Ecosystem of the Salton Sea

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The Salton Sea is a saline lake in southeastern California. The lake occupies about 930 km^2, and its elevation is 70.7 meters below mean sea level, the deepest depth being about 12.8 meters. The lake was formed between 1905 and 1907 when a flood cut through irrigation headworks and the flow of the Colorado River entered the Salton sink [*MacDougal*, 1914]. The sea receded by evaporation until 1920 to its elevation of about −76.2 meters, its salinity being slightly higher than that of the ocean. Since then drainage water from irrigation has equaled or exceeded evaporation, and the sea has risen. The changing salinity of the Salton Sea water is presently about 37–38‰, and its *p*H was about 8.1–8.3 during the study period between 1967 and 1970. Although the total salinity of the Salton Sea is similar to that of ocean water, its chemical compositions are significantly different, most conspicuously in the ratio of sulfate to chloride. Sulfate accounts for 9.2% of the anions (equivalent basis) in the ocean and 28.0% of the anions in the Salton Sea [*Pomeroy and Cruse*, 1965]. The Salton Sea water has been saturated with respect to carbonates and calcium sulfate. The chloride content of the Salton Sea is primarily a result of inflow through irrigation canals, leaching of the soils of the surrounding valleys, and diffusion from the bottom, which is composed of salt crust. However, if the level of the Salton Sea falls as expected, the total loss of the water by evaporation would only slightly exceed the total gain of the water; thus the salinity would increase [*Pomeroy and Cruse*, 1965]. The Salton Sea follows the mean atmospheric temperature quite closely, probably owing to its shallow depths, and for a major part of the year the sea is quite well mixed. The region is noted for hot dry summers and warm dry winters, and the temperature of the sea ranges from 9° to 36°C. During the hot summer months the decay of organic matter from the bottom results in an intermittent anoxia [*Carpelan*, 1961*a*].

MICROBIAL LIFE

Although the salinity of the sea is only slightly above that of the oceans, the ionic composition differed from that of marine water because it resulted from evaporation of Colorado River water. The types of microorganisms found in the sea are, however, very similar in nature to marine organisms. The flood that entered the Salton basin in 1907 was practically freshwater, but many of the bacterial species isolated from the sea between 1967 and 1969 are slightly halophilic, like the typical marine bacteria. They grow best in the presence of 2.5–5.0% salt [*Kim and Nakaji*, 1969]. Species of halotolerant bacteria capable of growing in the presence of up to 15% salt were obtained, whereas obligate halophilic bacteria that require and grow in 20–30% salt were not found in our investigations. The majority of the bacteria are Gram-negative motile rods, like many of the marine bacteria. Luminous bacteria, which are known to occur in the marine habitat, are also present in the sea, but there they are free-living rather than symbiotic, pathogenic, or saprophytic. Four species were isolated from the sea and identified as species of the genus *Photobacterium*, but they differed from the known species of the genus [*Nakaji and Kim*, 1968]. One of the interesting characteristics of these bacteria is that two of the four species show a very dim luminescence, unlike the known species of this kind, which luminesce brightly. A bacteriophage active against one of the isolated species of luminous baeteria was also isolated from the sea by an enrichment technique. Sulfate-reducing bacteria are abundant in the black silky-textured sediments that are collected from the shoreline to about 183–274 meters offshore.

Sulfur-oxidizing bacteria, namely, photosynthetic bacteria, are also abundant in the mud samples. These photosynthetic bacteria are also slightly halophilic. The sulfate reducers and sulfur oxidizers must play a key role in the cycle of sulfur and are important in the ecology of the sea, the water of which is saturated with sulfates. Most of the fungi that have been isolated from the sea are typical species of marine yeasts, such as *Rhodotorula, Candida,* and *Sporobolomyces*. The marine yeasts grow at 5°C but not at all or poorly at >30°C, and they carry out oxidative rather than fermentative processes [*Fell and van Uden,* 1963].

PLANT LIFE

The principal plants of the sea, both near the shore and in the open water, consist of the individually floating cells of the phytoplankton. Most of them are microscopic single-celled algae composed of diatoms, green algae, and dinoflagellates but not seaweeds. According to *Carpelan* [1961*b*], who studied phytoplankton and zooplankton in the sea in the mid-1950's, the dinoflagellates (species of *Glendonium* and *Exuviella compressa* were the most prevalent) averaged about 1000 cells per ml during most of the year, and they seemed subject to local blooms. The maximum numbers of diatoms (*Cyclotella* sp. and *Nitzschia longissima* were the most prevalent) appeared in late winter and spring and exceeded 15,000 per ml. The blue green algae, consisting of at least nine species, grew and were restricted to the bottom in shallow quiet areas. Only small numbers of the green alga were present (possibly *Westells botryoides*) during the winter, but they exceeded the number of all other phytoplankton cells during early summer by reaching up to 40,000 colonies (160,000 individual cells occurring in groups of 4) per ml. However, Carpelan stated that because of their small size the mass of the green alga is very small. When both size and numbers are considered, the diatoms and dinoflagellates make up the great bulk of plant material produced in the sea. He also estimated that the productivity at the surface of the Salton Sea would seem to be about 4 times greater than that of fertile coastal seawater. The high plant productivity creates a potential food source for fish, but it also deposits organic matter on the bottom, which could create anoxic conditions in summer.

ANIMAL LIFE

Some of the numerically significant animals in the plankton are rotifers, annelids, barnacles, and copepods [*Carpelan,* 1961*d*]. The worm and the barnacle are not planktonic during their entire life and are most prevalent in spring and fall. The largest numbers of total plankton occur in late summer when large populations of the copepod and rotifer become predominant (1590 per liter in 1955 and 1717 per liter in 1954). In contrast, zooplankton is sparse in the winter with 1–15 per liter, and the food chain in the sea becomes weak [*Carpelan,* 1961*d*]. On the other hand, the Salton Sea provides a difficult environment for the varieties of marine animals because of the extremely wide range of annual temperature, the lack of dissolved oxygen at the bottom in summer, the absence of suitable habitats such as rocks and inundated structures, the lack of visible plants, a heavy algae bloom, a poor food chain, and the changing salinity. Furthermore, the vast amount of inflow through irrigation canals from the surrounding farming areas brings agricultural pesticides and fertilizers into the sea. The inflow was about 1.85 million km^3 in 1963 [*Pomeroy and Cruse,* 1965].

Various invertebrate animals including crab, squid, oyster, shrimp, and clams were introduced into the sea in the 1950's [*Carpelan,* 1961*c*], but there is no evidence that any of these varieties have flourished. According to *Walker et al.* [1961*a*] the introduction of longjaw mudsuckers from San Diego Bay in 1930 was evidently the start of the present population in the sea. In 1961, nine species of fish, most of which were planted early in the 1950's by the California Department of Fish and Game, were evident. Some of them, such as the corbina, the bairdiella, and the sargo, are taken by anglers. The presence of only two food chains [*Walker et al.,* 1961*b*] in the sea presents a weakness in the ecology. The most important chain to the sport fishery is: phytoplankton to zooplankton to detritus to detritus-eating worm (*Neanthes*) to worm-eating fish (bairdiella and sargo) to fish-eating fish (corbina). The level represented by *Neanthes* is a weak link, since they are the only organisms in the sea converting detritus into food for other fish and since they are also killed regularly by anoxia in the deep waters during the summer. Of secondary importance is the food chain: phytoplankton to zooplankton to threadfin shad to corbina. The threadfin shad enters the sea via irrigation laterals, and there has been no sign that this species spawns in the sea [*Walker et al.*, 1961*a*].

ORIGIN OF THE LIFE FORMS FOUND IN THE SEA

Clearly, the fish found in the sea today are some of the species that have adapted to survive, since they were introduced in the 1950's. The desert pupfish, which is considered to be the only native species in the sea, is known to tolerate extreme environmental conditions [*Walker et al.*, 1961*a*]. They are known even to survive and spawn in the isolated pools where the salinity has exceeded 2 times that of ocean water and the temperatures are often >99°F in summer and sink as low as 35°–36°F. There are no large visible plants such as seaweeds in the sea, probably because they have never been introduced. Whether they would survive and propagate if they were introduced should be investigated if the presence of the plants in the sea is desirable. The existence of large numbers of free-living luminous bacteria in the sea is of interest to microbial ecology. They were probably introduced in the early 1950's with many of the fish and other fauna (some fish and fauna were introduced as early as 1929). Such bacteria could also have been introduced by the sea gulls presently living at the sea.

A comparison of two populations of *Neanthes succins*, one found in the Salton Sea (introduced in 1930) and the other from Alamitos Bay, was made to determine the quantitative composition of free amino acids [*Mearns and Reish*, 1969]. Glutamine occurred in significantly higher concentrations in the Alamitos Bay samples, whereas L-alanine appeared in significantly higher concentrations in the Salton Sea specimens. Mearns and Reish stated that the differences observed between these two populations could be the result of genetic changes in the ensuing 37 years of isolation, environmental differences, food differences, or some other factors.

SALTON SEA AS A POLLUTED ENVIRONMENT

Lying in the bottom of the lowest elevation of the Salton sink and having no outlet for outflow, the Salton Sea is bound to receive surface inflow of about 1.85 million km^3 each year, mostly through irrigation canals from the surrounding farming areas. The principal avenues of wastes entering the sea are the New and Alamo rivers, which discharge a total annual volume of approximately 1.23 million km^3 into the south end of the sea [*California State Department of Public Health*, 1958]. The rivers are composed chiefly of irrigation or drainage waters into which the sewage, both treated and untreated, from Mexicali and the communities of Imperial Valley is disposed. The bacteriologic quality of the Salton Sea water, which is determined by coliform counts, is unfit for recreational purposes, especially around the mouths of the rivers and ditches. Despite the high salinity of the water, high densities of coliforms, generally agreeing with coliform distributions investigated by the *California State Department of Public Health* [1958, 1963], were observed during our investigation in 1967–1968. Water samples taken at the mouth of the Alamo River in October 1967 showed a most probable number in excess of 6000 per 100 ml. When the survival of coliform bacteria in the Salton Sea samples was compared with that in the Pacific Ocean samples, the measuring device being the difference in the survival of cells of *Escherichia coli*, the cells died more rapidly in the Pacific Ocean samples than in the Salton Sea samples. Of the Salton Sea samples the survival of the bacteria in the samples collected from the mouth of the Alamo River was better than the survival in the samples collected from the sea itself, probably because the water at the mouth of the river is diluted and contains less salts and more organic matter and nutrients. The area is also noted for a heavy algae bloom, which it had for much of the time during each year of our studies, probably owing largely to the high concentrations of nutrients supplied by the river. Another major pollutant that is washed into the sea and threatens its life consists of the agricultural chemicals from the surrounding farming areas, which cover 1.2 million km^2. The Salton sink is the natural repository of the drainage water and the residual salts. Agriculture is dependent for its survival on the use of the sink for disposal. The Salton Sea is in turn dependent on agriculture for its existence [*Pomeroy and Cruse*, 1965]. Almost all the pesticides and fertilizers washed and drained from the surrounding farming areas enter the sea and have probably been accumulated in the sea. Some of them are, of course, degraded or used by the organisms in the sea. It is frightening to speculate how much of the stable chlorinated hydrocarbons such as DDT could have accumulated in the tissues of the fish living in the sea.

FUTURE OF THE SALTON SEA

According to the calculated projection [*Pomeroy and Cruse*, 1965] the future chlorosities of the Salton Sea may reach the probable critical range for fishery and water contact sports by 1980, an annual inflow of 1.3 million km^3 being assumed. Because of the uncertainty concerning the inflow of the water, which depends on the farming, one cannot be sure of the critical dates. However, the calculated and projected chlorosity indicates that the Salton Sea will have a chlorosity of 22.78 g/1, which is equivalent to a salinity of about 50.00‰, by 1980. It was further projected that by 1990 the total chlorosity would reach about 27.00 g/l, which is equivalent to a salinity of about 59.00‰. The *p*H of the Salton Sea water varies from time to time. It was recorded as 8.3–8.8 in 1955 [*Carpelan*, 1961*a*], 7.6–7.9 in 1964 [*Pomeroy and Cruse*, 1965], and 8.1–8.3 in 1968 (our studies). As the farming is practiced in the surrounding areas, the sea will receive certain amounts of agricultural pesticides and fertilizers each year and add to the already existing chemicals. Wastes originating from the communities and entering the sea should increase as the communities expand. Thus the water quality of the sea will be lowered, and algae bloom will be encouraged, anoxic conditions being created when the algae decay. Close to the sea a strong unpleasant odor, probably stemming from the putrefaction of organic matter, is readily noticeable. A sudden massive die-off of millions of fish occurs every year in the sea. For instance, a solid band of dead 9- to 18-cm gulf croaker was formed along a 13-km stretch of the north shore of the sea during the first week of March 1968. Toxic algae poisoning was blamed as the principal cause of death by officials of the State Department of Fish and Game, but it is also very possible that the pesticides that wash into the sea could cause such a sudden die-off. The Salton Sea, which now attracts >1.5 million visitor days each year [*Pomeroy and Cruse*, 1965] for recreational activities, will not have too bright a future unless some changes are made to control the conditions of the sea.

CONCLUDING REMARKS

Various recommendations have been made by several groups of investigators in an effort to save the dying sea. A group of biologists, headed by *Walker et al.* [1961*b*], made management recommendations on biological grounds concerning only those actions that would directly benefit the fishery. They encouraged: (1) limiting the fish fauna to a few forms so that production of the most desirable species would be highest, (2) planting new fishes only if the present fishery proved inadequate, (3) strengthening the food chain by introducing zooplankters, mysids, and amphipods, (4) securing information on growth and catch of the existing fish and pursuing high rates of fish harvest, and (5) investigating methods to control the salinity of the sea. A cooperative study made by various agencies including the *California State Department of Public Health* [1958] recommended continuous investigation of the bacteriologic quality of the Salton Sea water and indicated the necessity for certain communities to treat their sewage. Their second report [*California State Department of Public Health*, 1963], which was made 4 years later, indicated that though some improvements had been made the sea was still receiving untreated sewage. A group of engineers headed by Pomeroy suggested some constructive plans to control the Salton Sea water in their report [*Pomeroy and Cruse*, 1965] prepared for the California State Water Quality Control Board. Their suggestions were: (1) to control plankton bloom, possibly by removing nutrients by essentially engineering techniques and by harvesting fish at a greatly increased rate, (2) to maintain a stable surface elevation by either importing supplemental water during low periods or exporting water during high periods, and (3) to control salinity by removing water from the sea at a rate that will remove chloride as fast as it flows in, by removing water to a diked-off part of the sea or to an evaporation area adjacent to the sea, and by removing salt by desalinization. They also added that any plan to control the condition of the Salton Sea would be expensive but that the values to be preserved would be well worth it.

Despite all these recommendations and efforts we are not likely to see a single fish living in the sea in the near future if all the agricultural chemicals are allowed to continue to wash in indiscriminately. Also, since the fish population of the warm turbid water is overcrowded, an epidemic disease might endanger the life of the sea. Therefore it is urgent and important to control, in addition to the increasing salinity, the sewage and agricultural chemicals entering the sea if the Salton Sea is to be saved.

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