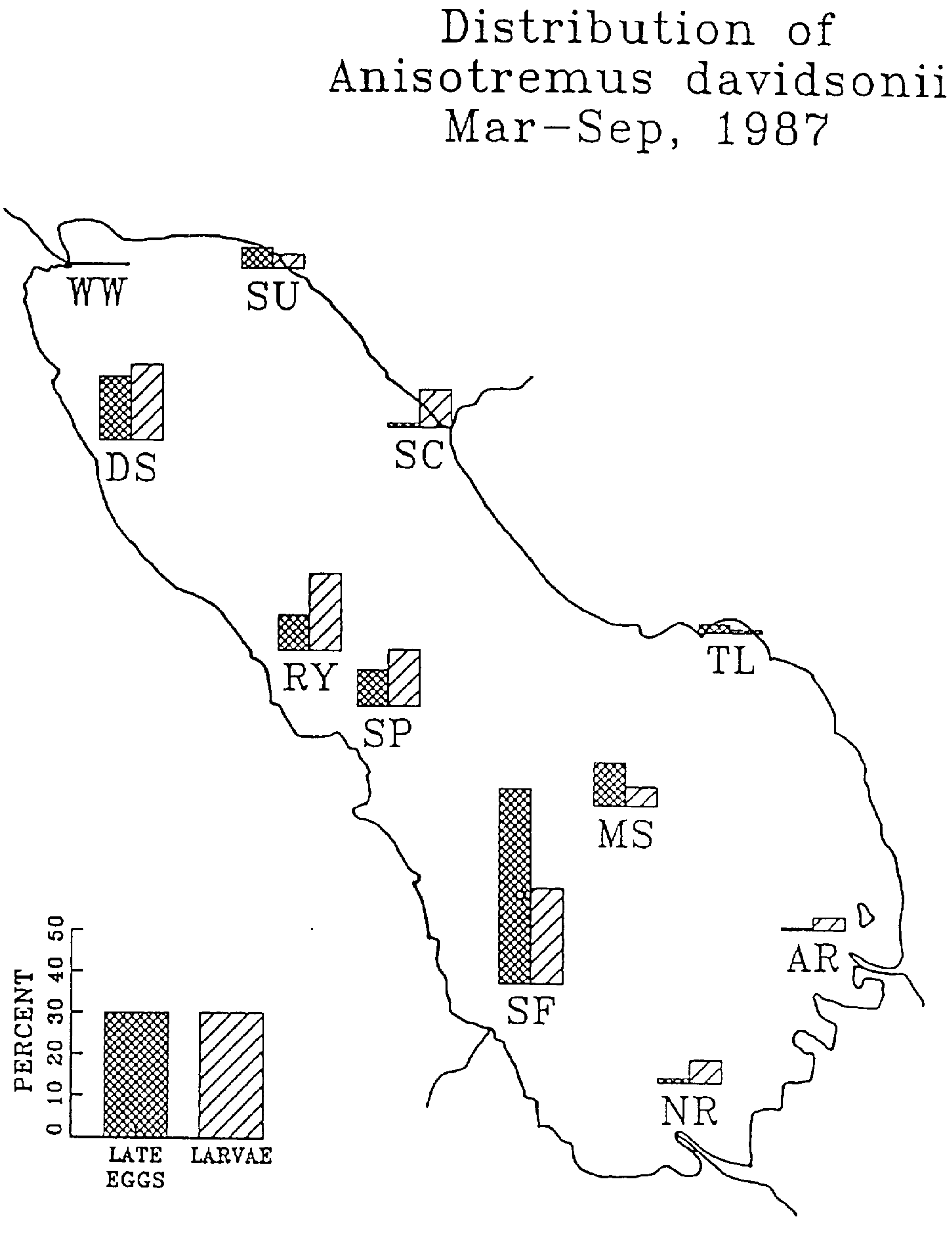


Figure 6. Proportional distribution of identifiable eggs for

Bairdiella icistia, 1987

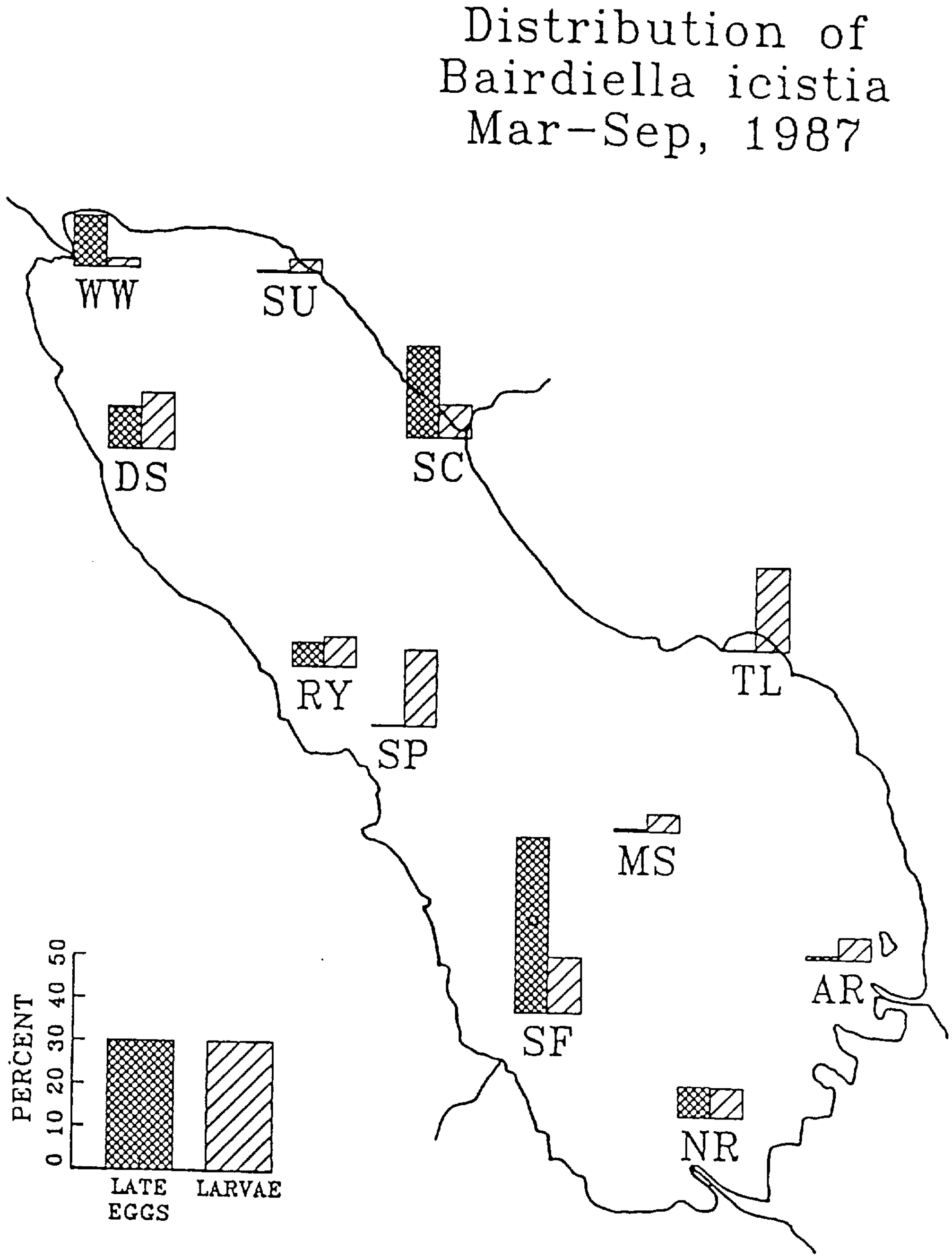


Figure 7. Proportional distribution of identifiable eggs for

Cynoscion xanthulus, 1987

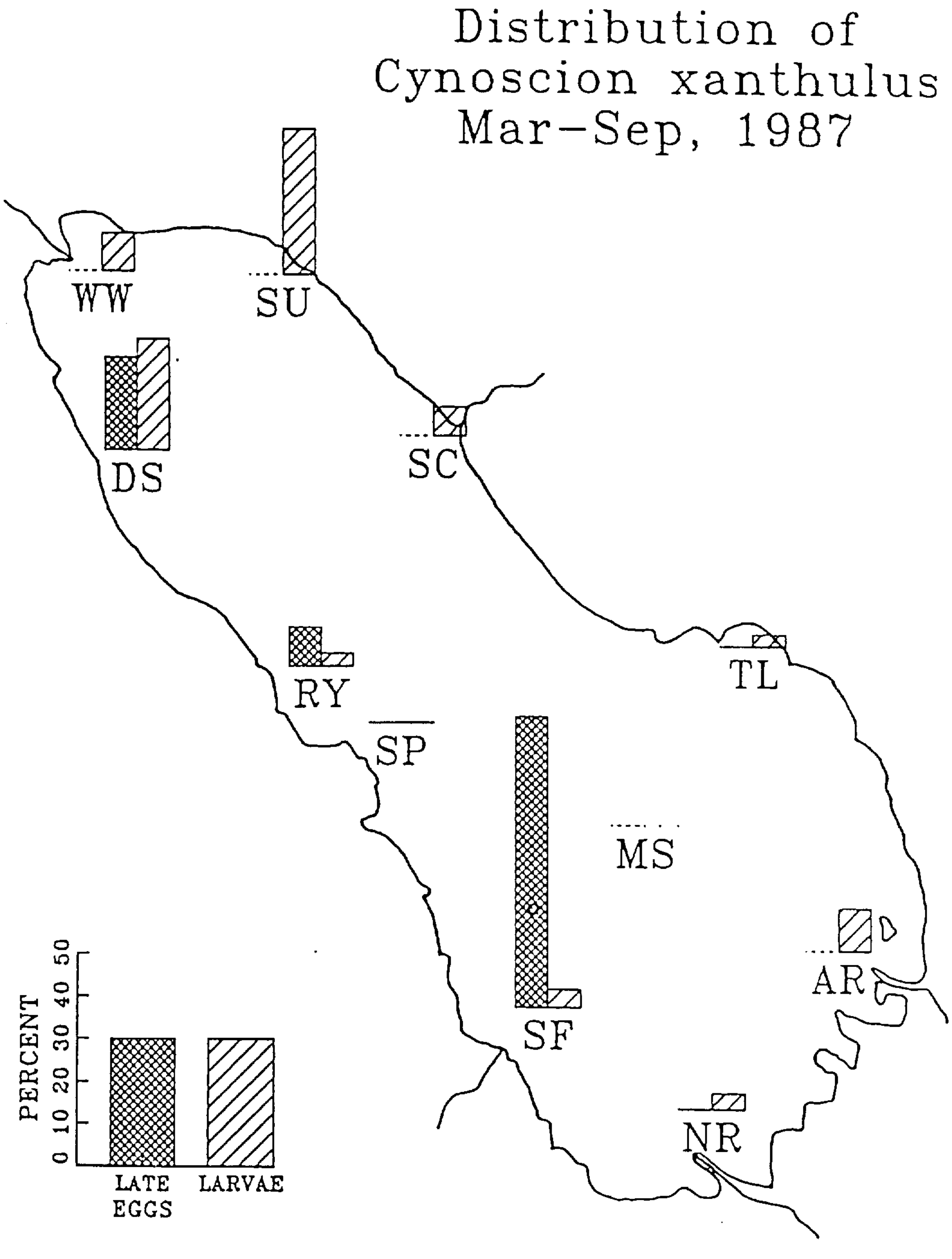


Figure 8. Proportional distribution of identifiable eggs for

<u>Anisotremus davidsoni</u>, 1988

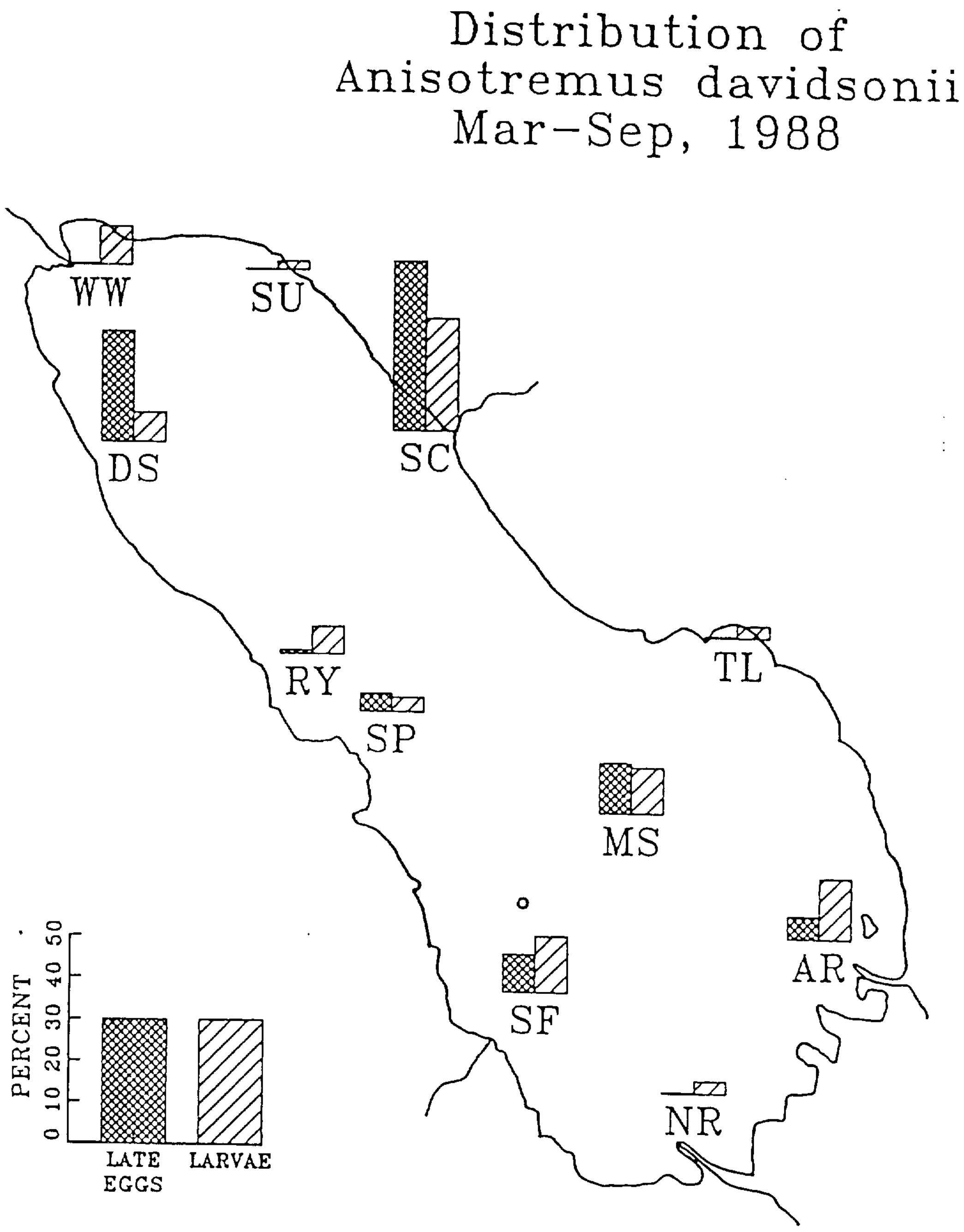


Figure 9. Proportional distribution of identifiable eggs for

Bairdiella icistia, 1988

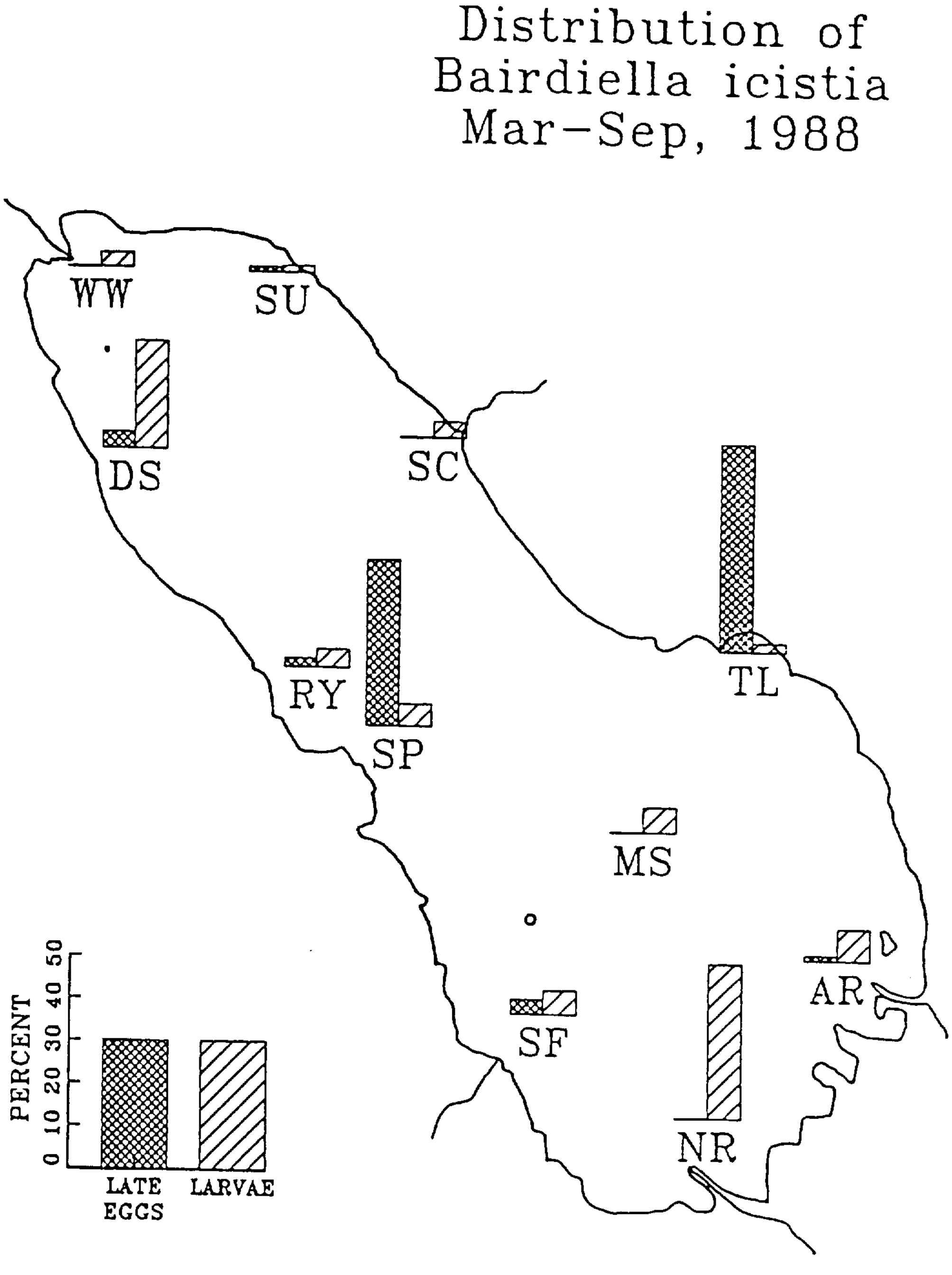


Figure 10. Proportional distribution of identifiable eggs for

Cynoscion xanthulus, 1988

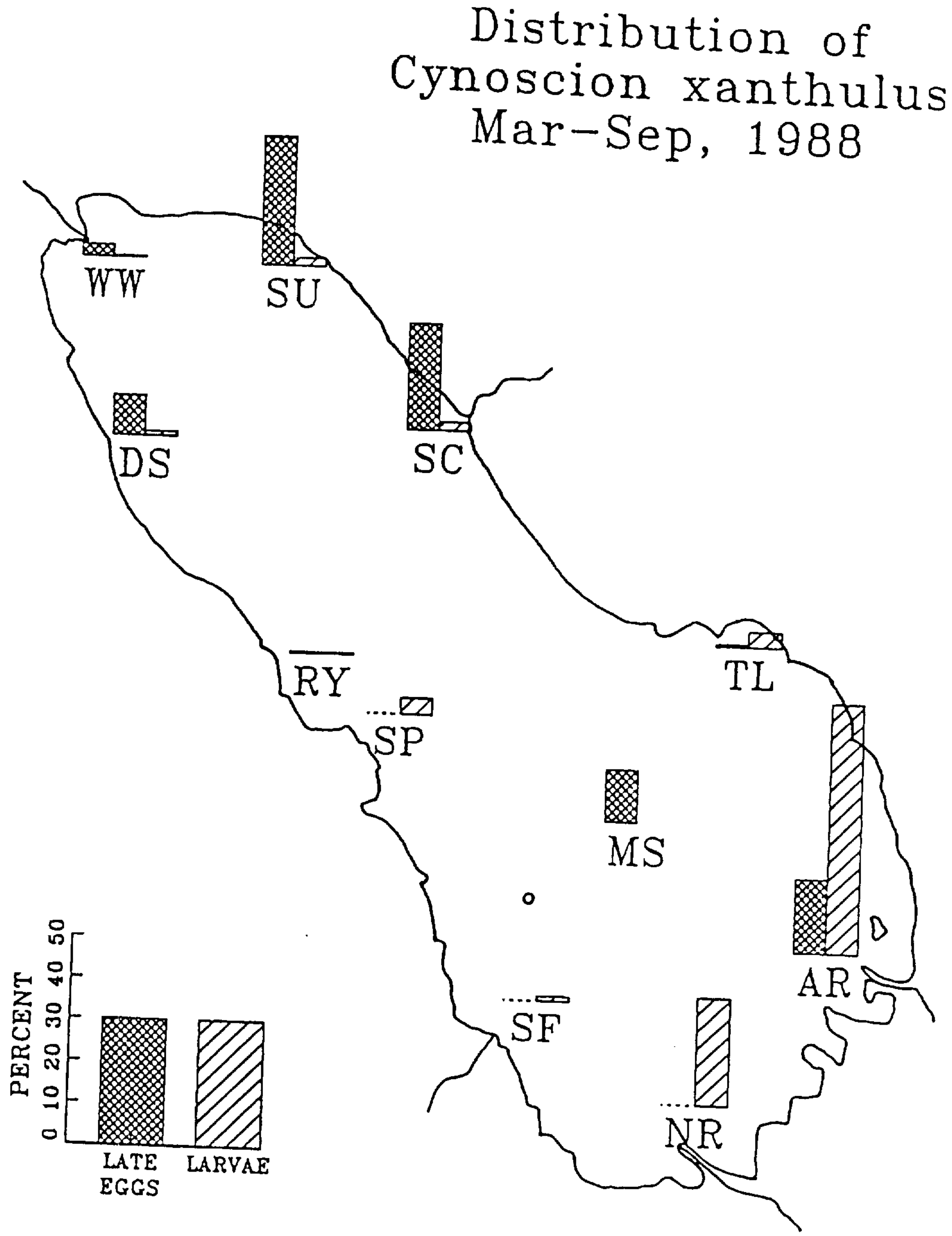


Figure 11. Proportional distribution of identifiable eggs for

Anisotremus davidsoni, 1989

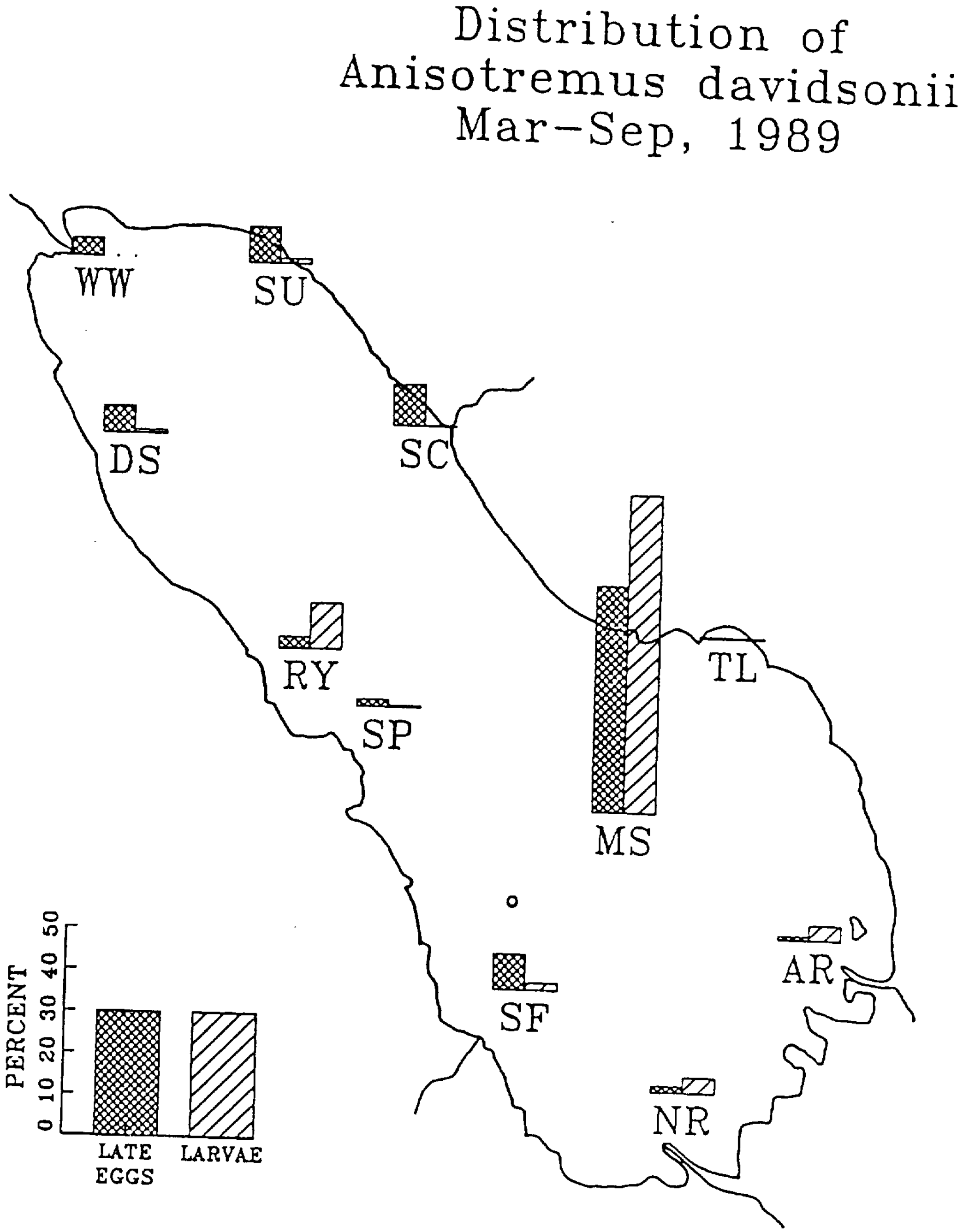


Figure 12. Proportional distribution of identifiable eggs for *Bairdiella icistia*, 1989

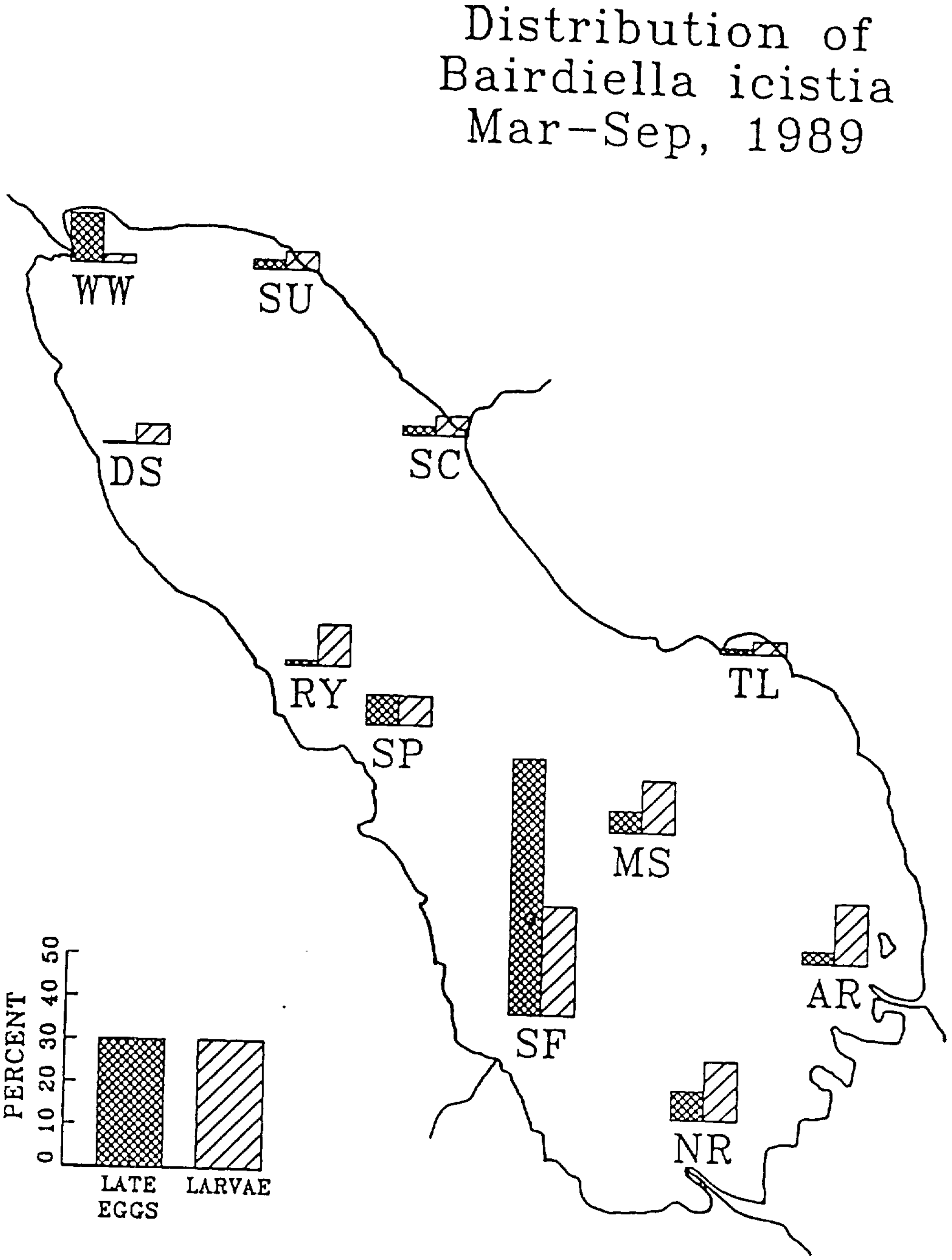
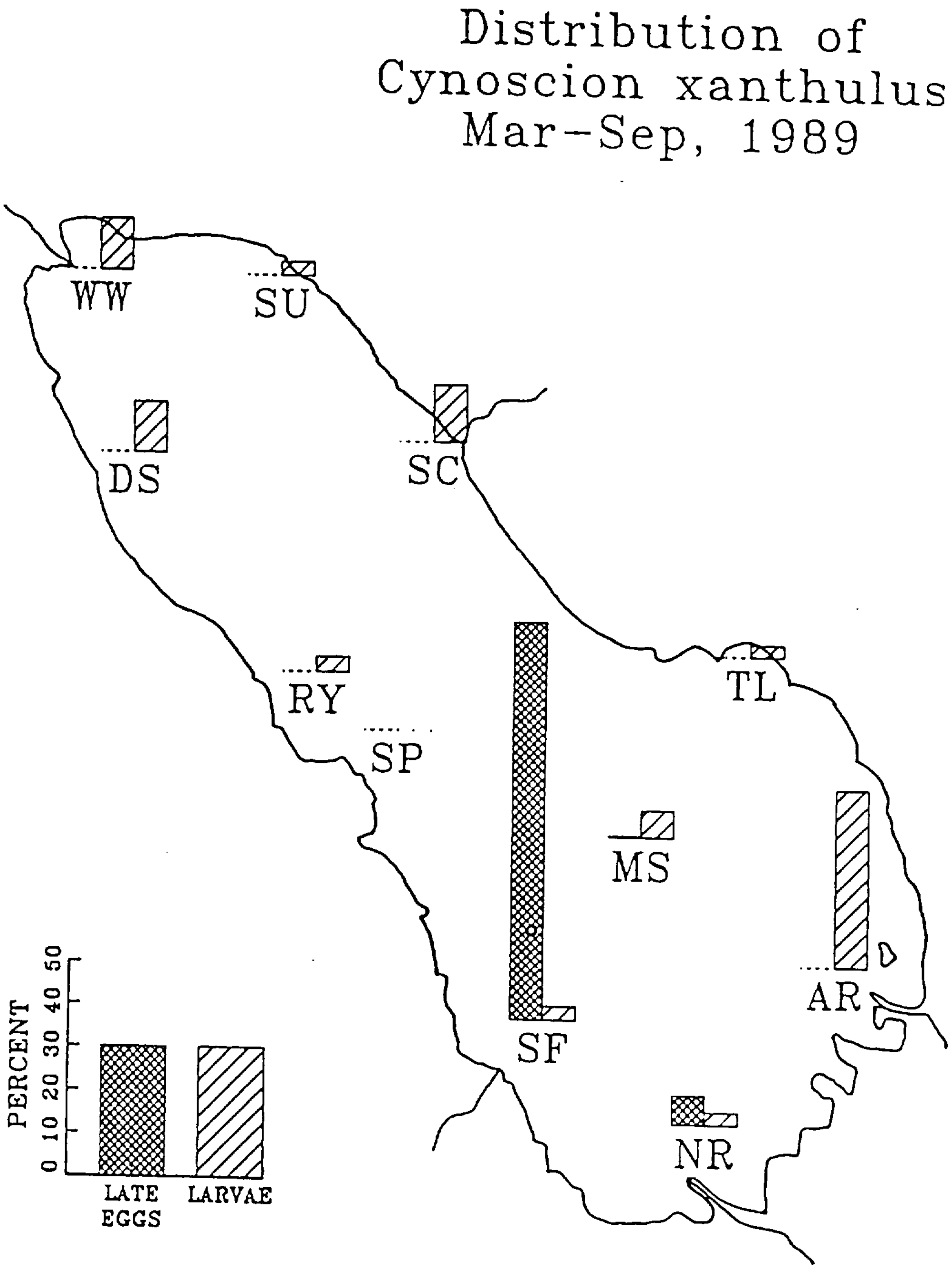


Figure 13. Proportional distribution of identifiable eggs for

<u>Cynoscion xanthulus</u>, 1989



nearshore stations (less than two meters in depth) and offshore stations (greater than two meters in depth) during the course of the study (January 1987 through June 1989) indicate that:

Temperature

The temperatures did not vary significantly between comparisons: offshore-nearshore (Fig. 14), deep water-shallow water (Fig. 15), or outflow-non-outflow (Fig. 16) stations. Summer temperatures equalled or exceeded 30°C except in deeper waters. Winter temperatures dropped to 15°C with the coldest temperature recorded in 1989 (11°C).

pH

The measurements of pH varied from 8.03 to 8.07 (Fig. 17-19) with the lowest measurements in deeper water samples (Fig. 19.). Deeper water samples generally show lower pH values than the surface samples, however, the differences are not biologically relevant.

Dissolved Oxygen

The dissolved oxygen levels fluctuate widely over the three year study. The dissolved oxygen values recorded at the Salton Sea in both outflow and non-outflow stations as well as nearshore and offshore stations were very high (Figs. 20-22). Carpelan (1961) found that saturation values for oxygen in Salton Sea water were approximately 5 mg/L at 20°C and 4 mg/L at 30°C. The Salton Sea is a eutrophic body

Figure 14. Mean temperature comparison by year for offshore-nearshore

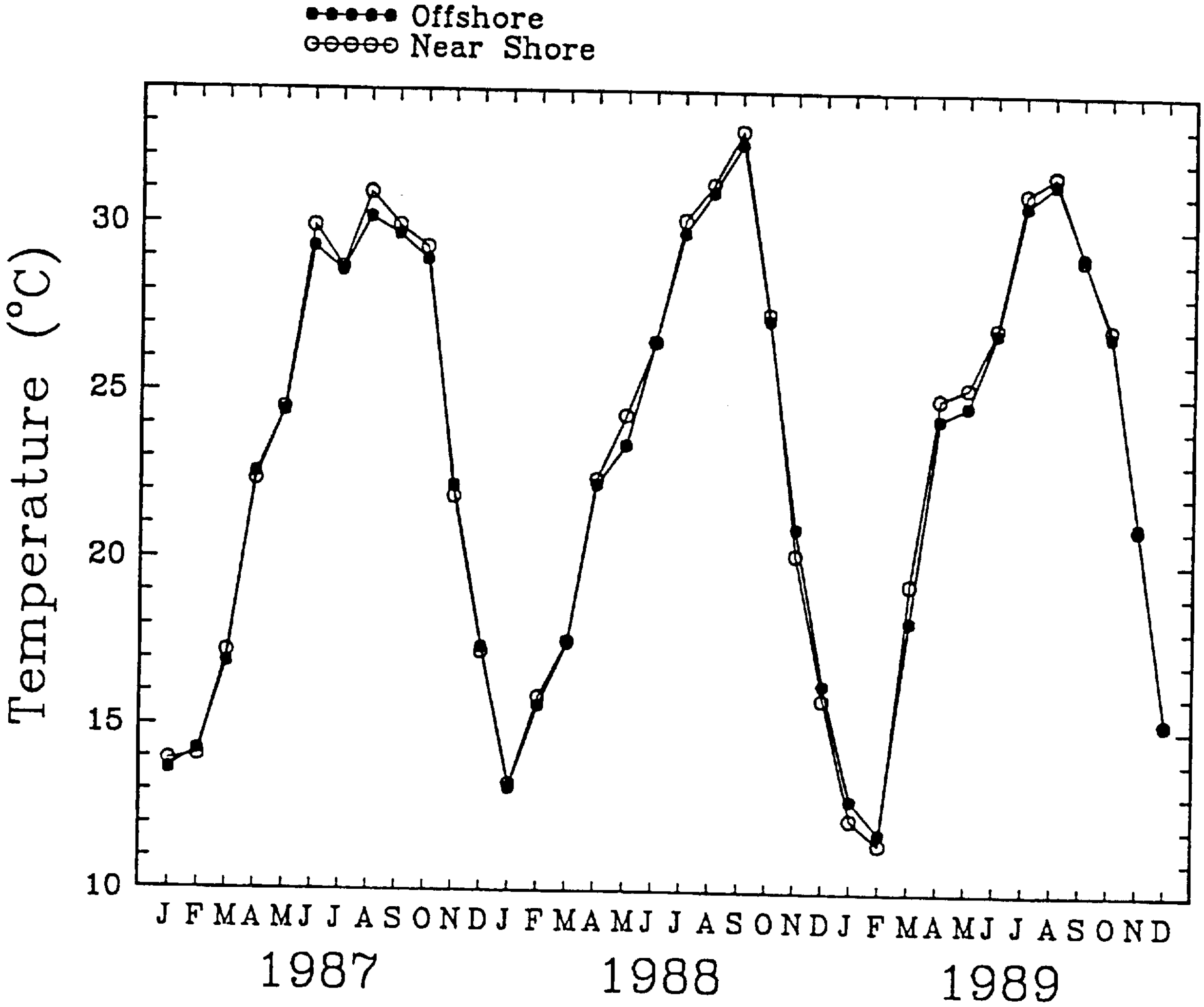


Figure 15. Mean temperature comparison deep water-shallow water

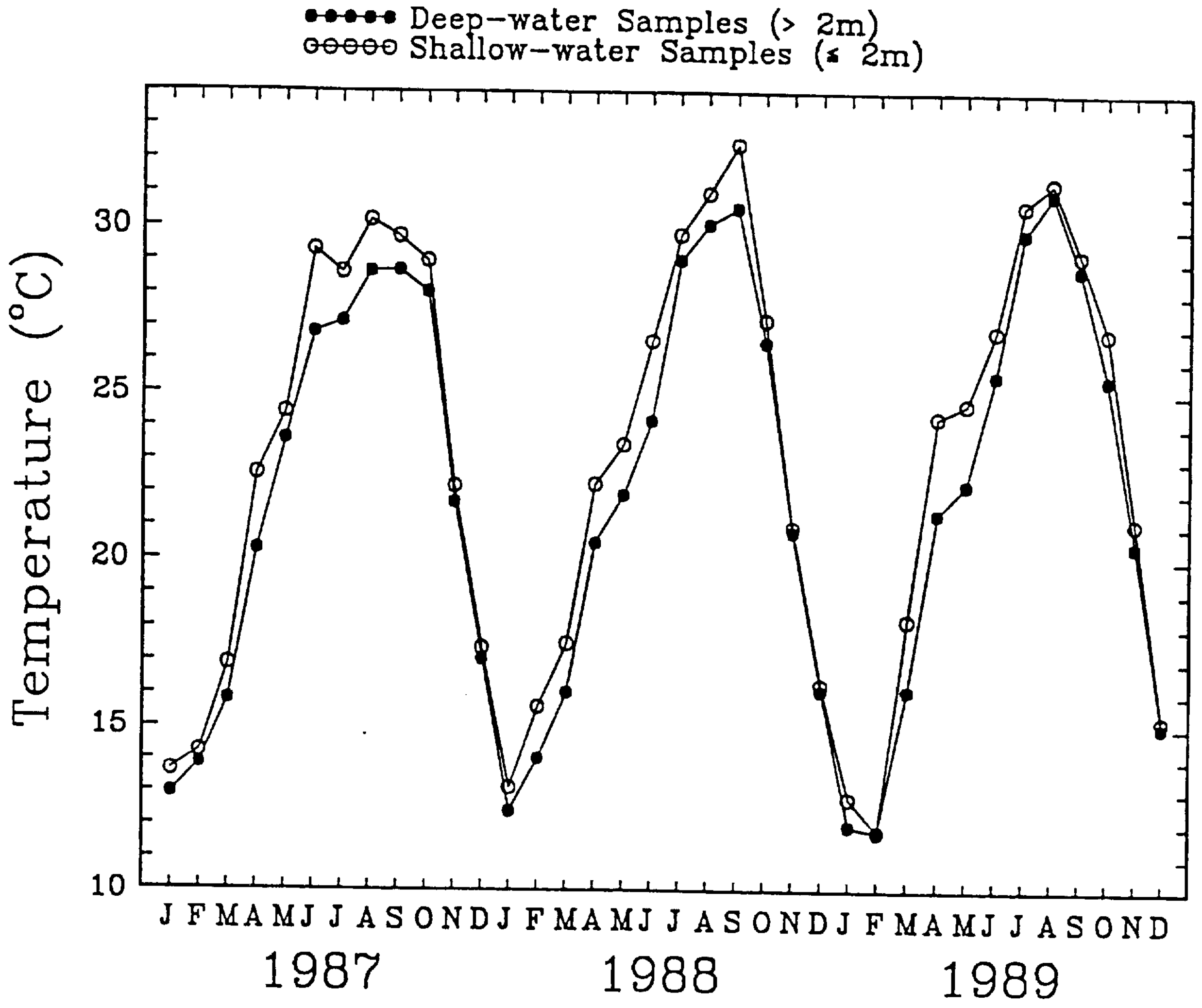


Figure 16. Mean temperature comparison outflow vs. non-outflow

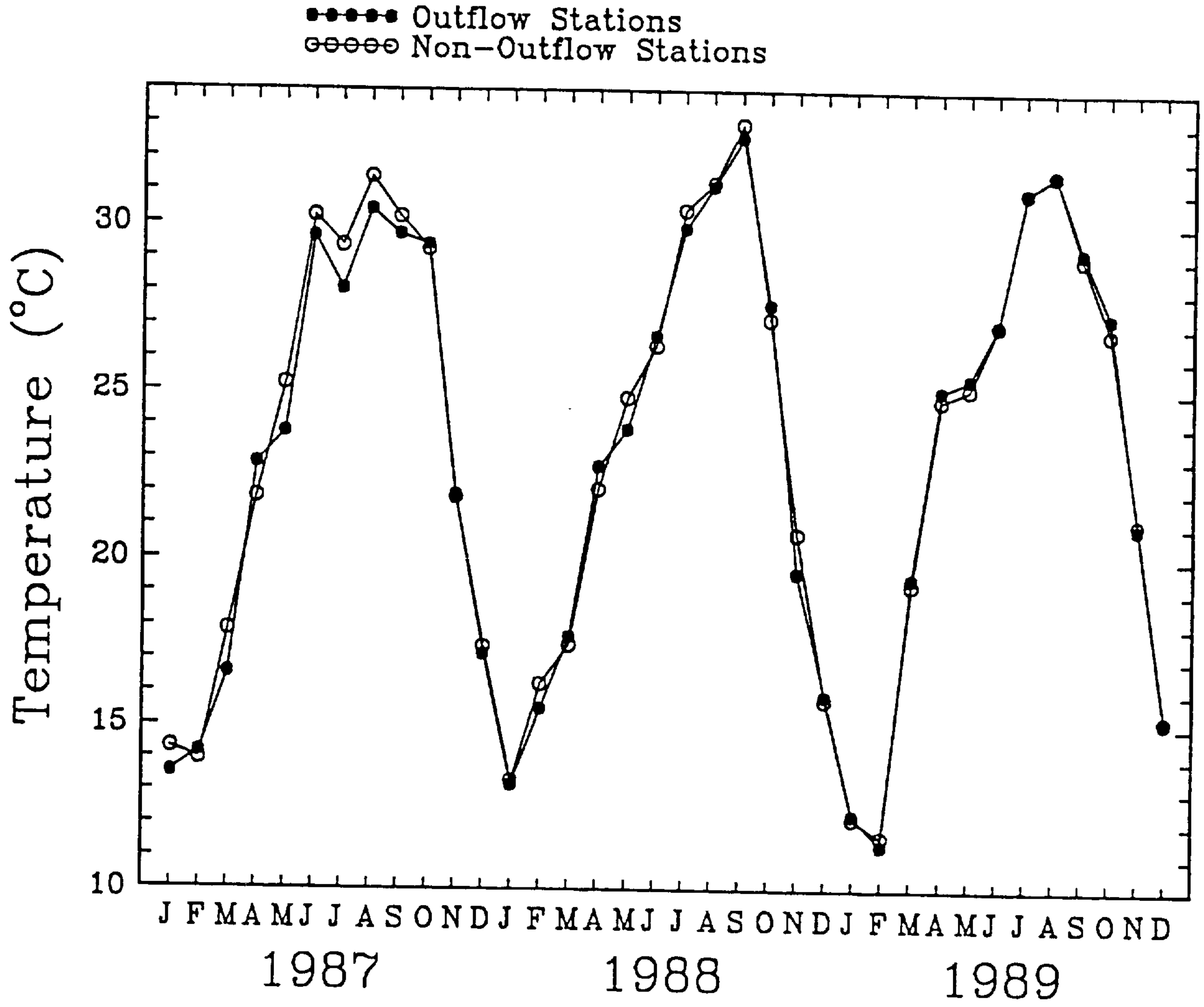


Figure 17. Mean pH comparison by year for offshore-nearshore

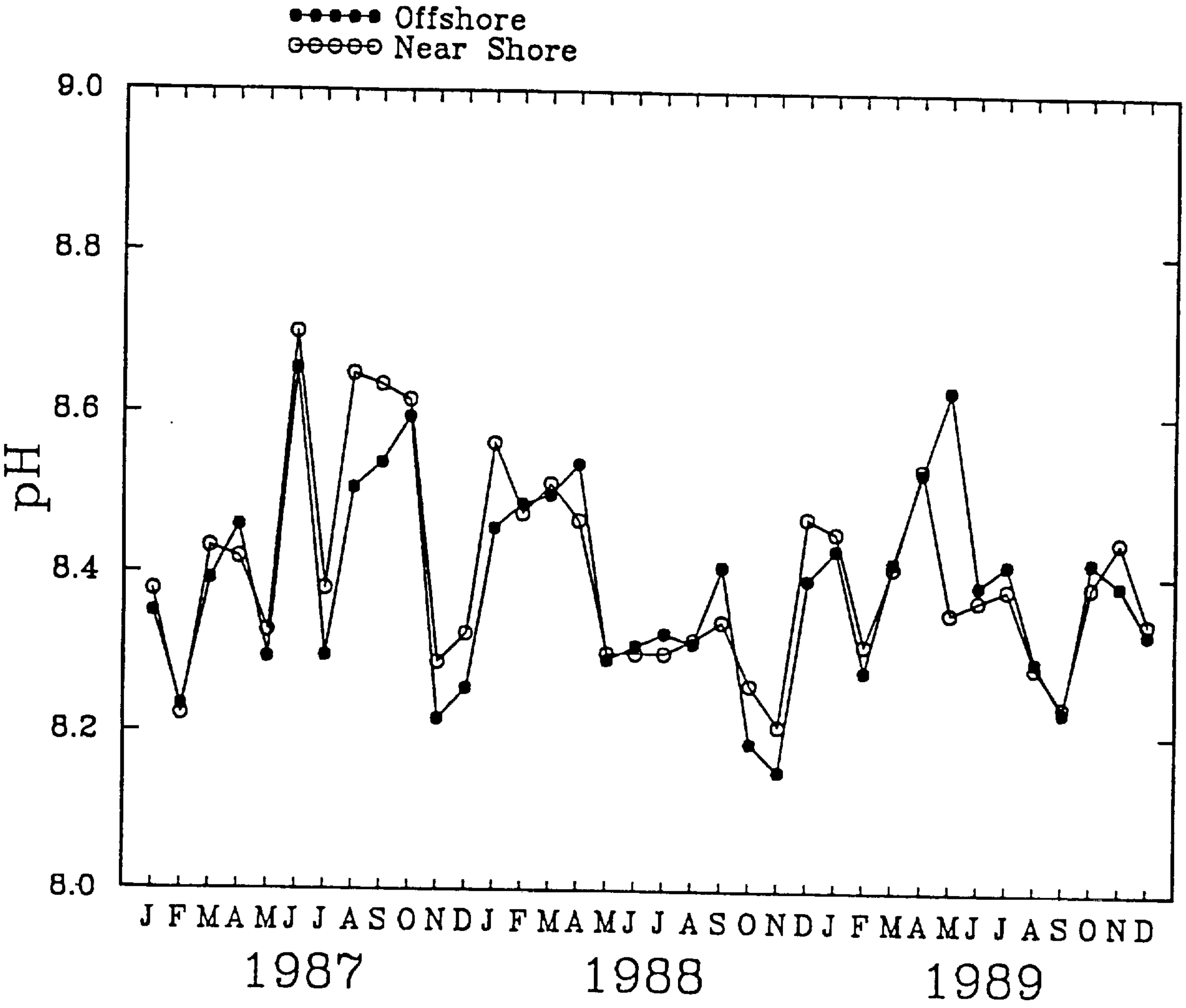


Figure 18. Mean pH comparison by year for deep water-shallow water

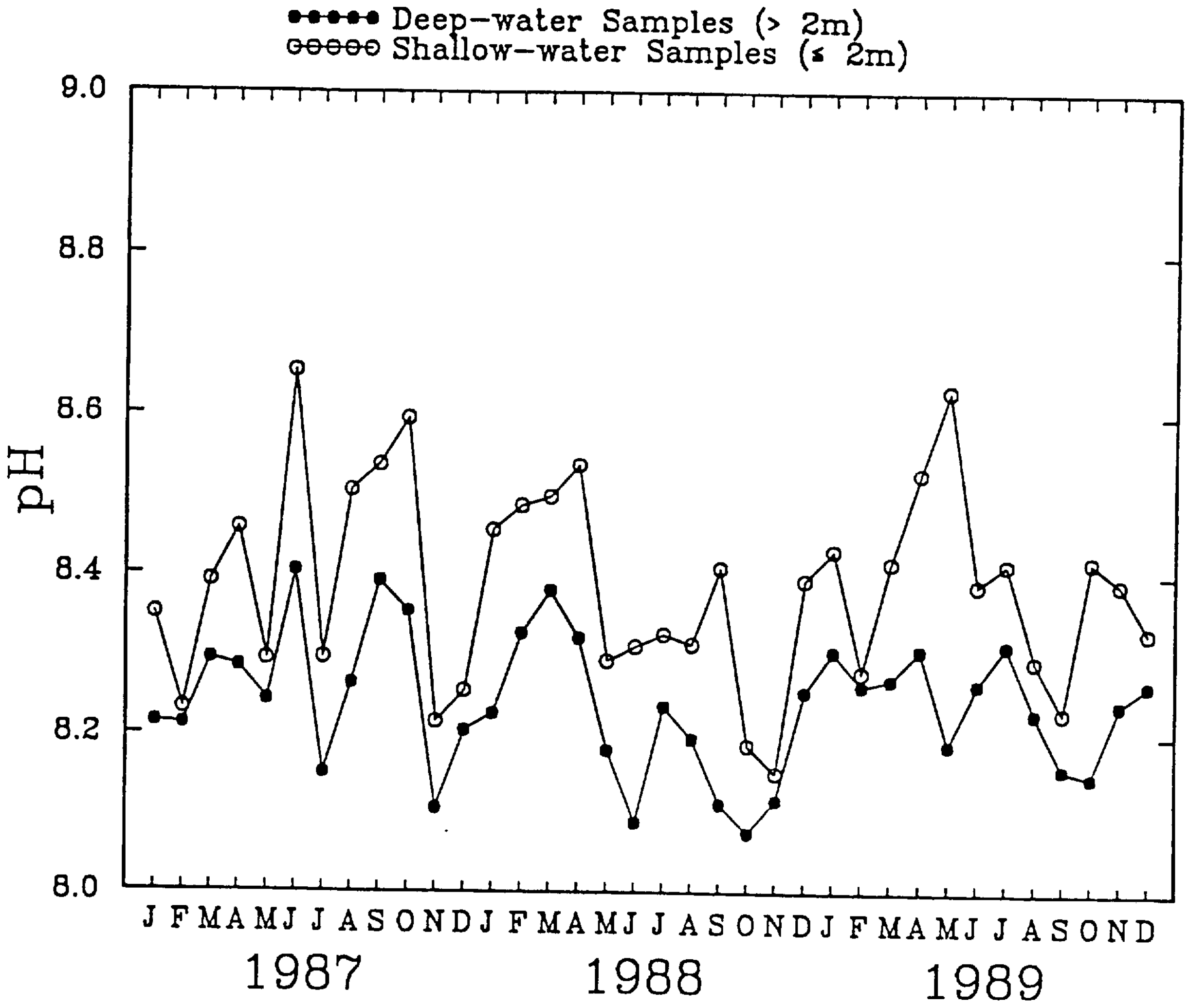


Figure 19. Mean pH comparison by year for outflow vs. non-outflow

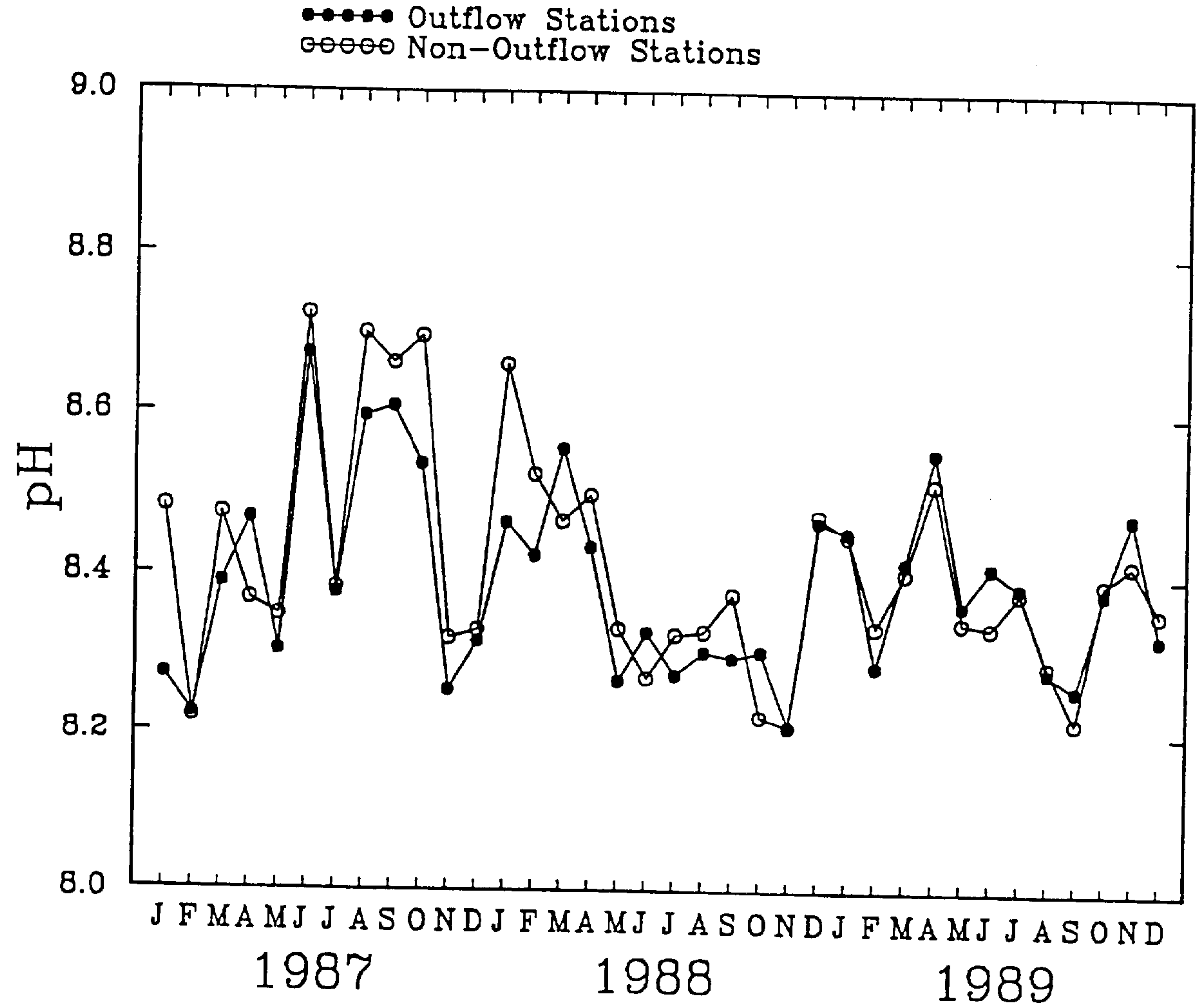


Figure 20. Mean dissolved oxygen comparison by year for offshore-nearshore

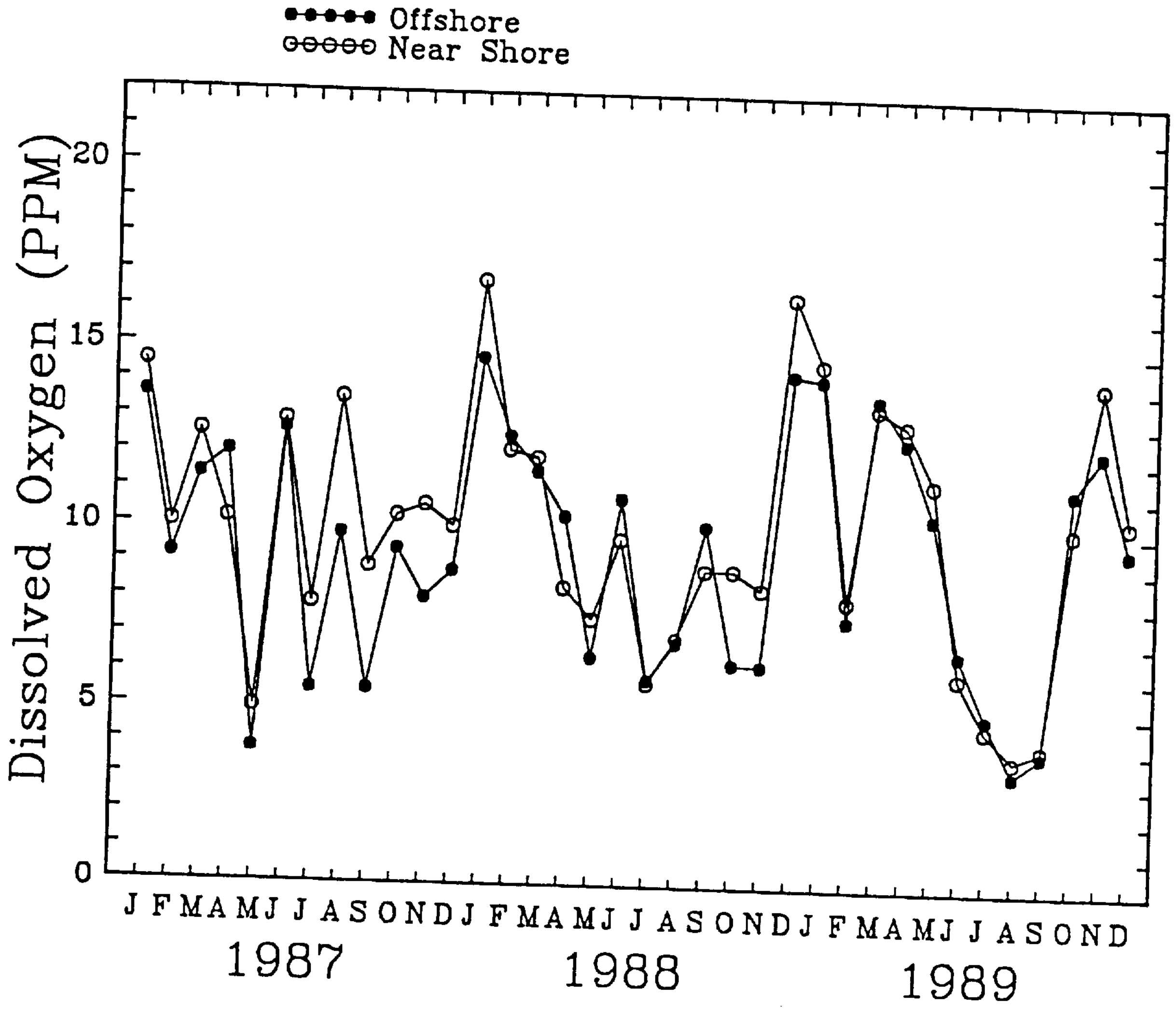


Figure 21. Mean dissolved oxygen comparison by year for outflow vs. non-flow

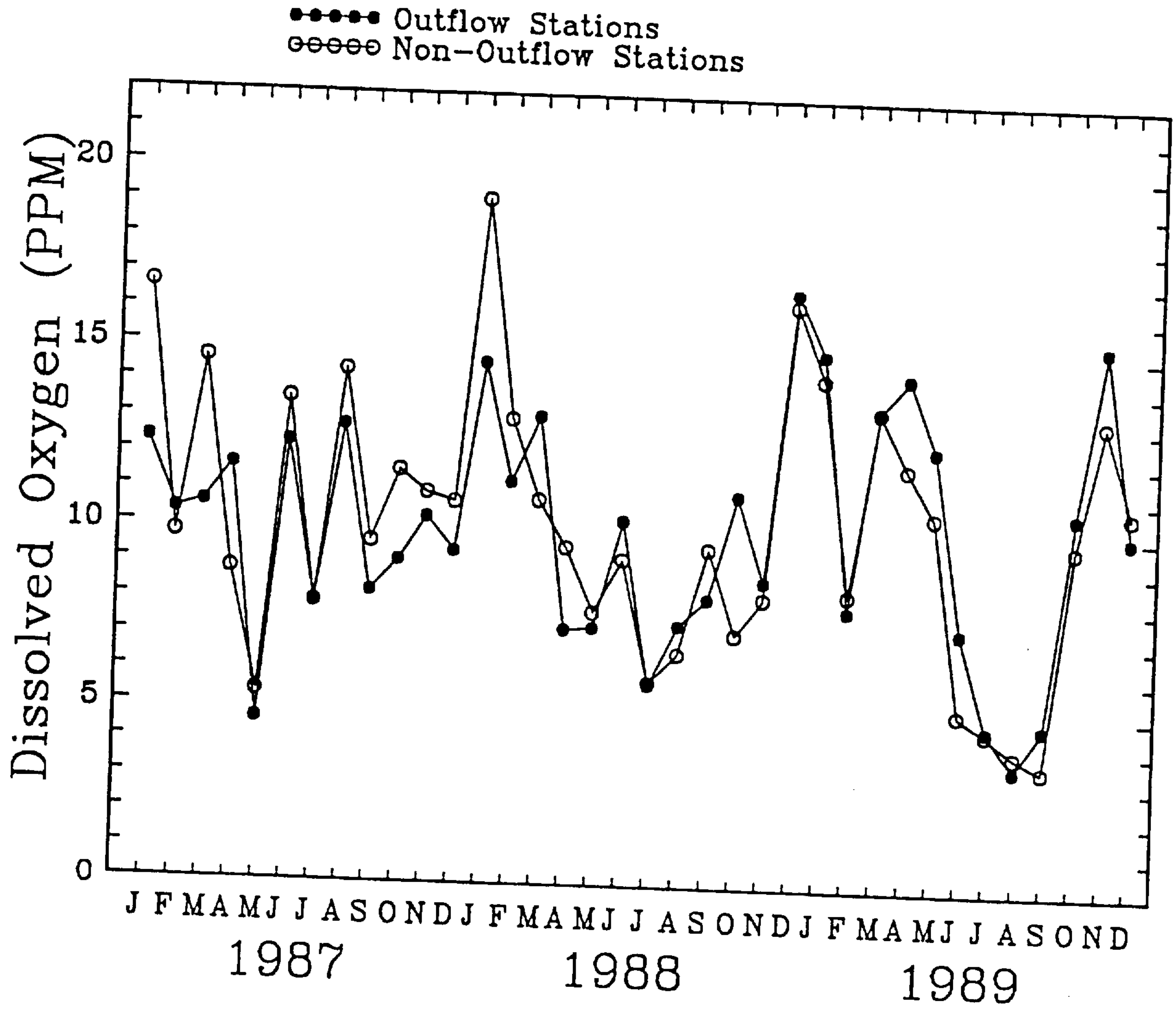
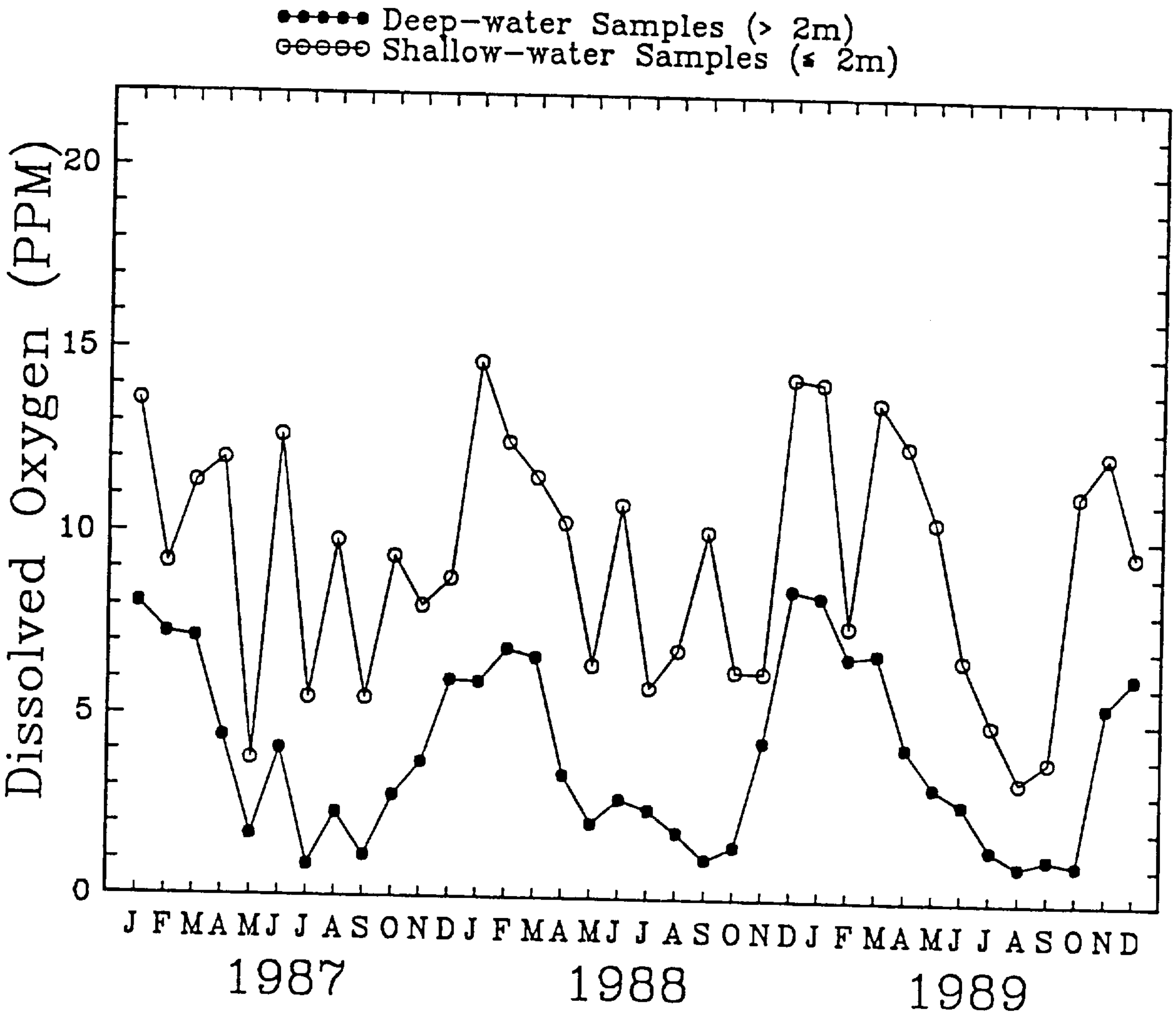


Figure 22. Mean dissolved oxygen comparison by year for deep water-shallow water



of water, extremely nutrient rich. Algal blooms combined with the effects of wind can cause such high readings.

Electrical Conductivity

The mean values for electrical conductivity (Figs. 23-25) fluctuated during the three years of the study with a mean low of approximately 48.9 to a mean high of 53.8 mmho/cm. The total dissolved solid level fluctuated from 38 to 44 ppt Salton Sea water (Fig. 26). During the period of the study, southern California experienced a four-year drought. The drought combined with a mandated water conservation effort to conserve 100,000 acre feet of irrigation water from entering the Sea per year may have exacerbated the increase in total dissolved solids (TDS). The increase in TDS is described as a linear regression $y = 38.931 + 0.066154X$, with a correlation coefficient $R = 0.72941$.

Figure 23. Mean conductivity comparison by year for offshore-nearshore

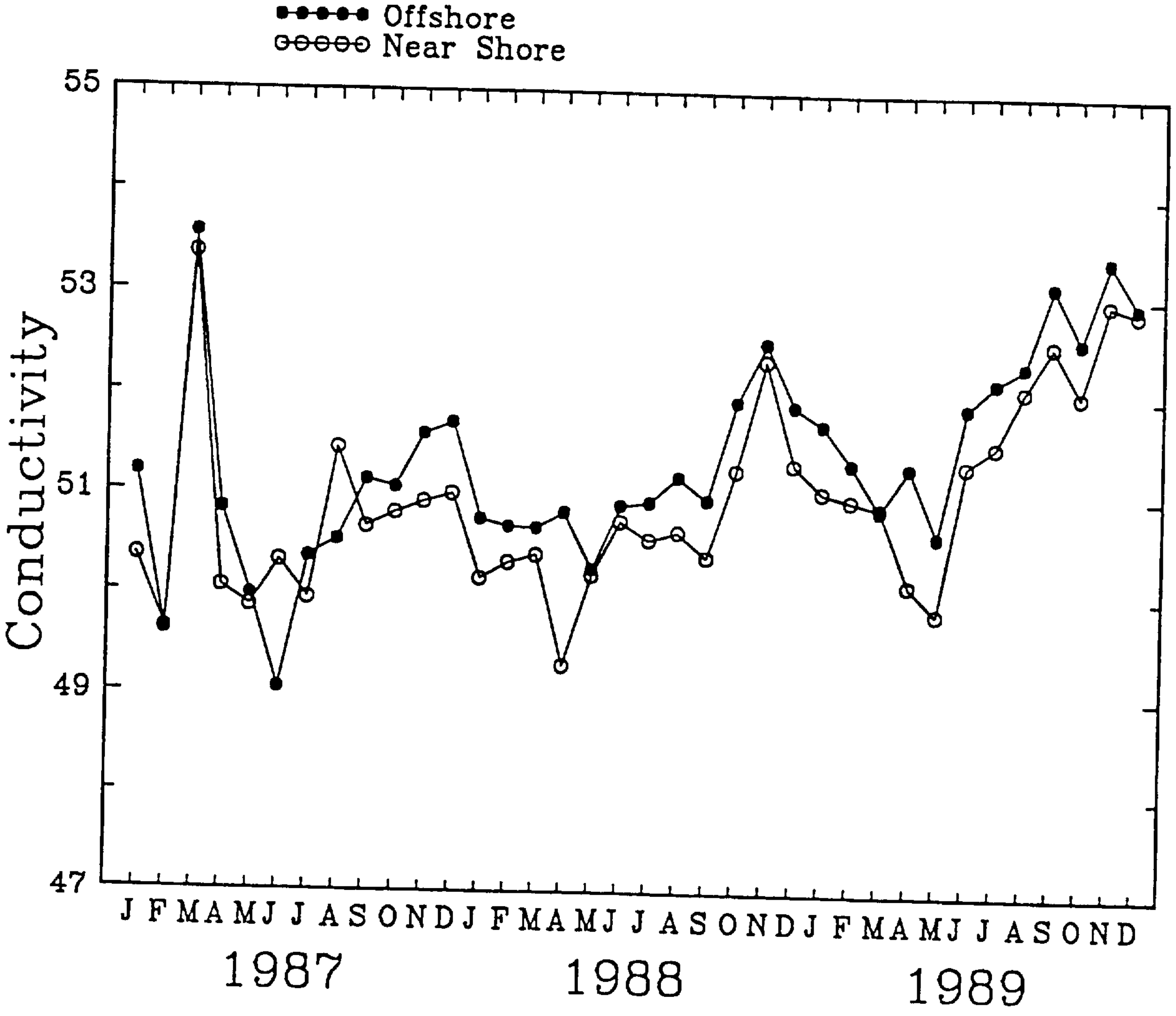


Figure 24. Mean conductivity comparison by year for outflow vs. non-flow

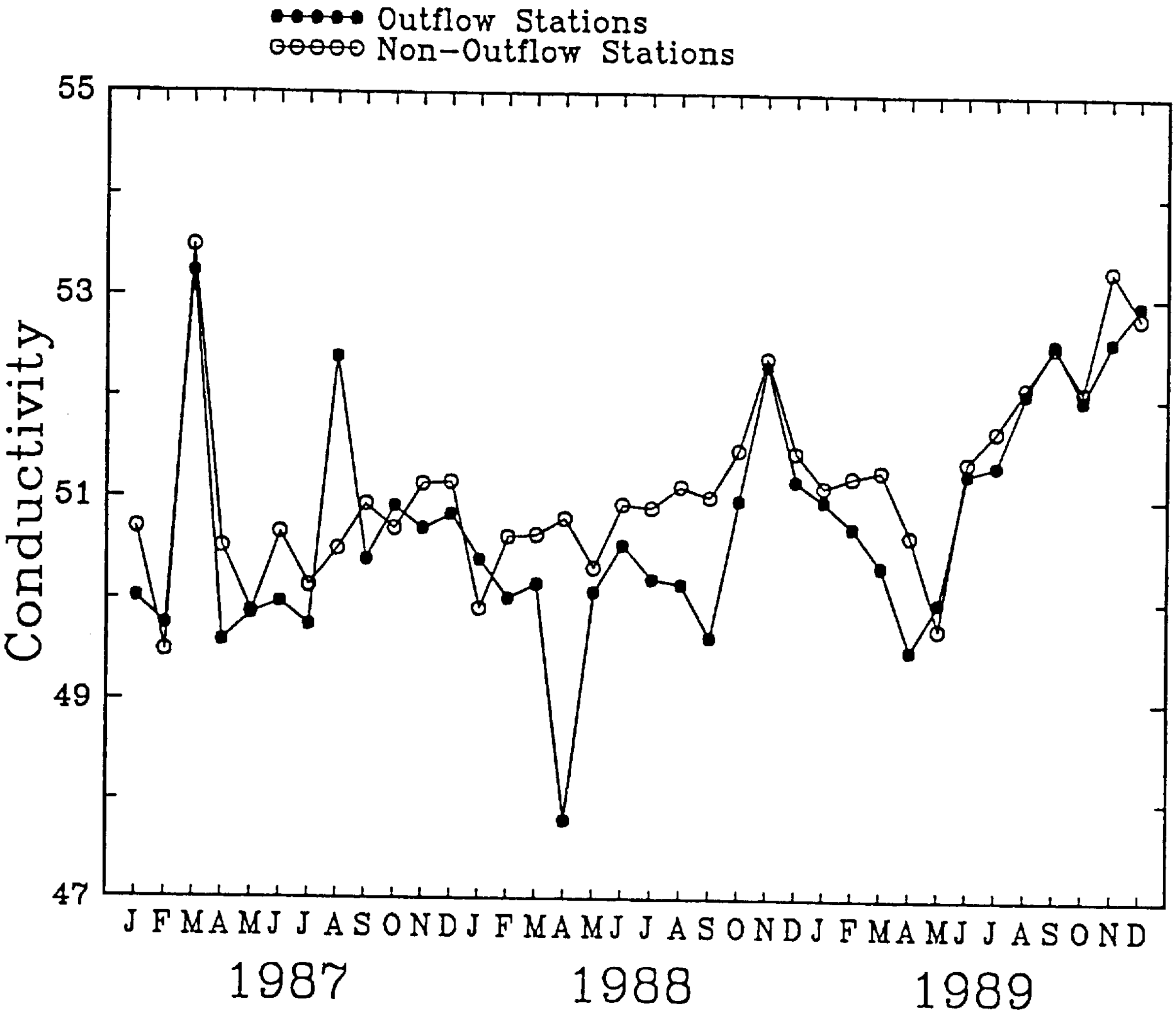


Figure 25. Mean conductivity comparison by year for deep water-shallow water

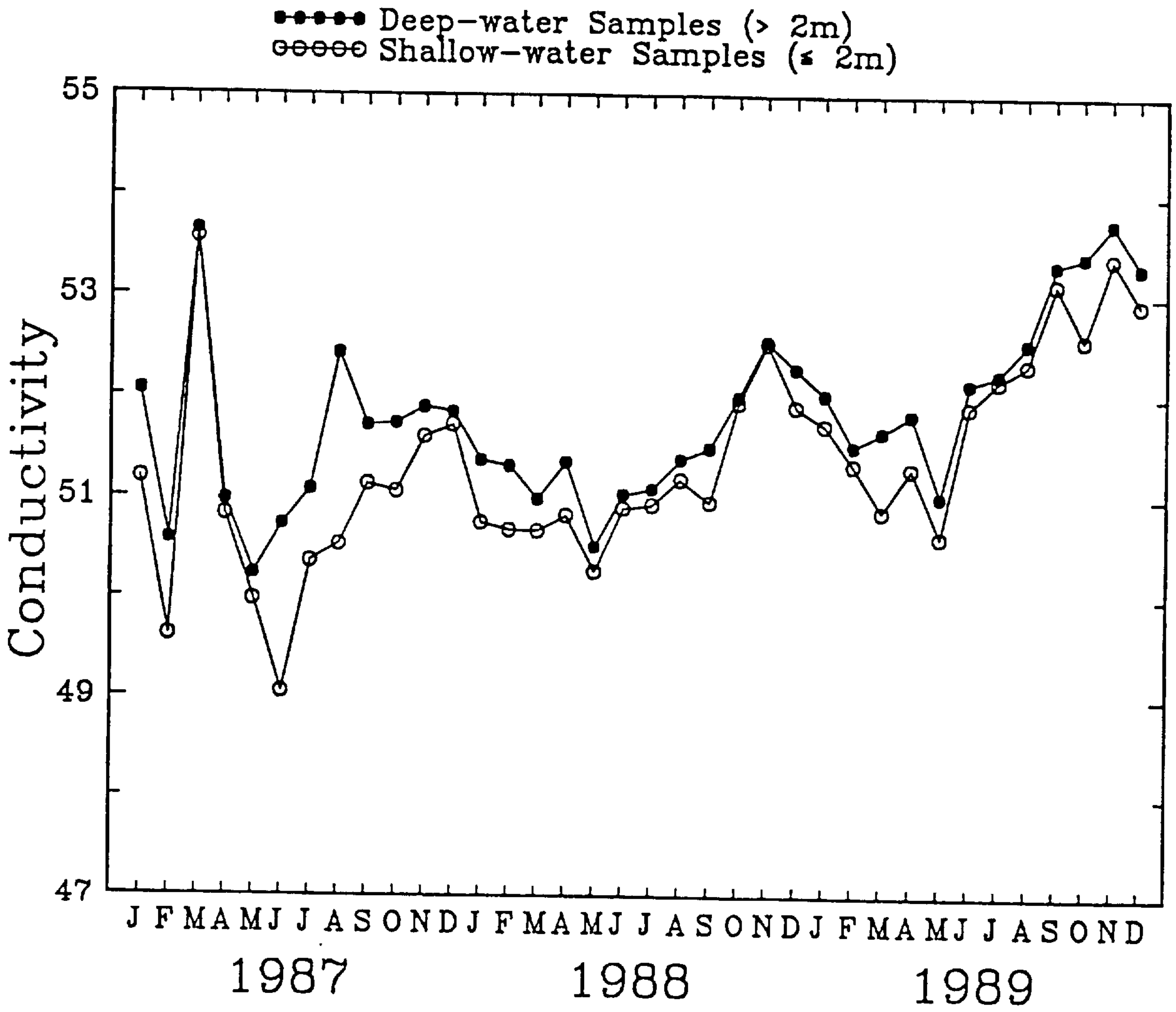
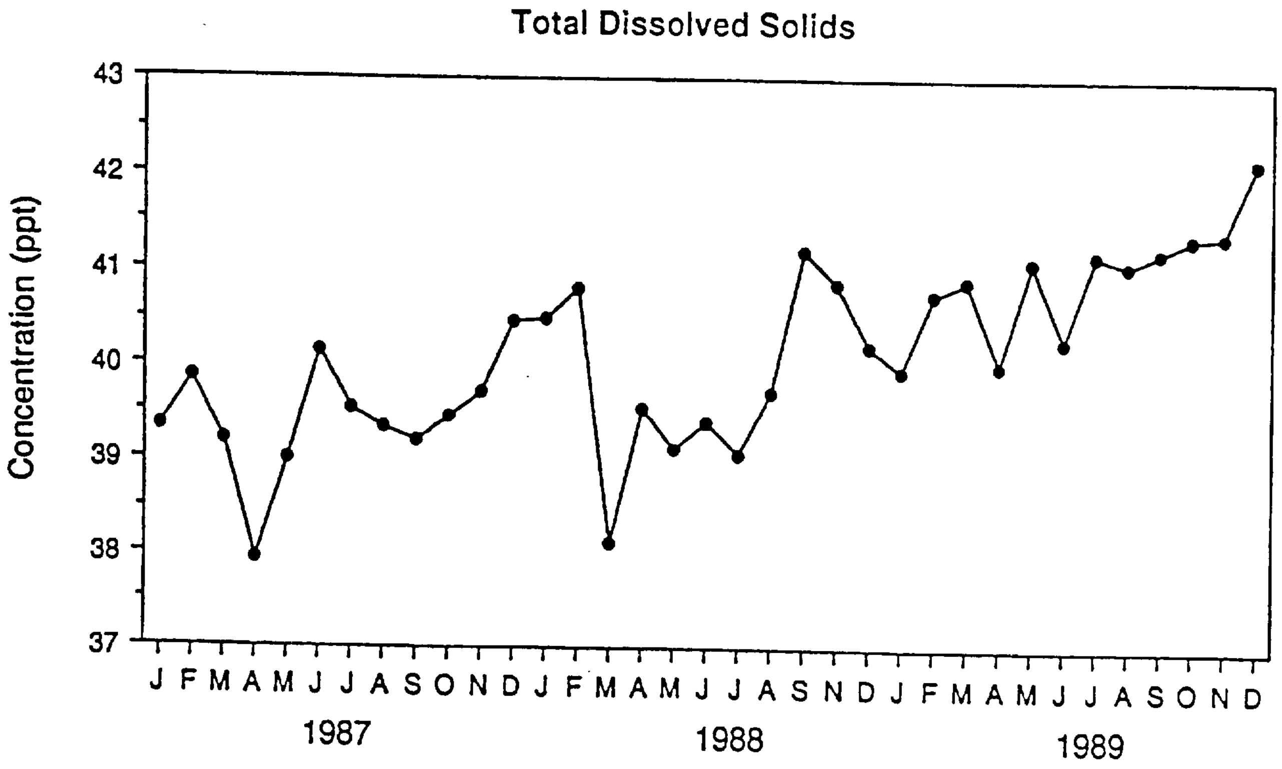


Figure 26. Total dissolved solid by year



DISCUSSION

Since the introduction of the three sportfish species, the Salton Sea has become progressively more saline. Currently the elevation of the Sea is relatively stable because there is an equilibrium between inflow of water and evaporation from the Sea. Annual inflow is approximately 1,300,000 acre feet and evaporation is about 6 feet per year. Approximately 46% of the inflow is from the Alamo River and 38% is from the New River. The remaining 16% of inflow to the Sea comes from the Whitewater River/Coachella Valley storm water channel, San Felipe Creek, Salt Creek, small agricultural drains and ground water seepage. Although the water level is currently stable, the salinity of the Sea is increasing.

Salt importation increased from 1945 to 1962 from 3.95 million tons per year to 5.59 million tons per year. Currently about 5 million tons per year of salt is carried into the Sea from its tributaries, but no salt is removed since the Sea has no outlets. The current total dissolved solid (TDS) contents is approximately 45,000 mg/L (milligrams per liter) or 45 ppt. The TDS of the Sea increases by about 800 mg/L per year (California Regional Water Quality Control Board-Colorado River Basin).

During the years of the field survey, the TDS fluctuated from 38 ppt in 1987 to 44 ppt in 1989. Brocksen and Cole (1972), Lasker et al. (1972) and May (1975a, 1975b) found that 40 ppt salinity exceeds the upper tolerance limits of Salton Sea fish during embryonic and larval development. The salinity bioassays conducted on eggs and larvae by Occidental College, after prolonged adult acclimation to higher salinities, showed that adults acclimated to 35, 40 (Corvina), and 45 (Sargo) ppt Salton Sea water could successfully spawn. When the fertilized eggs from 35 and 40 ppt acclimated adults were subjected to salinities of 45 ppt and above, significant increases in egg mortality occurred.

The eggs spawned by parents acclimated to 45 ppt Salton Sea water demonstrated arrested development before closure of the blastopore prior to the collapse of the chorion (Matsui et. al., in prep.).

The field data substantiate the laboratory bioassays which indicate that the adult fish can successfully continue to spawn at higher salinities. Early developmental stages of eggs continued to exist in the plankton tows as the TDS levels continued to increase during the years of the survey. With each successive year, the number of ichthyoplankton declined as a result of a significant decline in both the late egg and early larval stages. The exception to this was Bairdiella with significantly more late larvae occurring in the samples with each progressive year. May (1975a) implied that adult acclimation to high salinity would be similarly ineffectual in aiding embryonic survival at high salinity since acclimation of the parent fish to low salinity did not significantly affect the tolerance of Bairdiella eggs. The exception would be where genetic adaptation occurred.

Though the data indicate that the 40 ppt salinity barrier to egg and larval survival described by previous investigators may be somewhat low, the fact that the Sea is now averaging close to 45 ppt means that reproductive failure is close at hand. As adults are tolerant of salinities up to 55 ppt and demonstrate the abilities to grow and develop gametes (Matsui et. al., in prep.), the fish may exist in the Sea for many years but will decrease rapidly by attrition. The attrition of Cynoscion, a long-lived species may be hastened by the attrition of Bairdiella, a shorter-lived species that serves as prey fish along with non-existent juveniles of Anisotremus and Cynoscion. The population could be maintained by hatchery methods until long-term solutions to the salinity problem are reached.

ACKNOWLEDGMENTS

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LITERATURE CITED

Ahlstrom, E. H. 1943. Studies on the Pacific pilchard or sardine (Sardinops caerulea). 4. Influence of temperature on rate of development of pilchard eggs in nature. U.S. Fish and Wildl. Serv., Spec. Sci. Rpt. 23, 26 pp.

Black, G. 1988. Description of Salton Sea sportfishery 1982-1983. Calif. Fish Game Adm. Rep. 88-9.

Brocksen, R. W. and R. E. Cole. 1972. Physiological responses of three species of fishes to various salinities. J. Fish. Res. Bd., Canada 19:399-405.

Calif. Reg. Water Quality Control Bd. 1991. Issue paper on Salton Sea water quality. November 20, 1991, 7 p.

Carpelan, L. 1961. Physical and chemical characteristics in the ecology of the Salton Sea, California in relation to the sportfishery. Calif. Dept. Fish Game Bull. No. 113.

Jordan, G. A., P. R. Garrahan, K. B. Iwanaga, S. V. Williams, A. B. Bond and M. L. Matsui. 1992. Pigment mapping technique for identifying intermediate and late-stage pelagic eggs of Anisotremus davidsoni (Pisces: Haemulidae), Bairdiella icistia, and Cynoscion xanthulus (Pisces: Sciaenidae) from the Salton Sea. Fish. Bull., in press.

Lasker, R., R. H. Tenaga and L. L. Chamberlain. 1972. The response of Salton Sea fish eggs and larvae to salinity stress. Calif. Fish Game 58:58-66.

May, R. C. 1975a. Effects of temperature and salinity on fertilization, embryonic development, and hatching in Bairdiella icistia (Pisces: Sciaenidae), and the effect of parental salinity acclimation on embryonic and larval salinity tolerance. Fish. Bull. 73:1-22.

May, R. C. 1975b. Effects of acclimation on the temperature and salinity tolerance of the yolk-sac larvae of *Bairdiella icistia* (Pisces: Sciaenidae). Fish. Bull. 73:249-255.

Smith, P. E. and S. L. Richardson. 1977. Manual of methods for fisheries resource survey and appraisal. Part 4. Standard techniques for pelagic fish egg and larval survey. Southwest Fish. Ctr. Admin. Rpt. LJ-77-11.

Whitney, R. R. 1961. The bairdiella, *Bairdiella icistia* (Jordan and Gilbert). *In* B. W. Walker (ed.), p. 105-151, The ecology of the Salton Sea, California. Calif. Dep. Fish Game, Fish Bull. 113.

Young, D. R. 1970. The distribution of cesium, rubidium, and potassium in the quasi-marine ecosystem of the Salton Sea. Ph.D. Diss., Univ. Calif. San Diego, 213 p.