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# Review of the Fisheries of the Salton Sea, California, USA: Past, Present, and Future

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**ABSTRACT:** The Salton Sea is an endorheic, 980-km$^2$ salt lake in the Sonoran Desert of southern California. The historical fish community switched from freshwater to marine species as salinity increased due to evaporation and brackish water inflows. Three species, bairdiella (*Bairdiella icistia*), orangemouth corvina (*Cynoscion xanthulus*), and sargo (*Anisotremus davidsoni*), established from introductions beginning in 1929. Thirty-four marine fish species from the northern Gulf of California were introduced between 1929 and 1956. During the late 1960s and early 1970s, a hybrid tilapia (*Oreochromis mossambicus* × *O. urolepis hornorum*) invaded the Salton Sea and became dominant by numbers and weight. Research has shown that nearshore and estuarine areas have the highest catch rates of tilapia (over 11 kg/50 m net/h). Orangemouth corvina, bairdiella, sargo, and the hybrid tilapia grew faster, but had shorter life spans than conspecifics elsewhere, and Salton Sea conspecifics of 50 years ago. All four species aggregated along the nearshore and estuarine areas in the summer for reproduction and relief from low oxygen conditions in the pelagic areas of the marine lake. Restoration alternatives for the Salton Sea must recognize the value of estuarine and nearshore areas as essential fish habitats for the Salton Sea fisheries ecosystem.

**KEY WORDS**: Salton Sea, bairdiella, orangemouth corvina, tilapia, restoration, salt lakes.

## I. HISTORY OF THE SALTON SEA

The Salton Sea (Sea) is an endorheic (closed basin), 980-km$^2$ desert salt lake bounded by the Gulf of California to the south, the Colorado River

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to the east, and the Anza-Borrego Desert to the west (Figure 1). The region is characterized by sparse rainfall (< 15 cm/y), clear skies, high evaporation rates, and intermittent strong wind, conditions that promote weathering and formation of sandy soils. The Sea is located in the Salton Sink, a below-sea level trough characterized by alluvial and Aeolian sand deposits. Ancient sources of sediment to the Salton Basin were the Colorado River and a mosaic of alluvial fans, braided streams, and lacustrine deposits.

The Salton Basin is the location of ancient Lake Cahuilla, which became extinct approximately 1500 AD (Schoenherr, 1988). Blake (1914) contended that the ancient lake was formed as the upper part of the Gulf of California with the Salton Sea becoming separated from the Gulf of California by the formation of the Colorado River Delta during the Pleistocene, giving rise to a 485,000 ha water body. An alternative hypothesis suggested that Lake Cahuilla was an ancient freshwater body, separated from the Gulf of California by a barrier formed by the Colorado River Delta (Free, 1914). Freshwater mollusks identified in the basin of Lake Cahuilla support the freshwater origin of the ancient lake (Stearns, 1902). Intermittent Colorado River invasions into the Salton Basin, and occasional inflows from the Gulf of California, have provided water during major tidal events (Kniffen, 1932; Sykes, 1937; Hubbs and Miller, 1947; Lawson, 1950; Weide, 1976). The long history of formation and extinction of Lake Cahuilla produced the rich alluvial soils of the Imperial and Coachella Valleys, now a vital agricultural region of the United States.

Indian legends and artifacts are evidence of the importance of Lake Cahuilla for early Amerindians who harvested mollusks and fish from the lake (Blake, 1858). Aquaculture and fish trapping might have also been practices of early Cahuilla Indians. Harvests of striped mullet (*Mugil cephalus*), humpback chub (*Gila cypha*), and bonytail (*Gila robusta*) were common. Early Cahuilla Indians might have trapped, cultured, and distributed fish to locations near Lake Cahuilla (McCown and McCown, 1982). As the lake gradually evaporated — leaving behind a depauperate fauna — Indians were forced to move to the foothills and valleys nearby.

In the winter of 1904 to 1905, a flood of the Colorado River broke through irrigation channels and headworks, redirecting the river's flow into the Salton Sink (Carpelan 1961a). The Colorado River was restored to its original direction in 1907, leaving behind an approximately 1000 $km^2$ freshwater lake, the Salton Sea.

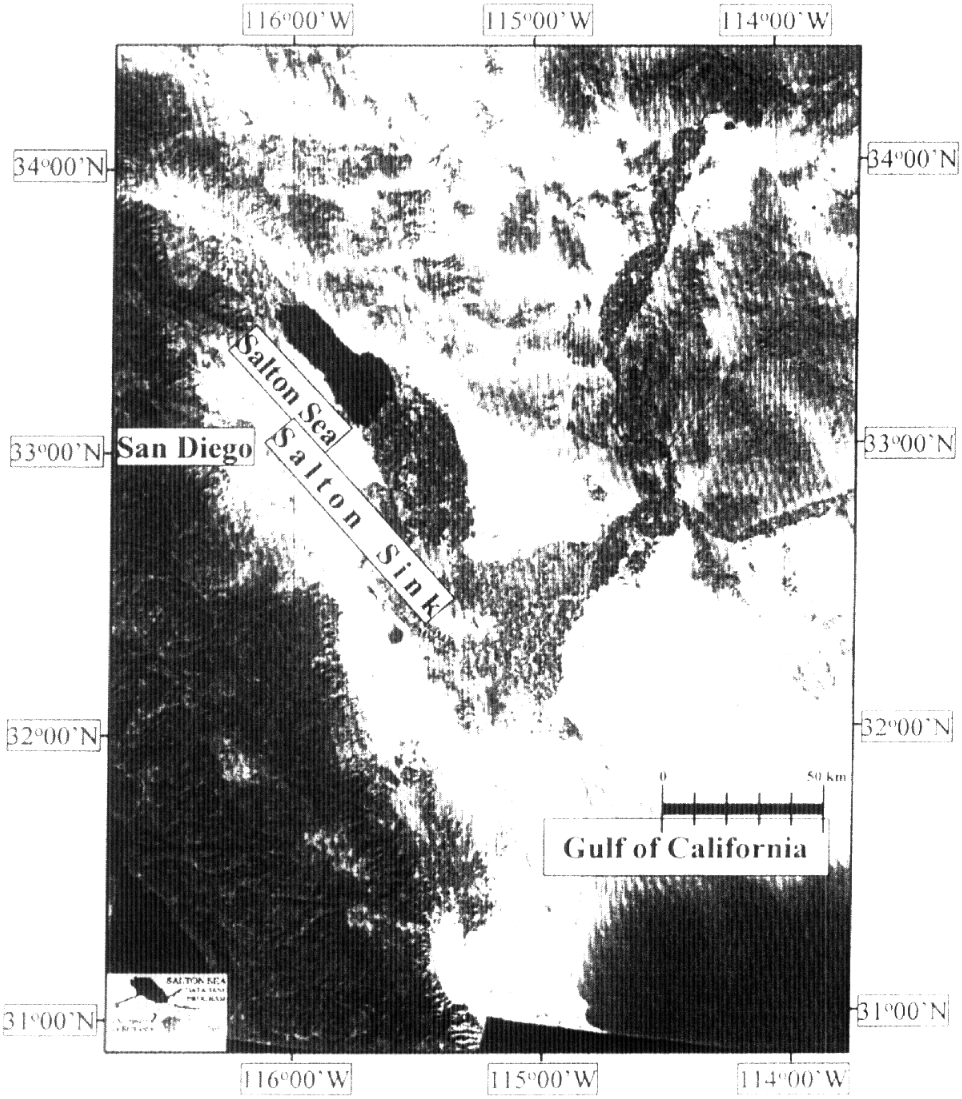


FIGURE 1. The Salton Sea in relation to the Gulf of California and the Salton Sink (from the Salton Sea Database— University of Redlands, California).

## II. THE MODERN SALTON SEA

The loss of over 90% of the wetland area of California has placed an increasing burden on remaining wildlife habitat, especially for sustaining migrant waterfowl from the Pacific Flyway. The Central Valley of California alone was covered with over 4 million acres of wetland before settlement in the 1800s by Europeans (Graham, 1998; Cohn, 2000). As a result of these losses, the Salton Sea has become one of the most critical links on the Pacific Flyway (Jehl, 1996). However, 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 (Jehl, 1996; Boyle, 1996; Kaiser, 1999; Cohn, 2000). The salinity of the lake 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 (Figure 2). Increased salinities, accelerated eutrophication, and outbreaks of diseases have been blamed for reproductive failures and mortalities of over 200,000 migratory water birds. Adverse environmental conditions have also affected fish larval survival (Matusi et al., 1991a, b), and been implicated in the deaths of millions of tilapia (Jehl, 1996; Boyle, 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

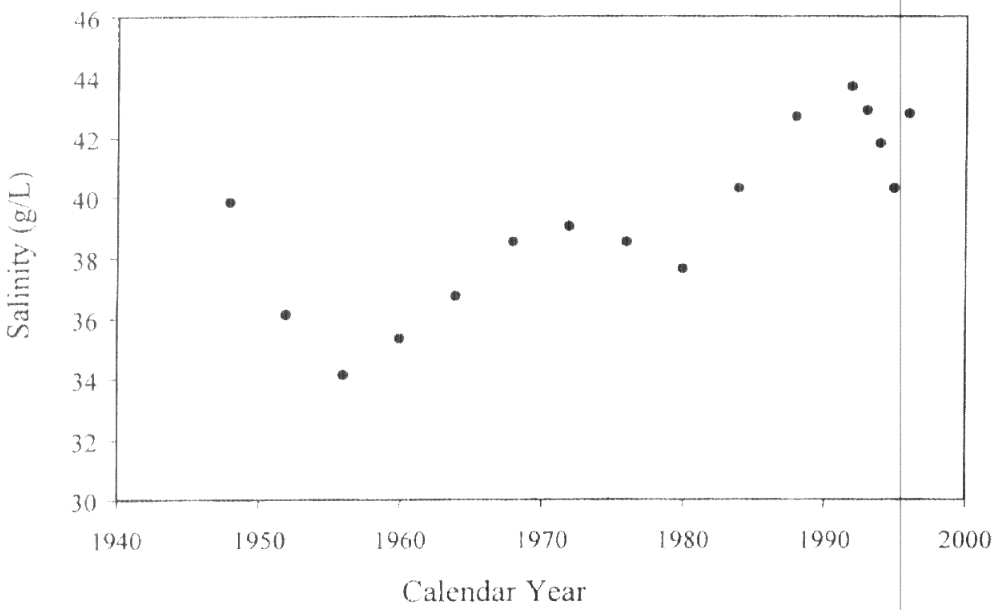


**FIGURE 2.** The progression of salinity increase by year at the Salton Sea (adapted from Setmire et al., 1991).

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). 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 water but all larvae died. Orangemouth corvina (*Cynoscion xanthulus*), acclimated to 35 to 40 g/l, spawned successfully when injected with leutinizing hormone-releasing hormone *a* (Thomas et al., 1994); but fish acclimated to 45 to 50 g/l failed to spawn even when induced. Simmons (1957) found that corvina in Laguna Madre, TX tolerated 70 g/l but did not spawn. Brockson and Cole (1972) concluded that the optimal salinity range for orangemouth corvina was 33 to 37 g/l. Mitsui et al. (1991b) sampled 11 Sea stations over 3 years enumerating late egg and early larval stages of orangemouth corvina, bairdiella (*Bairdiella icistia*) and sargo (*Anisotremus davidsoni*). Eggs and larval numbers declined as the Sea's salinity increased from 38 to 44 g/l from 1987 to 1989. Higher densities of larval fishes were found near the few freshwater inlets to the south of the Sea (New and Alamo Rivers).

All fish in the Sea are under stress due to the combination of high salinity, accelerated eutrophication, and dramatic water quality fluctuations. Fish may be dying due to regular infusions of deoxygenated water and toxic levels of ammonia and sulfide from infrequent lake turnovers that combine with high and low temperature stresses (Carpelan, 1961b). 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 likely decreases respiratory efficiency (Kuperman and Matey, 1999; Kuperman et al., 2001).

At present, the Sea is used primarily for recreation and as a repository for agricultural wastewaters. The Sea is designated by the state of California as a repository for nutrient-rich drainage waters from several commercial farms in the Imperial Valley. As a result, it has 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 Sea at 1.88 fish/angler/h, one of the highest catch rates recorded in the state (CDFG, 1971).

Recreational use of the Sea peaked in the 1950s. Fueled by the productive fishery, angling soared after World War II. Golf courses, marinas, and yacht clubs multiplied along the Sea shores. After the creation of a state park at the Sea in the 1960s, visitation to the lake was sometimes highest among California state parks (Graham, 1998). Recurrent fish and bird die offs have negatively imprinted public perception and visitation has now plummeted, despite the Sea's still productive fishery (Riedel et al., 2001), diverse wildlife, and unique scenery.

## III. FISHERIES OF THE SALTON SEA

### A. FRESHWATER AND MARINE PHASES (EARLY 1900s TO EARLY 1960s)

Archaeological excavations in the basin of ancient Lake Cahuilla have found six species of freshwater fish (Table 1). Schoenherr (1988) reports desert pupfish (*Cyprinodon macularis*) inhabiting Lake Cahuilla. After the Sea was formed, Evermann (1916) reported sizeable populations of many freshwater fishes native to the Colorado River. Most disappeared by 1929 as salinity increased. Rainbow trout (*Oncorhynchus mykiss*) and razorback suckers (*Xyrauchen texanus*) were still reported, striped mullet were scarce, and desert pupfish were common along the north shore. Mosquitofish (*Gambusia affinis*) were introduced prior to 1929 from the east coast of the United States for insect control and were "abundant at several points along the shore" (Walker et al., 1961; Table 2). Other fish species of importance during the early phases of the Sea were striped mullet and longjaw mudsucker (*Gillichthys mirabilis*).

TABLE 1
**List of Ancient and Modern Fishes Present in Lake Cahuilla and the Salton Sea**

| |
|---|
| **Species from Ancient Lake Cahuilla** (Yohe 1990) |
| Machete (*Elops affinis*) |
| Bonytail (*Gila robusta*) |
| Striped mullet (*Mugil cephalus*) |
| Colorado squawfish (*Ptychocheilus lucius*) |
| Humpback sucker (*Xyrauchen texanus*) |
| Humpback chub (*Gila cypha*) |
| **Species present at the Salton Sea** (Riedel et al. 2001) |
| *Salton Sea tilapia (Oreochromis mossambicus × O. urolepis hornorum)* |
| Bairdiella (*Bairdiella icistia*) |
| Orangemouth corvina (*Cynoscion xanthulus*) |
| Sargo *(Anisotremus davidsoni)* |
| Threadfin shad (*Dorossoma petenense*) |
| Striped mullet (*Mugil cephalus*) |
| Longjaw mudsucker (*Gillichthys mirabilis*) |
| Desert pupfish (*Cyprinodon macularis*) |

TABLE 2

**Fish Introductions to the Salton Sea from 1929 to 1956 (Reproduced from Walker et al. 1961)**

| Date (dd/mm/yy) | Number | Species | Common Name | Origin |
|---|---|---|---|---|
| 20/10/29 | 900 | *Morone saxatilis* | striped bass | Tracy California |
| 24/10/29 | 1500 | *Morone saxatilis* | striped bass | Tracy California |
| 21/10/30 | 1800 | *Morone saxatilis* | striped bass | San Francisco Bay |
| 13/11/30 | 500 | *Gillichthys mirabilis* | longjaw mudsucker | San Diego Bay |
| 13/11/34 | 15000 | *Oncorhynchus kisutsh* | silver salmon | Not specified |
| 02/10/48 | 43 | *Anchoa mudeoloides* | anchovy | Guaymas |
| 23/12/48 | 1000 | *Cetengraulis mysticetus* | anchoveta | San Diego coast |
| | 12 | *Caranx caballus* | green jack | San Diego coast |
| 10/05/50 | 5000 | *Cetengraulis mysticetus* | anchoveta | San Felipe |
| 12/05/50 | 29 | *Albula vulpes* | bonefish | San Felipe |
| | 2 | *Cetengraulis mysticetus* | anchoveta | San Felipe |
| | 1 | *Paralichthys aestuarius* | halibut | San Felipe |
| | 40 | *Colpichthys regis* | silverside | San Felipe |
| | 1 | *Eucinostomus argenteus* | spotfin mojarra | San Felipe |
| | 2 | *Trachinotus paitensis* | paloma pompano | San Felipe |
| | 27 | *Cynoscion xanthulus* | orangemouth corvina | San Felipe |
| | 14 | *Cynoscion parvipinnis* | shortfin corvina | San Felipe |
| | 1 | *Cynoscion macdonaldi* | totuava | San Felipe |
| | 7 | *Menticirrhus undulatus* | California corbina | San Felipe |
| | 1 | *Menticirrhus nasus* | corbina | San Felipe |
| | 15 | *Micropogon mealops* | croaker | San Felipe |
| | 57 | *Bairdiella icistia* | bairdiella | San Felipe |
| 14/12/50 | 25 | *Mugil curema* | white mullet | San Felipe |
| | 600 | *Colpichthys regis* | silverside | San Felipe |
| | 1 | *Paralichthys woolmani* | halibut | San Felipe |
| | 1 | *Scomberomorus concolor* | Monterey Spanish mackerel | San Felipe |
| | 1 | *Menticirrhus undulatus* | California corbina | San Felipe |
| | 12 | *Eucinostomus argenteus* | spotfin mojarra | San Felipe |
| | | *Eucinostomus gracilis* | mojarra | San Felipe |
| 15/12/50 | 15 | *Mugil cephalus* | striped mullet | San Felipe |
| | 60 | *Mugil curema* | white mullet | San Felipe |
| | 70 | *Colpichthys regis* | silverside | San Felipe |
| | 1 | *Nematistius pectoralis* | roosterfish | San Felipe |
| | 1 | *Menticirrhus undulatus* | California corbina | San Felipe |
| | 75 | *Eucinostomus argenteus* | spotfin mojarra | San Felipe |
| | | *Eucinostomus gracilis* | mojarra | San Felipe |
| 28/03/51 | 30 | *Cetengraulis mysticetus* | anchoveta | San Felipe |
| | 300 | *Leuresthes sardina* | grunion | San Felipe |
| | 3 | *Cynoscion xanthulus* | orangemouth corvina | San Felipe |
| | 2 | *Cynoscion parvipinnis* | shortfin corvina | San Felipe |
| 31/03/51 | 48 | *Albula vulpes* | bonefish | San Felipe |
| | 6 | *Anchoa mundeoloides* | anchovy | San Felipe |
| | 8 | *Cetengraulis mysticetus* | anchoveta | San Felipe |
| | 5 | *Mugil curema* | white mullet | San Felipe |
| | 3 | *Colpichthys regis* | silverside | San Felipe |

Table 2. (continued)

| Date (dd/mm/yy) | Number | Species | Common Name | Origin |
|---|---|---|---|---|
| | 4 | *Paralichthys aestuarius* | halibut | San Felipe |
| 31/03/51 | 140 | *Hypsopsetta guttulata* | diamond turbot | San Felipe |
| | | *Etropus crossotus* | flounder | San Felipe |
| | 65 | *Anisotremus davidsoni* | sargo | San Felipe |
| | 12 | *Paralabrax maculatofasciatus* | spotted bass | San Felipe |
| | 7 | *Girella simplicidens* | opaleye | San Felipe |
| | 2 | *Halichoeres* sp | wrasse | San Felipe |
| | | *Cynoscion xanthulus* | orangemouth corvina | San Felipe |
| | 200 | *Cynoscion othonopterus* | scalyfin corvina | San Felipe |
| | | *Cynoscion parvipinnis* | shortfin corvina | San Felipe |
| | | *Cynoscion macdonaldi* | totuava | San Felipe |
| | 10 | *Bairdiella icistia* | bairdiella | San Felipe |
| | 2 | *Menticirrhus nasus* | corbina | San Felipe |
| | 1 | *Eucinostomus argenteus* | spotfin mojarra | San Felipe |
| | 63 | *Gillichthys seta* | mudsucker | San Felipe |
| | 72 | *Colpichthys regis* | silverside | San Felipe |
| | 6000 | *Engraulis mordax* | northern anchovy | Los Angeles |
| Harbor | | | | |
| | 44 | *Cynoscion parvipinnis* | shortfin corvina | San Felipe |
| | 35 | *Micropogon mealops* | croaker | San Felipe |
| | 4 | *Menticirrhus undulatus* | California corbina | San Felipe |
| | 1 | *Trachinotus paitensis* | paloma pompano | San Felipe |
| | 26 | *Opisthonema libertate* | Pacific thread herring | San Felipe |
| 15/05/53 | 50 | *Cynoscion parvipinnis* | shortfin corvina | San Felipe |
| | 38 | *Cynoscion xanthulus* | orangemouth corvina | San Felipe |
| | 4 | *Menticirrhus undulatus* | California corbina | San Felipe |
| 10/03/55 | 3000 | *Cetengraulis mysticetus* | anchoveta | Gulf of California |
| 10-11/05/55 | 114 | *Cynoscion parvipinnis* | shortfin corvina | San Felipe |
| | 4 | *Cynoscion xanthulus* | orangemouth corvina | San Felipe |
| 04-05/56 | 8 | *Cynoscion macdonaldi* | totuava | San Felipe |
| | 1 | *Cynoscion othonopterus* | scalyfin corvina | San Felipe |
| | 1545 | *Cynoscion parvipinnis* | shortfin corvina | San Felipe |
| | 59 | *Cynoscion xanthulus* | orangemouth corvina | San Felipe |

Striped mullet likely entered the Sea during the 1904 to 1907 Colorado River flooding event and became a commercially important fish (Hendricks, 1961b). Commercial mullet fishing began in 1915, peaked at over 36 metric tons, and declined by 1921 (Janssen, 1937). Striped mullet fishing was banned in 1931, revived in 1943, but was banned again in 1953. The few striped mullet present in the 1950s occurred mostly in association with the freshwater inlets and reproduced mostly in those areas from October to November (Hendricks, 1961b). Hendricks (1961b) postulated that the Sea striped mullet population was maintained by occasional invasions from the Colorado River, especially before 1941. The absence of young fish in the 1950s were an indication of recruitment failure and a striped mullet population destined to disappear. A remnant striped mullet population still exists in the Sea (Riedel et al., 2001).

Longjaw mudsuckers were introduced to the Sea in 1930 from San Diego Bay to provide a bait fishery (Walker et al., 1961; Table 2). The natural range for longjaw mudsuckers is from central California to the Gulf of California. Spawning of Sea longjaw mudsucker peaks in January and February (Walker et al., 1961). Adult distribution is mostly along the shore in association with embayments and cover (Walker et al., 1961). Longjaw mudsuckers are captured in those areas today and are used for bait in the orangemouth corvina sportfishery.

Threadfin shad (*Dorosoma petenense*) were introduced in the Colorado River from Tennessee in 1953 (Kimsey, 1954; Table 2). The fish spread from the Colorado River to the canal systems of the Imperial Valley and into the Sea. Threadfin shad was first captured at the Sea in 1955 mostly in association with the incoming tributaries (Hendricks, 1961a). Salton Sea threadfin shad diet has been observed to be mostly phyto- and zooplankton (Hendricks, 1961a). Threadfin shad are important forage fish, having been commonly observed in orangemouth corvina stomachs (Hendricks, 1961a).

Desert pupfish is the only fish native to the Salton Sea and endemic to the Salton Sink (Baird and Girard, 1853; Shoenherr, 1988). Desert pupfish prefer low energy, shallow water habitats rich in structures such as rooted vegetation (Marsh and Sada, 1993). They can survive extreme conditions of salinity and dissolved oxygen, as well as extreme variations in those conditions (Lowe and Heath 1969). Desert pupfish were reported abundant at the Sea, with over 10,000 individuals in a single shoreline pool (Barlow, 1961). The desert pupfish was listed as endangered by the sate of California in 1980 (CDFG 1980) and federally in 1986 (FWS 1986) because of habitat alterations and contamination, and invasion of exotics (FWS 1986). Fish surveys during the 1950s and 1960s indicated that desert pupfish are declining (Schoenherr, 1979), possibly due to introduction of exotic species, reproductive failures due to selenium toxicity, and habitat modifications (Black, 1980; Bennett, 1998).

## B. HYPERSALINE PHASE (MID 1960s - PRESENT)

This phase includes the period during which tilapia established in the lake. In 1964 to 1965, the hybrid tilapia (*Oreochromis mossambicus* × *O. urolepis hornorum*) escaped to the Sea by two routes: (1) an aquarist fish farm near Niland (St Amant, 1966), 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). In 1967, tilapia were caught by a few anglers in the Sea (Hoover and St Amant, 1970). By the 1980s, tilapia quickly dominated the fish community of the Sea as the salinity rose above 35 g/l to hypersaline levels and became the dominant fish species in the Sea and the most important prey for the increasing numbers of piscivorous birds. Tilapia became a popular recreational fish in the late 1970s. A 1976 flood might have allowed additional tilapia to escape from irrigation ditches into the Sea (N. Niver, personal communication).

Since the 1950s there have been reports of large fish die-offs in the Sea, especially in the summer when strong winds completely mix the water column. Walker et al. (1961) followed one such turnover in 16 to 18 July 1956 that depleted oxygen to the surface, causing massive fish kills. More recently, millions of tilapia have died due to anoxia. In January 1997 we estimated dead tilapia biomass at 100 g/m$^2$ across the entire pelagic area of the lake due lake turnover. Fish die-offs have created economic hardship on desert towns with few other alternative economic opportunities.

## C. MOST ABUNDANT FISH SPECIES

The modern Salton Sea is dominated by tilapia and bairdiella (Costa-Pierce and Riedel, 2000; Riedel et al., 2001; Table 4). Orangemouth corvina are the top predator. Tilapia are opportunistic feeders, and the bairdiella and sargo are mostly demersal. Fish species present in the Sea, but unimportant numerically and in total biomass, are striped mullet, threadfin shad, and the longjaw mudsucker (Walker et al., 1961; Riedel et al., 2001).

Riedel et al. (2001) reported gill net tilapia catch rates over 6 kg/50 m net/h at the Sea (Table 5). Such catch rates are many times higher than gill net catches reported from tropical reservoirs and lakes (Amarasinghe 1987; Amarasinghe and De Silva, 1990; De Silva, 1988; De Silva, 1991). Salton Sea catch rates for tilapia and bairdiella were, however, patchy within the lake (Table 5), which attests to a large variation in habitat quality.

Habitat preference for fish within the Sea may be determined by wind-driven, episodic deoxygenation events. Tilapia and bairdiella aggregate in shallow, nearshore areas in the summer (Figure 3) for reproduction and to escape the pelagic area, whose hypolimnion is deoxygenated during summer (Walker et al., 1961; Riedel et al., 2001). Orangemouth corvina are less abundant in the pelagic area throughout the year (Table 5), indicating a stronger preference for the nearshore areas of the Sea (Riedel et al, 2001; Figure 3).

TABLE 3
**Temperature and Salinity Tolerances for Adult *Oreochromis mossambicus* Adapted from Costa-Pierce and Riedel (2000).**

| | Effects | References |
|---|---|---|
| **Temperatures (°C)** | | |
| 5.5 | Total mortality | Li et al., 1961 |
| 8–10 | Total mortality | Chimits, 1957 |
| 8.3–9.4 | Total mortality | Kelly,1956 |
| 8-10 | Low temperature tolerance limits | Chervinski, 1982 |
| 11 | Total mortality after 5 d at this temperature | Allanson et al., 1962 |
| 11 | Survived at 5‰ | Allanson et al., 1971 |
| 12 | Survives this extreme temperature by inhabiting the estuarine area of the Kowie River, South Africa | Allanson et al., 1971 |
| 15 | Suffer from cold stress | Caulton, 1978 |
| 15 | Cold stress and fungal infections occurred | Al Amoudi et al., 1996 |
| Below 20 | Severe *Saprolegnia* infection if exposed beyond 120 hours | Allanson et al., 1971 |
| **Salinities (g/L)** | | |
| 14 | Highest growth rate at 28°C | Payne et al., 1988 |
| 30 | Grew well; reproduced in ponds | Chimits, 1957 |
| 30 | Reproduced in ponds | Vaas and Hofstede, 1952 |
| 49 | Reproduced | Popper and Lichatowich, 1975 |
| 61 | Gradual transfer allowed successful adaptation | Dange, 1985 |
| 40–55 | Grew and reproduced | Riedel et al., 2001 |
| 120 | Adapts well to gradual changes in salinities | Whitfield and Blaber, 1976 |

Riedel et al. (2001) also report a strong preference between the surface and bottom of the lake for tilapia and bairdiella at different times in the year (Figure 4). In the summer, the few fish that remain in the pelagic area move toward the surface, possibly to minimize the detrimental effects of oxygen deprivation. In the winter, fish tend to remain near the bottom to feed on the abundant pile worms (Carpelan and Linsley, 1961).

There is evidence that Salton Sea fish are a fast growing, shorter-lived population. Riedel et al. (2001) report faster growth and shorter life spans for Salton Sea fish than conspecifics elsewhere and conspecifics of the first introductions decades ago (Table 6; Figure 5).

## *1. Tilapia*

Tilapias are native to Africa (Trewavas, 1983). Because of their importance in aquaculture, tilapia, especially *O. mossambicus*, are the most

TABLE 4

**Species, Total Catch By Numbers, By Weights, and Catch Per Unit Efforts (CPUE; kg/50 m net/h) By Area for Fish Sampled from the Salton Sea, CA between 1999 and 2000.**

| Species | Total catch by number | Total catch by weight (kg) | CPUEs |
|---|---|---|---|
| **Major Species Sampled** | | | |
| Salton Sea tilapia *(Oreochromis mossambicus × O. urolepis hornorum)* | P (613), N (2072), E (2102) | P (223.9), N (746.0), E (934.7) | P (0.1), N (2.5), E (4.2) |
| Bairdiella (*Bairdiella icistia*) | P (2775), N (1339), E (767) | P (269.5), N (114.9), E (95.3) | P (0.1), N (0.4), E (0.3) |
| Orangemouth Corvina (*Cynoscion xanthulus*) | P (22), N (195), E (111) | P (28.8), N (514.9), E (201.7) | P (*), N (1.4), E (1.3) |
| Sargo (*Anisotremus davidsoni*) | P (82), N (15), E (0) | P (17.9), N (6.0), E (0) | P (*), N (*) |
| **Minor Species Sampled** | | | |
| Threadfin shad (*Dorossoma petenense*) | P (0), N (15), E (116) | P (0), N (0.8), E (6.9) | E (*) |
| Striped mullet (*Mugil cephalus*) | P (0), N (0), E (4) | P (0), N (0), E (6.8) | E (*) |
| **Fish not sampled, but present in the Salton Sea according to Walker et al. 1961** | | | |
| Longjaw mudsucker (*Gillichthys mirabilis*) | | | |
| Desert pupfish (*Cyprinodon macularis*) | | | |

* *indicates a CPUE less than 0.1. P = pelagic, N = nearshore, E = estuaries. (adapted from Riedel et al., 2001)*

TABLE 5

**Catch per unit effort (kg/ 50 m net/h) ± SEM by area and season for fish sampled from the Salton Sea, CA between 1999 and 2000**

| | *1999* | | | *2000* | | |
|---|---|---|---|---|---|---|
| | Nearshore | Pelagic | Estuarine | Nearshore | Pelagic | Estuarine |
| **Orangemouth Corvina** | | | | | | |
| Spring | 3.03 ± 1.38 | 0.03 ± 0.01 | 0.45 ± 0.21 | 3.74 ± 1.29 | 0.04 ± 0.03 | 3.90 ± 1.46 |
| Summer | 0.32 ± 0.14 | 0.01 ± 0.01 | 0.42 ± 0.21 | 0.79 ± 0.36 | 0 | 0.37 ± 0.15 |
| Fall | 0.48 ± 0.47 | 0.02 ± 0.02 | 0.27 ± 0.16 | 0.05 ± 0.05 | 0 | 3.59 ± 2.30 |
| Winter | 0.45 ± 0.30 | 0.08 ± 0.06 | 0.02 ± 0.02 | 4.77 ± 2.18 | 0 | 1.60 ± 1.30 |
| **Bairdiella** | | | | | | |
| Spring | 0.12 ± 0.03 | 0.37 ± 0.08 | 0.21 ± 0.10 | 1.55 ± 0.51 | 0.10 ± 0.04 | 0.14 ± 0.11 |
| Summer | 0.73 ± 0.14 | 0.15 ± 0.06 | 0.56 ± 0.12 | 0.62 ± 0.01 | 0.01 ± 0.01 | 0.58 ± 0.20 |
| Fall | 0.30 ± 0.09 | 0.06 ± 0.03 | 0.84 ± 0.24 | 0.12 ± 0.06 | 0 | 0.40 ± 0.26 |
| Winter | 0.04 ± 0.02 | 0.05 ± 0.03 | 0.08 ± 0.03 | 0 | 0.15 ± 0.06 | 0.01 ± 0.01 |
| **Tilapia** | | | | | | |
| Spring | 1.01 ± 0.20 | 0.29 ± 0.90 | 1.09 ± 0.29 | 1.56 ± 0.89 | 0.02 ± 0.01 | 1.44 ± 0.57 |
| Summer | 6.65 ± 1.35 | 0.14 ± 0.06 | 12.3 ± 4.70 | 0.90 ± 0.41 | 0.02 ± 0.01 | 3.48 ± 1.16 |
| Fall | 2.93 ± 1.50 | 0.01 ± 0.06 | 11.4 ± 3.60 | 3.34 ± 0.84 | 0.02 ± 0.01 | 1.08 ± 0.50 |
| Winter | 0.28 ± 0.08 | 0.17 ± 0.05 | 1.13 ± 0.40 | 1.59 ± 0.80 | 0.03 ± 0.01 | 1.70 ± 0.96 |
| **Number of observations** | | | | | | |
| Spring | 8 | 12 | 4 | 8 | 12 | 6 |
| Summer | 16 | 24 | 8 | 8 | 11 | 6 |
| Fall | 8 | 12 | 4 | 8 | 12 | 6 |
| Winter | 16 | 24 | 9 | 8 | 12 | 6 |

*From Riedel et al. 2001*

widely distributed exotic fish worldwide. Research on tilapia in the United States has been conducted on their use as food, vegetation control, and game fish (Dill and Cordone, 1997; Costa-Pierce and Rakocy, 1997, 2000). Tilapia have become established in all 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; Table 3), probably because they evolved from a marine ancestor (Myers, 1938; Trewavas, 1983), but are stenothermal (Hargreaves, 2000; Table 3). *O. mossambicus* can survive water temperatures 15 to 40°C, but grow optimally at 25 to 37°C (Al Amoudi et al., 1996). Tilapias cease to feed below 16°C (Kelly, 1956) and reproduce at

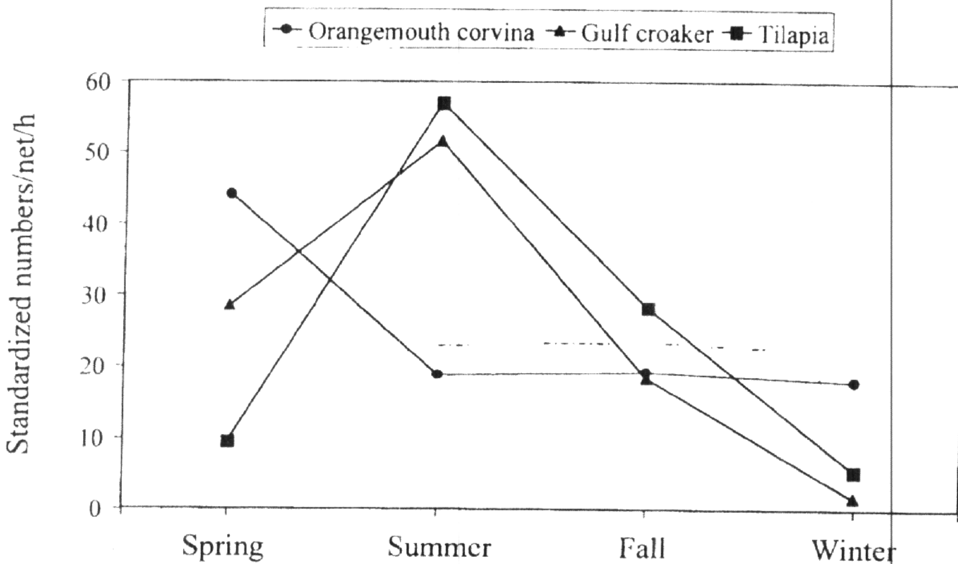


**FIGURE 3.** Standardized catch per unit effort (CPUE; fish numbers/50 m net/h) by season for three Salton Sea species sampled with multipanel gill net sets during 1999 and 2000 in the nearshore and estuarine areas combined. Percent CPUE was the fraction of a season's CPUE from the sum of the CPUEs of all easons. Standardization was done by converting CPUEs for each species to percent values (from Riedel et al., 2001).

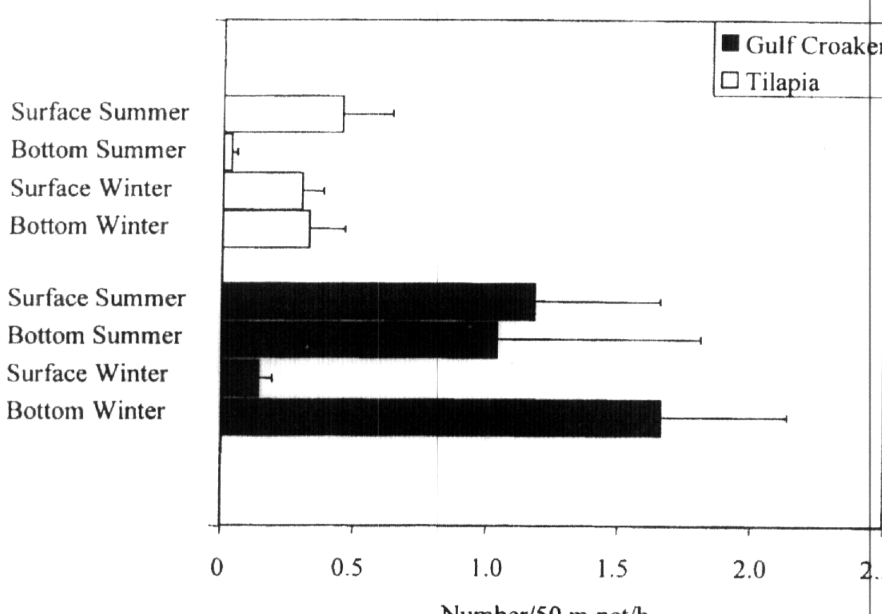


**FIGURE 4.** Vertical distribution of tilapia (*Oreochromis mossambicus* × *O. urolepis hornorum*) and Gulf croaker (*Bairdiella icistia*) catches during 1999 and 2000 in the Salton Sea. Numbers are average kg/50 m nets/h ± standard error of the mean, n = 18 for all bars (from Riedel et al., 2001).

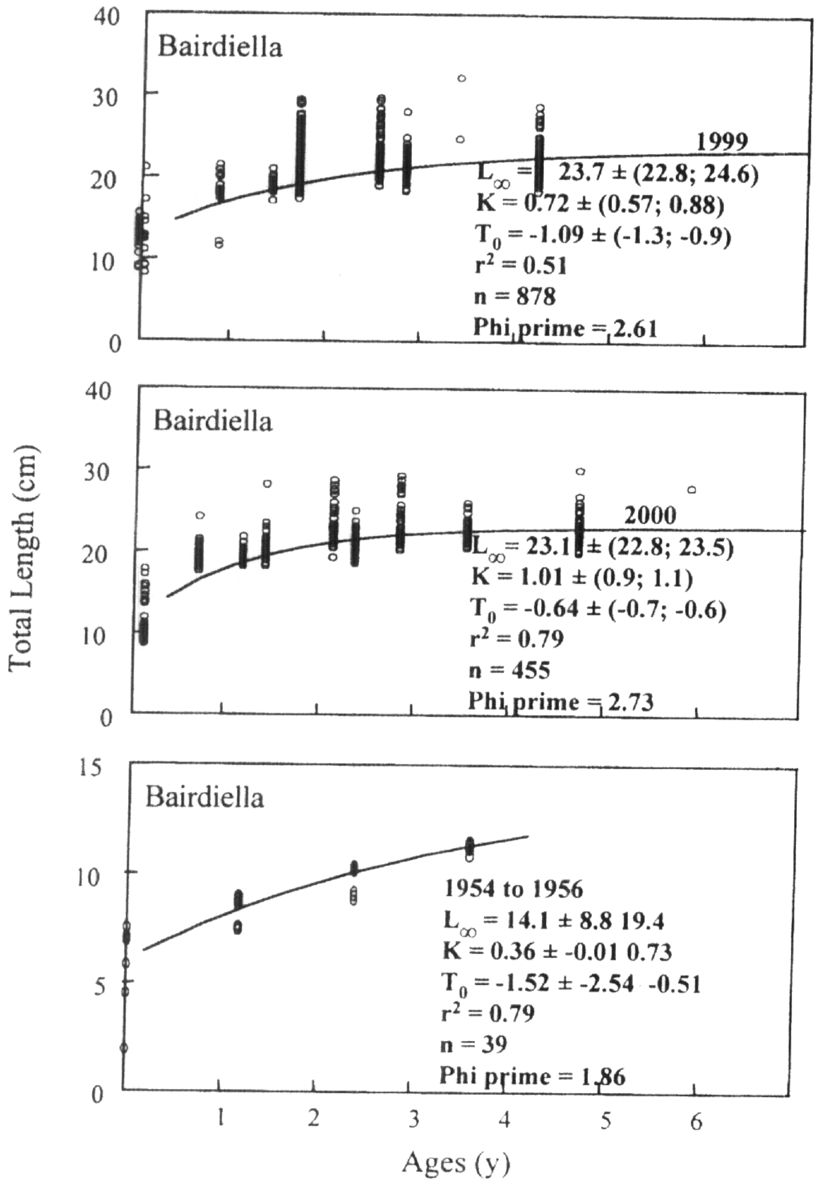


**FIGURE 5.** Von Bertalanffy growth function parameter estimates and phi prime growth performance indices (Moreau et al., 1986) for tilapia (*Oreochromis mossambicus* × *O. urolepis hornorum*), bairdiella (*Bairdiella icistia*), orangemouth corvina (*Cynoscion xanthulus*), and sargo (*Anisotremus davidsoni*) captured in the Salton Sea, California during 1999 and 2000. Numbers in parenthesis are lower and upper 95% confidence intervals of parameter estimates (from Riedel et al., 2001).

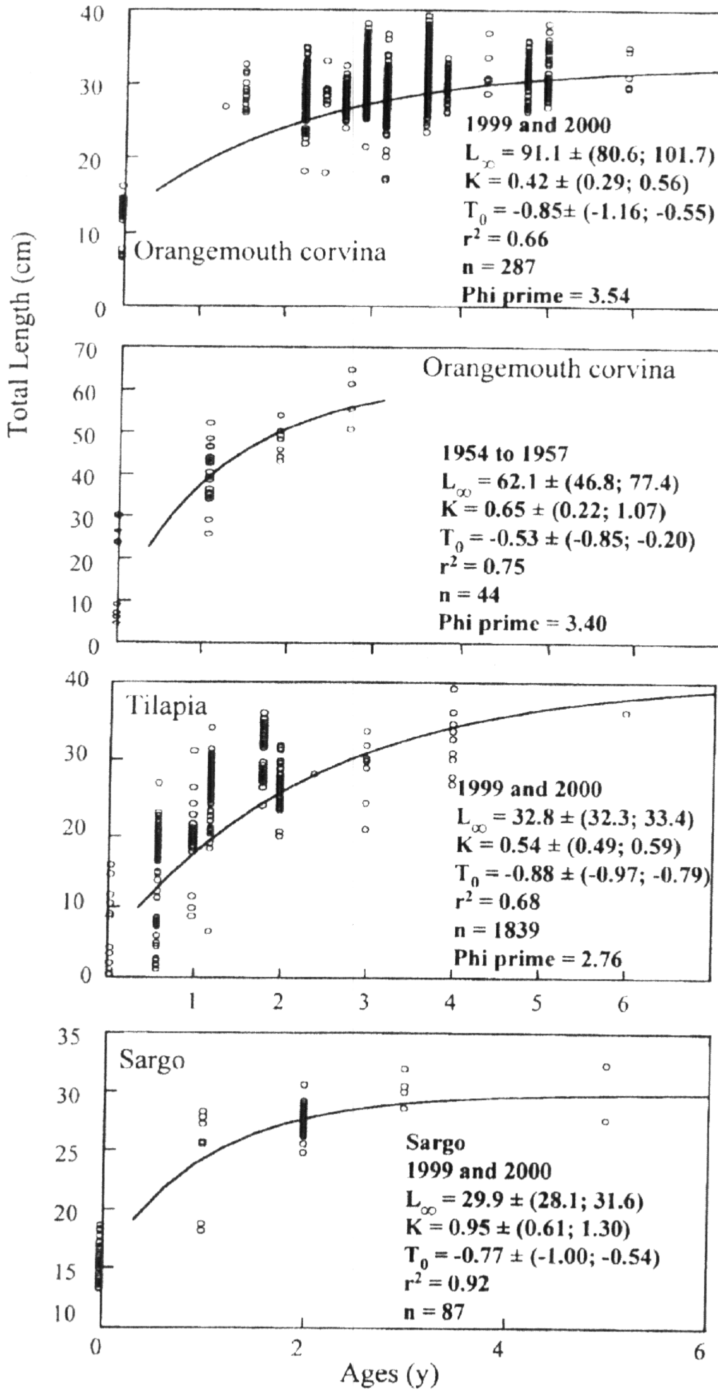
Orangemouth corvina
1999 and 2000
L∞ = 91.1 ± (80.6; 101.7)
K = 0.42 ± (0.29; 0.56)
T0 = -0.85± (-1.16; -0.55)
r2 = 0.66
n = 287
Phi prime = 3.54
Orangemouth corvina
1954 to 1957
L∞ = 62.1 ± (46.8; 77.4)
K = 0.65 ± (0.22; 1.07)
T0 = -0.53 ± (-0.85; -0.20)
r2 = 0.75
n = 44
Phi prime = 3.40
Tilapia
1999 and 2000
L∞ = 32.8 ± (32.3; 33.4)
K = 0.54 ± (0.49; 0.59)
T0 = -0.88 ± (-0.97; -0.79)
r2 = 0.68
n = 1839
Phi prime = 2.76
Sargo
Sargo
1999 and 2000
L∞ = 29.9 ± (28.1; 31.6)
K = 0.95 ± (0.61; 1.30)
T0 = -0.77 ± (-1.00; -0.54)
r2 = 0.92
n = 87
Total Length (cm)
Ages (y)

**FIGURE 5B.**

TABLE 6

**Age (y) and Mean Total 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 Conspecifics Sampled Elsewhere**

| | *N* | *Age* | *Mean total length ± SD* | *Mean total length from other studies* | *Ref.* |
|---|---|---|---|---|---|
| **Bairdiella** | 52 | 0+ | 13.0 ± 2.2 | - | |
| | 36 | 1+ | 18.6 ± 2.0 | 13.1 | Whitney, 1961a |
| | 606 | 2+ | 21.2 ± 2.0 | 15.4 | ditto |
| | 184 | 3+ | 22.4 ± 2.3 | 17.2 | ditto |
| | 2 | 4+ | 28.5 ± 5.3 | 17.3 | ditto |
| **Orangemouth corvina** | 9 | 0+ | 28.4 ± 8.0 | - | |
| | 62 | 1+ | 46.1 ± 11.6 | 11.0 | Whitney, 1961b |
| | 115 | 2+ | 65.9 ± 6.0 | 40.0 | ditto |
| | 10 | 3+ | 69.6 ± 4.9 | 50.2 | ditto |
| | - | 4+ | | | |
| | - | 5+ | | | |
| | 1 | 6+ | 83.0 | - | |
| **Sargo** | 32 | 0+ | 15.6 ± 1.5 | - | |
| | 2 | 1+ | 18.5 ± 0.4 | - | |
| | 33 | 2+ | 27.5 ± 1.4 | - | |
| | - | 4+ | | 25.0 | Love, 1996 |
| | - | 12+ | | 32.5 | ditto |
| **Tilapia** | 404 | 0+ | 8.0 ± 2.7 | 5.8 | Khoo and Moreau, 1990 |
| | - | 1+ | | | |
| | - | 2+ | | | |
| | 2828 | 3+ | 29.2 ± 1.8 | 25.0 | Khoo and Moreau, 1990 |
| | | | | 25.0 | Roux, 1961 |
| | | | | 20.6 | Hecht, 1980 |
| | | | | 15.0 | Koura and Bolock, 1958 |
| | 1314 | 4+ | 30.6 ± 2.5 | 26.0 | Khoo and Moreau, 1990 |
| | | | | 30.0 | Roux, 1961 |
| | | | | 25.5 | Hecht, 1980 |
| | | | | 18.0 | Koura and Bolock, 1958 |
| | 292 | 5+ | 32.9 ± 2.9 | 28.5 | Khoo and Moreau, 1990 |
| | | | | 32.5 | Roux, 1961 |
| | | | | 23.4 | Hecht, 1980 |

*Dashes indicate no data. (from Riedel et al. 2001).*

water temperatures only above 20 to 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 to 22°C compared with tilapia at 25 to 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 to 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 to 10 years, and 23 to 38 cm (Bruton and Allanson, 1974; Hodgkiss and Man, 1977; De Silva, 1991; James, 1989). 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 5 years old. Similarly, Hecht and Zway (1984) reported stunted tilapia mostly 5 years old or less in a hot spring. Salton Sea tilapia older than 5 years are not common (Riedel et al., 2001).

Sexual maturity may be reached after 6 months, which accounts for the high potential of tilapia to dominate fish communities (Trewavas, 1983). Gender ratios of Salton Sea fish are approximately uniform, except for tilapia (Riedel et al., 2001). Tilapia female to male sex ratios have been reported to vary between 0.4:1 and 7:1 in Sri Lankan freshwater lakes (De Silva and Chandrasoma, 1980). In contrast, Salton Sea tilapia sampled in 1999 and 2000 were predominantly males (79 %; Riedel et al., 2001). The skewed sex ratio from Salton Sea tilapia might be due to temperature (Wang and Tsai, 2000) or as a result of the skewed sex ratio that results from the cross between *O. hornorum* and *O. mossambicus* (Hickling, 1960; Fryer and Iles, 1972). Maximum size and weight of cultured *O. mossambicus* may be higher (Le Mare, 1950; Jubb, 1967).

Costa-Pierce and Doyle (1997) found Salton Sea tilapia 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. urolepis hornorum* from Tanzania, it was not possible to resolve if the 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 tilapia 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 Sea.

Costa-Pierce (1998) suggested that the Salton Sea tilapia "strain" may be an important partner in genetic improvement programs for saltwater tilapia aquaculture (Watanabe et al., 1997). Because 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 Sea, is not at present recommended. 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.

### *2. Bairdiella*

Bairdiella (family Sciaenidae) are native to the Gulf of California, where they inhabit estuarine and coastal areas (Walker et al., 1961; Johnson, 1978) and support commercial and sport fisheries (Jacob, 1948; Longhurst, 1964). Bairdiella rarely grows longer than 30 cm and is an important forage fish for the orangemouth corvina (Whitney, 1961a). *Bairdiella* spp has a wider distribution, occurring in the eastern Pacific and western Atlantic (Sasaki, 1989).

Fifty-seven croakers were introduced in 1950 into the Salton Sea, followed by the introduction of another 10 fish in 1951 (Walker et al., 1961; Table 2). The first account of a Salton Sea bairdiella was made in 1953 (Dill and Cordone, 1997).

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 bairdiella has a high salinity tolerance. The Atlantic croaker (*Bairdiella chrysoura*), 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).

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 (*Neanthes succinea*). Mok and Gilmore (1983) report peak spawning to occur between March and June for the Altantic croaker. Bairdiella from the Salton Sea have been reported to mature in 1 to 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 8 years (Lattin, 1986).

Beckwitt (1987) reported high genetic variability for Salton Sea bairdiella, suggesting potential adaptation to environmental change despite the low number of founders. Genetic variability of the Salton Sea bairdiella did not differ from the population in the Gulf of California except for few rare alleles observed in the latter population (Beckwitt, 1987). Introductions of bairdiella into the Salton Sea in the 1950s, however, raise the question of whether this species has become a new strain. The initial population of less than 100 quickly expanded to become one of the most numerous fish in the Sea. The episodic anoxia events, high summer temperatures, and gradual increases in salinity are a recipe for adaptation and possible speciation.

### *3. Orangemouth Corvina*

The orangemouth corvina belong to a widely distributed genus present in the eastern Pacific and western Atlantic Ocean (Sasaki, 1989). Orangemouth corvina are native to the Gulf of California, from they were first stocked in the 1950s into the Salton Sea. Orangemouth corvina stockings were followed by other introductions through 1956 (Table 2). Approximately 250 specimens were introduced during that period (Dill and Cordone, 1997). Orangemouth corvina may grow to 65 cm when 5 years old (Whitney, 1961b).

Orangemouth corvina in the Sea are hypothesized to spawn between April and August when water temperatures rise (Walker et al., 1961; Matsui, 1991b). Orangemouth corvina have been observed to produce a great sustained underwater sound associated with breeding (Fish and Cummings, 1972). Fish and Cummings (1972) provided evidence of spawning during the spring and summer based on intensity of sound production. Spawning of Salton Sea orangemouth corvina, however, may also extend through the fall (Whitney, 1961b; Matsui, 1991b). Information on the reproductive biology of orangemouth corvina is scarce. *Cynoscion* spp. are continuous spawners, starting reproduction in late spring through early fall. Brown-Petersen (1988) reports a spawning period between April and September and a spawning frequency of once every 2 days to once every 3 weeks for the closely related spotted seatrout (*C. nebulosus*). Thomas et al. (1994) report a spawning season from mid summer to fall with potential for multiple spawning in orangemouth corvina based on hormonal analyses of captive fish. An increase in gonad weight from mid summer to early fall reported by Riedel et al. (2001) agrees with the evidence from Thomas et al. (1994).

The orangemouth corvina is the most important sportfish 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, 9267 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 1 to 3 million fish (Hulquist, 1970). Adult orangemouth corvina are readily caught by anglers in the nearshore of the Sea. Maximum reported size is 32 pounds (Hulquist, 1970). Orangemouth corvina grow very rapidly in the Sea in comparison with other conspecifics (Blake and Blake, 1981; Warburton, 1969). Orangemouth corvina play a valuable ecological role as the most successful top carnivore in the Sea.

### *4. Sargo*

Sargo are distributed from central to southern Baja California and into the northern Gulf of California. Sixty-five sargo were introduced in the 1950s from the northern Gulf of California into the Salton Sea (Walker et al., 1961; Table 2). 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). Sargo are occasionally reported by Salton Sea anglers mostly as incidental catch.

The fish biology, behavior, 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 Sea. It is assumed this fish is also prey for the orangemouth corvina (Walker et al., 1961).

## *IV. THE FUTURE OF THE SALTON SEA*

Because of the ecological and recreational importance of the Salton Sea several restoration approaches (Table 7) are being contemplated. Restoring the Sea is an open-ended proposition because the lake progressed from freshwater to hypersaline, never stabilizing at environmental conditions that could be used as a target baseline for restoration. The objectives of restoration plans are, however, to keep the lake as a viable ecosystem to support migratory and resident biota, continued use as an agricultural wastewater repository, control of salinity and elevation, prevention of fish and wildlife die offs, and promotion of recreational opportunities (Borrego et al., 1999; SSA, 2000). Many restoration objectives may be conflicting and a prioritization taking into account ecological, societal, and financial interests is underway.

Restoration alternatives for the Sea are a combination of many different practices that take into account current scientific knowledge and future threats of reduced freshwater inflows (Table 7). Restoration practices may be grouped into ecological, technical, and societal. Ecological practices include fish harvesting, shoreline cleaning of fish carcasses, fish and wildlife disease control, and wetland reclamation. These practices may interact in that the implementation of one may obviate the need for implementing others. Fish harvests, for example, may control fish die offs and diseases, and control of diseases may obviate the need for shoreline cleanups by preventing or reducing fish and bird die offs.

Technical restoration alternatives are construction of solar ponds, enhanced evaporation systems using spraying towers, and the creation of displacement dikes. Evaporation-based approaches intend to remove salt from the lake, thus mimicking an open basin lake. Displacement dikes will serve the purpose of reducing the surface area of the lake and are intended to operate on the premise that the incoming freshwater tributaries will be more effective in stabilizing the salinity of a smaller lake. Technical restoration practices need to be carefully implemented to keep them from causing loss of wildlife or fish reproductive and feeding habitats. Societal practices include all activities aimed to enhance the infrastructure of the lake for boaters and anglers, and improve the economic status of surrounding communities by implementing a commercial fish harvest or ecotourism.

Highest densities and productivities of the Salton Sea fish community are in nearshore and estuarine areas (Riedel et al., 2001). Estuarine areas are preferred habitats likely due the relief provided by the oxygen-rich, lower-temperature waters and abundant food resources. In addition, spawning activities are concentrated in the nearshore areas, such as coves, bays, and harbors. Any restoration alternative should take these essential fish habitats into account. Proposed water withdrawals may expose prime fish habitats and negatively affect fish production. Actions should be taken to protect, not isolate critical spawning and nursery areas.

The use of pesticides, including DDT-based products until the 1970s, in the surrounding farms negatively colored public perception about the Sea in that the lake and its products are excessively contaminated. Current evidence shows, however, that water and sediment contamination is minimal (Vogl, 1999). Salton Sea fish have high concentrations of selenium, but no alarming levels of any other metal or organic contaminants (Setmire et al., 1993; Riedel et al., 2001). We feel that Salton Sea fish should be consumed with caution, but the lake is otherwise safe for human recreational and commercial usages.

Fish have been used as indicator species for estimating environmental change after anthropogenic or natural perturbations (Pereira et al., 1995; Shields et al., 1995; Kirchhofer, 1996; Whitfield, 1996; Wriedt and Schulz, 1997). It is likely that the Salton Sea biota will change after restoration plans are underway. An understanding of the fisheries ecology concomitant with these changes is pivotal to provide early warnings of the effects of restoration practices. Restoration practices may be successful in controlling salinity, but if detrimental effects on the fisheries are experienced, the Salton Sea may lose its importance as a wildlife sanctuary and recreational lake.

Implementation of a tilapia commercial harvesting at the Sea may benefit the economy of 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 large tilapia biomass in the Sea, fishery products may be commercialized as meals, food, or fertilizers. Given the high estimates of fish gill net catch rates (Riedel et al., 2001), the fishery may also benefit local communities, but more research needs to be completed to determine turnover rates, yields per recruit estimates, and overall sustainability of the fishery resources. Managing the Salton Sea for a sustained fishery is not only ecologically desirable but may be economically attractive.

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