The Aquatic Ecosystem of the Salton Sea

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Introduction

The water entering the Salton Sea contains high levels of nitrogen and phosphorous. These are the micronutrients which normally limit the productivity of inland water bodies. Tables 1 and 2 compare the average nutrient concentration of Salton Sea water with levels in other water bodies classified by productivity. The Salton Sea clearly rates at the upper end of eutrophic, i.e. highly productive, systems.

This high productivity is one of the attractive features of the Salton Sea. It is responsible for the Sea's popularity with both migrating birds and sport anglers. The path of productivity within the Sea however, is not always straightforward. The following is a brief review of what is known about the non-fish biota of the Salton Sea followed by a discussion of the trophic (feeding) interrelations.

Phytoplankton

The immediate beneficiaries of the high nutrient input to the Salton Sea are the phytoplankton. About a dozen species of algae have been identified from the Sea (Carpelan 1958, 1961; Arnal 1961).

Algae in the Sea include diatoms, algae which produce silicon cases (frustules), and a few green algae. The dominant group, particularly in summer however, is dinoflagellates, motile algae equipped with two flagella. Included in this group, and recorded from the Sea, are *Gymnodinium* and *Gonyaulax*, the two genera responsible for most "red tides" in coastal marine waters. Dinoflagellates utilize red pigments (xanthophylls), in addition to chlorophyll, for photosynthesis; this partially explains the sometimes dark color of the Sea.

Table 1. Comparison of Salton Sea total phosphorous and nitrogen levels with those from lakes of recognized trophic status (mg/m^3).

	Phosphorous			Nitrogen		
Classification	Mean	Range	Salton Sea	Mean	Range	Salton Sea
Oligotrophic	8.0	3 - 18		661	307-1630	
Mesotrophic	26.7	11 - 96		753	361-1387	
Eutrophic	84.4	16 -386	345	1875	393-6100	13,700
Hypereutrophic		750-1200				

Salton Sea data from RWQCB, 1980-1992 Classification data from Wetzel (1983)

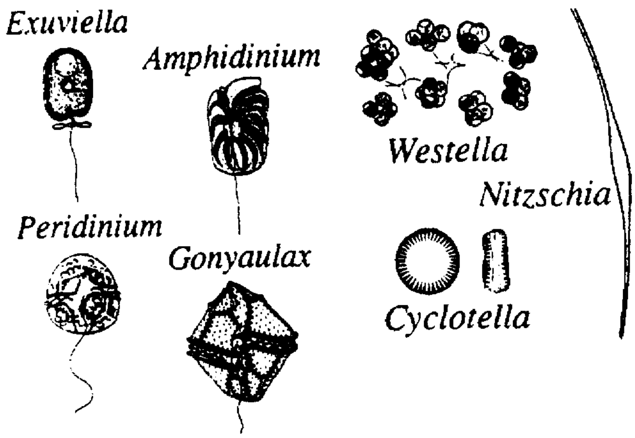

Figure 1. Examples of four dinoflagellate (left) and three other genera of algae recorded from the Salton Sea.

Foraminifera

Foraminifera are amoeba-like protozoa which secrete calcium carbonate cases (tests) with pores through which pseudopods for locomotion and feeding extend. They are characteristically marine organisms.

Foraminifera are abundant members of the benthos of the Salton Sea; over two dozen species have been recorded (Rogers 1949, Arnal 1961). They feed on bacteria and the rain of detritus (dead organic matter) from the productive plankton of the Sea.

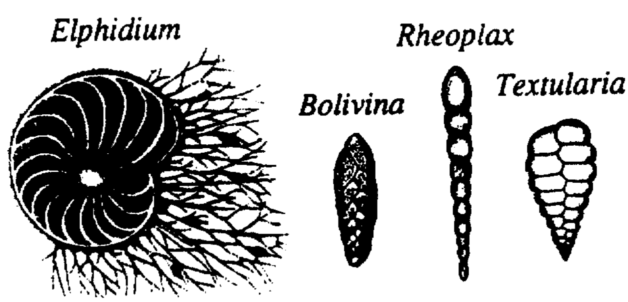

Figure 2. A live foraminiferan (left) showing the pseudopods extending through the calcium carbonate test, and the tests of three other genera recorded from the Salton Sea.

Rotifer

Rotifers are small, relatively simple, invertebrates characteristic of freshwater environments. *Brachionus plicatilis*, the species in the Salton Sea, is a medium-sized ($\lesssim$250 µm = .01 inch), completely planktonic rotifer. It is common in estuaries throughout the world. There is a large scientific literature on this species because of its value as food for fish larvae.

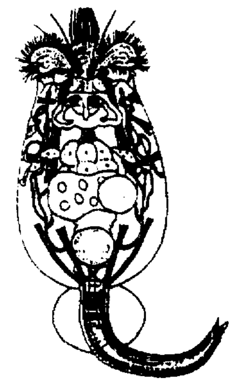

Figure 3. A female rotifer, *Brachionus plicatilis*, carrying a single egg.

Several facets of the life history of *B. plicatilis* are optimal at high temperature (Rico-Martinez and Dodson 1992, Snell 1986). *B. plicatilis* feeds most effectively on particles over 2 µm, i.e. it has only a mediocre ability to feed on bacteria so algae and protozoa are its dominant food (Vadstein et al. 1993).

Like most rotifers, *B. plicatilis* is generally parthenogenetic (females producing females) with the occasional appearance of males resulting in the sexual production of resting eggs. High salinity and temperature make production of males less likely and inhibit the hatching of resting eggs (Hino and Hirano 1984; Lubzens et al. 1980, 1985, 1993; Minkoff et al. 1983).

Epp and Winston (1977) reported that *B. plicatilis* is essentially an osmoconformer, although slightly hyperosmotic, and interpret this as an indication of marine ancestry for this species. A review of the literature led Miracle and Serra (1989)

to suggest that tolerance to high salinity increases at higher temperature. Population growth apparently ceases at 50 ppt (Pozuelo and Lubian 1993).
In the Salton Sea, *B. plicatilis* is most abundant in summer and autumn (Carpelan 1961). It is undoubtedly an important food item for the early life stage of Salton Sea fish.

Pileworm

The pileworm, *Neanthes succinea*, is a widely distributed north Atlantic species of polychaete annelid apparently introduced to the California coast when Virginia oysters were introduced into San Francisco Bay in 1869 (Carlton 1979). It tolerates salinities as low as 14 ppt (Fong 1991) and can reach 460 mm (18 inches) in length but is generally much smaller in the Salton Sea (Hartman 1936).

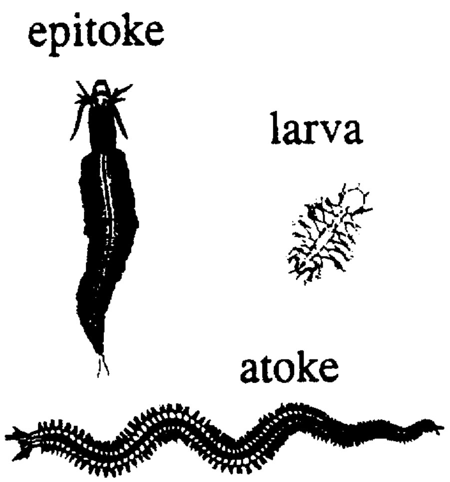

Figure 4. The three life stages of *Neanthes succinea*.

N. succinea usually constructs a U-shaped tube in the sediment. It is a deposit feeder, i.e. it ingests substrate to digest the organic fraction, and is relatively indiscriminate as to particle size (Fong 1987). *N. succinea* has a higher optimal temperature and tolerates lower oxygen levels better than related species (Kristensen 1983a, b).

In the Salton Sea, *N. succinea* occurs throughout the Sea in winter but is most abundant in mid-depth sediments where there is a confluence of high organic sediment content (which increases with depth) and sufficient oxygen (which decreases with depth). In summer, *N. succinea* disappears from the deeper areas, apparently due to low oxygen (Carpelan and Linsley 1961b). Worms are often missing their tail segments, presumably a result of feeding activity by fish when they protrude from the worm tubes.

Like many nereid worms, *N. succinea* reproduces by metamorphosing into sexually mature forms, epitokes, which then swarm, at night, at the water's surface fertilizing eggs which develop into planktonic larvae. In many species, and in other populations of *N. succinea*, swarming is an annual event synchronized by photoperiod and phases of the moon (Hardege et al. 1990, Fong 1991). In the Salton Sea, spawning occurs virtually throughout the year, although highest in spring and autumn (Carpelan and Linsley 1961b) and does not appear strongly related to lunar cycle (Carpelan and Linsley 1961a). The larval stage lasts about two weeks: worms can mature within 90 days.

Atokous (fully grown but sexually immature) *N. succinea* can tolerate salinities up to 67.5 ppt (Hanson 1972). Production of epitokes however, is depressed at 55 ppt and fertilization of eggs at 45 ppt (Kuhl and Oglesby 1979).

Barnacle

Barnacles are essentially highly modified shrimp (Darwin's description: "a shrimp in a calcareous house, standing on its head, kicking food into its mouth"). Balanus amphitrite is an western Atlantic species of barnacle which has spread throughout the world, apparently by ships, within the past century. It appeared in Hawaii in 1915, San Diego in 1921, Suez in 1924, northern Europe in 1929, and San Francisco in 1939 (Morris et al. 1980). It is now considered cosmopolitan in warm seas, particularly bays, where summer temperatures exceed the 20°C required for reproduction.

The Salton Sea population, *B. amphitrite saltonensis* (Rogers 1949), originated around 1943

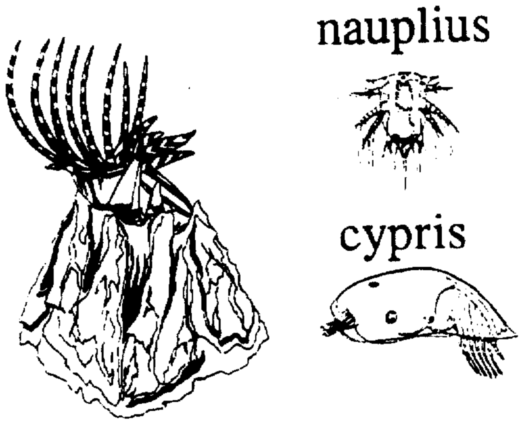

Figure 5. The three life stages of *Balanus amphitrite saltonensis*.

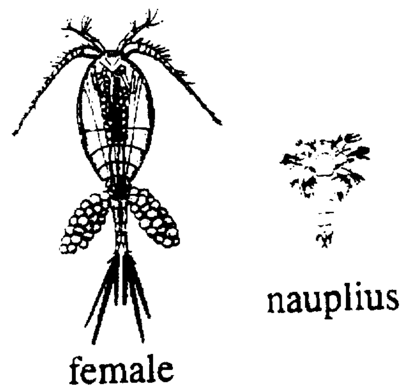

Figure 6. An adult female copepod (carrying two egg sacs) and a nauplius larva.

with barnacles transported via Navy buoys or flying boats from San Diego Bay (Hilton 1945). Flowerdew (1985) compared the genetic composition of six populations of *B. amphitrite* and recommended eliminating *B. a. saltonensis* as a subspecies, but Raimondi (1992) detected differences in larval morphology and development which remained consistent during culturing and which therefore, are probably attributable to genetic differentiation.

Like most barnacles, *B. a. saltonensis* passes through 6 naupliar larval stages and then a non-feeding cypris larval stage before settling and undergoing metamorphosis. In the Salton Sea, barnacle larvae can be found in the plankton through most of the year but predominantly in spring and early summer (Carpelan 1961).

Copepod

Copepods are small planktonic crustaceans. The copepod in the Salton Sea has been described as *Cyclops dimorphus* (Johnson 1953) and is abundant from mid-summer through autumn (Carpelan 1961). Copepods pass through six naupliar larval stages; both nauplii and adults undoubtedly serve as food for very young fish. Although some copepods are carnivorous, *C. dimorphus* in the Salton Sea apparently feeds on phytoplankton.

This copepod has recently been reconsidered as *Apocyclops dengizicus* (Dexter 1993), a species characteristic of hypersaline waters (Bayly 1972).

Discussion

Two traits stand out in this review of Salton Sea biota. First, the invertebrate fauna of the Salton Sea is, for the most part, a collection of highly successful, widely distributed, predominantly estuarine, species. It is not a simple transplant from the Gulf of California nor a highly specialized hypersaline fauna. Second, much of the seasonality common in the reproduction of marine species has been lost. This is undoubtedly an artifact of the southern California desert climate and has been a factor in the productivity of the Sea's fishery.

The path of productivity from the phytoplankton to the Sea's fishery is convoluted because of the lack of an adult planktivorous fish. The populations of the invertebrate herbivores (rotifers and copepods) can respond quickly to changes in algal abundance. This means there is almost always abundant food for larval fish. But the transfer of productivity via live organisms stops at this point. Without a predator to feed on them, the zooplankton die naturally and sink to the bottom of the Sea as detritus to be consumed by bacteria.

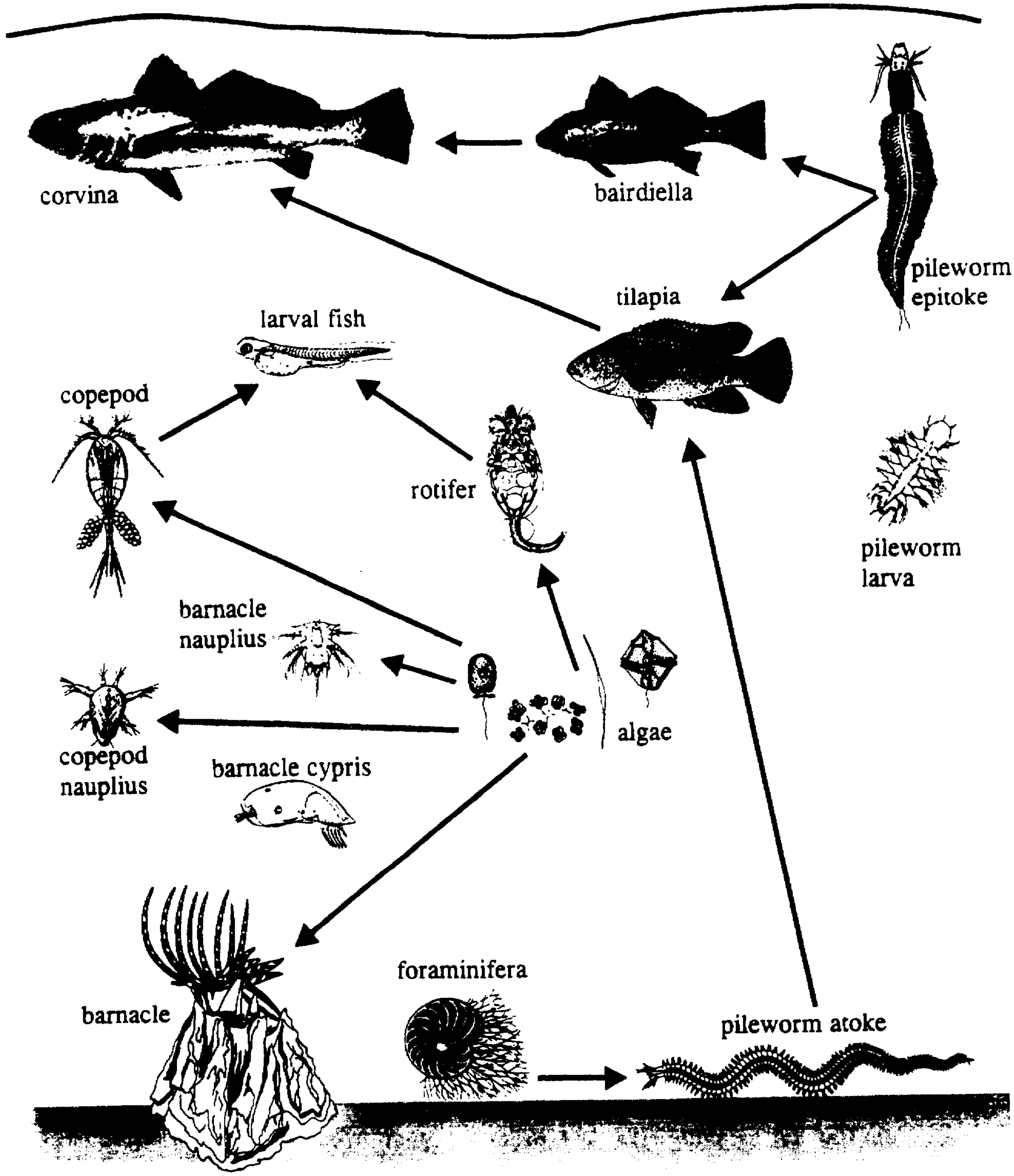

Figure 7. The basic trophic structure of the Salton Sea. Arrows indicate direction of energy flow. The transfer of energy from the plankton to the benthos is not depicted with an arrow, but note that there is no direct link from the plankton to the fish.

foraminifera, and pileworms (Arnal 1961, Carpelan 1961).

The lack of an effective planktivorous fish means that the productivity of the Sea has to travel through the benthos before reaching the fishery. There is however, a question about the effectiveness of bairdiella, historically the most important forage fish, in benthic feeding. Whitney (1961) reported that the condition (plumpness) of bairdiella correlated closely with the occurrence of pileworm swarming. This implies that bairdiella could not reliably feed on pileworms directly from the bottom of the Sea. If pileworm swarming were as highly seasonal in the Salton Sea as it is in other habitats, it is possible that bairdiella would not survive in the Sea. This apparent benthic feeding limitation of bairdiella may also explain their partial replacement by *Tilapia mossambica*. *T. mossambica* has a well-developed ability to forage food directly from benthic substrate (Bowen 1979).

Whether via bairdiella or tilapia, the Salton Sea food chain leading to corvina, the primary sport fish, is five or six steps:

1) phytoplankton
2) zooplankton
3) (bacteria/foraminifera)
4) pileworm
5) bairdiella/tilapia
6) corvina

In most lakes, the chain to reach a similar-sized sport fish would be only four steps:

1) phytoplankton
2) zooplankton
3) planktivorous fish
4) piscivorous fish (sport fish)

In conclusion, the successful, eurytopic nature of the Salton Sea's invertebrate fauna seems to indicate continued resilience for the Sea's community as a whole, but the pattern and length of the food chain apparently places the sportfishery at considerable risk.

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