Final Synthesis Document
Fish and Fisheries of the Salton Sea

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Background

There are three distinct phases of development of the fish community of the Salton Sea:

1. the ancient and modern freshwater phase;
2. the marine introduction and establishment phase;
3. the hypersaline tilapia phase.

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*, and *Xyrauchen texanus* (humpback sucker) (Yohe 1990). Desert Cahuilla Indians developed highly sophisticated stone traps to catch migrating fish in the ancient lake (Costa-Pierce 1985), the remains of which can be seen today along State Road 86 in Salton City, just north of the Tarantula Ridge.

After the modern Sea was formed in 1905-06, Evermann (1916) reported sizeable populations of the following fishes in order of their abundance.

Fish reported in the Salton Sea in 1916

Fish Species	Reported Abundance
Cyprinus carpio Common carp	"the most abundant species"
Mugil cephalus Striped mullet	"second most common"
Xyrauchen texanus Humpback sucker	"common" but several with a starved appearance
Salmo gairdneri (now *Oncorhynchus mykiss*) Rainbow trout	"common", some in "bleached but excellent condition"
Gila robusta Bonytail	"common, but not observed"
Cyprinodon macularius Desert pupfish	"found at Figtree John Spring"

Source: Walker et al. (1961)

Around the turn of the century the Salton Sea supported a fabulous mullet fishery. In 1918 a total of 91,000 pounds of mullet were taken by fishermen using nets a thousand feet long. Mullet as large as 21 pounds were being captured (Salton Sea National Wildlife Refuge [SSNWRR], n.d.).

In 1929, trout and humpback suckers were still reported. 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 San Felipe, Gulf of California (Table 1) (Walker et al. 1961). Of these, only the orangemouth corvina (*Cynoscion xanthulus*), bairdiella (*Bairdiella icistia*) and sargo (*Anisotremus davidsoni*) established and flourished in the Sea.

Mullet were reported in the late 1940's and 1950's as having huge fall spawning runs up the New and Alamo Rivers (see Appendix 1). In the 1950's, biologists reported a large annual die-off of mullet during November to January, stating that, "This loss of mullet is an annual event that has never been explained by ichthyologists" (Appendix 1). Large schools of mullet were noted until May-August 1963, but since then mullet were not mentioned again in any SSNWR reports (Appendix 1).

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 ppt to hypersaline levels.

The Hypersaline Phase

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 per hour, 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, both in winter from lower temperatures and strong winds, and in summer when strong southerly winds were able to completely mix the shallow water column. Walker et al. (1961) followed a summer turnover in 16-18 July 1956 which depleted oxygen to the surface, caused a massive fish kill, and also caused the disappearance of the pile worm (*Neanthes* spp.). 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 (personal conversations 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 grams per 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). Increasing salinities have been reported to impact fish reproduction and recruitment in the Sea. Brockson and Cole (1972) concluded the optimal salinities for the corvinas were 33-37 ppt. Laboratory studies by Mitsui et al. (1991a) showed that sargo (*Anisotremus davidsoni*) spawned when acclimated to 45 ppt Salton Sea water, but all larvae died. Orangemouth corvina (*Cynoscion xanthulus*) when acclimated to 35-40 ppt spawned successfully when injected with leutinizing hormone-releasing hormone "a" (LH-RHa) but fish acclimated to 45-50 ppt failed to spawn even when induced. Simmons (1957) found croakers in Laguna Madre, TX tolerated 70 ppt but did not spawn.

Mitsui et al. (1991b) sampled 11 Salton Sea stations over 3 years enumerating late egg and early larval stages of orangemouth corvina (*Cynoscion xanthulus*), bairdiella (*Bairdiella icistia*) and sargo (*Anisotremus davidsoni*). Eggs and larval numbers declined precipitously as the Sea's salinity increased from 38 to 44 ppt 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 frequent lake turnovers that combines with high and low temperature stresses. There is also strong circumstantial evidence implicating toxic algae in fish mortality events. Parasitic dinoflagellates have been found attached to tilapia gills (S. Hurlbert, pers. communication). 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. The current status of the piscivorous predators is unknown; but anglers reported higher catches in 1997-98; possibly due to the higher than normal rainfall experienced in the Imperial Valley due to El Nino. Is there a correlation between freshwater inputs and fish spawning and recruitment intensities in the Sea?

From field experience, 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 brackishwater delta areas are to the fish community and fishery in the Sea itself. If it is found that the majority of fish recruitment to occurs in the rivers and deltas, and that juvenile recruitment occurs by migration to the 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. Knowledge of fish biology and fish population dynamics is essential for any evaluation of management options of the Salton Sea fishery.

Fish Biology

Orangemouth Corvina (Cynoscion xanthulus, Family Sciaenidae)

Over the years orangemouth corvina has been 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 at a rate of 1.88 fish per angler-hour (Black 1974).

The orangemouth corvina population in the Salton Sea results from a very small founder population of only 59 individuals (Whitney 1961 [in Walker et al. 1961], Table 1). Larger founder stocks of the shortfin corvina (> 1,000 individuals) were seeded (Table 1). Shortfin corvina (*C. parvpinnis*) were reported as abundant in the Sea in the 1950's (Whitney 1961 [in Walker et al. 1961]), but no recent data exist on the status and relative abundances of the two closely related species (which are separated meristically by the shape of the caudal fin - in the orangemouth it's pointed – or slightly forked in the shortfin (Roedel 1953)). Genetic bottlenecks due to the restricted size of founder stocks of orangemouth corvina could be the reason why Whitney (1961 [in Walker et al. 1961]) reported "a fairly high percentage of abnormal individuals occurred in the population of orangemouth corvina in the Salton Sea".

Adult corvinas are wide-ranging predators and the adults inhabit both the pelagic and nearshore areas of the Sea.

Corvina grow very rapidly in the Sea in comparison with other croakers (Blake and Blake 1981; Warburton 1969). Maximum reported size is 32 pounds (Hulquist 1970).

Most sciaenids migrate offshore to spawn (Moe 1972). However, a closely related species *C. nebulosus* spawns within estuaries (Gunter 1945; Tabb 1966). In the Salton Sea, Matsui et al. (1991b) found an extended corvina spawning season from April to August. Whitney (1961 in Walker et al. 1961) hypothesized that physical oceanographic conditions in the Salton Sea affected corvina maturation and spawning, stating that, "stable summer conditions are important for sexual maturation". Whitney (1961 [in Walker et al. 1961]) reported that corvina spawned from summer into early fall, which agrees with results of ichthyoplankton tows of Mitsui et al. (1991b) who found larval corvina present in the Sea from July to October.

Fish and Cummings (1972) reported results from a hydrophone placed 8 km offshore in the middle of the northern basin at the deepest point in the Sea. They found an unusually quiet winter period followed by a huge increase in sound. They mention the increase in underwater sound was "the greatest sustained increase in underwater ambient noise level yet reported for any natural cause in either fresh or salt water" in spring" (Fish and Cummings 1972). They attributed the increases to be coincident with the peak of the corvina breeding season. Prentice et al. (1985) found orangemouth corvina males in the lab dramatically increased their drumming and courtship behaviors, then began to spermiate at water temperatures above 28°C and photoperiods greater than 10 hours light. Anglers reported fall and spring as the best sporting seasons for corvina (1997-98, personal communications). Whitney 1961 (in Walker et al. 1961) reported that the most successful corvina fishing was in the "vicinity of the mouth of the former Alamo River".

A 1970 California Fish and Game report estimated the corvina population in the Sea at one to three million fish (Hulquist 1970).

***Bairdiella* (Bairdiella icistia, Family Sciaenidae)**

Bairdiella species inhabit primarily shallow water estuarine areas (Johnson 1978). The Salton Sea fish, (*Bairdiella icistia*), is a common resident in inshore and littoral zone areas of the Sea. Bairdiella are small, rarely reaching over 0.5 kg maximum size, and are unimportant as gamefish. They have, however, been hypothesized as being important forage fish for the corvinas. The Salton Sea population is the result of only 67 fish introduced in 1950-51 (Table 1). Walker et al. (1961, p. 137-151) give descriptions of many types of different abnormalities of bairdiella caught in the Salton Sea. Many of these deformities could be the result of the small size of the founder population.

There is relatively little recent research on spawning of the bairdiella, 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).

Bairdiella reportedly mature in 1-2 years depending upon environmental conditions – with maturation time closely related to the abundances of pile worms (Walker et al. 1961, p. 114). Bairdiella are annual spawners with peak spawning periods in the Spring. Welsh and Breder (1923) found a peak spawning time of May in North Carolina for the closely-related Atlantic croaker. In the Salton Sea, Walker et al. (1961) found a peak spawning period of mid-May at about 73°F water temperature. Bairdiella exhibit a strong nearshore schooling behavior then migrate to deeper waters as adults.

The actual spawning areas of bairdiella in the Salton Sea are unknown, but it is expected to be in the offshore pelagic waters like most Sciaenids. However, a closely related sciaenid, *B. chrysoura* is known to spawn in estuaries (Gunter 1945).

Walker et al. (1961) reported that bairdiella have distinct inshore/offshore portions of their life history. Bairdiella move to deep water in late winter (Jan.-Feb.) then migrate to inshore areas in March-April and are reported to inhabit inshore areas until late summer. Fishermen report an increase in incidental catches during summer. Bairdiella are reported to be more active at the surface at night in both inshore and offshore areas because of the greater availability of their food (Walker et al. 1961). Pile worms spawn at dusk with free-swimming stages more abundant during dark periods. They reported that *Neanthes* (pile worms) were "the staple food item for all but the very young fish" (Walker et al. 1961, p. 156).

Further research on bairdiella spawning areas and migrations is important. If it is found, for example, that distinct pelagic spawning grounds exist; and that juvenile recruitment to the few nearshore coves/bays or the estuarine areas is important; these areas might be suitable sites for targeted fish conservation plans. Many estuarine-dependent fishes such as the starry flounder (*Platichthys stellatus*) show higher abundances in years when there are higher freshwater flows through estuaries (Moyle and Cech 1996).

The Salton Sea bairdiella has a high salinity tolerance. A related sciaenid, *Bairdiella chrysura,* has been found to grow well at 45 ppt in Laguna Madre, TX (Simmons 1957).

Many observers since the mid-1950's have reported extensive mortalities of bairdiella. Walker et al. (1961) attributed this to food shortages and starvation since many fish were "literally made of skin and bones" (page 160). They hypothesized that summer stratification and anoxic bottom waters killed the pile worms (their principal food) in the deeper water pelagic areas.

Sargo (Anisotremus davidsoni, Family Pristipomatidae)

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 bairdiella (reaching 2 kg) and are an important but declining gamefish in the Salton Sea. It is assumed this fish is also prey for the corvinas, but very little is known of their diet in the Sea (Walker et al. 1961).

Amazingly, the existing population of sargo in the Sea results from a single plant of just 65 fish from the Gulf of California in 1951 (Table 1). On December 6, 1956, a biologist recovered the first sargo from the Sea (Appendix 1). Fishermen in 1997-98 reported that many sargo were being caught with deformed bodies or incomplete gill flaps which may be one sign of a population falling apart due to genetic inbreeding due to the small size of the initial founder stocks. In addition, US Fish and Wildlife personnel in the southern part of the Sea had never seen a sargo over their years of setting experimental gill nets (K. Sturm, pers. communication).

The Tilapias in the Salton Sea

Tilapias are precocious mouthbrooders that migrate long distances and disperse their progeny widely beyond the area of initial introduction. As a result, the tilapias can quickly overpopulate suitable environments, impacting native fishes and habitats (Courtney 1997). Tilapias have been blamed for the decline of the endangered desert pupfish *(Cyprinodon macularis)*, the only native fish species known to inhabit the Salton Sea and its drains (Schoenherr, 1988). The Salton Sea tilapia has been identified as a hybrid Mozambique tilapia (*Oreochromis* spp.) (Costa-Pierce and Doyle 1997), and is unique in having a high heterozygosity in comparison with other imported tilapias, possibly due to its successful adaptation to the stressful environment of the Sea over 30+ generations (Costa-Pierce 1997). The Mozambique tilapia has a wide salinity tolerance (0-50 ppt, Watanabe 1997), but dies when water temperatures reach 5-10°C (Wohlfarth and Hulata 1983).

Studies of both Southern California and Arizona tilapias have been conducted using systematic (taxonomic) nomenclature based upon external color and appearance, distinctive spawning behaviors, and morphometric and meristic measurements (Minckley 1973; Barrett 1983; Lopez and Ulmer 1983). Barrett (1983) completed an extensive morphometric and meristic study of tilapias in the lower Colorado River basin. He reported that *Oreochromis mossambicus* and *Oreochromis urolepis hornorum* have hybridized to the extent that they are essentially one reproducing population. He also reported that *Oreochromis aureus* (the blue tilapia) was the "dominant cichlid in Arizona" and that "recent evidence indicated that *Oreochromis niloticus* (the Nile tilapia) genes were also present".

Anywhere in the tropical and subtropical aquatic environment where large scale introductions of exotic tilapias occur, there is a risk of interbreeding and hybridization among populations that may be morphologically and meristically distinct in the wild but reproductively compatible (due to their relatively "recent" divergence). Where a mixture of tilapia species have been stocked, reproductively viable hybrids have resulted, and the use of external characterizations for species determinations is fruitless (Wohlfarth and Hulata 1983; Pullin 1988).

Zill's Tilapia (Tilapia zillii) *in the Salton Sea*

Tilapia zillii are native to a large swath of north central sub-Saharan Africa from Senegal in West Africa through northern Zaire and the Sudan, and north into the Nile River basin and Asia Minor. Its distribution extends south to the central African rainforest and around Kisangani, Zaire where it meets the distribution of another closely-related substrate spawner, *Tilapia rendalli*. It is believed that *T. zillii* and *T. rendalli* were the same species until recent time when the 'drying' of Africa occurred and they became separated into a 'northern' form (*T. zillii*) and a 'southern' form (*T. rendalli*) (Trewavas 1983).

T. zillii are noted for their hardiness, having wide temperature (7-42°C) and salinity tolerances (upwards of 45°/oo) (Chervinski 1971). For example, during a sampling in the southern Salton Sea (a lagoon/wetland near Obsidian Butte) on March 6, 1995, I sampled *T. zillii* that had already spawned; the water temperature that day was 15°C and salinity 40°/oo.

T. zillii were imported to Southern California due to their ability to feed on nuisance aquatic weeds and other macrophytes which were clogging irrigation canals. It was hoped *T. zillii* could be a biological control agent to offset the high costs of mechanical and chemical controls (Hauser 1975a,b). *T. zillii* was first imported to California (University of California Davis and University of California Riverside [UCR]) in the 1960's from the Arizona Cooperative Fishery Unit (ACFU), University of Arizona, but these died out (Legner and Pelsue 1977). Another permit was issued on October 15, 1971 to import 150 *T. zillii* from the ACFU to the Division of Biological Control, UCR. Legner and Fisher (1980) reported the *T. zillii* in Arizona originated from just 3 male/female pairs imported from Israel in 1965.

Hauser (1977) found that at water temperatures below 16°C *T. zillii* became lethargic and lost equilibrium and were extremely vulnerable to predators and disease. In Imperial County irrigation canals, mortalities were observed in December-January and the fish were frequently stressed by low temperature from mid-December to March (Hauser 1974, 1977). Survival of the fish in Southern California occurred only in areas where warm seepage water or geothermal waters created thermal refugia for overwintering.

T. zillii have high fecundity and frequent spawning periodicities; a slow overall growth rate to a small maximum size; and a narrow temperature optimum for good growth. Fecundity in *T. zillii* is 10-20 times higher than mouthbrooding tilapias. Lowe-McConnell (1955) reported that 10 mixed sex *T. zillii* of just 2.6-4.8 cm total length produced 9,000 progeny in 9 months. Platt and Hauser (1978) found that at water temperatures less than 20°C, feeding rates on macrophytes and growth rates of *T. zillii* approached zero. Hauser (1977) concluded that due to its thermophilic nature, *T. zillii* would not be self-sustaining in Southern California irrigation ditches and canals without thermal refugia, and that any effective biological control of aquatic weeds in irrigation canals would require expensive annual restocking.

T. zillii have been implicated in the decline of the desert pupfish in the Salton Sea (Schoenherr 1988). In addition, *T. zillii* have been collected from Southern California coastal waters near a power plant off Huntington Beach, and in Upper Newport Bay in Orange County (Knaggs 1976). No known recent marine collections have been made. Cardone (in press) states that *T. zillii* has "not established breeding populations in coastal marine and estuarine waters".

The Mozambique Tilapia **(Oreochromis mossambicus)** *in the Salton Sea*

The Mozambique tilapia and the common carp are likely the two most widely spread exotic aquatic animals in the World. From the 1930-70's the Mozambique tilapia was spread throughout the world by fisheries biologists and managers for the control of nuisance aquatic weeds and insect pests, and for aquaculture and fisheries development.

Arizona imported its *Oreochromis mossambicus* stock from Hawaii early 1961. By October 1961, more than 27,000 progeny of the original Hawaii fish were produced in Arizona. These were stocked into the Gila Bend Canal. In January 1963, an unknown number of this stock was also released into the Yuma Canal (Barrett 1983). In 1962, in Arizona, McConnell (1966) began experiments with the "Malacca hybrids", importing a second stock of Mozambique tilapia from the Tishomingo (Oklahoma) National Fish Hatchery, and also bringing an unknown number of *Oreochromis urolepis hornorum* from Malacca, Malaysia (Hickling 1960). Reproductively viable hybrids of these two species were released widely to canals, dams, ponds and reservoirs in Arizona from 1965-1981 (Barrett 1983).

Hickling (1960) pioneered the "all male hybrid progeny" cross of a male *Oreochromis urolepis hornorum* (then called the "Zanzibar tilapia") and a female *O. mossambicus* ("Java tilapia") which gained worldwide attention. In December 1963, the California Department of Fish and Game (CDFG) obtained "8 males of the Zanzibar strain, plus 50 male and female fingerlings, and 6 adult males of the Java strain" from the Arizona Cooperative Fishery Unit (ACFU) for experimental use at the CDFG station in Chino, CA (Outdoor California 1964; St. Amant 1966). The fish were authorized for use as a biological control of aquatic weeds and insects in irrigation systems of Southern California on November 5, 1971; and the Mozambique tilapia and hybrids were officially stocked in Southern California thereafter.

By 1968, tilapias had been found in some 15 miles of irrigation canals (the Araz Drain and Reservation Main Drain) near Bard in Imperial County, CA (Hoover and St. Amant 1970). Since tilapia were not legally stocked into Southern California waters until 1971 (Pelzman 1973), these tilapias likely represented rapid colonization of California waters from 1961-63 stockings of Arizona tilapias in irrigation canals connected to California.

In a separate development, in January 1964, Mozambique tilapia were discovered illegally in 0.25 acre pond at a private tropical fish farm near the "Hot Mineral Spa" (Niland, CA) (St. Amant 1965). The pond was poisoned with rotenone and over 5,000 tilapia removed by the CDFG. However, in June 1965, CDFG workers observed a breeding population had reestablished in a drainage ditch choked with emergent macrophytes that was connected to the Salton Sea.

The Wami River Tilapia* (Oreochromis urolepis hornorum) *in the Salton Sea

The Wami River tilapia originates from the Wami River, in eastern Tanzania. *Oreochromis urolepis* has been found in four coastal locations in Tanzania, but the Wami River subspecies, *Oreochromis urolepis hornorum*, is known only from the Wami River (Trewavas 1983).

The Wami River tilapia is famous for its role as the male parental stock used with female *Oreochromis mossambicus* to produce "all male" hybrid progeny (Hickling 1960). An all male hybrid tilapia that could not reproduce excited worldwide interest. As a result, the Wami River tilapia was exported worldwide for aquaculture development and environmental control purposes.

McConnell (1965, 1966) began experimentation with the "Malacca hybrid" at the Arizona Cooperative Fisheries Unit by importing in 1962 an unknown number of Wami River tilapia (*O. u. hornorum*) from Malaysia. However, there were few controls taken to prevent mixing of parental stocks with the reproductively-viable hybrid progeny. As a result, uncontrolled hybridization and backcrosses occurred (Barrett 1983). Stated Barrett (1983, p. 5), "Both parental species and reciprocal hybrids were introduced into ponds to assess their survivorship and angler susceptibility".

Hybrids of *Oreochromis mossambicus* x *Oreochromis urolepis hornorum* were stocked extensively into the Salton Basin by Fish and Game officials to the point that it is unlikely that pure species lines of *Oreochromis urolepis hornorum* (the Wami River tilapia) or *O. mossambicus* exist. Costa-Pierce and Doyle (1997) reported that divergence from parental material in the tilapias of the Salton Sea has occurred. DNA marker data showed a distinct hybrid ecotype of *Oreochromis mossambicus* (likely a hybrid with *O. u. hornorum*) but of unusually high heterozygosity existed in the Salton Sea, likely due to the fish's adaptation to the unusual and stressful environment over 30+ generations (Costa-Pierce 1997). This finding is significant since isolated stocks of tilapias of high heterozygosity with unusual temperature and salinity tolerances could be of valuable use to tilapia aquaculture breeding programs worldwide.

The salinity tolerances of *O. u. hornorum* are little studied. Legner and Pelsue (1977) refer to large reproducing populations of "*T. hornorum*" in Coyote Creek, Los Angeles due to continuous power plant waste heat discharge into the creek at 85°F year round. He states, "Daily tidal washes of the site favor the persistence of this fish over the other two species (e.g. *O. mossambicus* and *T. zillii*) which are less interhaline (sic)". Talbot and Newell (1957) reported *O. u. hornorum* grow and reproduce in 33-39 ppt water. One aquaculture company in Niland, CA has selected tilapias from the Salton Sea for broodstock and reports persistence of a grayish-brownish tilapia fitting theTrewavas (1983) external characterization of *O. u. hornorum.*

Essential Fish Habitats

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

1. the freshwater areas of the New and Alamo Rivers,
2. the brackishwater areas of the New and Alamo Rivers,
3. shoreline or littoral zone areas and springs in the Sea,
4. pelagic areas.

Preliminary characterization of candidate EFH areas of the Salton Sea has been done in 1997-98. The Salton Sea has extensive riverine areas of 0-5 ppt salinity with dense riparian vegetation extending into the water. Sample netting in these areas in the Spring 1998 caught carp, mosquitofish, and catfish.

Littoral and open water areas are numerically dominated by tilapia. Tilapia spawning aggregations, called "arenas" (Trewavas 1983) were noted along the southern shoreline littoral areas near the influence of rivers. In a recent fly over by the military looking for a downed plane in the Salton Sea, extensive nesting areas were noticeable in aerial photographs of the open water areas of the southern basin of the Sea.

Brackishwater salinities from 10-30 ppt exist from 500 m to 1 km offshore of the Alamo and New Rivers. It is unknown what role if any these areas play in ensuring the sustainability of the fish community in the Salton Sea. Croakers normally spawn in pelagic areas and juveniles migrate into estuaries. Walker et al. (1961) reported that adult corvina congregated near the mouths of the freshwater rivers and other freshwater inlets into the Salton Sea, but it was unknown if these groupings were for spawning purposes or to seek waters with higher oxygen or water quality.

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Appendix 1

Fishery Highlights of Salton Sea NWR Reports

May 1940: "The one species that thrives in apparently good numbers is the mullet. An effort to introduce striped bass several years ago has evidently met with failure as none of this species has been caught or seen since."

October 1940: "Mullet from the Salton Sea are working up the Alamo and New Rivers in considerable numbers apparently to spawn. Many of these fish are stranded in water that is too shallow or jump out on silt bars where they die. Many turkey vultures are feasting on their remains."

October 1941: "A great number of mullet have been stranded or caught in shallow ponds where the [Alamo] river has been flowing...Pelicans and egrets have been feasting on the smaller species to be found in the shallow water."

Sept-Dec 1947: "In early October one fisherman took one 21 pound mullet from the Salton Sea. This appears to be somewhat of a large specimen since the average large mullet reported ranges from 8 to 12 pounds."

Sept-Dec 1948: "In mid-October mullet started their annual run up the Alamo River and a few open drainage ditches. Spawning to our knowledge never has actually taken place in the muddy stream and the headwaters are impossible for the fish to reach with dams and obstructions along the way to block upstream passage....

The run appeared over by early November...On December 15th commercial fishermen, active here for over 35 years went out in quest of mullet. One fisherman sold 25 tons through December...The best record is 1918 when a total of 91,000 pounds were taken by commercial fishermen with thousand foot nets."

Sept-Dec 1950: "Commercial fishing this season was reported to be only fair. Common carp were more in demand in Los Angeles markets than mullet according to one commercial fisherman."

May-Aug 1951: "When the New River was diverted the resultant ponds left a large number of fish stranded. Rescue efforts resulted in obtaining a large number of mullet for transfer back to the river. Most didn't survive the handling..."

Sept-Dec 1951: "The usual fall spawning run of mullet up the New and Alamo Rivers was not so pronounced as in previous years...

Three years ago CDFG transported a tank load of anchovies, sea bass, halibut and other species from San Felipe. This winter a commercial fisherman drawing up his mullet nets took a sea bass. This represents the first report or indication that any of the original stock still survived."

Jan-Apr 1952: "The take of mullet by commercial fishermen provides practically nothing to write about. It can be summed up thus - very light catch."

Sept-Dec 1952: "The fall spawning of mullet was perhaps the poorest in several years. No runs were reported or noted in the New River and at the Alamo River very few came within reach of the fishermen with their snag hooks, nets, etc. During late November and December, dead mullet were observed along the shores of the Sea. A one mile sample area...turned up 71 dead fish averaging about 18 inches in length. This loss of mullet is an annual event that has never been explained by ichthyologists. Some suspect bombing, night strafing of targets under aerial flares, or algal-induced suffocation during periods of calm weather. Considering the immensity of the Sea and the relatively low population of mullet as reported by commercial fishermen, it would appear that none of the mentioned causes would be of importance."

Jan-Apr 1953: "During March and April fishermen scouted the south half of the Sea constantly and found mullet in schools from the mouth of the New River on the south around to Truck Haven on the northwest side. A number of loads containing 1500 to 2000 fish were hauled to Los Angeles.

A large number of 'glass-eyed' mullet were again observed during fishing operations. It is believed the condition is becoming more prevalent each year."

May-Aug 1953: "Personnel from CDFG planted 3500 Japanese littleneck clams, 20,000 Japanese seed oysters, and many southern California mussels and clams during May. Within one week clams were reported to be dying but mussels and oysters were doing well.

...large numbers of orange-mouth white sea bass were...planted in the Sea...to be used as a control measure for the thousands of Bairdiella white sea bass which have now multiplied to such numbers that they are exceeding the food supply and becoming stunted. On April 10 one sweep of a 100-foot net near Salton Sea Beach yielded 10,000 of these fishes ranging in size from 4.5 to six inches in size, many of which were about to spawn. The overabundance of these small fish has made serious inroads upon the limited supply of the native marine pile worms.

Anchovies and anchovettas planted at the same time as the Bairdiella bass are reported to be thriving."

Sept-Dec 1953: "The fall run of mullet up the rivers was more active and marked with larger numbers of fish than in the past six years. In mid-October the fish were actively running in the Alamo River...

By early November the run was very active and between hunters and fishermen it became almost impossible to get to the delta except 'afoot. By that time fish were active on the New River also, but to our knowledge on one bothered to catch them. We asked two campers how many fish they would estimate were taken from the Alamo. From the reply we calculated the public could have hauled off about 9000 fish in the approximate 45 days of running.

There will be no commercial season at the Salton Sea this year to favor the plantings from the Gulf of California."

May-Aug 1954: "Countless thousands upon thousands of fish...continue to die apparently from suffocation, high temperatures and lack of food. As early as June the sea bass, stunted with large heads and knife-shaped bodies, started to belly-up and come floating shoreward. With the myriad numbers of this species...we fear for the existence of the pile worms which were reported none too abundant.

A number of mullet, scattered over a wide area, covering the south end of the Sea, likewise died as the water temperatures rose higher and higher."

Sept-Dec 1954: "The death of introduced marine fish...continued...From the air four distinct wind rows of dead fish could be seen and followed from Wister drain on the southeast shore of the Sea to Salton Sea Beach on the west.

Ten sample strips covered in October revealed about 136 fish every 10 feet of shoreline or 71,808 fish per mile - around 3,000,000 fish along the 40-odd miles of shoreline where they were thickest. The remaining 40 miles of shoreline contained only about one-fourth as many per mile...

Mullet runs were noted again this year starting about mid-October, however very few actually entered either the New or Alamo Rivers...From the air schools of several hundred could be seen out in deeper waters."

Jan-Apr 1955: "On February 16th it was noted that fish were still dying and floating shoreward on the Sea. From Mullet Island north and around the shoreline to the southwest edge of the sea small floating fish could be seen. Areas of most prominence were near Wister drain, the salt mine, Salton Sea Beach and about 3 miles of the northwest shoreline."

May-Aug 1955: "The usual number of dead mullet were seen floating on the Sea during the August 25th aerial survey. It is estimated that about 15 were on the water. Mainly these fish were found around the Alamo River delta and at the extreme north end of the Sea.

Northwest of Unit I, along the south side of the Sea we found more dead and dying croakers which were scattered so widely on the Sea last summer. Either the fish are surviving better or they have nearly all perished."

Sept-Dec 1955: "Dead and dying small corvina continue to float shoreward from the Sea.

Mullet started spawning, or at least were first noted moving up the Alamo River, November 3. On November 8 large schools of mullet were noted in the Sea around dead and submerged tamarisk growths west of the New River delta.

Sometime in February 6000 threadfin shad were introduced into Lake Havasu...In nine months the species has moved hundreds of miles to the Salton Sea where it is reported to be reproducing into the 'blue millions'."

May-Aug 1956: "Following is a compilation of several news releases in the Brawley News. Twenty corvina, including one weighing 16 pounds 9 ounces, have recently been netted by CDFG. Rapid growth was indicated by the fact that the big fellow was only three years old, while the one year fish average 3 pounds.

On June 24, Richard Easton of Westmorland became the first person to make a verified hook-and-line catch of a Salton Sea corvina. His history-making catch was made at the mouth of Salton Creek using shrimp for bait."

Sept-Dec 1956: "Dr. Boyd Walker reported that the Salton Sea was 'headed for certain fame as a deep sea fishery sports mecca.' The boast followed a gill-net cast which yielded more than 100 corvina weighing up to 15 pounds.

The main problem now seems to be in promoting sportfishing. It has been next to impossible to interest anglers in the idea of trying their luck on such a vast, unknown body of water. On December 2 a fishing derby was held and reports indicated a poor turnout of sportsmen with negative results for all.

During October biologists recovered 52 orangemouth corvina at the delta of the Alamo River in a 12-hour setting of one 300-foot gill net...They varied from 1.5 to 8 pounds in size. Scale studies indicate growth of approximately one pound the first year and three the second. Largest weighed nearly 17 pounds.

On December 6 biologist recovered the first sargo. The Salton Sea is now open to year-round fishing with no limit established."

Jan-Apr 1957: "Corvina were found abundant and believed to have spawned in February. Since 1948, when 1000 were introduced, it is estimated 65,000 now inhabit the Sea"

Jan-Apr 1959: "Excellent catches of orangemouth corvina have been made during the period. The writer and Mr. Leo Cox caught seven on May 10. Their combined weight was 45.75 pounds.

May-Aug 1959: "Early in August a record-breaking corvina weighing over 28 pounds was reported to have been caught on the north end of the Sea."

Jan-Apr 1960: "The Salton Sea continued to yield excellent catches of orangemouth corvina. This was particularly true of the Alamo River delta and off the dock at the AEC installation on the west side of the Sea. Largest fish caught was...18 pounds 3 ounces.

May-Aug 1960: "The largest corvina caught to date was taken...on May 18. It weighted 32.5 pounds...Many six-fish limits of 4-15 pound corvina were taken during this period."

Sept-Dec 1960: "Many limits of 6-12 pound corvina were taken through the first two weeks of October.

On December 8, California Fish and Game, with the assistance of the Marine Corps from Yuma, dropped 220 car bodies opposite the old Salt Works. It is hoped they will provide shelter for the corvina."

Jan-Apr 1961: "Corvina fishing during the latter part of the period was excellent. Many 9-15 pounders were brought in early in April. A 22 pound corvina was landed just off the mouth of the Alamo River while another was taken near the state park at North Shore."

May-Aug 1961: "completion of the Red Hill boat landing...

Limits of 6 corvina weighing 4-8 pounds were checked in by state wardens most every day of the period. Several fish weighing 17-18 pounds were caught southwest of Red Hill."

Sept-Dec 1961: "...anglers took to the Sea and were rewarded with nice catches of 4-5 pound corvina and half-pound sargo."

Jan-Apr 1962: "Corvina fishing continued excellent throughout the period. Several 15-17 pounders were landed late in the period...corvina and sargo limits may be increased next year."

May-Aug 1962: "Corvina fishing continues to be excellent and is even improving with bigger fish being caught each year...Many of the irrigation ditches contain a black strain of sailfin molly which is raised commercially by breeder near Niland."

Sept-Dec 1962: "There have been numerous reports...of the poor condition of the corvina, all of which appear to be undernourished"

Jan-Apr 1963: "Corvina fishing began to pick up in April as the weather warmed up with no large fish being taken. The limit on sargo has been raised to 25 indicating an increase in this species"

May-Aug 1963: "Corvina fishing continues to be excellent and is even improving with bigger fish being caught each year...we noted schools of large mullet jumping out of the water."

Sept-Dec 1963: "It seems very few people know or are aware of the possibility of the Salton Sea elevations declining in the near future...When the Sea begins to decline and the fishing does likewise there will be much hue and cry to bring more water into Salton Sea and maintain a stable elevation."

1964: "Corvina fishing continues to be good, although the fish are getting smaller. The limit has been six but will be nine in the 1965 season. Apparently over crowding has caused some stunting of growth."

1965: "Fishing in the Salton Sea is staying at the high level of the last three years with the limit on corvina raised from 6 to 9. The sargo perch is the next most important game fish and the gulf croaker has also been added to the list of game fish in the Sea."

1966: "Small tropical species, particularly mollies, are abundant in drain ditches but are of little importance...Reported catches have been good for corvina throughout the year, but sargo, perch and mullet fishing have been poor."

1967: "This year the fishing for corvina was not as successful as in the past."

1968: "During the year the Bureau finally made it legal to angle on the thousands of acres of refuge land covered by the Salton Sea."

1969: "The fish, mainly corvina, croaker, and sargo, are still holding their own against the rising salt concentration...but we wonder how much longer they can hold out against the rising salinity."

1970: "Corvina and croaker fishing was best during the hottest part of the year."

1971: "Corvina, croaker, mullet, and sargo provide excellent sport fishing. Most angling is for corvina. The limit on corvina is 9 fish, no limit on croaker, mullet, or sargo. Fishing is usually best during the hottest months of the year."

1972: "Corvina, sargo and croaker populations are all in good shape."

1973: "Saltwater fishing is going downhill rapidly...We have no direct control over the problem and the fisheries biologists say that the resource will no longer be able to survive if the salinity continues to increase. Present salinity is approaching 35 ppt and corvina will not be able to reproduce after 1975."

1974: "Over one-half million fish, croaker and sargo, were killed July 4-5 due to low dissolved oxygen and high water temperatures. During spring 1974, CDFG biologists found encouraging evidence that corvina are continuing to spawn despite the increasing salinity. However, if it continues to increase to 40 ppt the fishery may be in serious danger."

1989: "Increased salinity combined with below normal winter temperatures caused a major die-off of forage fish during 1987. The result of this die-off has been a dramatic decline in the fishery. Subsequently avifauna has also been impacted."

1993: "Two significant fish kills occurred on the refuge during November and December. Both incidents occurred in the Pumice Drain. An estimated 3000-5000 fish (mostly carp and tilapia) were killed in November and 800-1000 in December. The Carlsbad field office...offered no assistance in determining the cause...The cause of the fish kills remains unknown."

Table 1

Known Fish Introductions into the Salton Sea *

Date	Number	Species	Common Name**	Where Acquired
20 Oct 1929	900	*Roccus saxatilis*	striped bass	Tracy, California
24 Oct 1929	1,500	*Roccus saxatilis*	striped bass	Tracy, California
21 Oct 1930	1,800	*Roccus saxatilis*	striped bass	San Francisco Bay
13 Nov 1930	500	*Gillichthys mirabilis*	longjaw mudsucker	San Diego Bay
1934	15,000	*Oncorhynchus kisutch*	silver salmon	Forest Home Hatchery
2 Oct 1948	43	*Anchoa mundeoloides*	anchovy	Guaymas
23 Dec 1948	1,000	*Cetengraulis mysticetus*	anchoveta	San Diego (tuna boat)
	12	*Caranx caballus*	green jack	San Diego (tuna boat)
10 May 1950	5,000	*Cetengraulis mysticetus*	anchoveta	San Felipe
12 May 1950	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 megalops*	croaker	San Felipe
	57	*Bairdiella icistius*	bairdiella	San Felipe
14 Dec 1950	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 Dec 1950	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 Mar 1951	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 Mar 1951	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
	4	*Paralichthys aestuarius*	halibut	San Felipe
	140	*Hypsopsetta guttulata*	diamond turbot	San Felipe
		Etropus crossotus	flounder	San Felipe
	65	*Anisotremus davidsoni*	sargo	San Felipe
	12	*Paralabrax maculato-fasciatus*	spotted bass	San Felipe
	7	*Girella simplicidens*	opaleye	San Felipe
	2	*Halichoeres(?)*	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 icistius*	bairdiella	San Felipe
	2	*Menticirrhus nasus*	corbina	San Felipe
	1	*Eucinostomus argenteus*	spotfin mojarra	San Felipe
	63	*Gillichthys seta*	mudsucker	San Felipe
14 Dec 1951	72	*Colpichthys regis*	silverside	San Felipe
11 May 1953	6,000	*Engraulis mordax*	northern anchovy	Los Angeles Harbor
13 May 1953	44	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	35	*Micropogon megalops*	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 May 1953	50	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	38	*Cynoscion xanthulus*	orangemouth corvina	San Felipe
	4	*Menticirrhus undulatus*	California corbina	San Felipe
10 Mar 1955	3,000	*Cetengraulis mysticetus*	anchoveta	Gulf of California
10-11 May 1955	114	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	4	*Cynoscion xanthulus*	orangemouth corvina	San Felipe
Apr-May 1956	8	*Cynoscion macdonaldi*	totuava	San Felipe
	1	*Cynoscion othonopterus*	scalyfin corvina	San Felipe
	1,545	*Cynoscion parvipinnis*	shortfin corvina	San Felipe
	59	*Cynoscion xanthulus*	orangemouth corvina	San Felipe

* Prepared by John E. Fitch.
** Common family name used when no specific common name is available.