Final Report

Fish Biology and Fisheries Ecology of the Salton Sea

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Executive Summary

A study of the fisheries ecology and fish biology of the Salton Sea, California, a salt lake in the Lower Colorado Valley of the Sonoran Desert, was conducted between 1999 and 2000. Multi-panel, multi-mesh (1, 2, 7, 10, and 12.5 cm stretched mesh) gill nets were used to sample fish bimonthly (in 1999) and quarterly (in 2000) in riverine (1999 only), nearshore, pelagic, and estuarine habitats. Total lengths and weights were measured for all sampled fish. A subsample of fish was dissected for gonad weights (approximately 50 fish per sampling) and otoliths (approximately 100 fish per sampling). Ten species were captured. Tilapia (*Oreochromis mossambicus*) was the most dominant fish by number and weight at all habitats. Tilapia catch per effort (kg/h/net) was the highest for all fish, and highest in the estuarine habitat (> 11). Orangemouth corvina (*Cynoscion xanthulus*) were most abundant in the nearshore habitat, croaker (*Bairdiella icistia*) in the estuarine habitat, and sargo (*Anisotremus davidsoni*) most abundant in the pelagic habitat. Rivers were richest in the number of species (9 species, of which 6 were sampled in rivers only) and the lowest in fish abundance. Age and size distributions were unusually narrow for tilapia. Tilapia were mostly of the 1995 cohort, Gulf croaker and orangemouth corvina of the 1996 cohort, and sargo of the 1998 cohort. Gulf Croaker and sargo spawned during spring and summer. Orangemouth corvina spawned mostly during the summer, whereas tilapia spawned in the spring and continued throughout the summer. Gonadosomatic indices for tilapia were low compared with tilapia from other freshwater lakes in Southeast Asia. Sex ratios of tilapia were skewed towards males, whereas the sex ratios for croaker, orangemouth corvina, and sargo were near 1:1. Movement patterns of tilapia and croaker were toward the shore in the summer, with a slower dispersal toward pelagic waters in the fall and winter. Dissolved oxygen influenced movement patterns of fish for reproduction and feeding. Salton Sea fish grew faster, but had shorter life spans than conspecifics elsewhere and Salton Sea species of 5 decades ago. Adaptation to the high salinity and low dissolved oxygen of the Salton Sea may have come at a cost of reduced longevity for fish.

The Salton Sea was observed to be a highly productive lake for tilapia and croaker. Contrary to the current public paradigm, the Salton Sea supports a large fish community and could support a commercial fishery. The habitats most important for fish were the shallow regions of the nearshore and estuarine areas. Our initial beliefs of the incoming tributaries to the Salton Sea functioning as fish refugia have not been substantiated. We, therefore, conclude that the water quality of the lake is adequate for fish survival and reproduction. If the salinity keeps increasing, the lake may be lost as a potentially productive fishery and as a stopover for migratory avifauna.

1. Introduction

The Salton Sea is a 930 km^2 artificial salt lake of the Colorado Desert of southern California. It was created by winter floods in 1904–05, which broke through irrigation headworks that diverted water from the Colorado River into the Imperial Valley of California. The river flowed unabated for almost 2 years filling the Salton Sink, an ancient, below sea level basin. The Colorado River was controlled by one of the most massive engineering projects of its time, resulting in the creation of California's largest lake—a desert sea—in the midst of a hot, alkaline desert.

Over 30 species of marine fish were introduced from 1950–56 into the Salton Sea from Mexico's Gulf of California (Walker et al. 1961). Of these, only the orangemouth corvina (*Cynoscion xanthulus*, Jordan and Gilbert), croaker (*Bairdiella icistia*, Jordan and Gilbert) and sargo (*Anisotremus davidsoni*, Steindachner) established and flourished. In 1964–65, tilapia escaped to the Sea, and by the early 1970's dominated the fish community as the salinity rose above seawater levels (Dill and Cordone 1997). "Hitchhiker" organisms that came along with the original fish introductions flourished in the artificial marine ecosystem. Barnacle beaches (*Balanus amphitrite*, Linnaeus) line the shores of the Sea; pile worms (*Neanthes succinea*, Frey and Leukart) dominate the invertebrate community; and thick flagellate and cyanophyte blooms occur throughout the year (Setmire et al. 1993; Simpson and Hurlbert 1998; Simpson et al. 1998).

The Salton Sea is designated by the state of California as a repository for nutrient rich drainage waters from hundreds of commercial farms in the Imperial Valley. As a result, it has a high primary productivity, which in turn accounts for the high productivity of its fishery (Black 1974, 1988). In 1971, the California Department of Fish and Game (CDFG) recorded recreational fish catches at the Salton Sea at 1.88 fish/angler/h, one of the highest catch rates recorded in the state (CDFG 1971). Due to the abundance of prey and the destruction of over 90% of the area of California's original wetlands, millions of birds use the Salton Sea. Today, the Salton Sea is a vital link in the Pacific flyway and one of the most important wildlife refuges in North America.

Since 1992 massive deaths of fish and birds have occurred at the Salton Sea that have captured the attention of scientists, the public, and the press (Kaiser 1999). The salinity of the sea is currently 45 g/L and has been rising due to evaporation, dissolution of alkaline mineral deposits, and increased inputs of saline, nutrient rich, agricultural drainage waters. Increased salinities, accelerated eutrophication, and outbreaks of diseases have been blamed for reproductive failures and high larval mortalities for the introduced marine fish species (Matusi et al. 1991a, b), and have been implicated in the deaths of millions of tilapia and over 200,000 migratory water birds (Jehl 1996; Kaiser 1999). Salton Sea fish have wide salinity tolerances (Lasker *et al.* 1972; Prentice and Colura 1984; Prentice *et al.* 1989; Costa-Pierce and Riedel 2000), but a further increase in salinity may have adverse effects on reproduction (Hickling 1963; Chervinski and Yashouv 1971; Perry and Avault 1972), recruitment (Hodgkiss and Man 1977), and growth (Chervinski and Zorn 1974; Payne 1983; Payne and Collinson 1983).

Fish kills in the Salton Sea have been occurring due seasonal deoxygenation in the summer and possibly disease and parasite infestations. An understanding of the biology of the Salton Sea fish is a first step in determining the importance of the fish resource for the lake ecosystem and a key factor for evaluating restoration alternatives proposed for the lake.

1.1. Fisheries Background

The development through time of the fish community of the Salton Sea may be subdivided into two phases:

- the freshwater and marine phases,
- the hypersaline phase.

1.1.1. The Freshwater and Marine Phases

Lake Cahuilla filled the Salton basin to the Coachella Valley at various times until the latter part of the 16th century (Weide 1976). Archaeological excavations of the ancient lake basin have found the following species of freshwater fish: *Elops affinis* (machete) *Gila robusta* (bonytail), *Mugil cephalus* (striped mullet), *Ptchocheilus lucius* (Colorado squawfish), and *Xyrauchen texanus* (humpback sucker) (Yohe 1990).

After the modern Sea was formed in 1905-06, Evermann (1916) reported sizeable populations of many freshwater fishes native to the Colorado River. These rapidly disappeared by in 1929, trout and humpback suckers were still reported; mullet were reported as scarce; and desert pupfish were reported as common along the north shore. Mosquitofish (*Gambusia affinis*) were reported for the first time, and were "abundant at several points along the shore" (Walker et al. 1961).

Beginning in 1929, large introductions of striped bass, longjaw mudsuckers, salmon, and over 20 other marine species were planted into the Salton Sea. Introduced marine species were taken principally from the San Felipe area of the Gulf of California (Walker et al. 1961). Of these, the orangemouth corvina, croaker and sargo established and flourished in the Sea.

In 1964-65, an aggressive exotic species from Africa, the tilapia (family Cichlidae), escaped to the Sea by two routes: (1) an aquarist fish farm near Niland, and (2) from irrigation ditches where it was stocked purposefully by California and Arizona fisheries agencies for the control of nuisance aquatic weed and insect species (Costa-Pierce and Doyle 1997). The tilapias quickly dominated the fish community of the Salton Sea as the salinity rose above 35 g/l to hypersaline levels.

1.1.2. The Hypersaline Phase

This is the phase during which tilapia established in the lake. By the early 1980's tilapia became the dominant fish species in the Sea and the most important prey for the increasing numbers of piscivorous birds. Tilapia also became a popular recreational fish. In 1982-83, the combined recreational catch of sargo, corvina, bairdella, and tilapia averaged over 1.5 fish/h, one of highest yielding sport fisheries in the nation (Black 1988).

Since the 1950's there have been reports of large fish die-offs in the Salton Sea, especially in summer when strong southerly winds completely mixed the shallow water column. Walker et al. (1961) followed one such turnover in 16-18 July 1956 which depleted oxygen to the surface causing massive fish kills. Deoxygenation also caused the

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disappearance of the pile worm. This latter report is interesting because the worm has been found to be one of the major food items for the fish community in the Salton Sea (D. Dexter, personal communication). Disappearance of a major food resource could account for the many reports of fisherman who recall catching fish in poor condition in the fall-winter period (Interviews with Salton Sea fishermen, 1995-present).

More recently, millions of tilapia, and thousands of migratory birds have died and the recreational fishery has declined precipitously. In January 1997 we estimated dead tilapia biomass at 100 g/m^2 across the entire pelagic area of the huge marine lake. Problems in the recreational fishery have created economic hardship on desert towns with few other alternative economic opportunities.

Salton Sea fish have wide salinity tolerances (Lasker et al. 1972; Prentice et al. 1985). However, increasing salinities have been reported to impact fish reproduction and recruitment in the Sea. Laboratory studies by Mitsui et al. (1991a) showed that sargo spawned when acclimated to 45 g/l Salton Sea water but all larvae died. Orangemouth corvina, acclimated to 35-40 g/l, spawned successfully when injected with leutinizing hormone-releasing hormone "a" (LH-RHa); but fish acclimated to 45-50 g/l failed to spawn even when induced. Simmons (1957) found croakers in Laguna Madre, TX tolerated 70 g/l but did not spawn. Brockson and Cole (1972) concluded that the optimal salinities for the corvinas were 33-37 g/l.

Mitsui et al. (1991b) sampled 11 Salton Sea stations over 3 years enumerating late egg and early larval stages of orangemouth corvina, croaker and sargo. Eggs and larval numbers declined as the Sea's salinity increased from 38 to 44 g/l from 1987-89. Higher densities of larval fishes were found near the few freshwater inlets to the Sea (New and Alamo Rivers).

All fish in the Salton Sea are under stress due to the combination of elevated salinity, accelerated eutrophication, and dramatic water quality fluctuations that result in lethal water quality events. It is proposed that tilapias are dying due to regular infusions of deoxygenated water and toxic levels of ammonia from infrequent lake turnovers that combine with high and low temperature stresses. Parasitic dinoflagellates have been found attached to tilapia gills. The fine structure of tilapia gill filaments is 'clubby', which probably is due to one or more of the above stresses and is likely to decrease respiratory efficiency (S. Hurlbert, pers. communication).

It has been reported by anglers that the two rivers contain large fish populations, but it is unknown what the importance of these riverine habitats and the adjacent brackishwater deltas are to the fish community and fishery in the Sea itself. If it is found, for example, that the majority of fish recruitment to occurs in the rivers and deltas and that juvenile recruitment occurs by migration to pelagic areas of the Sea; rivers and deltas might be suitable sites for conservation, and/or serve as possible sites for mitigation hatcheries that could help restore the Sea's fishery when a salinity control plan is adopted. In addition, there is preliminary evidence that the large scale intensive harvesting of tilapia might be a mechanism to remove phosphorus from the lake and reverse eutrophication (S. Hurlbert, pers. communication). Knowledge of fish biology and fish population dynamics are essential for any evaluation of management options of the Salton Sea fishery.

2. Materials and Methods

2.1. Field Methods

Bimonthly samplings in 1999 and quarterly samplings in 2000 were conducted. Twelve stations covering riverine (1999 only), nearshore, pelagic, and river mouths habitats were sampled (Fig. 1). Gill nets were used in sampling fish. Gill nets consisted of five 10 m long x 2 m deep twisted nylon panels of 1, 2, 7, 10, and 12.5 cm stretched mesh. Two surface gill nets were set at stations over 2 meters deep (pelagic and nearshore habitats during 2000; Fig. 1) to observe changes during the year in habitat preferences within the water column. Surface nets were set in the other stations. Gill net set times were recorded for catch per unit effort (CPUE) calculations as an estimate of productivity. CPUE was defined as the number of fish sampled per hour.

Fish were weighed to the nearest gram and total length measured to the nearest millimeter. A random subsample of 30 fish from each station during each sampling period was taken for otolith extraction and a random sample of 15 for dissection. Individual fish were dissected for determinations of gonadosomatic indices (GSIs). GSIs were calculated as the percentage of the gonad weight from the total weight of fish (Anderson and Neumann 1996). Dissected fish were also weighed, measured (total length), and sexed.

Fish otoliths were used for age determination and growth estimation. Tilapia otoliths were viewed whole. Croaker and sargo otoliths were sectioned before viewing. Orangemouth corvina otoliths were broken at the focus and burned to aid in resolving annuli. A light microscope with reflected light was used to examine otoliths.

A simple light microscope with reflected light was used to examine otoliths whole. One age ring consisted of one complete opaque zone and one complete translucent zone. Otoliths were recorded as unreadable if the marks were obscured by crystalline structures. In some cases marks appeared extremely faint; those otoliths were also described as unreadable.

2.2. Data Analyses

Data were grouped for analyses. Data grouping was according to location for defining habitat types and according to time of sampling for defining seasons. Habitat types were of nearshore (stations close to shore), pelagic (stations in open water), river mouth (stations in the mixing zone between the rivers and the lake), and riverine (stations within the rivers). Time of collection (seasons) were during the Winter (December and February samples), Spring (April samples), Summer (June and August samples), and Fall (October samples).

Changes in CPUEs through space and time were used to estimate onshore and offshore movement patterns. Female GSIs were analyzed with linear factorial models (Neter et al. 1996). The response variable for GSIs was the percentage of gonad weight from the total body weight (Anderson and Neumann 1996) and the predictor was season. Horizontal and vertical movement patterns were analyzed independently with hierarchical linear factorial models (Winer et al. 1991). CPUE was the response variable used and habitat, season, and year were the factors tested. Habitat was nested within season and season within year.

A von Bertalanffy growth function (VBGF) was used to estimate fish growth (Bertalanffy 1951, Pauly 1981). Fish growth was analyzed by year. If the asymptotic 95% confidence limit of the parameter estimates describing the growth constant (K in Appendix 1, Section III) for 1999 and 2000 overlapped, or if there was no convergence in any parameter estimates for either year, data for 1999 and 2000 were combined and used to describe growth. Instantaneous total mortality estimates were determined using the exponential decay model

$$N_t = N_0 * e^{-Z}$$

where

N_t = number of fish during 2000
N_0 = number of fish during 1999
Z = total mortality.
Total mortality from 1999 to 2000 was calculated by species for each cohort prior to 2000. Each fish was assigned an age using a log-likelihood function for multiple length-frequency data (Fournier et al. 1990; Fournier et al. 1991). No estimate was reported if the 95% confidence intervals for the total mortality estimates overlapped.

2.3. Data Storage

All raw data is stored at the Gulf Coast Research Laboratory, Institute of Marine Sciences, University of Southern Mississippi. Electronic copies of data are in comma delimited text files, MS-Word documents, and MS-Access tables. The media of data storage are CD-ROM, 3.25 in diskettes, and magneto-optical disks. CD-ROM disk will be used for distribution.

3. Salton Sea Fish Biology

Ten fish were sampled between 1999 and 2000 (Table 1). Gulf croaker and tilapia were the most abundant, followed by orangemouth corvina and sargo. Tilapia was also the most important in weight, followed by orangemouth corvina, Gulf croaker, and sargo. All other species were of marginal importance in numbers and weight. Three species known to occur in the Salton Sea were not sampled (Table 1).

3.1. Tilapia

3.1.1. Background

Tilapias are natives to Africa (Trewavas 1983). Because of their importance in aquaculture, tilapia, especially *Oreochromis mossambicus*, are the most widely distributed exotic fish worldwide. Research on tilapia in the United States has been conducted for their use as food, vegetation control, and game fish (Dill and Cordone 1997; Costa-Pierce and Rakocy 1997, 2000). Tilapia have become established in subtropical regions of the United States (Costa-Pierce and Riedel 2000) and are an ecological problem in most ecosystems where they invaded (Courtney et al. 1984;

Courtney 1997; Courtney and Stauffer 1990). *O. mossambicus* are presently found in coastal regions of southern California, and the Salton Sea and adjacent drains (Page and Burr 1991; Dill and Cordone 1997).

Tilapia are euryhaline (Suresh and Lin 1992; Watanabe 1997; Costa-Pierce and Riedel 2000), probably because they evolved from a marine ancestor (Myers 1938; Trewavas 1983), but are stenothermal (Hargreaves 2000). *O. mossambicus* are known to survive water temperatures 15 - 40°C, but grow optimally at 25 –37°C (Al Amoudi et al. 1996). Tilapias cease to feed below 16°C (Kelly 1956), and reproduce at water temperatures only above 20 – 22°C (Chervinski 1982; Philippart and Ruwet 1982). At temperatures less than 25°C, routine metabolism (as measured by oxygen uptake rates), and growth rates decrease rapidly (Caulton 1978). Laboratory experiments showed a sharp depression of growth for tilapia kept at 20–22°C compared with tilapia at 25–28°C (Chmilevskii 1998). Onset of cold stress has been widely reported for *O. mossambicus* at water temperatures of 15°C and below (Allanson et al. 1962, 1971; Al Amoudi et al. 1996; Chmilevskii 1998). Lethal minimum temperatures reported for *O. mossambicus* range between 5.5–12.0°C (Costa-Pierce and Riedel 2000). *O. mossambicus* has been reported to survive lower temperatures at higher salinities, but has never been reported to survive water temperatures less than 5°C (Costa-Pierce and Riedel 2000).

Longevity and size of wild *O. mossambicus* vary between 3 - 10 years, and 23 - 38 cm (Bruton and Allanson 1974; Hodgkiss and Man 1977; De Silva 1991; James 1989). Maximum size and weight of cultured *O. mossambicus* may be higher (Jubb 1967; Le Mare 1950). Sexual maturity may be reached after six months, which accounts for the high potential of tilapia to dominate fish communities (Trewavas 1983).

The Mozambique tilapia invaded the Salton Sea from at least 2 sources (Costa-Pierce and Doyle 1997). Tilapia were first discovered illegally at a private tropical fish farm close to the Salton Sea in 1964. In 1965, tilapia escaped and were reported in a drainage ditch that was connected to the Sea (St. Amant 1966). In 1967, tilapia were caught by a few anglers in Salton Sea (Hoover and St. Amant 1970). In the late 1960's– early 1970's, tilapia also invaded the Sea from irrigation drainage ditches where they were stocked purposefully for the control of aquatic nuisance species (aquatic weeds and insects), first by Arizona, then by California fisheries and irrigation authorities (Costa-Pierce and Doyle 1997).

3.1.1.1. Identification of the Salton Sea tilapia

Six hundred tilapia were collected irregularly during both hot and cool seasons on 10 occasions from January 1995–March 1997. Fish were caught with a 1–3 cm, 100 m long beach seine along the littoral zone and in the wetlands of the Salton Sea. Freshly dead fish were also sampled from a boat using hand nets. Fish were put on ice and transported to the lab where fin rays, gill rakers and external markings were measured and recorded. Species determinations were made using the keys of Trewavas (1983) and Pullin (1988). *Tilapia zillii* from wetland areas were easily distinguished by external features (Trewavas 1983). However, meristics could not be used to determine species composition of *Oreochromis* collected from the littoral and pelagic areas of the Salton Sea. Therefore, microsatellite DNA analyses were accomplished in comparison to

reference samples of *Oreochromis niloticus*, *O. mossambicus*, and *O. urolepis hornorum* obtained from Africa, the UK, and Israel (see methods in Costa-Pierce and Doyle 1997).

The Salton Sea tilapia were found to have a strong affinity with natal *O. mossambicus*; however, there was some indication that genetic drift had occurred. Because of the small sample size of *O. u. hornorum* from Tanzania, it was not possible to resolve if the Salton Sea tilapia had a small but negligible component of *O. u. hornorum*. *O. u. hornorum* was never imported as a pure line to California from Africa (Costa-Pierce and Doyle 1997).

Surprisingly, the Salton Sea tilapia had the highest heterozygosities of any feral tilapias gathered from California, and were similar to reference samples from Africa (Costa-Pierce and Doyle 1997). These findings raise the possibility that the Salton Sea tilapia is a unique "strain" of tilapia; having adapted to the severe environmental conditions and concomitant intense selection pressures over 30+ generations in the Salton Sea.

Costa-Pierce (1998) suggested that the Salton Sea tilapia "strain" may be an important partner in genetic improvement programs for saltwater tilapia aquaculture (see Watanabe et al. 1997). However, with avian botulism, *Vibrios* and *Streptococcus* having been found in and on the Salton Sea tilapia, use of this potentially valuable strain, or movements of this fish outside of the Salton Sea, is not recommended at the current time. In addition, the Salton Sea tilapia could have potentially harmful environmental impacts on sensitive, enclosed marine ecosystems such as the northern Gulf of California biosphere reserve.

3.1.2. Findings

Tilapia CPUE ranged from <1 in the riverine habitat to over 11 in the estuarine habitat (Fig. 2). CPUE differed according to season, habitat, and year (Appendix I, Section I). Tilapia size and weight distribution was narrow (Fig. 3). Mean length and weight were of 28.3 cm and 398.2 g, respectively (Table 2). The 1995 cohort was dominant for tilapia throughout the two-year sampling period. No fish older than 5+ were observed (Fig. 3). Young of the year fish were observed along the shoreline of the lake in July and August 1999, but only sampled in December, 2000.

GSIs showed an increase in the summer (Fig. 4) and did not differ by year (Appendix I, Section II). Tilapia growth was not estimated during 1999 due to the lack of contrast in length, which precluded convergence of the VBGF. Data from 2000, which included juveniles (Fig. 3), was combined with 1999 data to describe tilapia growth (Fig. 5; Appendix I, Section III). Tilapia length at age were consistently larger than conspecifics elsewhere (Table 3). Tilapia total instantaneous mortality for the 1995 cohort was estimated to be 0.40 (Fig. 3), which corresponds to an absolute decrease of over 4 in CPUE. No sufficient data allowed mortality estimates for any other year class.

Tilapia sex ratios were skewed toward males in all except the riverine habitats (Table 4). Tilapia vertical distribution was a function of season and habitat (Fig. 6). In the pelagic habitat, tilapia were mostly sampled on the surface during the winter, spring, and summer. In the nearshore habitat, tilapia were mostly on the bottom (Fig. 6). Movement trend of tilapia was toward shore starting in the Spring and away from the shore in the Fall and Winter (Fig. 7).

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3.1.3. Conclusions

The high tilapia CPUE were expected due to the high primary productivity of the Salton Sea. Amarasinghe (1987) and Amarasinghe and De Silva (1990) reported catch per unit effort values ranging between 0.4 and 1.2 kg day^{-1} at four lakes with average *O. mossambicus* productivity of 63-918 kg ha^{-1} yr^{-1} in Sri Lanka (De Silva 1988). Gill nets in Sri Lanka are 50-75 m long and 1.5-2 m deep, set for an average of 12 hours per day (De Silva 1991). Overnight gill net sets conducted in this study yielded catches ranging from 50 to 112 kg in the nearshore and from 86 to 129 kg in the estuarine habitat, most of which were caught in a 10 m section of the 50 m long multipanel gill net, evidence for a high productivity of the Salton Sea.

Habitat quality for tilapia in the Salton Sea was not uniform. The pelagic zone, was of marginal quality as evidenced from low fish production. Higher productivities of fish (as per CPUE) were evident in areas closer to shore.

Maximum life span for tilapia have been reported to be between 8 (Mironova 1969; De Silva 1991) and 11 years (Fryer and Iles 1972; James 1989). Longevity of tilapia, however, has been reported to be inversely related to environmental quality (James 1989). Hodgkiss and Man (1977) reported that most tilapia in a thermally harsh reservoir were under five years old. Similarly, Hecht and Zway (1984) reported stunted tilapia mostly five years old or less in a hot spring. No Salton Sea tilapia older than five years were sampled. Salton Sea tilapia, however, were not stunted. Salton Sea tilapia (one and two years old) grew fast, reaching adult size quickly. On a consistent basis, Salton Sea tilapia length at age was higher than length at age from tilapia in other lakes and reservoirs (Table 3). Tilapia have been reported to increase food consumption (Watanabe 1989) and to lower routine metabolism (Ron et al. 1995) as salinity rises. A gradual salinity rise over the years in the Salton Sea might have led tilapia to become a faster growing, shorter lived strain fish.

GSIs for female tilapia have been reported to range between 2.3 and 2.7 in freshwater lakes in Sri Lanka (De Silva 1986). Tilapia GSI were similar during the reproductive season between the spring and summer. Tilapia peak spawning was in the spring and continued throughout the summer. Evidence of spawning was the high GSIs values and observations of young fish along the immediate nearshore zones. Because multimesh gill nets were used and because a multitude of habitats was sampled, the lack of juvenile fish in gill net sets is likely due to mortality before new recruits venture offshore in the fall.

Tilapia female to male sex ratio have been reported to vary between 0.4:1 and 7:1 in Sri Lankan freswater lakes (De Silva and Chandrasoma 1980). The skewed sex ratio from Salton Sea tilapia might be due to the low number of founders, and possibly inbreeding (Costa-Pierce and Doyle 1997).

The ability of tilapia to descend to deep water declines as fish grows (Caulton and Hill 1973). Tilapia were observed to compensate to depths of 11.5 m after over 72 h at great energy expense, but to readily swim to depth of 4 m or less (Caulton and Hill 1973). This corroborates with our observations in the pelagic habitat, where tilapia were mostly on the surface. In the nearshore, tilapia preferred the bottom, most likely because of the

presence of pile worm. The availability of pile worms may also explain why tilapia were in better condition closer to shore.

3.2. Gulf Croaker

3.2.1. Background

Gulf croakers (*Bairdiella icistia*), of the family Scianidae, support commercial and sport fisheries worldwide (Jacob 1948; Longhurst 1964). Gulf croakers are primarily estuarine, inhabiting shallow waters (Johnson 1978). The Salton Sea croaker is native to the Gulf of California. Fifty-seven croakers were introduced in 1950, followed by the introduction of another 10 fish in 1951 (Walker et al 1961). The first account of a Salton Sea croaker was made in 1953 (Dill and Cordone 1997). Gulf croakers are small, rarely reaching over 0.5 kg, an unimportant game fish, but are occasionally caught by anglers. Gulf croakers are, however, important forage fish for the orangemouth corvina (Whitney 1961a).

Whitney (1961a) reported that Gulf croakers have distinct inshore-offshore portions of their life history related to feeding and reproduction. Fish are known to move inshore in May and offshore in September following the abundance of pile worms. Mok and Gilmore (1983) report peak spawning to occur between March and June for the Altantic croaker (*B. chrysoura*). Gulf croaker from the Salton Sea have been reported to mature in 1-2 years and spawn in May and early June (Haydock 1971), grow to a maximum of 30 cm (Walker et al. 1961), and have a life span of up to eight years (Lattin 1986).

The Altantic croaker tolerates salinities ranging from freshwater to 45 g/L (Simmons 1957) and temperatures between 5 °C (Perret et al. 1971) to over 34 °C (Kilby 1955). The Salton Sea Gulf croaker has a high salinity tolerance. A related sciaenid, *Bairdiella chrysura*, has been found to grow well at 45 g/L in Laguna Madre, TX (Simmons 1957). There is relatively little recent research on spawning habits of the croaker, but most of what is known follows the classic descriptions of croaker spawning recorded by Kuntz (1914), Welsh and Breder (1923), and Walker et al. (1961).

3.2.2. Findings

The highest CPUE for croaker was of 1.6 kg/h in the nearshore habitat during the spring of 2000 (Fig. 2). Mean length and weight were of 20.5 cm and 98.4 g, respectively (Table 2). A weak recruitment was observed for croakers in 1999 and a stronger recruitment in 2000 (Fig. 8). The majority of the Gulf croaker comprised of the 1996 cohort (Fig. 8; Table 3).

Gulf croaker GSIs increased in the spring during 1999 and 2000 (Fig. 9) and was a function of season (Appendix I, Section II), indicating that spawning started during that season. Spawning season was of only one or two month in 2000. Gulf croaker grew at a faster rate during 2000 than 1999 (Fig. 10; Appendix I, Section III). No instantaneous total mortality estimate between 1999 and 2000 was determined because of the high variation in CPUEs.

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Gulf croaker sex ratios were skewed toward males in the pelagic habitat, skewed toward females in the river mouth habitat, and were of approximately equal in the nearshore habitat (Table 4). Gulf croaker were mostly demersal except in the pelagic habitat during the summer (Fig. 11). Based on trends in CPUE through time, the movement patterns were inshore from winter to summer (Fig. 7).

3.2.3. Conclusions

Gulf croakers were most abundant fish in the Salton Sea. The Salton Sea croaker is likely in better condition now than the population studied by Whitney (1961a). The croaker population in 1999 was consistently larger than that reported in Whitney (1961a) for all age classes where comparisons were possible (Table 3). As for tilapia, higher growth rates might have come at the expense of life span. The croaker population sampled in 1989 by Lattin (1986) had more older fish (5-8 years) than the population sampled in 1999. An adaptation to the high salinity and low dissolved oxygen of the Salton Sea may have come with a cost of reduced longevity for fish. The enhanced growth of the 2000 Gulf croaker might be due to the warmer spring temperature compared with 1999.

Gulf croaker mature in 1-2 years, depending upon environmental conditions (Whitney 1961a). Maturation time may be closely related to the abundance of invertebrates (Walker et al. 1961). Croakers are annual spawners with peak spawning periods in the spring. For the closely related Atlantic croaker, Welsh and Breder (1923) found a peak spawning time during May in North Carolina. Atlantic croaker exhibit a strong nearshore schooling behavior, then migrate to deeper waters as adults. In the Salton Sea, Walker et al. (1961) found a peak spawning period in mid-May at about 23°C water temperature. Similarly, Haydock (1971) reported peak spawning based on GSIs during May and early June. GSIs were reported to average 10 and be as high as 12 (Haydock 1971). The Salton Sea Gulf croaker spawning season was shorter than congeners elsewhere (N. Brown-Petersen, pers. comm.), which may be an adaptation to match juvenile with food base or avoid competition with juvenile tilapia in the Salton Sea.

Based on the trend in GSIs observed in this study and on the higher catches in the nearshore habitat during the summer months, the croaker moved to shallow waters to spawn. The inshore movement of Salton Sea croaker for spawning, unlike the movement pattern of the Atlantic croaker, may be an adaptation to low levels of dissolved oxygen and scarcity of food in the summer in the pelagic habitat.

3.3. Orangemouth Corvina

3.3.1. Background

The orangemouth corvina (*Cynoscion xanthulus*), are native to the Gulf of California and is the most important sport fish in the Salton Sea (Black 1974). Orangemouth corvina were first stocked in the 1950s, followed by other introductions through 1956. Approximately 250 specimens were introduced during that period (Dill

and Cordone 1997). Orangemouth corvina may grow to 65 cm when five years old (Whitney 1961a).

Orangemouth corvina in the Salton Sea are hypothesized to spawn between April and August when water temperatures rise (Walker et al. 1961; Matsui 1991b). Fish and Cummings (1972) have provided evidence of spawning occurring during the spring and summer based on intensity of sound production. Spawning of Salton Sea orangemouth corvina, however, has also been hypothesized to extend through the fall (Whitney 1961b; Matsui 1991b).

The orangemouth corvina, is the most important gamefish in the Salton Sea even though it comprised only 3% of the catch when monitored by Black (1988). At the peak of the sport fishery in 1970, 9,267 corvina were caught. The catch rate was 1.88 fish per angler-hour (Black 1974). A 1970 California Fish and Game report estimated the corvina population in the Sea at one to three million fish (Hulquist 1970).

Adult corvinas are wide-ranging predators; but the adults inhabit principally the open water areas of the Sea. However, the fish are readily caught by anglers in the nearshore. Maximum reported size is 32 pounds (Hulquist 1970).

Corvina grow very rapidly in the Sea in comparison with other croakers (Blake and Blake 1981; Warburton 1969). Corvina also play a valuable ecological role as the most successful top carnivore in the Salton Sea.

3.3.2. Findings

The highest CPUE for orangemouth corvina was of 4.8 kg/h in the nearshore habitat in the winter 2000 (Fig. 2). Mean length and weight were of 58.9 cm and 2274.8 g, respectively (Table 2). The strongest recruitment for orangemouth corvina was observed in 1999 (Fig. 12). As for the Gulf croaker, orangemouth corvina were mostly of the 1996 cohort (Fig. 12; Table 3).

Orangemouth corvina GSIs did not show any seasonal pattern (Fig. 13; Appendix I, Section II). The only significant factor was habitat, due to orangemouth corvina preferring the nearshore year round. No difference in growth rates was found between 1999 and 2000 (Fig. 14; Appendix I, Section III). No instantaneous total mortality estimate between 1999 and 2000 was determined because of the high variation in CPUEs.

No consistent pattern in sex ratio was found for orangemouth corvina (Table 4). Orangemouth corvina were mostly demersal during all seasons in the nearshore and pelagic habitats (Fig. 15). Orangemouth corvina were mostly concentrated in the nearshore; no offshore movement trends for orangemouth corvina were observed (Fig. 7).

3.3.3 Conclusions

Orangemouth corvina was the third most abundant species and were mostly confined to nearshore and estuarine areas. Orangemouth corvina CPUEs surpassed that of tilapia in the nearshore habitat during the spring of 1999 because of large size compared with the other species. Compared with the orangemouth corvina sampled by Whitney (1961b), the population sampled in 1999 reached larger sizes for all age classes where comparisons were possible (Table 3). The stock of orangemouth corvina might, therefore, be in better condition than the stock of decades ago.

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Prentice et al. (1989) suggest two peaks of spawning for orangemouth corvina when experimentally induced to spawn under summer and fall conditions. Fish and Cummings (1972) show evidence of peak spawning for Salton Sea orangemouth corvina only once a year. Based on the lack of seasonal pattern in GSIs presented in this study, evidence for multiple spawning of orangemouth corvina is supported.

The fact that orangemouth corvina were associated with the nearshore is evidence that shallow habitats are of better quality, possibly offering better feeding and nursery. The most likely location for sampling corvina was the bottom of locations close to shore. Remains of tilapia and croaker (mostly on the bottom in the nearshore) were commonly observed in the stomachs of orangemouth corvina. Orangemouth corvina preferred the bottom probably because of the more ready access to food, namely other fish.

3.4. Sargo

3.4.1. Background

Sargos (*Anisotremus davidsoni*) are distributed from central to southern Baja California and into the northern Gulf of California. Sixty-five sargo were introduced from the northern Gulf of California population into the Salton Sea (Walker et al. 1961). Sargo are a schooling species preferring shallow subtidal habitats. They mostly congregate around structures. Spawning of sargo occurs mostly during late spring and throughout summer (Love 1996). The eggs are pelagic and the juveniles migrate inshore where they may congregate with juveniles of other species. Sargo are demersal, feeding mostly on benthic invertebrates (Love 1996). Salton Sea sargo biology and behavior, however, have not yet been investigated. Sargo are occasionally reported by Salton Sea anglers mostly as incidental catch.

The fish biology and fisheries for sargo are little known in the Salton Sea. Sargo are closely related to Pacific porgies (Family Sparidae), salema, and Pacific flagfin mojarras (Family Gerreidae). Sargo are larger than croaker (reaching 2 kg) and are important gamefish in the Salton Sea. It is assumed this fish is also prey for the corvinas (Walker et al. 1961).

3.4.2. Findings

Sargo were sampled only in the nearshore and pelagic habitats. Sargo CPUE was of 0.01 ± 0.004 SEM, n = 248 and not a function of year, season, or habitat. Mean length and weight were of 23.9 cm and 267.9 g, respectively (Table 2). Some evidence of sargo recruitment was observed (Fig. 16). Sargo age distribution was distinctly bimodal, with peaks in the 1996 and 1998 cohorts (Fig. 16; Table 3). Data for sargo growth was estimated for 1999 and 2000 combined because not enough fish were caught during 2000. Sargo was the species with second fastest growth rate (Fig. 17; Appendix I, Section III). No instantaneous total mortality estimate between 1999 and 2000 was determined because of the high variation in CPUEs.

Sargo GSI was highest in the summer (Fig. 18) and sex ratios was skewed toward males in both, the nearshore and pelagic habitats (Table 4). Sargo were mostly demersal

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at all seasons, except in the fall (no fish sampled) (Fig. 19). No offshore or inshore movement trends for sargo were calculated because of lack of fish.

3.4.3. Conclusions

Sargo was the least abundant species sampled. Many factors about this species in the Salton Sea remain unanswered because no analyses were possible. Whether the sargo population is declining or has remained small may only be answered by continuous monitoring of the fishery. Sargo is an important sport fishery in the southern California Bight (Watson and Walker 1992), but whether the sargo will ever be a sough after species in the Salton Sea will depend on if the stock of sargo becomes abundant enough to match that of the other three species discussed above.

Sargo recruitment was observed, which indicates that the species is reproducing. Walker et al. (1961) reports the presence of sargo in the Salton Sea, but did not provide any information about its abundance and potential for supporting a fishery. Sargo established, but probably never flourished in the Salton Sea. The increase in GSIs during the summer (onset of spawning) is evidence that this species is still reproducing at the current Salton Sea salinity. There is some evidence that Salton Sea sargo growths faster than its conspecific in the Pacific coast of southern California, where four year old fish have been measured to be 25 cm long (Love 1996), whereas Salton Sea two year old sargo have been measured to be 27.5 cm on average.

3.5. Essential Fish Habitats

There are four fish habitats that could be classified as essential for Salton Sea fish (EFHs):

- the freshwater areas of the New and Alamo Rivers,
- the brackishwater or estuarine areas of the New and Alamo Rivers,
- the shoreline or nearshore zones in the Sea, and
- the open or pelagic areas.

There are extensive riverine areas of 0-5 g/L salinity with dense riparian vegetation extending into the water, which proved not important EFHs. Sample netting in these areas in 1999 caught carp, mosquitofish, and catfish, in addition to few tilapia, juvenile corvina, and croakers. Nearshore and estuarine areas were preferred by tilapia, croaker, and corvina. Tilapia spawning aggregations, called "arenas" (Trewavas 1983) and mature adult croakers were noted along the shoreline. Nearshore and estuarine habitats are, therefore, considered EFH.

4. Conclusions

The higher abundance of tilapia over the other species may be a consequence of the high adaptability to stressful environmental conditions and their reported ability to use a wide variety of natural foods (Mironova 1969; Trewavas 1983). Tilapia are known for tolerating low dissolved oxygen, high salinities, and to shift readily from a

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phytoplankton diet to alternate food sources (Trewavas 1983; Suresh and Lin 1992). *O. mossambicus* have been observed to reproduce in water with salinity as high as 49 mg l^{-1} (Popper and Lichatowich 1975) and tolerate up to 120 g/l (Whitefield and Blaber 1979). Conversely, croaker and sargo are much less plastic in their salinity tolerances and food habits, being limited to benthic invertebrates (Quast 1961; Whitney 1961a) and possibly pelagic crustaceans or larger zooplankton. Orangemouth corvina are top predators (Whitney 1961b), and are therefore expected to be less abundant than tilapia.

Due to the high salinity of the lake, the riverine habitat was expected to serve as refugia for fish. This was not observed. The estuarine habitat yielded very high catches, especially during the summer. The high levels of dissolved oxygen in the river/lake mixing zone of the estuarine habitat (in excess of 12 g/l) might have been a contributing factor for the high catches. Conversely, the low oxygen levels prevailing in the pelagic habitat in the summer (Fig. 21) may be the strongest factor for making the pelagic habitat of low quality for fish. Salinity, therefore, may not be as much a limiting factor now as is dissolved oxygen, especially during hot months.

Salinity, however, will become a limiting factor if it continues to rise. In a study of some physiological responses of Salton Sea Gulf croaker, orangemouth corvina, and sargo to increased salinities, Brocksen and Cole (1972) reported an optimum range salinity of 33-37 g/L for growth, food consumption and conversion, and respiration. That range has been surpassed at the Salton Sea today. Even if the fish are now better adapted to higher salinities will not change the fact that there is an upper threshold for Salton Sea fish. This threshold may first affect reproduction by affecting eggs, reducing fertilization, and larval development (May, 1974, 1975, 1976; Matsui et al. 1991b). Effects on reproduction may cause an abrupt collapse in the fishery. Efforts to curb the salinity increase of the Salton Sea are underway and hopefully will occur before it is not late to prevent catastrophic declines of fish.

The fish of the Salton Sea are not evenly distributed throughout the lake. Any restoration alternative should take this into account. When permanently closing off areas of the lake, caution should be taken to not isolate critical nursery or feeding areas. Similarly, because the nearshore habitat has a high CPUE, partially loosing that habitat might affect yields of sport or commercial fishery.

A promising undertaking towards restoring the lake is the implementation of a commercial fishery. A commercial fishery may benefit many, if not all, components of the Salton Sea fauna. When exploiting a virgin fish resource, younger, faster growing individuals may benefited from the harvest of older, slower growing fish (Schaefer 1954, Hilborn and Walters 1992), and incidence of disease (and possibly periodic dioffs) may be lowered. Harvest, therefore, may increase fish yield. Given the high estimates of fish CPUE, the fishery may also benefit local communities on a sustained basis. The product of the fishery may be commercialized as meal, food, or fertilizer. Our research work has provided some evidence that fish growth of the Salton Sea is higher than conspecifics elsewhere. With an accelerated growth, fish stocks may sustain a higher fishing pressure before showing signs of overexploitation, adding to the expected benefits of a commercial fish harvest at the Salton Sea. Similarly, stocking of game fish for enhancing the sport fishery may prove beneficial. Orangemouth corvina is the only game fish currently in the lake. If other game fish establish in the lake, local communities may further benefit economically from sport fishery revenues. In summary, managing the lake

for a sustained fishery is not only economically promising, but also ecologically desirable.

4.1. Fisheries Management Considerations

Even in shallow environments like the Salton Sea, tilapia are not evenly distributed throughout the lake. Highest densities and productivities of the fish are in nearshore and estuarine areas (the EFH). Any fisheries management or restoration alternative should take this into account. In addition, spawning activities are concentrated in the very nearshore area, in coves, bays and harbors. Actions should be taken to protect, and not isolate these critical spawning and nursery areas.

In the case of the Salton Sea, implementation of a commercial fishery for the tilapias may benefit not only the fisheries ecosystem but also the surrounding communities. The Salton Sea harbors what is likely the largest unfished tilapia population in the world. When exploiting a virgin fish resource, younger, faster growing individuals benefit from the harvest of older, slower growing fish (Schaefer 1954; Hilborn and Walters 1992), and incidence of diseases (and possibly periodic die-offs) may be decreased. Given the extraordinary estimates of tilapia biomass in the Salton Sea, an expanded fishery may be commercialized as meal, food, or fertilizer. Stocking of additional predatory game fish to harvest the tilapia by predation and enhancing the sport fishery may also prove beneficial since the orangemouth corvina is the only large game fish currently in the Sea and its numbers are limited in comparison to numbers of forage fishes available (Table 3). If other game fish were to establish in the lake, local communities may obtain increased economic benefits from sport fishery revenues.

Due to the extreme saline conditions, the riverine habitats were expected to serve as the most essential fish habitat and refuge for the tilapia. This was not observed. Estuarine and nearshore habitats had the highest tilapia catches. Possibly the high levels of dissolved oxygen in the river/lake mixing zone of the estuarine habitat was the cause. Salinity, therefore, may not be as much a limiting factor now as is dissolved oxygen, especially during hot months.

References

Al Amoudi, M., A.-F. El-Sayed and A. El-Ghobashy, 1996. Effects of thermal and thermo-haline shocks on survival and osmotic concentration of the tilapias *Oreochromis mossambicus* and *Oreochromis aureus* x *Oreochromis niloticus* hybrids. J. of the World Aqua. Soc. 27:456–461.

Allanson, B., M. Ernst and R. Noble. 1962. An experimental analysis of the factors responsible for periodic fish mortalities during winter in the buslveld dams in the Transvaal, South Africa. Biological Problems in Water Pollution, p. 293–297.

Amarasinghe, U., 1987. Growth overfishing: a potential danger in the Sri Lankan reservoir fishery. In S. De Silva (ed.) Reservoir Fishery Management and Development in Asia. International Development Research Center, Katmandu, Nepal:105-112.

Amarasinghe, U. and S. De Silva, 1990. Empirical approaches for evaluating efficiencies of different fishing methods in tropical, shallow reservoirs: a Sri Lankan case study. In S. De Silva (ed.) Reservoir fisheries of Asia. Proc. 2nd Asian Res. Fish. Workshop, International Development Research Center, Hangzhou, People's Republic of China:217-227.

Anderson, R. and R. Neumann, 1996. Length, weight, and associated structural indices. In B. R. Murphy and D. W. Willis (eds.). Fisheries techniques. Am. Fish. Sco., Bethesda, Maryland: 447-482.

Bertalanffy, L. von 1951. Theoretische biologie, zweiter Band : Stoffwechsel, Wachstum. A. Franke Verlag, Bern.

Black, G., 1974. The party boat fishery of the Salton Sea and the apparent effect of temperature and salinity on the catch of orangemouth corvina, *Cynoscion xanthulus*. Inland Fish. Admin. Report 74-5, Cal. Dept. Fish and Game, Sacramento, CA.

Black, G., 1988. Description of the Salton Sea sportfishery 1982-83. Cal. Fish and Game Adm. Rep. 88-9.

Brocksen, R. W. and R. E. Cole, 1971. Physiological responses of three species of fishes to various salinities. J. Fish. Res. Bd Can. 29:399-405.

Bruton, M. and B. Allanson, 1974. The growth of *Tilapia mossambicus* in Lake Sibaya, S. Afr. J. of Fish Biol. 6:701-715.

California Department of Fish and Game, 1971. Annual report. Sacramento, CA.

Caulton, M., 1978. The effect of temperature and mass on routine metabolism in *Sarotherodon (Tilapia) mossambica* (Peters). J. of Fish Biol. 13:195–201.

Caulton, M. and B. Hill, 1973. The ability of *Tilapia mossambica* to enter deep water. J. Fish Biol. 5:783-788.

Chervinski, J., 1982. Environmental physiology of tilapias. In R. Pullin and R. Lowe-McConnell, (eds.) The biology and culture of tilapias. ICLARM, Manila, Philippines :119–128.

Chervinski, J. and A. Yashouv, 1971. Preliminary experiments on the growth of *Tilapia aurea* in seawater ponds. Bamidgeh 23:125-129.

Chervinski, J. and M. Zorn, 1974. Note on the growth of *Tilapia aurea* and *Tilapia zilii* in seawater ponds. Aquaculture 4:249-255.

Chmilevskii, D., 1998. The influence of low temperature on the growth of *Oreochromis mossambicus*. J. of Ichth. 38(1):92-99.

Costa-Pierce, B. and R. Doyle, 1997. Genetic identification and status of tilapia regional strains in southern California. In B. Costa-Pierce and J. Rakocy (eds.), Tilapia Aquaculture in the Americas, I. World Aquaculture Society, Baton Rouge, LA: 1-21.

Costa-Pierce, B. and J. Rakocy, 2000. B. A. Costa-Pierce and J. Rackocy (eds.) Tilapia Aquaculture in the Americas, 2. The World Aquaculture Society, Baton Rouge, Louisiana:260.

Costa-Pierce, B. and J. Rakocy, 1997. B. A. Costa-Pierce and J. Rackocy (eds.) Tilapia Aquaculture in the Americas, 1. The World Aquaculture Society, Baton Rouge, Louisiana, 258 p.

Costa-Pierce, B. and R. Riedel, 2000. Fisheries ecology of the tilapias in subtropical lakes of the United States. In B. A. Costa-Pierce and J. Rakocy (eds.) Tilapia Aquaculture in the Americas, 2. The World Aquaculture Society, Baton Rouge, Louisiana:1-20

Courtenay, W, Jr., D. Hensley, J. Taylor and J. McCann, 1984. Distribution of exotic fishes in the continental United States. In W. Courtenay, Jr. and J. Stauffer, Jr., (eds.) Distribution, biology, and management of exotic fishes. John Hopkins University Press, Baltimore: 41–77.

Courtenay, W., 1997. Tilapias as non-indigenous species in the Americas: environmental, regulatory and legal issues. In B. Costa-Pierce and J. Rakocy, (eds.) Tilapia aquaculture in the Americas, 1. The World Aquaculture Society, Baton Rouge, Louisiana:18–33.

Courtenay, W. and J. Stauffer, 1990. The introduced fish problem and the aquarium fish industry. J. World Aqua. Soc. 21:145–159.

De Silva, K., 1991. Growth rate and the role of *Oreochromis mossambicus* in the fishery of a tropical, upland, deep reservoir in Sri Lanka. Fish. Res. 12:125-138.

De Silva, S., 1986. Reproductive biology of *Oreochromis mossambicus* populations of man-made lakes in Sri Lanka: a comparative study. Aqu. Fish. Man. 17:31-47.

De Silva, S., 1988. Reservoir of Sri Lanka and their fisheries. FAO Fish. Tech. Pap. (298):128 p.

De Silva, S. and J. Chandrasoma, 1980. Reproductive biology of *Sarotherodon mossambicus*, an introduced species, in an ancient man-made lake in Sri Lanka. Env. Biol. Fish. 5(3):253-259.

Dill, W. A. and A. J. Cordone, 1997. History and status of introduced fishes in California, 1871-1996. Cal. Dept. Fish Game, Bull 178.

Fish, J. and W. Cummings, 1972. A 50-dB increase in sustained ambient noise from fish (*Cynoscion xanthulus*). 52(4):1266-1270.

Fournier, D., J. Sibert, J. Majkowski, and J. Hampton. 1990. MULTIFAN, a likelihood-based method for estimating growth parameters and age composition for multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). Can. J. Fish. Aquat. Sci. 47:301-317.

Fournier, D. J. Sibert, and M. Terciero. 1991. Analysis of length frequency samples with relative abundance data for the Gulf of Maine northern shrimp (*Pandalus borealis*) by the MULTIFAN method. Can J. Fish. Aquat. Sci. 48:591-598.

Fryer, G. and T. D. Isles, 1972. The cichlid fishes of the Great Lakes of Africa. T. F. H., Neptune City, New Jersey, 641 p.

Hargreaves, J., 2000. Tilapia culture of the southeast United States. In B. A. Costa-Pierce and J. Rakocy (eds.) Tilapia Aquaculture in the Americas, 2. The World Aquaculture Society, Baton Rouge, Louisiana: 60-81.

Haydock, I, 1971. Gonad maturation and hormone-induced spawning of the gulf croaker, *Bairdiella icistia*. Fish. Bul. 69(1):157-180.

Hecht, T., 1980. A comparison of the otolith and scale methods of ageing, and the growth of *Sarotherodon mossambicus* in a Venda impoundment (southern Africa). S. Afr. J. Zool. 15(4):222-228.

Hecht, T. and P. Zway, 1984. On the stunted mocambique tilapia *Sarotherodon mossambicus* of the Matiovila Hot Spring, Kruger National Park. Koedoe 27:25-38.

Hickling, C., 1963. The cultivation of tilapia. Sci. Am. 208(5):143-152.

Hilborn, R. and C. Walters. 1992. Quantitative fisheries stock assessment. Chapman and Hall, New York.

Hodgkiss, J. and H. Man, 1977. Age composition, growth and body condition of the introduced *Sarotherodon mossambicus* (Cichlidae) in {Plover Cove reservoir, Hong Kong. Environ. Biol. Fishes 2(1):35-44.

Jacob, P. K., 1948. Sciaenids of the west coast of Madras Province. J. Bombay Nat. Hist. Soc. 48:118-124.

James, N. P. E.,1989. A life-history approach to the biology of Oreochromis mossambicus in the Eastern Cape, South Africa. Master of Science Thesis, Rhodes University, Grahamstown, 206 p.

Jehl, J.R., 1996. Mass mortality events of eared grebes in North America. American Journal of Field Ornithology 67(3):471–476.

Johnson, G. D., 1978. Development of fishes of the mid-Atlantic Bight. Biol. Serv. Prog., Fish Wild. Serv. 4:1-314.

Jubb, R., 1967. Freshwater fishes of Southern Africa. Cape Town: A. Balkema.

Kaiser, J., 1999. Battle over a dying sea. Science 284:28–30.

Kelly, H., 1956. Preliminary studies on *Tilapia mossambica* Peters relative to experimental pond culture. Proceedings of the Annual Conference of Southeast game and Fish Commission 10:139–149.

Kilby, J. D., 1955. The fishes of two Gulf Coast marsh areas of Florida. Tulane Stud. Zool. 2:175-247.

Khoo, H. W. and J. Moreau, 1990. opulation characteristics of Oreochromis mossamnbicus in the Seleter reservoir (Singapore) assessed through length-frequency analysis. Hirano, R. and I. Hanyu (eds.) The second Asian fisheries forum, Asisan Fisheries Society, Manila, Philippines, 991p.

Koura, R. and A. R. Bolock, 1958. Age, growth and survival of *Tilapia mossambica* in Egyptian ponds. Notes Mem. Hydrobiol. Dep. U. A. R., 41:1-18.

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

Lattin, G., 1986. Age and growth of the *Bairdiella icistia* in the Salton Sea using scales and otoliths. M. Sc. Publication, California State University, Long Beach.

Le Mare, D. 1950. The application of the principles of culture to estuarine conditions in Singapore. Proc. Pac. Fish. Coun. 2:175-180.

Longhurst, A. R., 1964. Bionomics of the Scianidae of tropical West Africa. J. Cons. Int. Explor. Mer 29 :93-114.

Love, M., 1996. Probably more than you want to know about the fishes of the Pacific Coast. Really Big Press, Santa Barbara, California, 381 pp.

May, R. C., 1974. Factors affecting buoyancy in the eggs of *Bairdiella icistia*. Mar. Biol. 28:55-59.

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

May, R. C., 1976. Effects of Salton sea water on the eggs and larvae of *Bairdiella icistia*. Calif. Fish and Game 62(2):119-131.

Matsui, M., A. Bond, G. Jordan, R. Moore, P. Garrahan, K. Iwanaga and S. Williams, 1991a. Abundance and distribution of ichthyoplankton in the Salton Sea, California in relation to water quality. California Fish and Game Report on Sport Fish Restoration Federal Aid Project F-51-R. California Department of Fish and Game, Sacramento, CA

Matsui, M., G. Lattin, R. Moore, C. Mulski, and A. Bond, 1991b. Salinity tolerance of *Cynoscion xanthulus*. California Fish and Game Report on Sport Fish Restoration Federal Aid Project F-51-R, Sacramento, CA..

Mironova, N., 1969. The biology of *Tilapia mossambica* under natural and laboratory conditions. Ichthyology 9:506-514.

Mok, H. and R. Gilmore, 1983. Analysis of sound production in estuarine aggregations of *Pogonias cromis*, *Bairdiella chrysura*, and *Cynoscion nebulosus* (Scianidae). Bull. Inst. Zool., Academia Sinica 22(2):157-186.

Myers, G. 1938, Freshwater fishes and West Indian zoogeography. Smithsonian Report for 1927 (pub. 3465):339–364.

Neter, J. M. Kutner, C. Nachtsheim, and W. Wasserman, 1996. Applied linear statistical models. Irwin, Boston, 1408 pp.

Page, L, and Burr, 1996. Freshwater fishes. Houghton Miffin, Boston, 342 p.

Pauly, D. 1981. The relationship between gill surface area and growth performance in fish: a generalization of the von Bertalanffy's theory of growth. Meeresforschung 28:251-282.

Payne, A. 1983, Estuarine and salt-tolerant tilapias. Pages 534-543 in Proceedings, international symposium on tilapia in aquaculture. Tel-Aviv University, Tel-Aviv.

Payne, A. and R. Collinson, 1983. A comparison of the biological characteristics of *Sarotherodon niloticus* with those of *S. aureus* and other tilapia of the delta and lower Nile. Aquaculture 30:335-351.

Perret, W. S., W. R. Latapie, J. F. Pollard, W. R. Mock, G. B. Atkins, W. J. Gairdy, and C. J. White, 1971. Fishes and invertebrates collected in trawl and seine samples in Luisiana estuaries. P. 39-105. in W. S. Perret (ed.), Cooperative ulf of Mexico Inventory and Study, Louisiana. Phase IV, Biology. Section I. Lousiana Wildlife Fish. Comm., New Orleans.

Perry, W. and W Avault, 1972. Comparison of striped mullet and tilapia for added production in caged catfish studies. Prog. Fish Cult. 34:229-232.

Phillippart, J-Cl. and J-Cl. Ruwet, 1982. Ecology and distribution of tilapias. In R. Pullin and R. Lowe-McConnell, eds. The biology and culture of tilapias. ICLARM, Manila, Philippines.

Popper, D. and T. Lichatowich, 1975. Preliminary success in predator control of Tilapia mossambica. Aquaculture 5:213-214.

Prentice, J., and R. Colura. 1984. Preliminary observations of orangemouth corvina spawn inducement using photoperiod, temperature, and salinity cycles. World Mar. Soc. J. 15:162-171.

Prentice, J., R. Colura and B. Bumguardner, 1989. Observations on induced maturation and spawning of orangemouth corvina. Cal. Fish and Game 75: 27-32.

Quast, J., 1961. The food for the bairdiella. Pages 153-164. In B. Walker (editor) The ecology of the Salton Sea, California, in relation to the sportfishery. Cal. Dep. Fish and Game Bull. 113.

Ron, B., S. K. Shimoda, G.K. Iwama and E.G. Grau, 1995. Relationships among ration, salinity, 17alpha-methyltestosterone and growth in the euryhaline tilapia, Oreochromis mossambicus. Aquaculture 135:185–193.

Roux, P. J., 1961. Growth of Tilapia mossambica in some Trasnvaal impoundments. Hydrobiologia 18:165-175.

Sasaki, K. 1989. Phylogeny of the family Sciaenidae, with notes on its zoogeography. Memoirs of the Faculty of Fisheries 36:1-137.

Schaefer, M., 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Bull. Inter-Am. Trop. Tuna Com. 1:27-56.

Setmire, J, Schroeder, R., Densmore, J., Goodbread, S., Audet, D. and W. Radke, 1993. Detailed study of the water quality, bottom sediment and biota associated with irrigation drainage in the Salton Sea area, California. US Geological Survey, Sacramento, CA.

Simpson, E. and S. Hurlbert, 1998. Salinity effects on the growth, mortality and shell strength of Balanus amphitrite from the Salton Sea, California. Hydrobiologia 381:179–190.

Simpson, E., M. Gonzales, C. Hart and S. Hurlbert, 1998. Salinity and fish effects on Salton Sea microecosystems: benthos. Hydrobiologia 381:153–177.

Simmons, E. G., 1957. An ecological survey of the upper Laguna Madre of Texas. Pub. Inst. Mar. Sci. Texas 4:156-200.

Suresh, A. and C. Lin, 1992. Tilapia culture in saline waters: a review. Aquaculture 106:201-226.

Trewavas, E., 1983. Tilipiine fishes of the genera Sarotherodon, Oreochromis, and Danakila. British Museum of Natural History, London.

Walker, B., R. Whitney, and G. Barlow, 1961. Fishes of the Salton Sea. Pages 77-92. In B. Walker (ed.) The ecology of the Salton Sea, California, in relation to the sportfishery. Cal. Dep. of Fish and Game Bull. 113.

Watanabe, W., 1997. Saltwater culture of the Florida red and other saline-tolerant tilapias: a review, p. 55-141. In B. Costa-Pierce and J. Rakocy (editors.) Tilapia aquaculture in the Americas. World Aquaculture Society Books, Baton Rouge, LA.

Watson, W. and H. Walker, Jr., 1992. Larval development of sargo (Anisotremus davidsoni) and salema (Xenistius californiensis) from the southern California Bight. Bull. Mar. Sci., 51(3):360-406.

Weide, D. 1976. Regional environmental history of the Yuha desert, p. 9-20 in Background to the prehistory of the Yuha Desert region (P.J. Wilke, ed.) Ballena Press, Ramona, CA.

Welsh, W. and C. Breder, 1924. Contributions to life histories of Scienidae of the eastern U. S. coast. Fish. Bull. 39:141-201.

Winer, B, D. Brown, and K. Michels. 1991. Statistical principles in experimental design. McGraw-Hill, New York.

Whitfield, A. and S. Blaber, 1979. The distribution of the cichlid Sarotherodon mossambicus in estuarine systems. Environ. Biol. Fish 4:77-81.

Whitney, R., 1961(a). The bairdiella, *Bairdiella icistius*. Pages 105-152. *In* B. Walker (editor) The ecology of the Salton Sea, California, in relation to the sportfishery. Cal. Dep. of Fish and Game Bull. 113.

Whitney, R., 1961(b). The orangemouth corvina *Cynoscion xanthulus*. Pages 165-183. *In* B. Walker (editor) The ecology of the Salton Sea, California, in relation to the sportfishery. Cal. Dep. of Fish and Game Bull. 113.

Yohe, R.M. 1990. Archeological investigations of five sites located at one eleven la Quinta Center in the city of La Quinta, central Riverside County, California. Unpublished Report, Archaeological Research Unit, University of California, Riverside.

Table 1. Species, total catch by numbers, by weights, and catch per unit efforts (CPUEs as kg/h) by habitat for fish sampled from the Salton Sea, CA between 1999 and 2000. CPUEs are average catch per hour per net. * indicates a CPUE less than 0.1. P= pelagic; N= nearshore; E= estuarine; R= riverine.

Species	Total Catch by Number	Total Catch by Weight (kg)	Habitats (CPUEs)
Major Species Sampled			
Tilapia (Oreochromis mossambicus)	P (613), N (2072), E (2102), R (85)	P (223.9), N (746.0), E (934.7), R (28.6)	P (0.1), N (2.5), E (4.2), R (0.1)
Croaker (Bairdiella icistia)	P (2775), N (1339), E (767), R (0)	P (269.5), N (114.9), E (95.3), R (0)	P (0.1), N (0.4), E (0.3)
Orangemouth Corvina (Cynoscion xanthulus)	P (22), N (195), E (111), R (5)	P (28.8), N (514.9), E (201.7), R (0.2)	P (*), N (1.4), E (1.3), R (*)
Sargo (Anisotremus davidsoni)	P (82), N (15), E (0), R (0)	P (17.9), N (6.0), E (0), R (0)	P (*), N (*)
Minor Species Sampled			
Threadfin shad (Dorossoma petense)	P (0), N (15), E (116), R (5)	P (0), N (0.8), E (6.9), R (<0.1)	E (*)
Carp (Cyprinus carpio)	P (0), N (0), E (0), R (2)	P (0), N (0), E (0), R (0.9)	R (*)
Channel catfish (Ictalurus punctatus)	P (0), N (0), E (0), R (6)	P (0), N (0), E (0), R (1.4)	R (*)
Flathead catfish (Pylodictis olivaris)	P (0), N (0), E (0), R (1)	P (0), N (0), E (0), R (<0.1)	R (*)
Mosquitofish (Gambusia affinis)	P (0), N (0), E (0), R (6)	P (0), N (0), E (0), R (<0.1)	R (*)
Striped mullet (Mugil cephalus)	P (0), N (0), E (4), R (0)	P (0), N (0), E (6.8), R (0)	E (*)
Fish not sampled, but present at the Salton Sea			
Redbelly tilapia (Tilapia rendalii)			
Longjaw mudsucker (Gillichthys mirabi)			
Desert pupfish (Cyprinodon macularis)			

Table 2. Summary statistics for Salton Sea fish sampled between 1999 and 2000.

			Length (cm)				Weight (g)			
Species	Biomass (kg)	N	Min	Max	Mean	SD	Min	Max	Mean	SD
Gulf Croaker	479.7	4881	8.0	33.0	20.46	<0.1	5.9	459.1	98.4	0.4
Common carp	0.9	2	29.5	33.7	31.6	2.1	389.9	505.3	447.6	57.7
Channel Catfish	1.4	6	12.7	44.0	26.0	1.8	4.6	658.0	232.0	1.9
Orangemouth corvina	745.6	333	18.1	88.5	58.9	0.4	6.0	6800.0	2274.8	49.5
Flathead Catfish	<0.1	1	13.0	13.0	13.0	<0.1	15.0	15.0	15.0	<0.1
Mosquito fish	<0.1	6	4.0	4.7	5.2	0.5	0.3	1.3	0.8	0.2
Sargo	24.0	97	13.2	32.3	23.9	0.2	38.1	579.2	267.9	0.8
Striped Mullet	6.8	4	51.3	58.8	52.7	12.2	1434.1	2225.8	1694.8	107.8
Threadfin Shad	7.8	136	8.1	22.4	17.7	0.8	4.9	94.8	57.1	4.5
Tilapia	1933.3	4872	3.2	40.4	28.3	0.2	0.4	1045.0	398.2	5.1

Table 3. Age (y) and mean length (cm) ± one standard deviation for Salton Sea fish sampled in 1999 and 2000 compared with Salton Sea fish sampled in the mid 1950s and species sampled elsewhere.

	N	Age	Mean total length ± SD	Mean total length from other studies
Gulf croaker	52	0+	13.0 ± 2.2	-
	36	1+	18.6 ± 2.0	13.1 [a]
	606	2+	21.2 ± 2.0	15.4 [a]
	184	3+	22.4 ± 2.3	17.2 [a]
	2	4+	28.5 ± 5.3	17.3 [a]
Orangemouth corvina	9	0+	28.4 ± 8.0	-
	62	1+	46.1 ± 11.6	11.0 [b]
	115	2+	65.9 ± 6.0	40.0 [b]
	10	3+	69.6 ± 4.9	50.2 [b]
	-	4+		
	-	5+		
	1	6+	83.0	-
Sargo	32	0+	15.6 ± 1.5	n/a
	2	1+	18.5 ± 0.4	n/a
	33	2+	27.5 ± 1.4	n/a
	-	4+		25.0 [c]
	-	12+		32.5 [c]
Tilapia	404	0+	8.0 ± 2.7	5.8 [d]
	-	1+		
	-	2+		
	2828	3+	29.2 ± 1.8	25.0 [d] 25.0 [e] 20.6 [f] 15.0 [g]
	1314	4+	30.6 ± 2.5	26.0 [d] 30.0 [e] 25.5 [f] 18.0 [g]
	292	5+	32.9 ± 2.9	28.5 [d] 32.5 [e] 23.4 [f]

[a] – from Whitney 1961. Salton Sea croaker.
[b] – from Whitney 1961. Salton Sea Orangemouth corvina.
[c] – from Love 1996. Sargo from the Pacific coast of southern California
[d] – from Khoo and Moreau 1990. Tilapia from Singapore reservoirs.
[e] - from Roux 1961. Tilapia South African impoundments (data taken from impoundment with fastest growing tilapia)
[f] – From Hecht 1980. Tilapia from South African impoundments
[g] – From Koura and Bolock 1958. Tilapia from Egyptian ponds.

Table 4. Female proportions by species and habitat for Salton Sea fish sampled between 1999 and 2000.

	1999			2000		
	Female	Male	Prop. Female	Female	Male	Prop. Female
Orangemouth Corvina						
Estuary	19	23	0.45	24	15	0.62
Nearshore	61	84	0.42	21	23	0.48
Pelagic	3	1	0.75	4	4	0.50
River						
Gulf Croaker						
Estuary	473	121	0.78	46	9	0.84
Nearshore	376	281	0.57	371	270	0.58
Pelagic	595	1296	0.31	243	603	0.29
River						
Tilapia						
Estuary	225	1389	0.14	70	64	0.52
Nearshore	233	1274	0.15	77	155	0.33
Pelagic	106	409	0.21	46	43	0.52
River	68	7	0.91			

	1999 and 2000		
	Female	Male	Prop. Female
Sargo			
Estuary			
Nearshore	5	8	0.38
Pelagic	29	46	0.39
River			

Figure 1. Station locations at the Salton Sea. Open circles are for stations deeper than 2 meters, closed circles are for stations 2 meters or less; φ = latitude, λ = longitude.

Whitewater River

North Shore

Salt Creek

N O φ: 33°29.8' N λ: 115°54.9'W

P O φ : 33°26' N λ: 115°56'W

N ● φ: 33°24'N λ: 116°03'W

Wister Drain

P O φ : 33°20' N λ: 115°50'W

N O φ : 33°14.6' N λ: 115°36.3'W

Mullet Island

● < 2 meters
O > 2 meters
N Nearshore
P Pelagic
E Estuarine
R Riverine

P O φ : 33°14' N λ: 115°45'W

E ● φ : 33°12.9' N λ: 115°37.4'W

R ● φ : 33°12.4' N λ: 115°37'W

N ● φ: 33°09'N λ: 115°48'W

φ : 33°08' N λ: 115°41.6'W

E ●

R ●

San Felipe Creek

φ : 33°07.8' N λ: 115°41.6'W

Alamo River

New River

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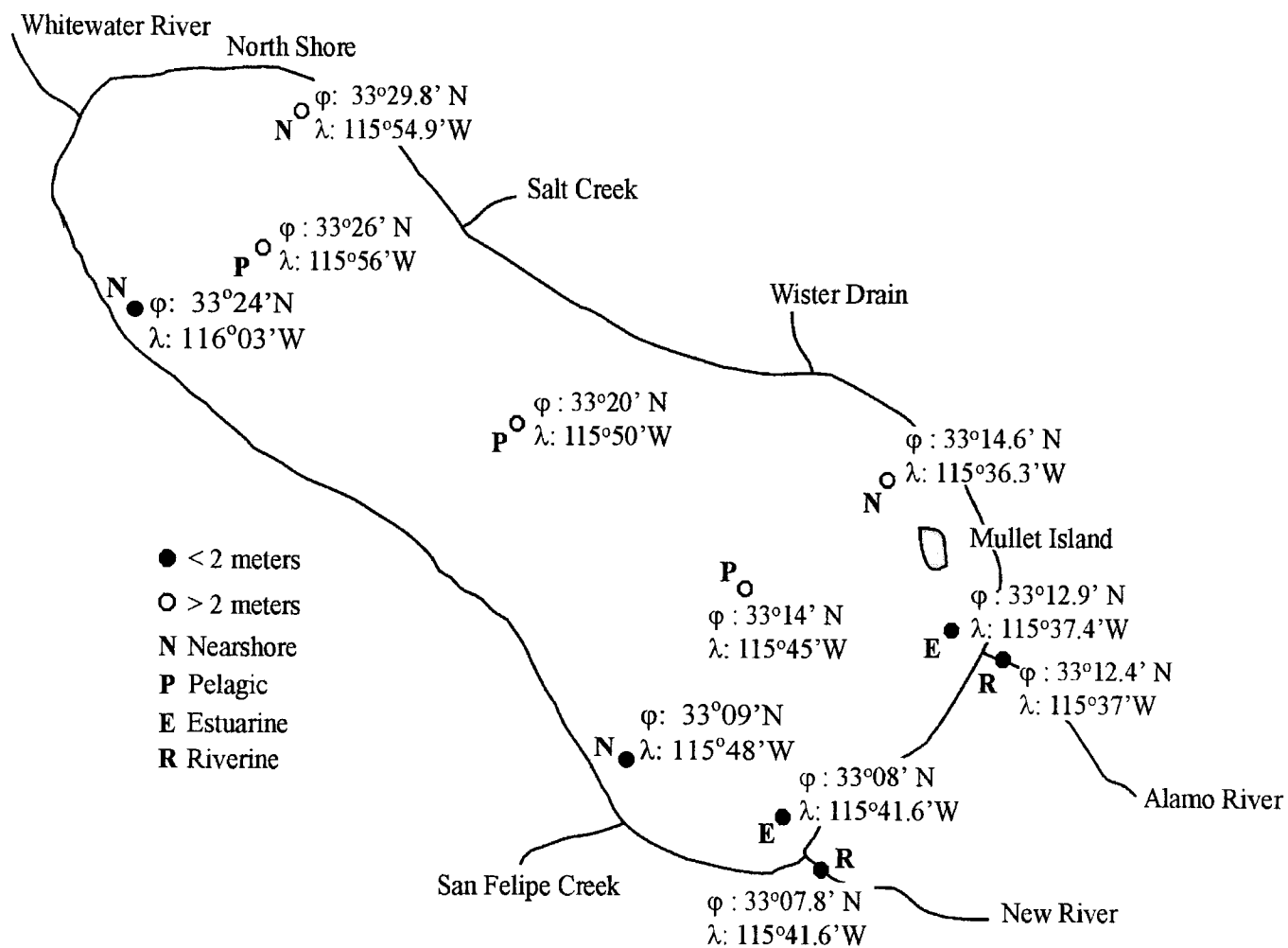
Figure 2. Catch-per-effort (kilograms/hour/net) of tilapia (*Oreochromis mossambicus*), croaker (*Bairdiella icistia*), orangemouth corvina (*Cynoscion xanthulus*), and sargo (*Anisotremus davidsoni*) by habitat type (excluding rivers), season, and year of the Salton Sea, California.
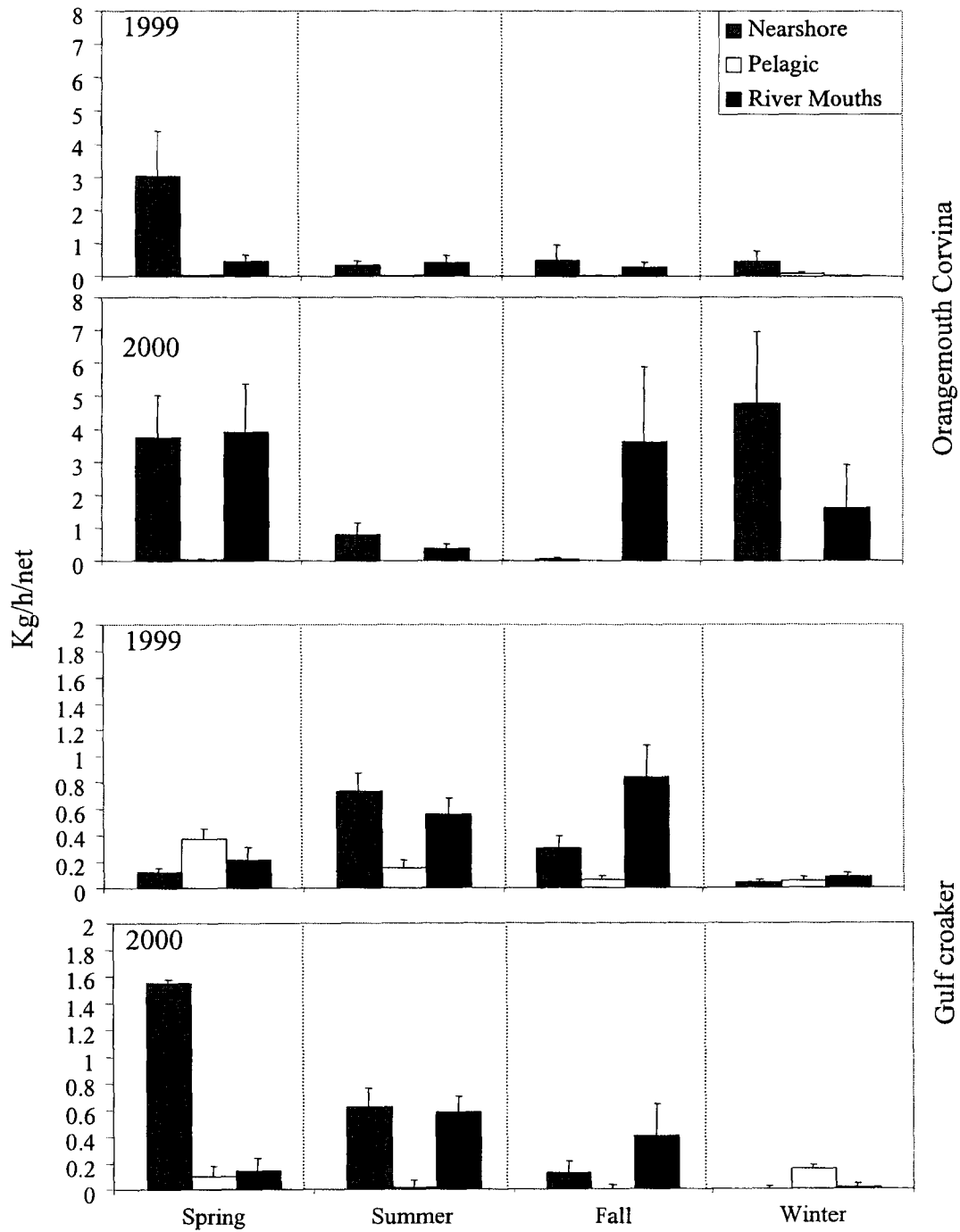
Figure 2. (Concluded).
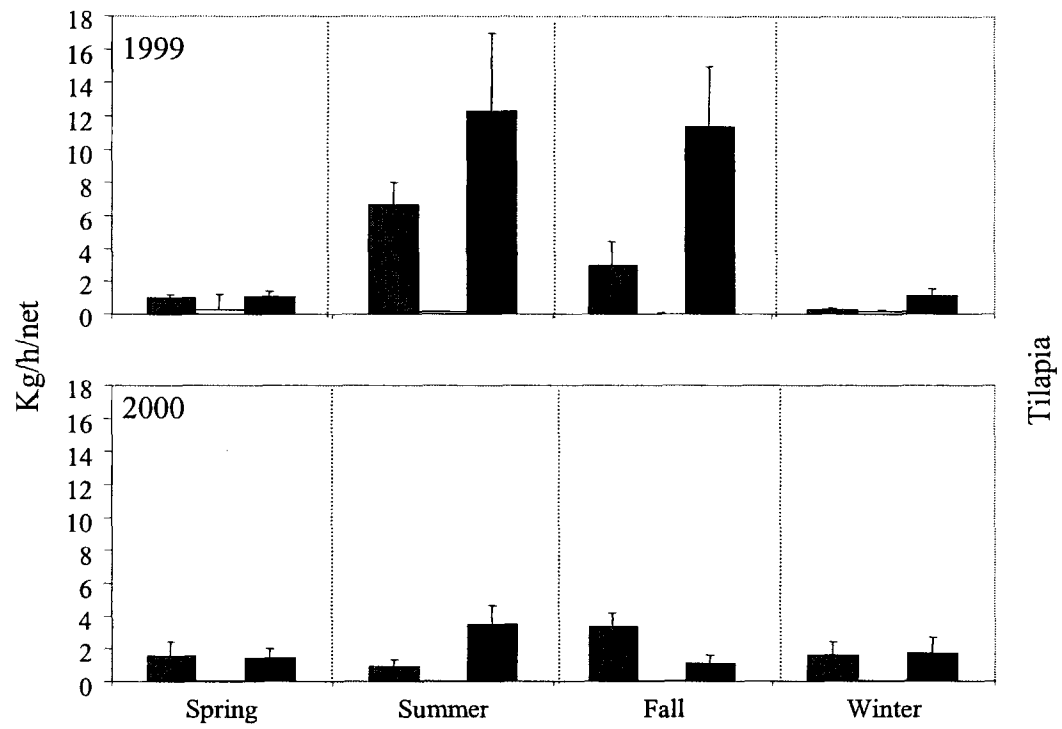
Figure 3. Tilapia size distribution, juvenile recruitment, and adult mortality for 1999 and 2000. Fish less than 15 cm are less than a year old. Fish larger than 20 cm are 3 and 4 years old (in 1999), and 4 and 5 years old (in 2000). The broken line represents juvenile fish recruiting to the population and the solid line represents adult mortality estimates from gill net catch rates. Numbers associated with lines are catches per unit of effort (CPUEs = number of tilapia caught per 50 m net per hour). Bars are standard errors of CPUEs averaged over seasons and Salton Sea habitats. Z is instantaneous mortality rate for the 1995 cohort.
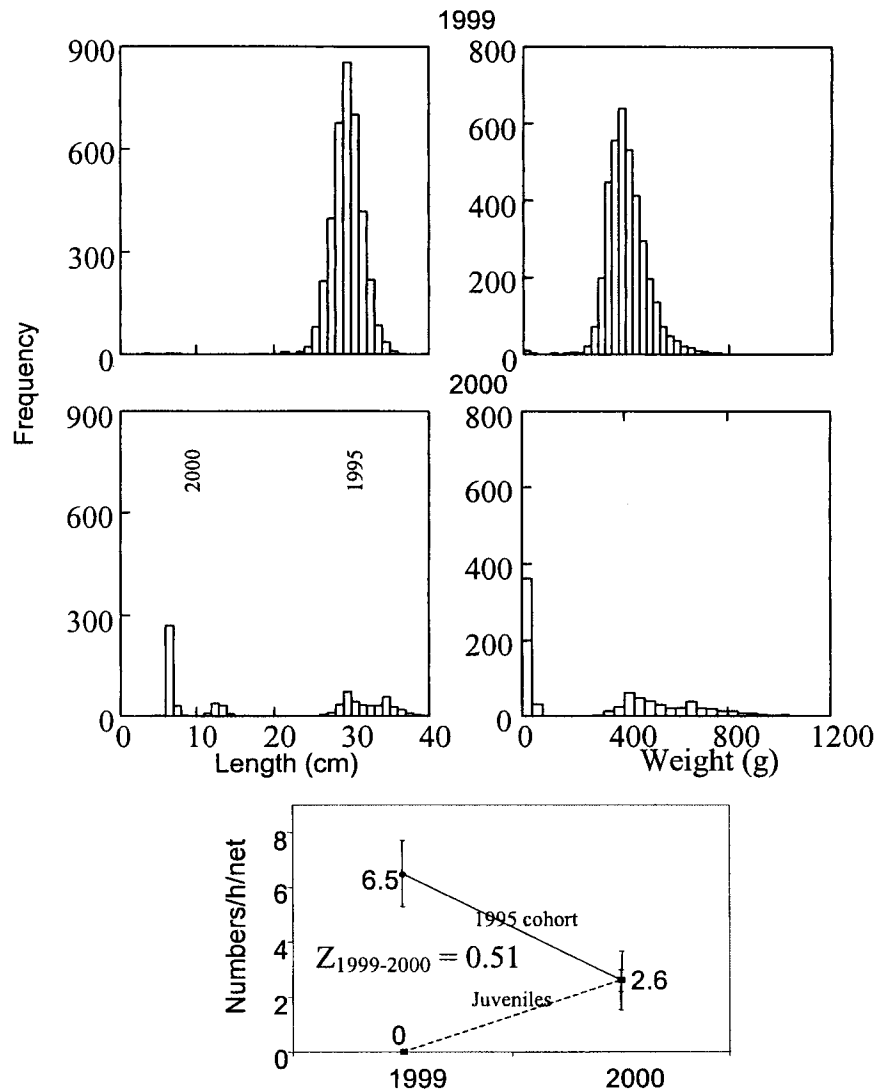
Figure 4. Gonadosomatic indices ((gonad weight/total body weight) x 100) by seasons and year for female tilapia (*Oreochromis mossambicus*) sampled in the Salton Sea, California during 1999 and 2000.
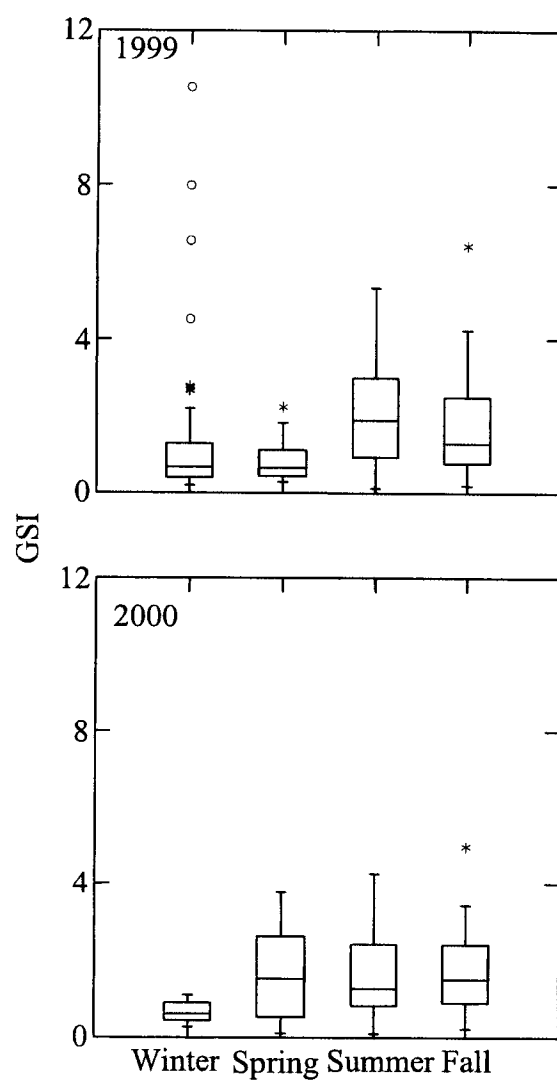
Figure 5. Von Bertalanffy growth function for the tilapia (*Oreochromis mossambicus*) sampled in the Salton Sea, California during 1999 and 2000.

Tilapia
1999 and 2000
$L_{max} = 32.8 \pm 0.28$
$K = 0.54 \pm 0.02$
$T_0 = -0.88 \pm 0.04$
$r^2 = 0.68$
$n = 1839$
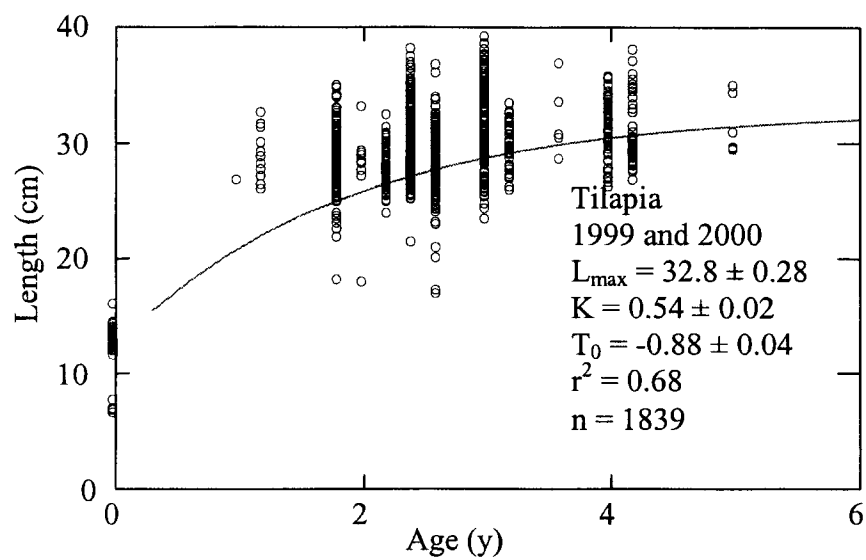
Figure 6. Vertical distribution of tilapia (*Oreochromis mossambicus*) catches during 1999 in the Salton Sea. Numbers are average kg/h for 50 m gill nets ± standard deviation; n = number of replicates.

■ Nearshore Bottom □ Nearshore Surface ▨ Pelagic Bottom ⊠ Pelagic Surface

Winter
0.6 ± 0.6 (n = 12)
0.4 ± 0.7 (n = 12)
3.3 ± 4.2 (n = 8)
1.9 ± 1.6 (n = 8)

Spring
1.4 ± 0.6 (n = 6)
0.1 ± 0.1 (n = 6)
2.0 ± 1.2 (n = 4)
3. 6 ± 1.4 (n = 4)

Summer
0.7 ± 0.9 (n = 12)
<0. 1 ± <0.1 (n = 12)
8.5 ± 5.7 (n = 8)
22.1 ± 14.2 (n = 8)

Fall
<0.1 ± 0.1 (n = 6)
0.5 ± 0.6 (n = 6)
2.1 ± 1.2 (n = 4)
10.4 ± 11.6 (n = 4)

Factor p-values:
Season: < 0.01
Habitat: < 0.01
Water Column Location: < 0.1

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Figure 7. Seasonal movement of Salton Sea fish based on mean catch rates ± SEM (kg/net/h) from multipanel gill net sets during 1999 and 2000. Tilapia catch rates increased in the nearshore and river mouth habitats during warm months and decrease during cool months.
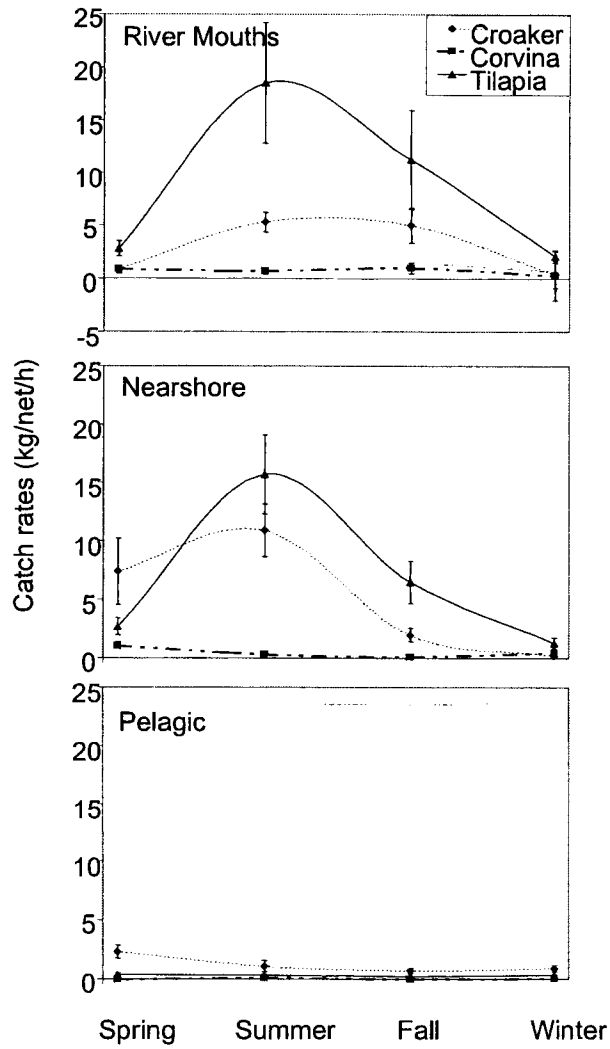
Figure 8. Length and weight distribution for the Gulf croaker (*Bairdiella icistia*) sampled at the Salton Sea between 1999 and 2000.
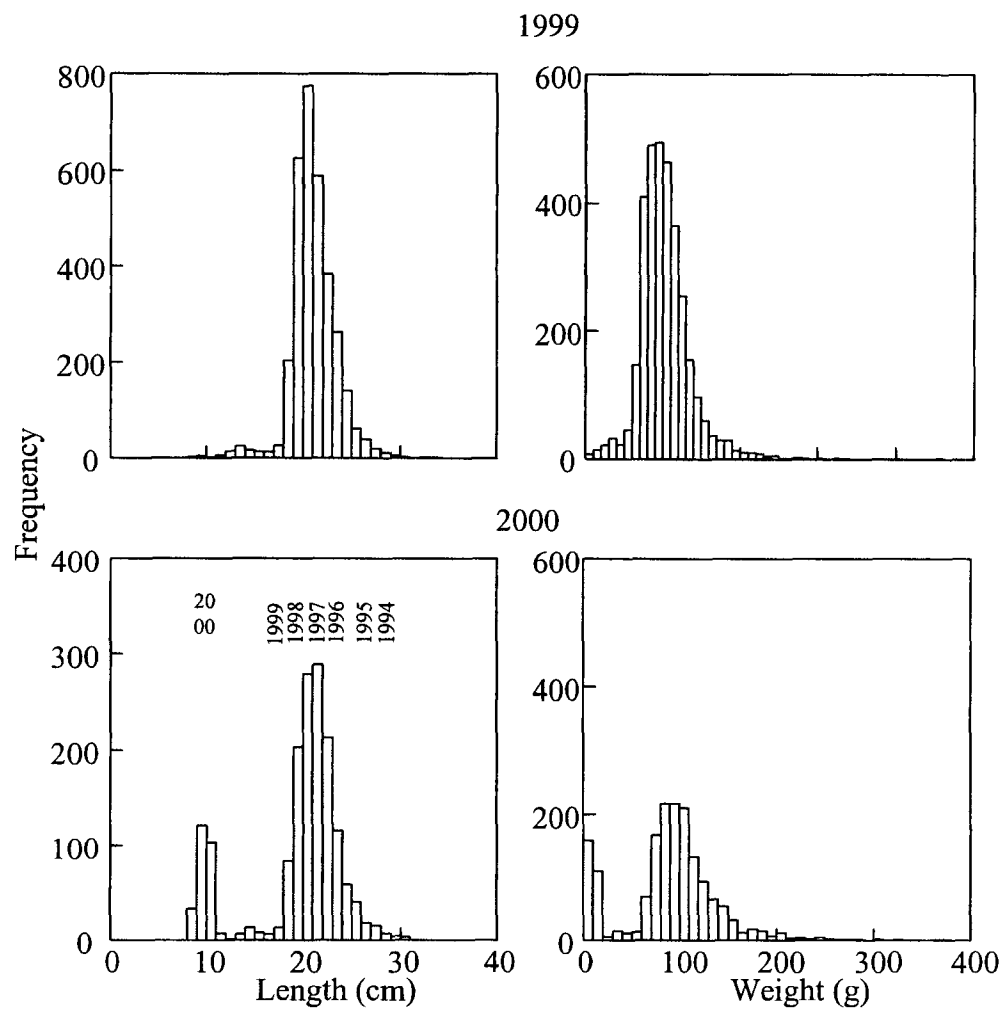
Figure 9. Gonadosomatic indices (percent of gonad weight from total weight of fish) for croaker (*Bairdiella icistia*) from the Salton Sea, California; bars indicate one standard deviation.
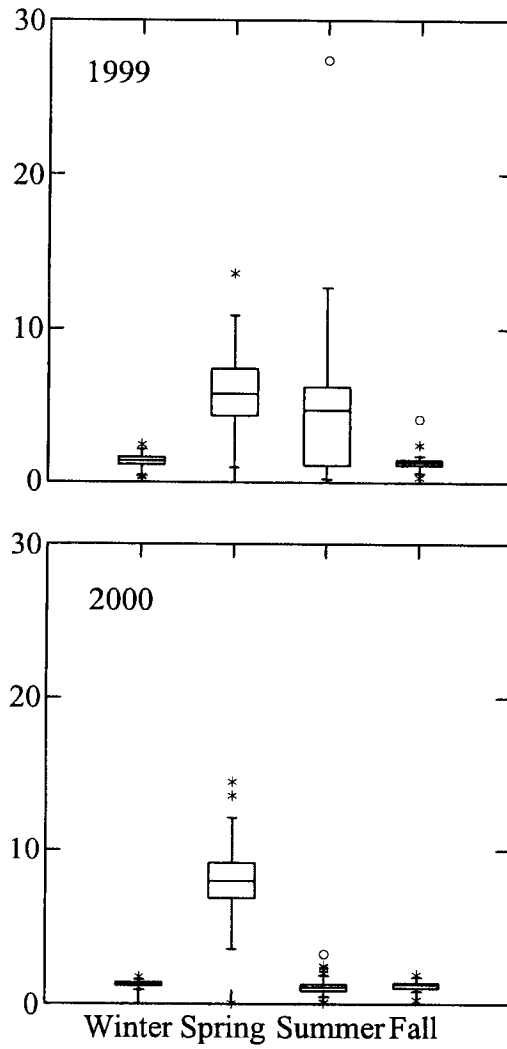
Figure 10. Von Bertalanffy growth function for the Gulf croaker (*Bairdiella icistia*) sampled in the Salton Sea, California during 1999 and 2000.

Gulf croaker
1999
$L_{max} = 23.7 \pm 0.45$
$K = 0.72 \pm 0.08$
$T_0 = -1.09 \pm 0.11$
$r^2 = 0.51$
$n = 878$

2000
$L_{max} = 23.1 \pm 0.18$
$K = 1.01 \pm 0.06$
$T_0 = -0.64 \pm 0.04$
$r^2 = 0.79$
$n = 455$

Length (cm)

Age (y)
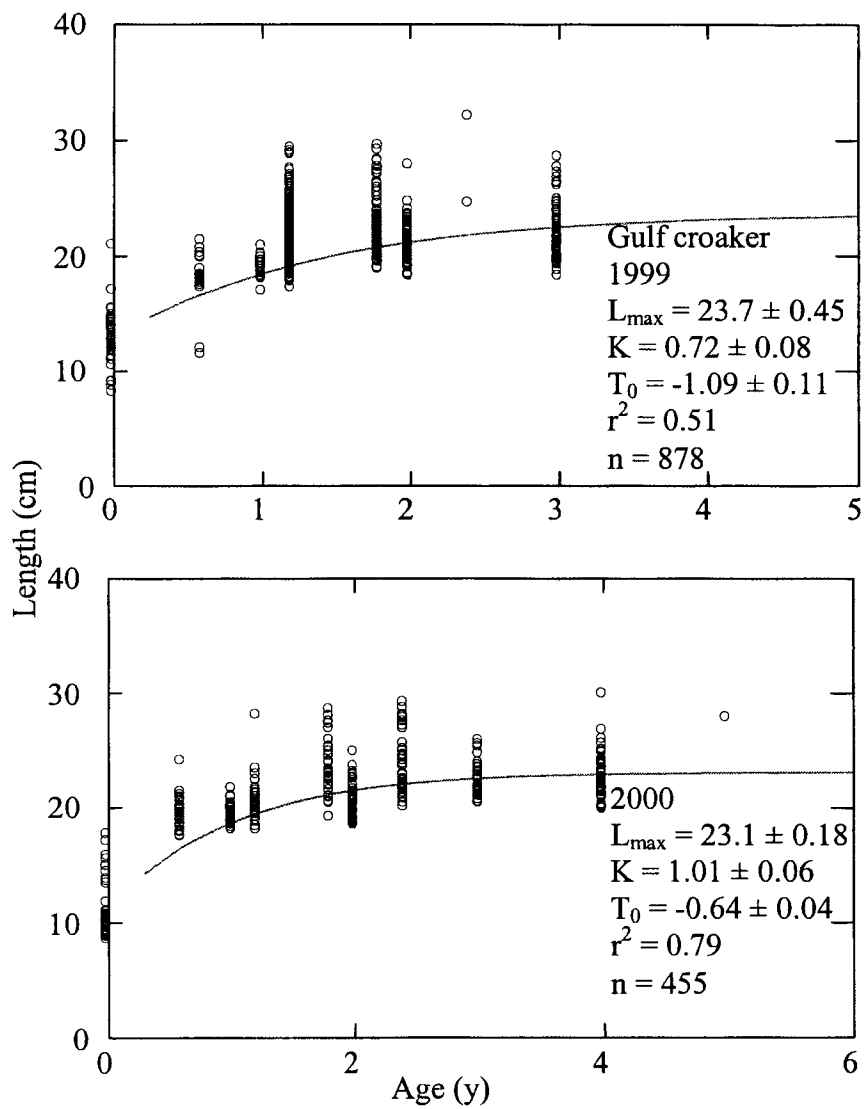
Figure 11. Vertical distribution of croaker (*Bairdiella icistia*) catches during 1999 in the Salton Sea. Numbers are average kg/h for 50 m gill nets ± standard deviation; n = number of replicates.

■ Nearshore   □ Nearshore   ■ Pelagic   ▨ Pelagic

Winter
0.3 ± 0.5 (n = 12)
1.5 ± 2.1 (n = 12)
<0.1 ± 0.1 (n = 8)
0.8 ± 0.7 (n = 8)

Spring
2.6 ± 2.9 (n = 6)
4.6 ± 2.4 (n = 6)
0.9 ± 0.7 (n = 4)
1.0 ± 0.6 (n = 4)

Summer
1.7 ± 2.3 (n = 12)
1.5 ± 3.9 (n = 12)
5.2 ± 4.5 (n = 8)
10.4 ± 5.6 (n = 8)

Fall
0 (n = 6)
1.6 ± 1.4 (n = 6)
1.1 ± 1.4 (n = 4)
4.33 ± 2.4 (n = 4)

Factor p-values:
Season: < 0.01
Habitat: < 0.01
Water Column Location: < 0.01

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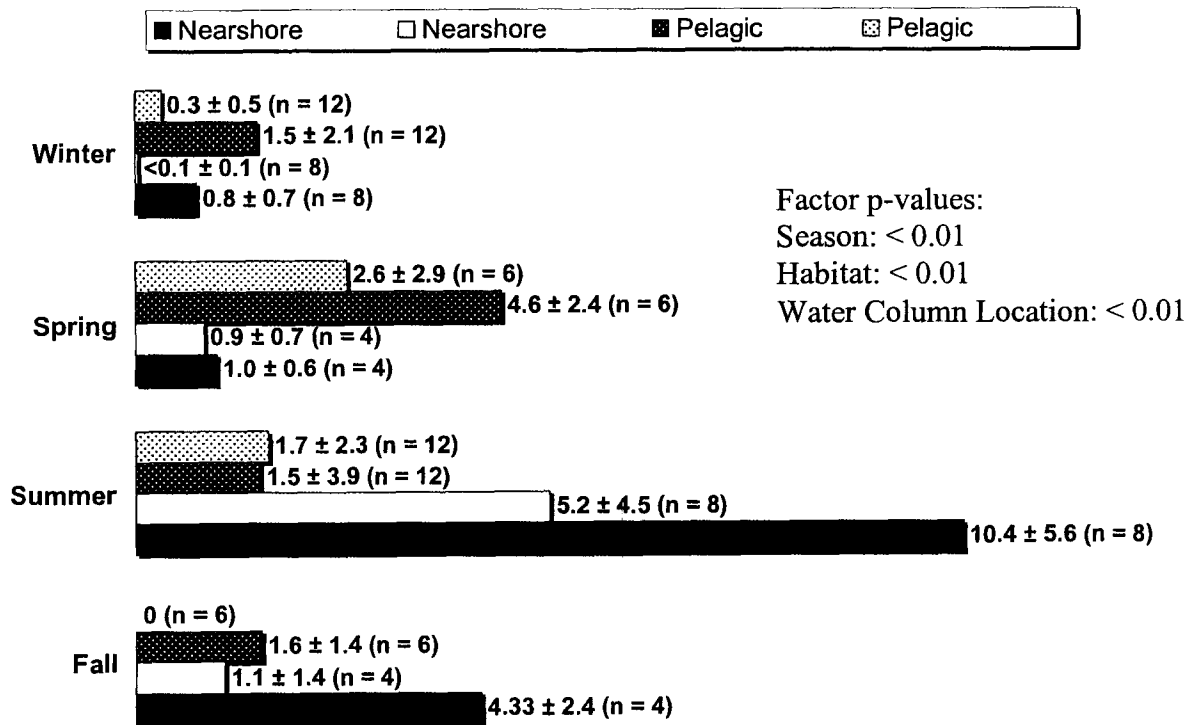
Figure 12. Length and weight distribution for the orangemouth corvina (*Cynoscion xanthulus*) sampled at the Salton Sea between 1999 and 2000.
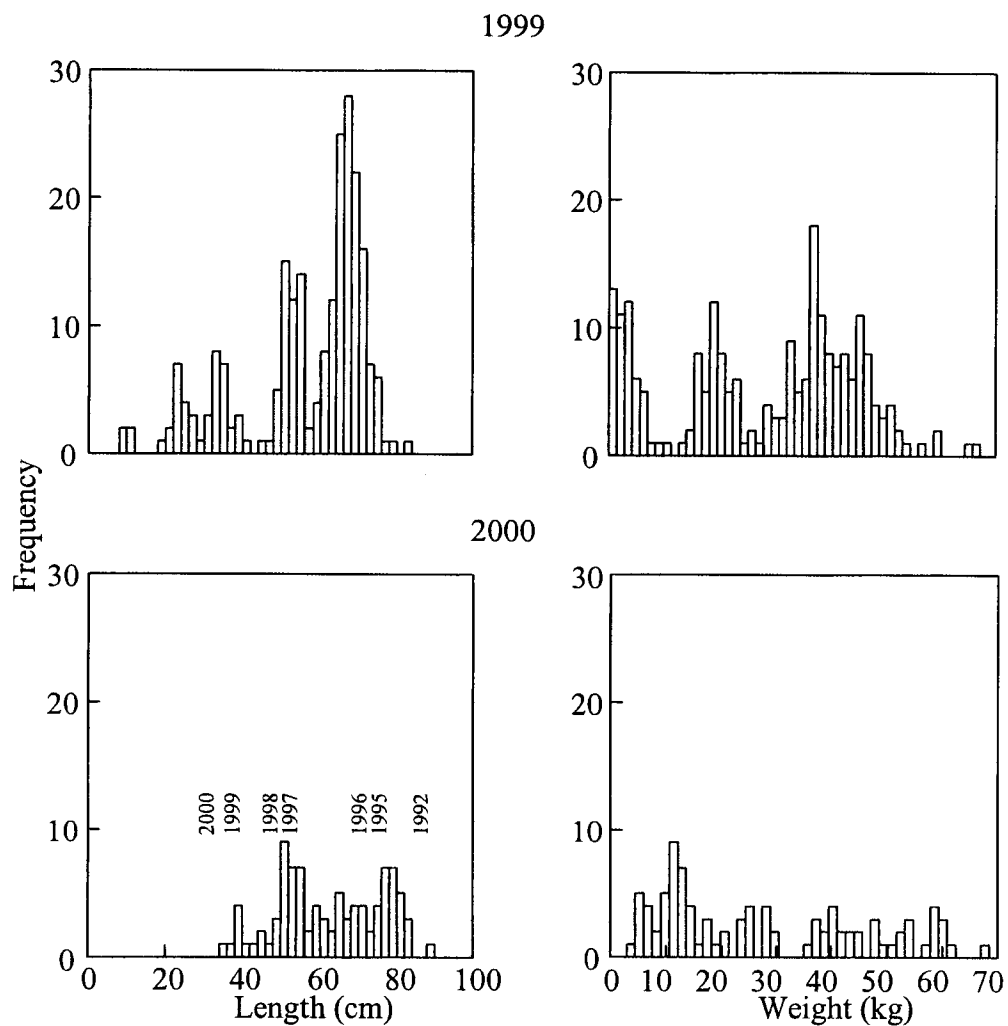
Figure 13. Gonadosomatic indices (percent of gonad weight from total weight of fish) for orangemouth corvina (*Cynoscion xanthulus*) from the Salton Sea, California; bars indicate one standard deviation.
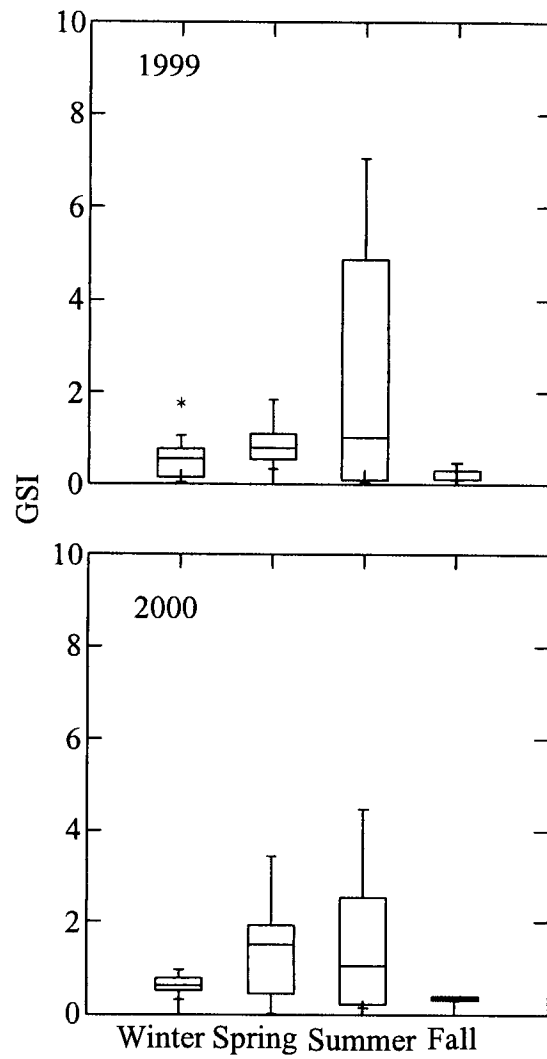
Figure 14. Von Bertalanffy growth function for orangemouth corvina (*Cynoscion xanthulus*) sampled in the Salton Sea, California during 1999 and 2000.

Orangemouth corvina
$L_{max} = 91.1 \pm 5.3$
$K = 0.42 \pm 0.07$
$T_0 = -0.85 \pm 0.15$
$r^2 = 0.66$
$n = 287$
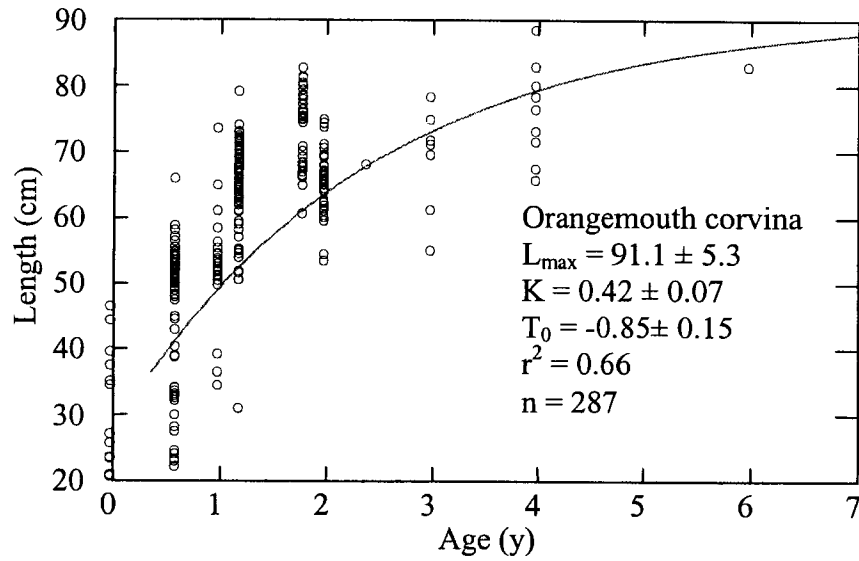
Figure 15. Vertical distribution of orangemouth corvina (*Cynoscion xanthulus*) catches during 1999 in the Salton Sea. Numbers are average kg/h for 50 m gill nets ± standard deviation; n = number of replicates.

Legend: ■ Nearshore   □ Nearshore   ▨ Pelagic   ▨ Pelagic

Winter
0 (n = 12)
0.2 ± 0.3 (n = 12)
0.1 ± 0.2 (n = 8)
0.5 ± 0.9 (n = 8)

Spring
<0.1 ± <0.1 (n = 6)
<0.1 ± <0.1 (n = 6)
0.3 ± 0.2 (n = 4)
2.0 ± 1.8 (n = 4)

Summer
0 (n = 12)
<0.1 ± <0.1 (n = 12)
0.2 ± 0.2 (n = 8)
0.2 ± 0.3 (n = 8)

Fall
0 (n = 6)
<0.1 ± 0.1 (n = 6)
0 (n = 4)
0.5 ± 0.5 (n = 4)

Factor p-values:
Season: < 0.05
Habitat: < 0.01
Water Column Location: < 0.05

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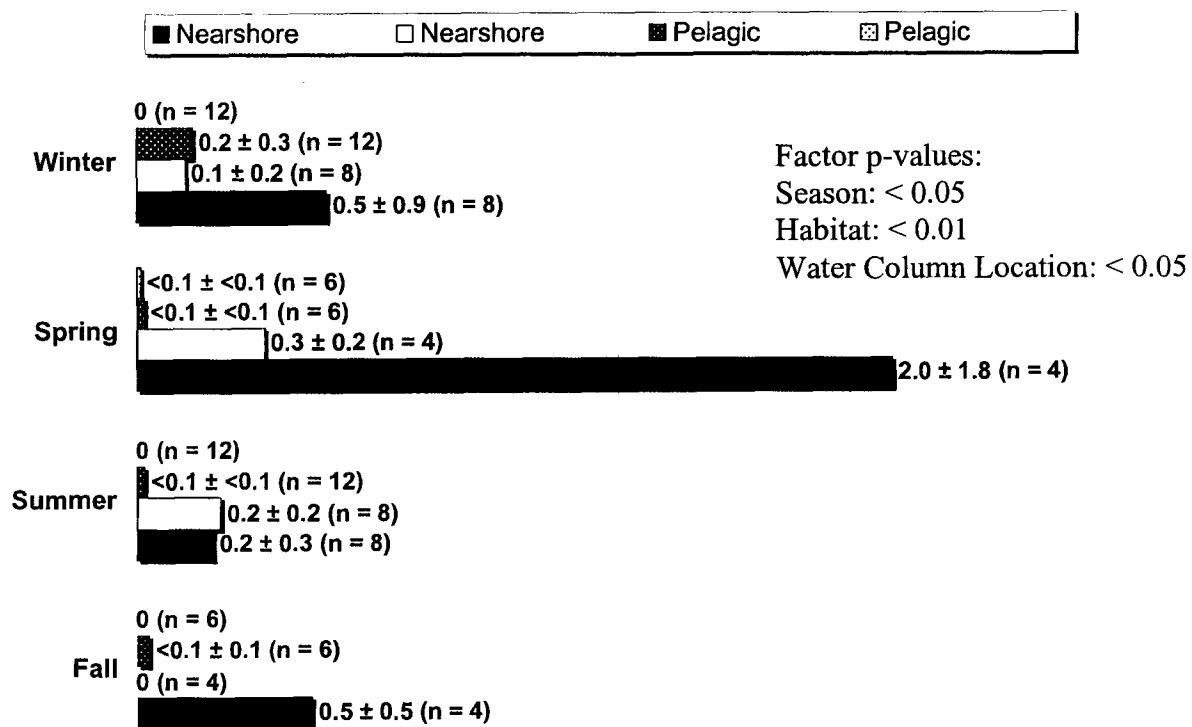
Figure 16. Length and weight distribution for the sargo (*Anisotremus davidsoni*) sampled at the Salton Sea between 1999 and 2000.
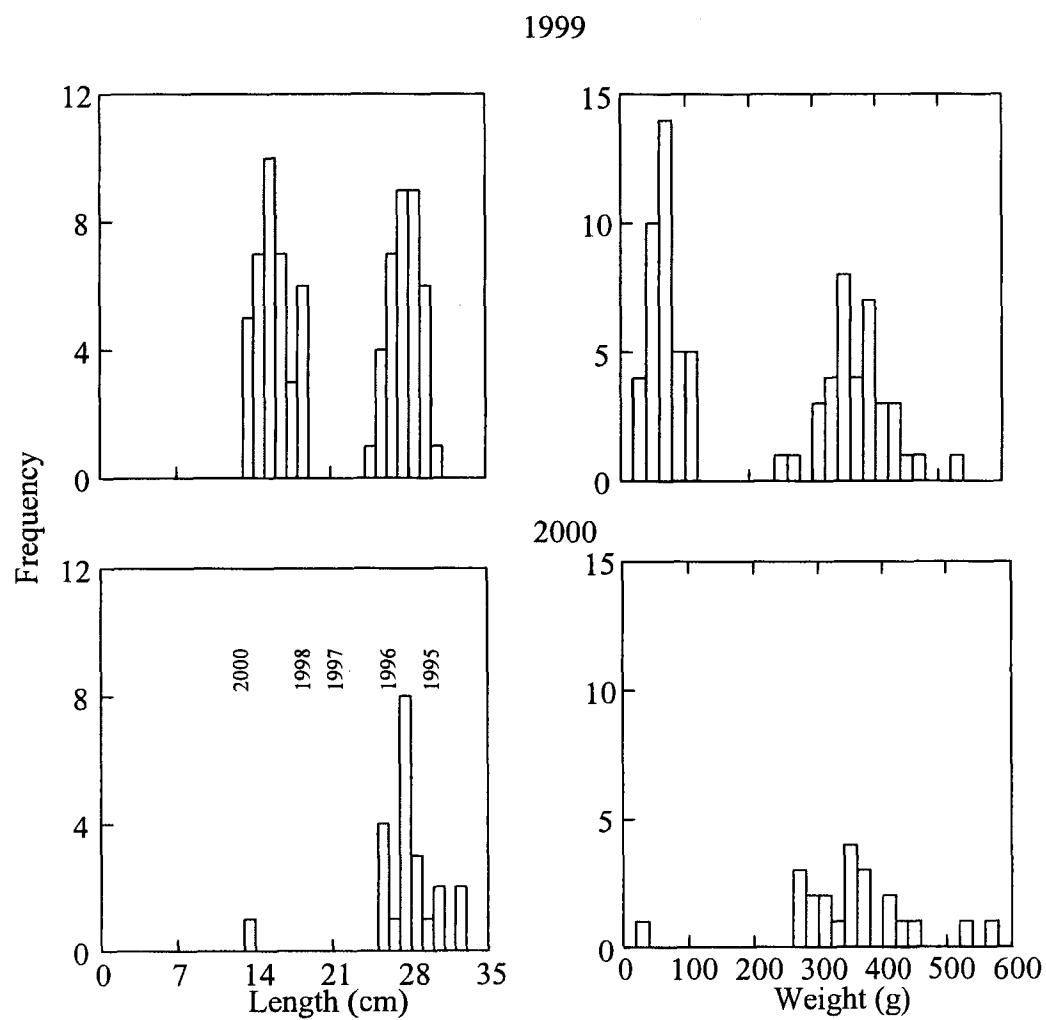
Figure 17. Von Bertalanffy growth function for sargo (*Anisotremus davidsoni*) sampled in the Salton Sea, California during 1999 and 2000.

Sargo
1999 and 2000
$L_{max} = 29.9 \pm 0.89$
$K = 0.95 \pm 0.17$
$T_0 = -0.77 \pm 0.11$
$r^2 = 0.92$
$n = 87$
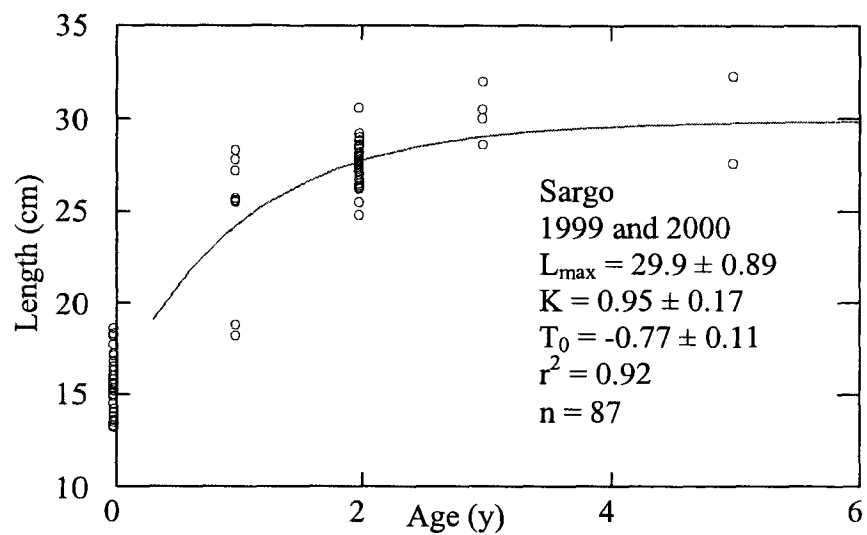
Figure 18. GSI for sargo (*Anisotremus davidsoni*) sampled in the Salton Sea, California during 1999.
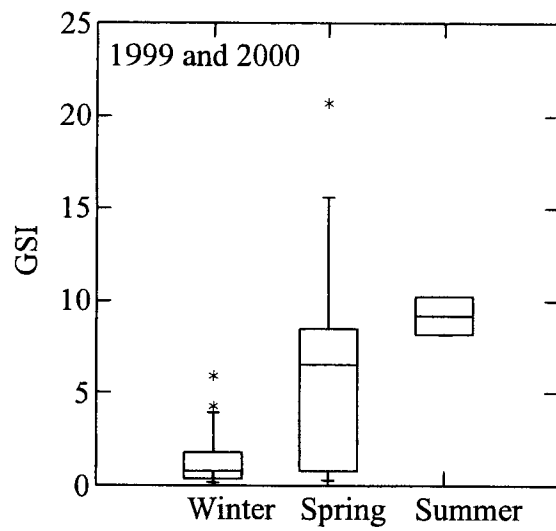
Figure 19. Vertical distribution of sargo (*Anisotremus davidsoni*) catches during 1999 in the Salton Sea. Numbers are average kg/h for 50 m gill nets ± standard deviation; n = number of replicates.
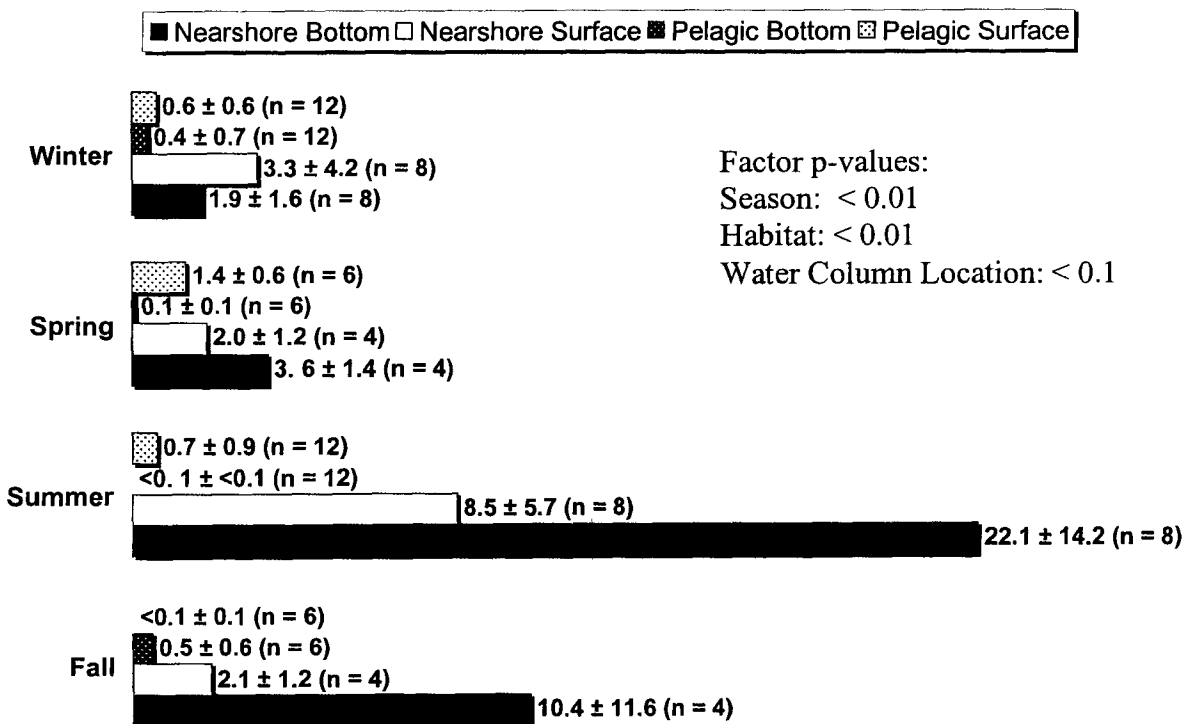

Fal
0 (n = 10)
0 (n = 10)

Factor p-values (after dropping
factor habitat):
Season: < 0.05
Habitat: > 0.1 (dropped)
Water Column Location: < 0.01

Summer
0 (n = 20)
<0.1 ± 0.1 (n = 20)

Spring
0 (n = 10)
0.1± 0.1 (n = 10)

Winter
<0.1± <0.1 (n = 20)
0.1± 0.2 (n = 20)
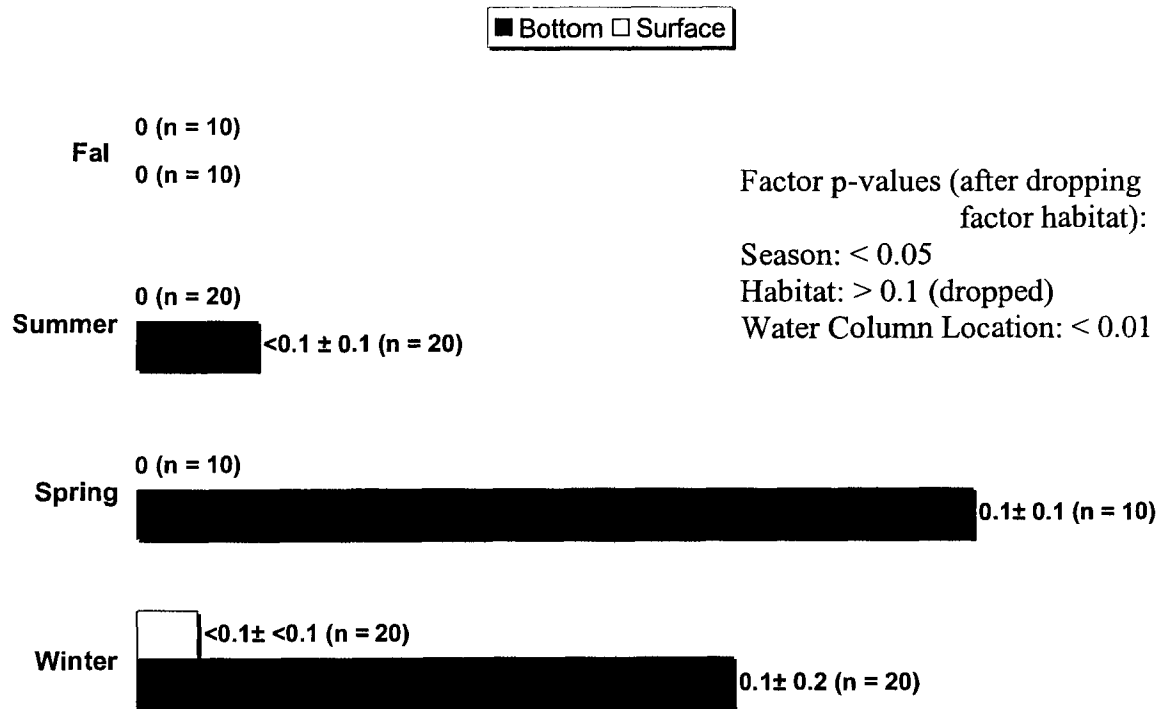
■ Bottom □ Surface

Figure 20. Dissolved oxygen (mg/l) by habitat and season for 1999 at the Salton Sea; solid lines = surface; dashed lines = bottom; nearshore data for spring is missing.
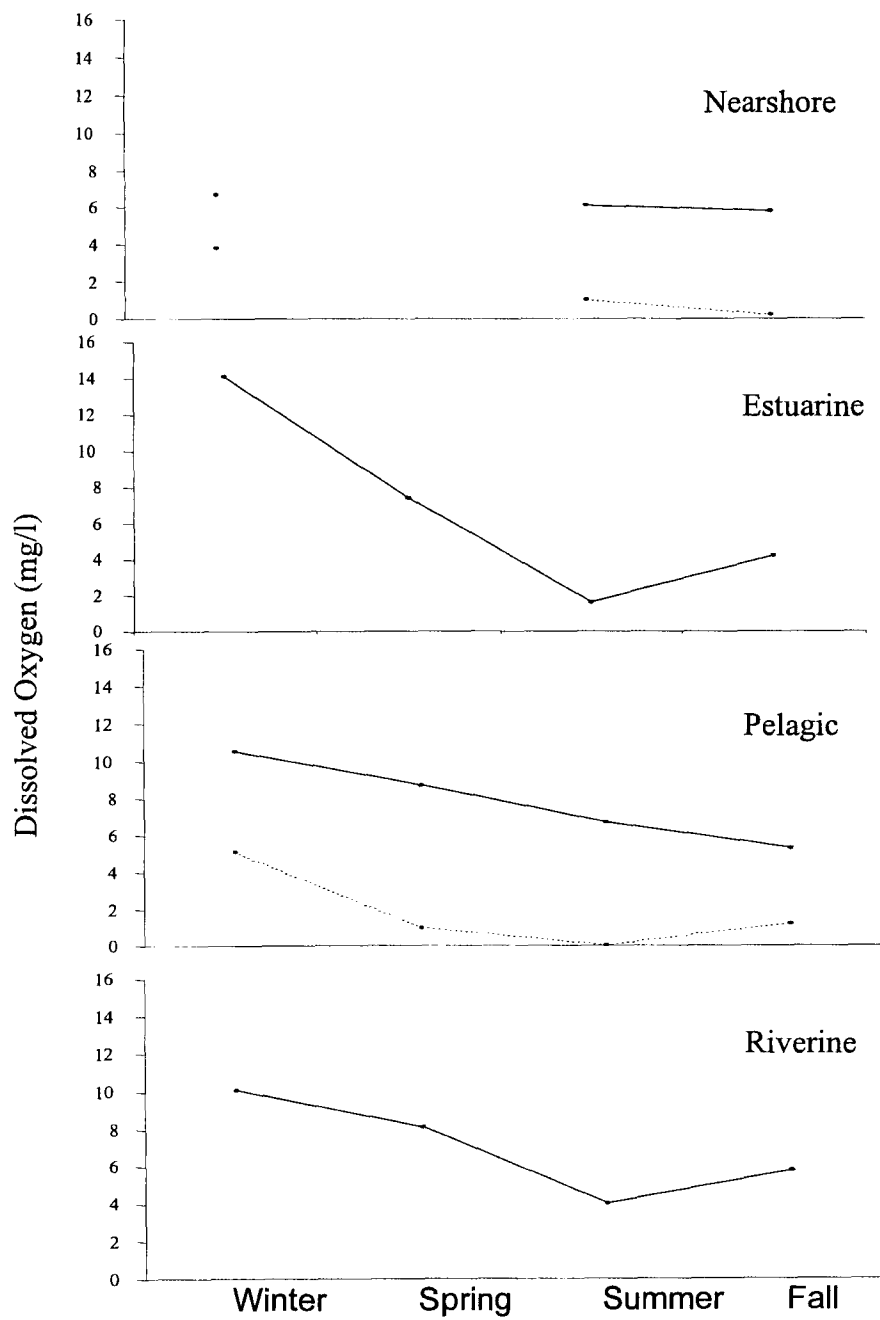
Appendix I

Section I. Results for catch per unit effort by species

Species:
COR = orangemouth corvina
BAI = Gulf croaker
SAR = sargo
TIL = tilapia

Season:
BSP = spring
CSU = summer
DFA = fall
AWI = winter

Habitat:
R = river mouths
N = nearshore
P = pelagic

Model: CPUE = SEASON + HABITAT + YEAR + SEASON(YEAR) + HABITAT(SEASON) + error

Orangemouth Corvina

```
Data for the following results were selected according to:
     (SPECIES$= "COR")

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:
YEAR$ (2 levels)
   00, 99
SEASON$ (4 levels)
   AWI, BSP, CSU, DFA
HABITAT$ (3 levels)
   E, N, P

The following effects have lost degrees of freedom.
```

| | Initial | Lost | Final |
Effect	df	df	df
SEASON$	3	1	2
SEASON$(YEAR$)	6	2	4
HABITAT$(SEASON$)	8	2	6

```
Dep Var: NUMPERHR   N: 248   Multiple R: 0.4816   Squared multiple R: 0.2319
```

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Model	32.5166	15	2.1678	4.6705	0.0000
Error	107.6814	232	0.4641		

49

Test for effect called: YEAR$

Test of Hypothesis

        Source   SS   df   MS   F   P

   Hypothesis   1.6315   1   1.6315   3.5151   0.0621
   Error   107.6814   232   0.4641

Test for effect called: SEASON$

Test of Hypothesis

        Source   SS   df   MS   F   P

   Hypothesis   1.9609   2   0.9804   2.1124   0.1233
   Error   107.6814   232   0.4641

Test for effect called: HABITAT$

Test of Hypothesis

        Source   SS   df   MS   F   P

   Hypothesis   4.2635   2   2.1317   4.5928   0.0111
   Error   107.6814   232   0.4641

Gulf Croaker

Data for the following results were selected according to:
      (SPECIES$= "BAI")

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:
YEAR$ (2 levels)
   00, 99
SEASON$ (4 levels)
   AWI, BSP, CSU, DFA
HABITAT$ (3 levels)
   E, N, P

The following effects have lost degrees of freedom.

                            Initial Lost Final
Effect   df   df   df
SEASON$(YEAR$)   6   3   3
HABITAT$(SEASON$)   8   2   6

Dep Var: NUMPERHR   N: 248   Multiple R: 0.5847   Squared multiple R: 0.3418

                    Analysis of Variance

Source   Sum-of-Squares   df Mean-Square   F-ratio   P
Model   2889.7057   15   192.6470   8.0329   0.0000
Error   5563.8791   232   23.9822

50

```
Test for effect called:     YEAR$

Test of Hypothesis

        Source       SS        df       MS            F              P

  Hypothesis      49.0730      1     49.0730        2.0462         0.1539
  Error         5563.8791    232     23.9822

  -------------------------------------------------------------------------
  ------------------------------------------

Test for effect called:     SEASON$

Test of Hypothesis

        Source       SS        df       MS            F              P

  Hypothesis     543.6711      3    181.2237        7.5566         0.0001
  Error         5563.8791    232     23.9822

  -------------------------------------------------------------------------
  ------------------------------------------

Test for effect called:     HABITAT$

Test of Hypothesis

        Source       SS        df       MS            F              P

  Hypothesis      13.0379      2      6.5189        0.2718         0.7622
  Error         5563.8791    232     23.9822
```

Sargo

```
Data for the following results were selected according to:
      (SPECIES$= "SAR")

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:
YEAR$ (2 levels)
   00, 99
SEASON$ (4 levels)
   AWI, BSP, CSU, DFA
HABITAT$ (3 levels)
   E, N, P

The following effects have lost degrees of freedom.

                          Initial  Lost  Final
Effect                         df    df     df
HABITAT$                        2     1      1
SEASON$(YEAR$)                  6     3      3
HABITAT$(SEASON$)               8     1      7


Dep Var: NUMPERHR   N: 248   Multiple R: 0.2742   Squared multiple R: 0.0752


                    Analysis of Variance


Source        Sum-of-Squares   df  Mean-Square   F-ratio      P
Model                 0.3800   15       0.0253    1.2577    0.2305
Error                 4.6735  232       0.0201
```

51

Tilapia

```
Data for the following results were selected according to:
     (SPECIES$= "TIL")

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:
YEAR$ (2 levels)
   00, 99
SEASON$ (4 levels)
   AWI, BSP, CSU, DFA
HABITAT$ (3 levels)
   E, N, P


The following effects have lost degrees of freedom.

                        Initial  Lost  Final
Effect                      df    df     df
HABITAT$                     2     1      1
SEASON$(YEAR$)               6     3      3
HABITAT$(SEASON$)            8     1      7
```

Dep Var: NUMPERHR   N: 248   Multiple R: 0.6178   Squared multiple R: 0.3817

Analysis of Variance

```
Source         Sum-of-Squares   df  Mean-Square    F-ratio      P
Model               9207.7070   15     613.8471     9.5466   0.0000
Error              14917.5763  232      64.2999
 Test for effect called:     YEAR$
```

Test of Hypothesis

```
        Source          SS        df        MS            F              P

  Hypothesis      232.6368        1     232.6368       3.6180         0.0584
  Error         14917.5763      232      64.2999
```

Test for effect called: SEASON$

Test of Hypothesis

```
        Source          SS        df        MS            F              P

  Hypothesis     2074.5597        3     691.5199      10.7546         0.0000
  Error         14917.5763      232      64.2999
```

Test for effect called: HABITAT$

Test of Hypothesis

```
        Source          SS        df        MS            F              P

Hypothesis      1316.4229        1    1316.4229      20.4732         0.0000
Error          14917.5763      232      64.2999
```

Section II. Results for gonadosomatic index (GSI) by species

Model: GSI = SEASON + YEAR + error

Corvina

```
Data for the following results were selected according to:
     (GSI> 0) AND (SEX$= "F")

Effects coding used for categorical variables in model.
```

Categorical values encountered during processing are:
SEASON$ (4 levels)
    FALL, SPRING, SUMMER, WINTER
YEAR$ (2 levels)
    00, 99

Dep Var: GSI   N: 118   Multiple R: 0.3047   Squared multiple R: 0.0928

                        Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
SEASON$	94.8236	3	31.6079	1.1569	0.3296
YEAR$	5.0655	1	5.0655	0.1854	0.6676
SEASON$*YEAR$	51.0083	3	17.0028	0.6223	0.6020
Error	3005.2276	110	27.3203		

Croaker

```
Data for the following results were selected according to:
     (GSI> 0) AND (SEX$= "F")

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:
YEAR$ (2 levels)
   00, 99
SEASON$ (4 levels)
   FALL, SPRING, SUMMER, WINTER

Dep Var: GSI   N: 539   Multiple R: 0.7690   Squared multiple R: 0.5914

                    Analysis of Variance
```

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
YEAR$	13.2912	1	13.2912	2.9014	0.0891
SEASON$	2708.5514	3	902.8505	197.0873	0.0000
YEAR$*SEASON$	496.8210	3	165.6070	36.1511	0.0000
Error	2432.4932	531	4.5810		

Sargo

```
Data for the following results were selected according to:
     (GSI> 0) AND (SEX$= "F")

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:
SEASON$ (3 levels)
   SPRING, SUMMER, WINTER

Dep Var: GSI   N: 32   Multiple R: 0.5545   Squared multiple R: 0.3075


                    Analysis of Variance
```

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
SEASON$	241.5877	2	120.7938	6.4386	0.0049
Error	544.0634	29	18.7608		

Tilapia

```
Data for the following results were selected according to:
     (GSI> 0) AND (SEX$= "F")

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:
SEASON$ (4 levels)
   FALL, SPRING, SUMMER, WINTER
YEAR$ (2 levels)
   00, 99

Dep Var: GSI   N: 328   Multiple R: 0.2647   Squared multiple R: 0.0701

                    Analysis of Variance
```

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
SEASON$	29.3799	3	9.7933	5.4408	0.0012
YEAR$	0.0788	1	0.0788	0.0438	0.8344
SEASON$*YEAR$	15.4069	3	5.1356	2.8532	0.0374
Error	575.9930	320	1.8000		

Section III. Results for the von Bertalanffy growth function fit by species and year

Model: Length = K * {1 – EXP[-K * (Age – T)]} + error

Parameters:
L = asymptotic length (cm)
K = growth constant
T = age of fish at zero length

Year:
99 = 1999
00 = 2000

Corvina

```
The following results are for:
   YEAR$         = 99

   Iteration
No.      Loss         L            K            T
   0 .167833D+05 .110668D+03 .210446D+00-.197132D+01
   1 .163068D+05 .101089D+03 .263693D+00-.153502D+01
   2 .159028D+05 .972042D+02 .302725D+00-.128768D+01
   3 .157318D+05 .918943D+02 .387650D+00-.821382D+00
   4 .140584D+05 .948196D+02 .423979D+00-.673715D+00
   5 .140494D+05 .960971D+02 .409750D+00-.707288D+00
   6 .140490D+05 .956972D+02 .414183D+00-.701521D+00
   7 .140490D+05 .958343D+02 .412808D+00-.703531D+00
   8 .140490D+05 .957931D+02 .413238D+00-.702914D+00
   9 .140490D+05 .958061D+02 .413104D+00-.703108D+00
  10 .140490D+05 .958020D+02 .413146D+00-.703048D+00
  11 .140490D+05 .958033D+02 .413133D+00-.703066D+00

Dependent variable is LENGTH
```

Source	Sum-of-Squares	df	Mean-Square
Regression	692450.1773	3	230816.7258
Residual	14049.0327	194	72.4177
Total	706499.2100	197	
Mean corrected	38758.8928	196	

```
      Raw  R-square (1-Residual/Total)       =      0.9801
Mean corrected R-square (1-Residual/Corrected) =    0.6375
         R(observed vs predicted) square     =      0.6375
```

				Wald Confidence Interval	
Parameter	Estimate	A.S.E.	Param/ASE	Lower < 95%>	Upper
L	95.8033	9.6757	9.9014	76.7202	114.8864
K	0.4131	0.0974	4.2412	0.2210	0.6053
T	-0.7031	0.1623	-4.3323	-1.0231	-0.3830

```
The following results are for:
   YEAR$          = 00

 Iteration
 No.    Loss        L           K           T
   0 .583186D+04 .100000D+03 .400000D+00-.700000D+00
   1 .430161D+04 .101419D+03 .313951D+00-.107941D+01
   2 .402612D+04 .104847D+03 .259580D+00-.142392D+01
   3 .399398D+04 .110971D+03 .202994D+00-.192546D+01
   4 .373703D+04 .110094D+03 .212523D+00-.196101D+01
   5 .373677D+04 .110794D+03 .209849D+00-.197469D+01
   6 .373677D+04 .110630D+03 .210615D+00-.197035D+01
   7 .373677D+04 .110679D+03 .210396D+00-.197161D+01
   8 .373677D+04 .110666D+03 .210459D+00-.197125D+01
   9 .373677D+04 .110670D+03 .210441D+00-.197135D+01
  10 .373677D+04 .110668D+03 .210446D+00-.197132D+01
```

Dependent variable is LENGTH

```
     Source    Sum-of-Squares   df  Mean-Square
 Regression      368822.4034     3  122940.8011
   Residual        3736.7666    87      42.9513


      Total      372559.1700    90
Mean corrected   15008.8890    89
```

```
     Raw   R-square (1-Residual/Total)       =      0.9900
Mean corrected R-square (1-Residual/Corrected) =      0.7510
        R(observed vs predicted) square      =      0.7510
```

```
                                                  Wald Confidence Interval
Parameter       Estimate     A.S.E.    Param/ASE    Lower < 95%> Upper
L               110.6684    27.4264      4.0351     56.1556     165.1813
K                 0.2104     0.1223      1.7206     -0.0327       0.4536
T                -1.9713     0.7235     -2.7248     -3.4093      -0.5333
```

The following results are for:
   YEAR$ = 99 and 00

```
 Iteration
 No.    Loss        L           K           T
   0 .202892D+05 .100000D+03 .400000D+00-.700000D+00
   1 .186667D+05 .906501D+02 .424039D+00-.836921D+00
   2 .185967D+05 .911486D+02 .423228D+00-.854019D+00
   3 .185967D+05 .911364D+02 .423394D+00-.853689D+00
   4 .185967D+05 .911389D+02 .423360D+00-.853757D+00
   5 .185967D+05 .911384D+02 .423367D+00-.853743D+00
```

Dependent variable is LENGTH

```
     Source    Sum-of-Squares   df  Mean-Square
 Regression      1.06046E+06     3  353487.2419
   Residual      18596.6544    284      65.4812


      Total      1.07906E+06   287
Mean corrected   55197.1814   286
```

```
     Raw   R-square (1-Residual/Total)       =      0.9828
Mean corrected R-square (1-Residual/Corrected) =      0.6631
        R(observed vs predicted) square      =      0.6631
```

```
                                                  Wald Confidence Interval
Parameter       Estimate     A.S.E.    Param/ASE    Lower < 95%> Upper
L                91.1384     5.3446     17.0524     80.6183     101.6585
K                 0.4234     0.0702      6.0350      0.2853       0.5615
T                -0.8537     0.1532     -5.5729     -1.1553      -0.5522
```

Gulf Croaker

The following results are for:
    YEAR$ = 99

```
Iteration
No.      Loss        L           K           T
  0  .404794D+04 .230000D+02 .800000D+00-.900000D+00
  1  .379957D+04 .236772D+02 .728251D+00-.107228D+01
  2  .379720D+04 .237174D+02 .723553D+00-.109435D+01
  3  .379720D+04 .237184D+02 .723349D+00-.109481D+01
  4  .379720D+04 .237185D+02 .723342D+00-.109482D+01
```

Dependent variable is LENGTH

Source	Sum-of-Squares	df	Mean-Square
Regression	386720.0573	3	128906.6858
Residual	3797.2027	875	4.3397
Total	390517.2600	878	
Mean corrected	7733.4072	877	

Raw R-square (1-Residual/Total)	=	0.9903
Mean corrected R-square (1-Residual/Corrected)	=	0.5090
R(observed vs predicted) square	=	0.5090

				Wald Confidence Interval	
Parameter	Estimate	A.S.E.	Param/ASE	Lower < 95%>	Upper
L	23.7185	0.4539	52.2550	22.8276	24.6093
K	0.7233	0.0778	9.2934	0.5706	0.8761
T	-1.0948	0.1075	-10.1890	-1.3057	-0.8839

The following results are for:
    YEAR$ = 00

```
Iteration
No.      Loss        L           K           T
  0  .189238D+04 .237185D+02 .723342D+00-.109482D+01
  1  .172462D+04 .233704D+02 .848896D+00-.814603D+00
  2  .169576D+04 .231408D+02 .982526D+00-.645307D+00
  3  .168782D+04 .231338D+02 .100802D+01-.648556D+00
  4  .168778D+04 .231248D+02 .101340D+01-.645027D+00
  5  .168778D+04 .231227D+02 .101439D+01-.644389D+00
  6  .168778D+04 .231223D+02 .101457D+01-.644270D+00
  7  .168778D+04 .231223D+02 .101460D+01-.644249D+00
```

Dependent variable is LENGTH

Source	Sum-of-Squares	df	Mean-Square
Regression	197745.6484	3	65915.2161
Residual	1687.7816	455	3.7094
Total	199433.4300	458	
Mean corrected	8035.7198	457	

Raw R-square (1-Residual/Total)	=	0.9915
Mean corrected R-square (1-Residual/Corrected)	=	0.7900
R(observed vs predicted) square	=	0.7900

				Wald Confidence Interval	
Parameter	Estimate	A.S.E.	Param/ASE	Lower < 95%>	Upper
L	23.1223	0.1770	130.6540	22.7745	23.4701
K	1.0146	0.0628	16.1483	0.8911	1.1381
T	-0.6442	0.0467	-13.7912	-0.7361	-0.5524

Sargo

```
The following results are for:
   YEAR$           = 99 and 00

 Iteration
 No.     Loss      L          K          T
   0 .275795D+03 .300000D+02 .950000D+00-.770000D+00
   1 .275116D+03 .298643D+02 .952288D+00-.770741D+00
   2 .275116D+03 .298627D+02 .952645D+00-.770521D+00
   3 .275116D+03 .298624D+02 .952698D+00-.770487D+00
```

Dependent variable is LENGTH

Source	Sum-of-Squares	df	Mean-Square
Regression	48419.7037	3	16139.9012
Residual	275.1163	84	3.2752
Total	48694.8200	87	
Mean corrected	3240.4526	86	

```
      Raw  R-square (1-Residual/Total)        =     0.9944
Mean corrected R-square (1-Residual/Corrected) =    0.9151
         R(observed vs predicted) square       =     0.9151
```

				Wald Confidence Interval	
Parameter	Estimate	A.S.E.	Param/ASE	Lower < 95%> Upper	
L	29.8624	0.8929	33.4430	28.0867	31.6381
K	0.9527	0.1727	5.5158	0.6092	1.2962
T	-0.7705	0.1143	-6.7410	-0.9978	-0.5432

Tilapia

```
The following results are for:
   YEAR$           = 99 and 00

 Iteration
 No.     Loss      L          K          T
   0 .990719D+04 .330000D+02 .540000D+00-.900000D+00
   1 .983322D+04 .328206D+02 .540402D+00-.877681D+00
   2 .983322D+04 .328202D+02 .540429D+00-.877665D+00
   3 .983322D+04 .328202D+02 .540430D+00-.877662D+00
```

Dependent variable is LENGTH

Source	Sum-of-Squares	df	Mean-Square
Regression	1.56213E+06	3	520709.2581
Residual	9833.2157	1836	5.3558
Total	1.57196E+06	1839	
Mean corrected	31011.8208	1838	

```
      Raw  R-square (1-Residual/Total)        =     0.9937
Mean corrected R-square (1-Residual/Corrected) =    0.6829
         R(observed vs predicted) square       =     0.6829
```

				Wald Confidence Interval	
Parameter	Estimate	A.S.E.	Param/ASE	Lower < 95%> Upper	
L	32.8202	0.2875	114.1646	32.2564	33.3840
K	0.5404	0.0232	23.2458	0.4948	0.5860
T	-0.8777	0.0446	-19.6955	-0.9651	-0.7903

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