THE SALTON SEA AND THE PUSH FOR ENERGY EXPLOITATION OF A UNIQUE ECOSYSTEM[1/]

Glenn F. Black
California Department of Fish and Game
15378 Bird Farm Road
Chino, CA 91710

ABSTRACT

The Salton Sea, California's largest inland water, provides habitat for nine species of fish, 35 shore birds, 47 water birds and 4 rails. This includes important wintering habitat for 36 species of migratory waterfowl. The Sea and its fauna furnish 1.5 million recreation days annually for southern California. Recreational activities include fishing, hunting, boating, camping and nature study.

Threats to the Sea's fish, wildlife, and associated recreational uses include oil and geothermal brine spills into the aquatic environment and the elevation of the Sea's salinity due to the diversion of large amounts of freshwater for use by the geothermal industry for cooling and reinjection to control subsidence. In addition, proposed water conservation measures in the Imperial Valley may cause water normally used for irrigation, and thus eventually entering the Sea, to be used elsewhere in the State. Major diversions of freshwater from the Sea will cause the salinity to rise to levels unsuitable for the successful reproduction of fish and major invertebrate species. The effects on avian fauna are not well understood. However, the loss of fish and major invertebrate life in the Sea will have detrimental impacts on some piscivorous avifauna.

Means for preserving the fish, wildlife and recreational resources of the Sea are linked to the same types of energy development that may cause their disappearance. The use of Salton Sea water by the geothermal industry for cooling/reinjection and the impoundment of a portion of the Sea for the dual purpose of a solar energy producing salt pond and as a means of removing salts from the main body of the Sea could provide long-term answers. These answers will not materialize without the commitment of local, state, and federal agencies.

INTRODUCTION

California's largest inland water, the Salton Sea, is located in the southeastern part of the state (Figure 1) in a desert basin lying 85 m (278 ft) below sea level and receiving an average annual rainfall of only 5 cm (2 in) (Hely et al. 1966). This rainfall contributes an average 43,000 dam^3 (35,000 acre-feet) or 2.5% of the total annual inflow while agricultural runoff provides a mean of 1.7 million dam^3 (1.4 million acre-feet) or 97.5% of the total annual inflow to the Sea (U.S. Bureau of Reclamation 1981).

[1/]Glenn Black's presentation of this paper was judged by the Nelson-Hooper Award Committee to be the best presentation at the Annual Meeting.

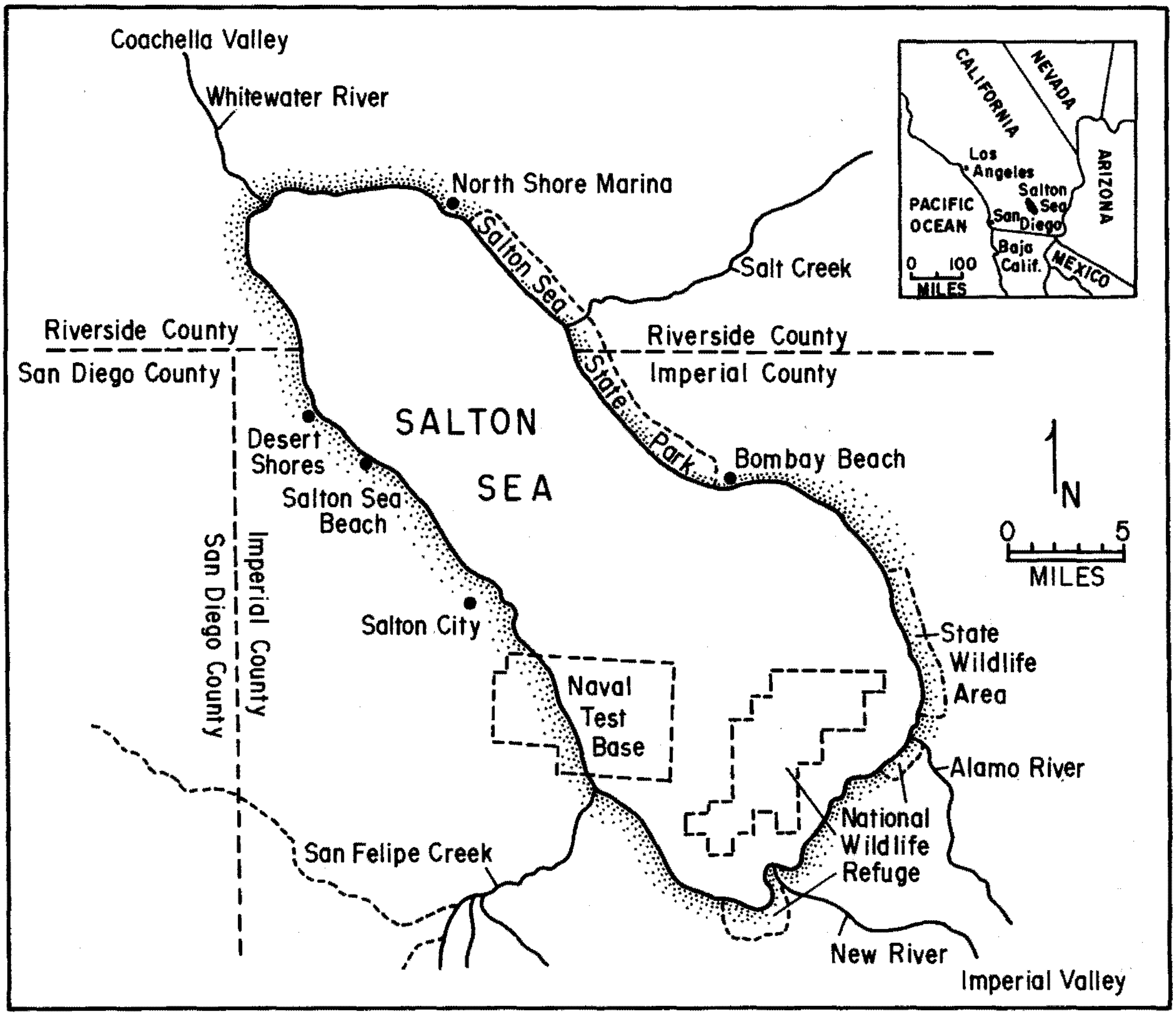

Figure 1. The Salton Sea.

Major agricultural areas border the north (Coachella Valley) and the south (Imperial Valley) ends of the Sea. The Colorado River provides water to the agricultural lands of these valleys via the Coachella and All American canals. Salt-laden agricultural wastewater is collected and carried to the Sea by an elaborate network of drains which either empty directly into the Sea or into one of three major rivers (Alamo, New, and Whitewater, Figure 1) that in turn flow to the Sea. It is important to note that the Salton Sea is a "closed system" having no outlet.

This paper presents information on the values of the Salton Sea as habitat for fish and birds and the recreational use of the above mentioned natural resources. Threats to these resources in the forms of energy development and water conservation measures are also discussed along with possible alternatives that would allow for perpetuation of this important ecosystem for future generations.

FISH

In 1916, the fish of the Salton Sea consisted primarily of freshwater species that entered from the Colorado River; these included the carp, bonytail chub, humpback sucker, rainbow trout, and the striped mullet (Evermann 1916) (See Table 1 for list of all scientific names of species used in paper.) Only one fish native to the region encompassed by the Sea resided there; that was the desert pupfish, which was endemic to springs and seeps in the Salton Basin (Evermann 1916). Due to increasing salinities, only the humpback sucker, striped mullet, and desert pupfish remained in the Sea by 1929 (Coleman 1929). Striped mullet provided a very limited sport and commercial fishery (Thompson and Bryant 1920) until the 1940's when several dams built along the lower Colorado River prevented their movement from the Gulf of California into the Sea via the Colorado River and the All-American Canal. Mullet were not capable of spawning in the Sea and eventually were extirpated along with the humpback sucker (Walker et al 1961).

Table 1. Scientific and Common Names of the Fish, Birds, and Invertebrates Discussed in this paper.

Fish			
Sargo	Anisotremus davidsoni	Bonytail chub	Gila elegans
Bairdiella	Bairdiella icistia	Longjaw mudsucker	Gillichthys mirabilis
Orangemouth corvina	Cynoscion xanthulus	Striped mullet	Mugil cephalus
Desert pupfish	Cyrinodon macularius	Sailfin molly	Poecilia latapinna
Carp	Cyprinus carpio	Rainbow trout	Salmo gairdnerii spp.
Red shiner	Dorosoma petenense	Cichlid	Sarotherodon sp.
Mosquito fish	Gambusia affinis	Humback sucker	Xyrauchen teranus
Birds			
Pintail	Anas acuta	American coot	Fulica americana
American widgeon	A. americana	Bald eagle	Haliaectus leucocephalus
Green-winged teal	A. crecca	Black-necked stilt	Himantopus mexicanus
Northern shoveler	A. clypeata	Least bittern	Ixobrychus exilis
Cinnamon teal	A. cyanoptera	California gull	Larus californicus
Mallard	A. platyrhynchos	California black rail	Laterallus jamaicensis coturnicula
Great blue heron	Ardea herodias	Northern phalarope	Lobipes lobatus
Canada goose	Branta candeusis	Black-crowned night heron	Nxcticorax nycticorax
Aleutian Canada goose	B.C. leucopareia	Ruddy duck	Oxyura jamaicensis
Greenbacked heron	Butorides striatus	Osprey	Pandion haliaetus
Great egret	Casmerodius albus	Brown pelican	Pelecanus occidentalis californicus
Snowy plover	Charadrius alexandrinus	American white pelican	P. erthrorhynchos
Killdeer	C. vociferus	Double-crested cormorant	Phalacrocorax avritus
Snow goose	Chen caerulescens	White-faced ibis	Plegadis chihi
Snowy egret	Egretta thula	Yuma clapper rail	Rallus longirostris yumanensis
American peregrine falcon	Falco peregrinus anatim		
Eared grebe	Podiceps nigricellis		
American avocet	Recurvirostra americana		
Invertebrates			
Brine shrimp	Artemia salina	Pileworm	Neanthes succinea
Barnacle	Balanus amphitrite	Water boatman beetle	Trichocorixa reticulata

From 1950-56, in a series of fish transplants involving 30 species acquired from the Gulf of California at San Felipe, Baja California, the California Department of Fish and Game was successful in maintaining reproducing populations of three species of sportfish: the orangemouth corvina, the bairdiella, and the sargo (Walker et al 1961). During the late 1970's a fourth sportfish became established in the Sea; an unidentified cichlid belonging to the genus Sarotherodon and probably a hybrid. This sportfish is now the most numerous fish in the Sea (California Dept. Fish & Game, Region 5 Fisheries files 1979-81).

At present, several non-game fish inhabit the Sea: these include desert pupfish; mosquitofish; longjaw mudsucker; threadfin shad; and the sailfin molly. All but desert pupfish are introduced non-native species which provide a forage base for several of the sportfish. These fish together with the unidentified cichlid have competed for food, preyed upon, and interferred with the spawning activities of desert pupfish to the extent that the pupfish has been displaced in many of its former habitats (Schoenherr 1979; Black 1980; Matsui 1981). The desert pupfish was listed by the State of California as an endangered species in 1980 and is currently under "status review as a Category 1 species proposed for federal listing by the U.S. Fish and Wildlife Service (Federal Register 1982).

Several aquatic invertebrates are important as forage for the fish and possibly some of the aquatic-dependent birds. Pileworms live in the bottom muds and make up a major portion of the adult bairdiella's diet (Walker et al 1961). Barnacles live attached to substrates such as buildings, pilings and trees and are the major item fed upon by sargo (California Dept. Fish and Game, Region 5 Fisheries files 1979-81).

WILDLIFE

Habitat for more than 345 identified avian species is provided by the Sea and the surrounding desert and agricultural lands. This includes wintering habitat for migratory waterfowl along the Pacific flyway. An annual one day midwinter waterfowl census of the Sea, the State and federal refuges, private duck-hunting clubs adjacent to the Sea, and backwaters of the Sea's major tributaries have averaged 116,000 ducks, geese, and coots over the last 13 years (J. Garcia, Region 5 Wildlife Biologist, Calif. Dept. Fish & Game, pers. comm. 1982). Thirty-six species of migratory waterfowl have been reported from the Sea; the most common are: mallard, pintail, green-winged teal, cinnamon teal, American widgeon, northern shoveler, ruddy duck, Canada goose, snow goose, and American coot (Garrett and Dunn 1981).

Thirty-five species of shorebirds, 47 waterbirds and 4 rails have been reported from the Sea, its mudflats, marshes and riparian areas (McCaskie 1970; U.S. Dept. Interior, Fish and Wildlife Service 1970). Nesting shorebirds include: snowy plover; killdeer; American avocet; and the black-necked stilt (McCaskie 1970). Important water birds nesting at the Salton Sea include: great blue heron; green-backed heron; double-crested cormorant; great egret; snowy egret; black-crowned night heron; least bittern; and the white-faced ibis (McCaskie 1970). Breeding habitat also is utilized by the federal and state listed Yuma clapper rail, and the state-listed California black rail (Garrett and Dunn 1981). Thousands of shorebirds and waterbirds use the Sea annually for resting and feeding; Leitner and Grant (1978) censused more than 4,000 American white pelicans on one occasion in 1977. Another species of major importance is eared grebe, which uses the open water areas of the Sea by the thousands during the winter; it is not known whether these are some of the same migrants that also use Mono Lake (J. Melack, Professor of Biology, University of California at Santa Barbara, pers. comm.). Habitat is also furnished for such previously unmentioned endangered, threatened, rare, and species of concern as the brown pelican, Aleutian Canada goose, southern bald eagle, American peregrine falcon and osprey (U.S. Dept. Interior, Bureau of Land Management 1980).

RECREATION

The Salton Sea and its associated fish and wildlife provide for more than 1.5 million recreational days annually; this includes activities such as fishing, hunting, boating, camping, nature study, and sightseeing (State of Calif., Water Resources Control Board 1969).

Recreation facilities exist along 22 km (14 mi) of shoreline managed as a state park, at 8 private marinas, on 25 km^2 (6,200 ac) of wetlands managed by the state and federal governments and on 14 km^2 (3,400 ac) of wetlands managed by 55 private duck clubs (Frederickson 1980).

Approximately 64,000 waterfowl hunters use the public and private lands annually (Frederickson 1980; Garcia 1981) along with an estimated 350,000 to 400,000 fishermen who use the Sea (Hulquist 1981). The sportfishery is considered to be one of the best self-sustaining sportfisheries in the state (Black 1983).

POSSIBLE THREATS TO FISH AND WILDLIFE

Oil and gas development, a water conservation program, geothermal energy, and solar energy development are currently being proposed for the Salton Sea and surrounding areas. The cumulative impacts of these proposals on fish and wildlife could drastically alter and possibly destroy their habitats or in the case of the latter two proposals they could help to maintain these resources for the future.

Oil and Gas Development

In 1982 the U.S. Bureau of Land Management (BLM) leased approximately 350 km^2 (220 mi^2) or approximately 38% of the Salton Sea for oil and natural gas development. This was done after the BLM completed an environmental assessment (EA) that addressed only the impacts from natural gas development and not oil (U.S. Bureau of Land Management 1982). The reason given by BLM for this omission was that there was only a 1% chance of finding oil thus there was no need to address the impacts should it be found and subsequently developed. There was no mention by BLM of doing an EA should oil be located at a later date. It is of interest to note that BLM neglected to even mention in the Final Environment Impact Statement (EIS) for the California Desert Conservation Area that they administered these lands in and surrounding the Salton Sea (U.S. Dept. of Interior, Bureau of Land Management 1980).

The impacts to fish and wildlife from chronic or major oil spills in a closed system, subject to high winds could be significant. Oil spills could affect fauna found at or far removed from the spill site. The different components of an oil spill could smother benthic organisms such as pileworms and the buoyant and semi-buoyant eggs of fish living in the Sea. An oil spill during the winter months when migratory bird concentrations are at their highest could have a drastic impact on tens of thousands of waterfowl and waterbirds. Oil adheres to a birds feathers and causes flightlessness and eventually death. There are no offshore relatively "safe areas" in the Salton Sea that a spill could occur or be permitted to dissipate since all areas provide habitat for fish and birds at least on a seasonal basis.

Water Conservation

It is anticipated that the demand for Colorado River water will exceed the average supply in the 1990's due to maximum diversions in the lower basin from the central Arizona Project and to increased demands in the upper basin (State of Calif., Dept. Water Resources 1980). The Bureau of Reclamation (BREC) has begun a water conservation opportunities study in the Imperial Irrigation District (IID) to look at means of annually conserving and diverting, before it reaches the Salton Sea, as much as 430,000 dam^3 (350,000 acre-feet) of Colorado River water - possibly through canal and lateral lining, regulating reservoirs, and wastewater re-use (U.S. Dept. of Interior, Bureau of Reclamation 1981). This could represent an average 25% decrease in the annual flow of freshwater to the Sea.

The projected effects of this level of water conservation on the surface elevation and salinity of the Sea by the year 2010 will be to lower the surface elevation 5 m (16 ft) and raise the salinity 2.5 times the present day levels to 96,000 parts per million total dissolved solids (PPM IDS) (U.S. Dept. of Interior, Bureau of Reclamation (1981). It should be noted that it is not known what level of water conservation will be instituted by the BREC and IID between now and the 1990's. This is because the California Department of Water Resources (1980) has said that there will be surplus flows in the Colorado River, downstream from Lake Mead, at least until 1985 when the Central Arizona Project is scheduled to begin diversions. California is entitled to 50% of any surplus flows and one of the uses of this water can be for wildlife refuges on an interim basis (State of Calif., Dept. Water Res. 1980). Furthermore, an interagency task force on the increased use of Colorado River water has identified high wildlife benefits and little or no cost for new facilities, maintenance, and water delivery of 91,500 dam^3 (75,000 acre-feet) to the Salton Sea for dilution of salts (State of Calif., Dept. of Water Res. 1982). It remains to be seen what effects a water conservation program will have on surface elevation and salinity, especially if short-term excess flows in the Colorado River can be allocated for the Sea.

Geothermal Energy

The Imperial Valley includes four known geothermal resource areas (KGRA's) (Figure 2) which may be able to generate 3,000 to 5,000 MW of electrical energy for 30 years (Layton 1978). A fifth KGRA has recently been identified by Imperial County and a master environmental impact report (EIR) has been drafted for rezoning and allowing geothermal development within this area (K. Moore, Calif. Dept. Fish and Game, Fishery Biologists, pers. comm. 1982). An important requirement for geothermal energy development is sufficient cooling water for power plants. In addition to needing water for cooling, geothermal power plants within the Salton Sea, Heber and Brawley KGRA's are required by Imperial County to reinject a minimum of 80% of withdrawn geothermal fluids back into the ground to control subsidence. In order to do this they will need sources of water to replace that lost in producing electricity from hot brines.

To date, approximately 293,000 dam^3 (240,000 acre-feet) of water has either been appropriated or is being considered for such action by the State Water Resources Control Board for use on an annual basis by geothermal developers in the Imperial Valley (Univ. Calif. at Los Angeles, Env. Science and Engineering 1982). The majority, 233,000 dam^3 (190,000 acre-feet), of this water will be diverted annually from the two major freshwater tributaries to the south end of the Sea, the New and the Alamo Rivers, while 61,000 dam^3 (50,000 acre-feet) of water will be taken from the Sea itself. This would result in a net diversion of 171,000 dam^3 (140,000 acre-feet of freshwater) from entering the Sea each year; this is about 10% of the mean annual inflow to the Sea. The overall effects of these and future freshwater diversions that might be granted would be to reduce the surface elevation of the sea and increase the salinity. The impacts of this on fish, wildlife, and recreation will be discussed later in this paper.

It is of interest to note that a 1974 report (U.S. Dept. of Interior, Bureau of Reclamation and State of Calif., Resources Agency) on the feasibility of different salinity control methods suggested that Salton Sea water could be used by geothermal developers as reinjection water to control ground subsidence and remove salts from the Sea. Several years later, Layton (1978) suggested the same thing and stressed that it could benefit the geothermal industry because it would free steam condensate for cooling and would have the added benefit of lowering the Sea's salinity. Goldsmith (1976) even went so far as to estimate that 148,000 dam^3 (120,000 acre-feet) of Salton Sea water would have to be removed annually for 40 years to reduce salinity levels a total of 5,000 ppm TDS.

In addition to affecting the water level and salinity of the Sea through water source usage, ruptures in pipes carrying geothermal fluids to and from the power plants could release toxic geothermal brines into adjacent irrigation drains or directly into the Sea. A 1982 report (Univ. Cal. Los Angeles; Env. Science and Engineering) has shown that the following elements are found in geothermal brines of the Salton Sea KGRA at levels that are toxic to fish and invertebrates and/or have a high potential for bioaccumulation. These elements are arsenic, barium, iron, manganese, lead, boron, and zinc. The brines from this KGRA are also known to have extremely high TDS concentrations ranging from 200,000 to 350,000 ppm TDS; 5 to 9 times more saline than the Salton Sea (Westec Services 1981).

Geothermal development alone will increase the salinity anywhere from 46,000 to 50,000 ppm TDS; the lower figure represents the use of "some" Salton Sea water for cooling (Table 3). The word "some" is not explained in the UCLA (1982) report. Without a commitment by the geothermal industry to use more than some Salton Sea water for cooling, the effect on the fish from high salinities will remain unchanged from that caused by a no development-no water conservation scenario (Table 3).

Various combinations of a minimum water conservation program (161,000 dam^3 or 132,000 acre-feet) or a maximum program (427,000 dam^3 or 350,000 acre-feet) and a solar salt pond and/or geothermal are shown to yield predictions for salinity of the Sea ranging from 43,000 to 105,000 pmm TDS and surface elevations ranging from 70 m (-230 ft) to -76 m (-250 ft); (Table 3). Salinities greater than 70,000 ppm TDS would result in the extirpation of all fish and at least one major invertebrate species from the Sea (Table 2) which could in turn impact piscivorous birds. The lowering of the surface elevations from present levels by as much as 8 m (25 ft.) would significantly reduce (40%) the surface area of the Sea for resting and feeding areas for migratory birds (see Table 3).

POSSIBLE SOLUTIONS FOR PERPETUATION OF PRESENT ECOSYSTEM

The projections made in the previous section make it clear that at the present it is impossible to know exactly what the salinity and water elevation will be in 20 years because there are so many unknowns related to energy development and water conservation in the area. It also becomes obvious that developers of these energy resources have the potential for either drastically altering this unique ecosystem or perpetuating it as it now exists for future generations. A short-term solution for slowing the rate of increase in salinity was discussed in another section; it involved the transport of surplus water from the lower Colorado River to the Salton Sea via the All-American Canal and associated canals in the Imperial Valley. These surplus flows would only be available for possibly the next 10 years; however the flows could procure time for a permanent solution to be implemented. A permanent solution for stablizing salinity and water elevation is tied to energy development, namely geothermal development and solar salt ponds. Geothermal energy development can either hasten the destruction of the aquatic resources by using large quantities of freshwater that ordinarily would enter the Sea or it can aid by removing salts and possibly even lowering the salinity to levels that are optimum for aquatic life by removing Salton Sea water for use in power plant cooling and control of ground subsidence. A large scale solar salt pond, as discussed in a previous section, along with the removal of Salton Sea water by geothermal power plants could provide the permanent solution for perpetuation of this ecosystem.

However, there are a large number of decision making entities at the state, federal, and local level that control water use, water quality, and energy development at the Sea. It seems imperative that they be convinced that the Sea has many valuable resources that should not be traded off against one another and that they cooperate in maintaining the Sea in its current state. It is important that all parties be aware that it is possible to develop energy resources and yet maintain the fish, wildlife, and recreational values of the Salton Sea. For these reasons, the California Fish and Game Commission adopted a policy in April of 1982 that called for the preservation of the Salton Sea's fish, wildlife, and recreational benefits for present and future generations. The policy recognized the value of the Sea as a repository for agricultural drainage water and for its valuable energy resources. The commission urged the formation of a multi-agency task force whose purpose would be to "prepare a program designed to permanently stabilize Salton Sea salinity and water elevation at levels which will sustain and perpetuate existing fish and wildlife resources concomitant with energy development and related projects" (State of Calif., Fish and Game Comm. 1982). Nine months have passed since this recommendation was adopted by the commission and such a task force still does not exist. Without a task force and some kind of water management plan the habitats of the fish and wildlife of the Sea will most likely be drastically changed, even within our generation.

Spills of geothermal brines could have local short-term or remote synergistic detrimental impacts on fish and invertebrates in the Sea, dependent upon the frequency and magnitude of these spills. These impacts could also be transferred to the avian life that are dependent on these fish and invertebrates for food.

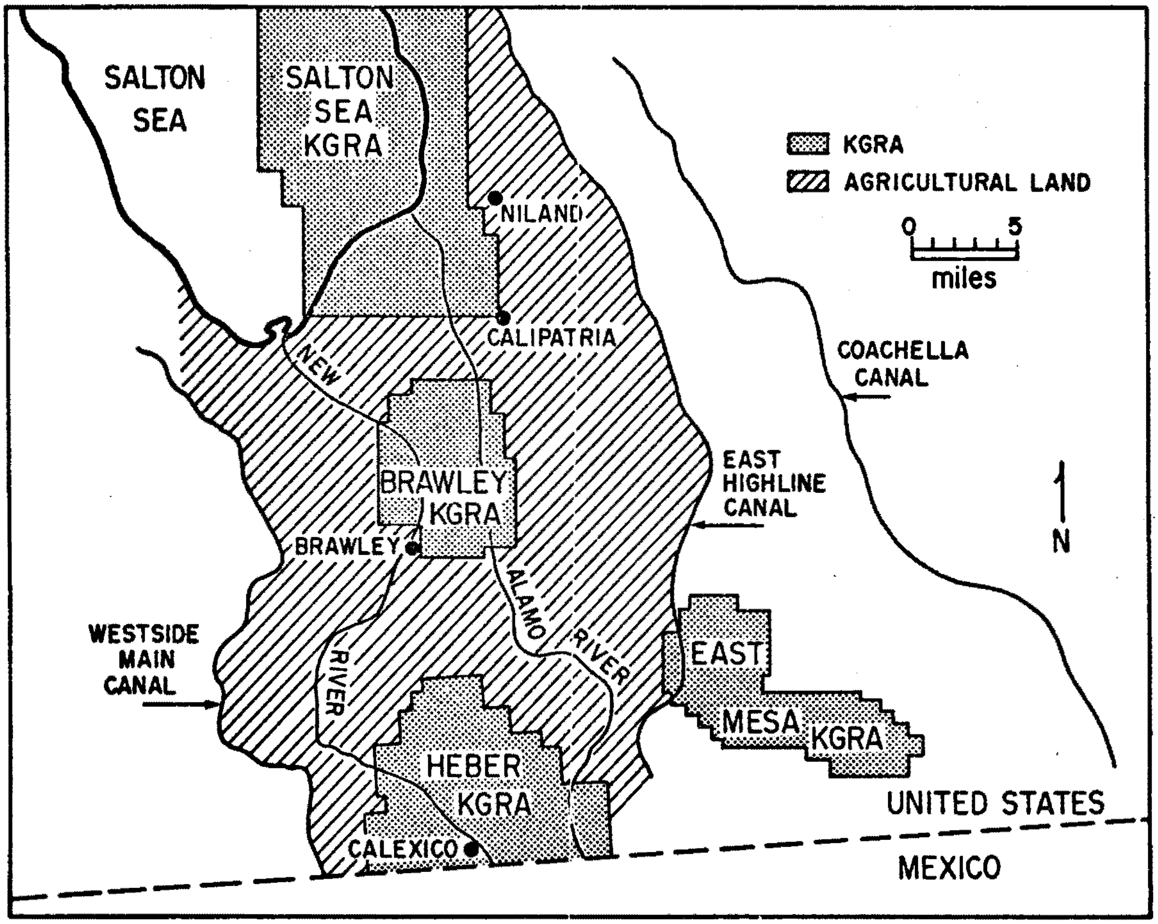

Figure 2. The Imperial Valley, California and its known geothermal resource areas (KGRA's).

The probability of a major spill (250,000 gallons) occurring during a 30 year operation of a single geothermal power plant is thought to be 1 in 500 (Westec Services 1981). However, the record of the geothermal industry at the Geysers in northern California suggests that the probability of smaller spills may be very high. Twenty-nine spills, due to equipment failures, have occurred since 1965. These spills have resulted in 50 to as much as 150,000 gallons of steam condensate being released into the environment (State of Calif., Energy Commission 1981). Geothermal brines at the Salton Sea are known to be highly corrosive on equipment used in geothermal power plants (Westec Services 1981). Thus equipment failure and subsequent release of toxic materials should be expected.

Another potential impact that may be related to geothermal energy development is that of avian mortality due to collisions with above-ground power plant transmission lines. The development of geothermal energy within the Salton Sea KGRA will result in the construction of between 30 and 81 power plants many of which would be within areas of known major avian flight corridors such as the wildlife refuges, the Salton Sea shoreline, and the major rivers (Leitner and Grant 1978; Westec Services 1981). Significant avian mortalities could result from collision with above-ground power transmission lines associated with these power plants (Westec Services 1981).

Solar Energy

On the southwest side of the Salton Sea is a U.S. Navy test base (Figure 1) which is currently being considered for a pilot project to produce electricity by trapping the sun's heat within a salt pond. This concept has been proven effective in Israel on the Dead Sea. Large quantities of Salton Sea water would be required to create the solar pond; such ponds are composed of two layers, a lower one with high salt concentration (90,000 ppm TDS) and temperature (195 degrees F; 90 degrees C) and an upper one with salinity similar to that of the Salton Sea (40,000 ppm TDS) and ambient temperature (Jet Propulsion 1981). Initial plans are for a 5 MW pond covering 1 km^2 (0.4 mi^2) to be placed in the Sea. If the initial project proves to be economically feasible, then a 600 MW solar pond in or adjacent to the Sea, covering approximately 80 km^2 (50 mi^2) will be developed. (Jet Propulsion Lab, Calif. Inst. of Technology 1981).

The adverse effects on fish and wildlife from the impoundment of such a large portion of the Salton Sea for a solar salt pond would be elimination of fish and invertebrates from within the impoundment and removal of the area as wading, resting and feeding habitat for migratory and resident birds. In addition, avian mortality could result from transmission power lines associated with the power plant. It is not known whether avian-mortality will result from birds diving into the high temperature lower layer of the pond because the water throughout will be extremely clear and no food items will be present to attract the birds.

The overall benefits of a solar pond on the Sea's fish and widlife could far outweigh the detrimental aspects. Approximately 4.5 million metric tons (5 millon tons) of salt enter the sea annually through irrigation run-off (Hely et al 1966) and only insignificant amounts leave this "closed system" through chemical reactions, precipitation of salts, and biological processes. A joint federal/state report in 1974 (U.S. Dept. Int. Bureau of Reclamation and Calif. Res. Agency) investigated methods for controlling salinity at the Salton Sea. The report recommended the impoundment of 48 km^2 (30 mi^2) to 80 km^2 (50 mi^2) of the Sea. The Salton Sea water within the impoundment would be allowed to evaporate in shallow ponds within the area and the salts that remained would be disposed of elsewhere. This would be a continual process, which over a period of 10 to 20 years would reduce the salinity of the Sea from 40,000 ppm TDS to 35,000 ppm TDS at costs ranging from $58 million to $141 million. The current proposal for a solar salt pond on the Salton Sea would not only serve to produce electrical energy but also remove salts and thus control salt levels within the Sea (Jet Propulsion Lab, Calif. Inst. of Technology 1981).

Impacts of Elevated Salinities on Fish and Wildlife

It is extremely important to remove salts from the Salton Sea because without achieving this objective salts will eventually become so concentrated that aquatic life will not be able to survive (U.S. Dept. Int., Bureau of Reclamation and Calif. Res. Agency 1979; Black 1983). The effects of elevated salinity levels on the aquatic organisms in the Sea is only partially understood but the best available information has been summarized (Table 2). Optinum salinities for growth of orangemouth corvina, sargo, and bairdiella have been determined to range from 33,000 to 37,000 ppm TDS (Brocksen and Cole 1972).

Laboratory studies have shown that salinities of 40,000 ppm TDS and higher cause extremely high and even total mortality of developing embryos and larvae of bairdiella and sargo (Lasker et al 1972). Ninety-six hour shock bioassay treatments indicate that juvenile orangemouth corvina and sargo cannot tolerate salinities of 62,500 ppm TDS while bairdiella can; bairdiella could not survive 75,000 ppm TDS levels (Hanson 1970). The highest tolerable salinity that has ever been reported for any species from the cichlid genus Sarotherodon is 150% of sea water or approximately 50,000 ppm TDS (Chervinski and Yashouv 1971). Information on the endangered desert pupfish indicates that juveniles have been found in salinities up to 90,000 ppm TDS (Barlow 1958) but the eggs of this species will not hatch in salinities higher than 70,000 ppm TDS (Kinne and Kinne 1962).

Table 2. The Effects of Salinity on Salton Sea Fish and Invertebrate Reproduction, Growth and Survival

Species	Effects of Different Salinity Levels (ppm TDS)							
	40,000	45,000	50,000	62,500	70,000	75,000	80,000	90,000
*Orangemouth corvina	mortality of larvae?	growth in adults ceases(b)		mortality of adults(f)				
* Bairdiella	mortality of larvae(b)	growth in adults hampered(b)				mortality of adults(f)		
*Sargo	mortality of larvae(b)	growth in adults hampered(b)		mortality if adults(f)				
Sarotherodon sp.			mortality of adults?(c)					
**Desert pupfish					mortality of eggs(g)			mortality of juveniles(h)
Pile worm			mortality of early life stages(d)			mortality of adults(d)		
Barnacles			can tolerate salinities at least this high (e)					

*33,000 to 37,000 ppm TDS considered to be optimum salinity for growth(a)
**35,000 ppm TDS considered to be optimum salinity for growth(a)

(a) Broksen and Cole 1972
(b) Lasker et al 1972
(c) Chervinski and Yashouv 1971
(d) Kuhl and Ogksby 1979
(e) Vittor 1968
(f) Hanson 1970
(g) Kinne and Kinne 1962
(h) Barlow 1958

Not only will the fishes of the Sea be adversely affected by high salinities but so will at least one of the major invertebrate species, the pileworm, which is considered to be a major forage item for the various sportfish (Walker et al 1961). Adult pileworms may not be able to survive salinities greater than 80,000 ppm TDS and total mortality of the young may take place at 50,000 ppm TDS and higher (Kuhl and Oglesby 1979). Barnacles, on the other hand, can tolerate salinities at least as high as 50,000 ppm TDS (Vittor 1968); it is not known what the maximum salinity tolerance is for this species (See Table 2).

Very little is known about increases in salinity and its specific impacts on wildlife. Work done by Anderson (1970) in south San Francisco Bay suggests that diving ducks, grebes, one species of gull, and some shorebirds do feed on items existing in highly saline salt evaporation ponds. With the exception of brine shrimp and water-boatman beetles, which are not present in the Salton Sea, the food organisms available to these birds in both areas are similar; brine flies, polychaete worms, rotifers, and copepods are common to both places. This would indicate that increasing salinity at the Salton Sea may not impact usage by certain groups of birds. However, the disappearance of all fish from the Sea would have detrimental impacts on fish-eating birds (herons, pelicans, and egrets) which feed in water with salinity varying from freshwater to that of Salton Sea water.

It is not clear how significant the Salton Sea is to migratory waterfowl although it is known that large numbers of several species have come to rely heavily upon Lake Albert in Oregon, as well as Mono Lake and the Salton Sea in California as resting areas (Steinhart 1980). The continued viability of the Salton Sea as rich waterfowl habitat may be extremely important to such species as eared grebes, California gulls, northern phalaropes, snowy plovers and others that occur there in large numbers. This is especially true when considering the possible fate of Mono Lake.

FUTURE PROJECTIONS FOR SALTON SEA SALINITY AND WATER ELEVATION

UCLA's Environmental Science and Engineering section has made predictions for surface elevation and salinity of the Salton Sea by the year 2000 based on different energy and water conservation scenarios (Table 3) (Univ. Cal. Los Angeles, Env. Science and Engineering 1982). The salinity of the Sea is projected to rise to 44,000 ppm TDS (approximately 6,000 ppm TDS higher than at present) without energy development or a water conservation program and the surface elevation will drop from -69 m (-227 ft.) to - 68 m (-224 ft)(Table 3). Even this level of salinity will mean that reproduction may not take place for most if not all of the sportfish (Table 2); if this level of salinity is maintained for a number of years then these fish will be extirpated from the Sea. This points out the need for salts to be removed from the Sea regardless of whether there is energy development or a water conservation program. Table 2 indicates that either a solar salt pond or a solar pond in conjunction with geothermal could be highly beneficial to fish life by maintaining salinities at 35,000 ppm TDS or 39,000 ppm TDS. However, the latter of these two scenarios may cause a 2 m (6 ft.) rise in the level of the Sea which could inundate mudflats, marshes, and irrigation drains utilized by shorebirds and rails.

Table 3. Projections for Salinity and Water Elevation at the Salton Sea for the Year 2000 (Univ. Calif. Los Angeles, Envir. Science and Engineering 1982)

Scenario	Salinity (ppm TDS)	Elevation (Meters below sea level
Current Status	38,000	69
No Energy Development and No Water Conservation	44,000	68
Solar Pond Only (60 MW)	35,000	70
Geothermal Only - 5 Sources of Cooling Water	46,000 - 50,000	69 - 70
Geothermal & Solar Pond	39,000	71
Minimum Water Conservation Only (161,000 dam^3)	53,000	70
with: Solar Pond	43,000	72
Geothermal	59,000	71
Solar & Geothermal	48,000	73
Maximum Water Conservation Only (427,000 dam^3)	88,000	74
with: Solar Pond	83,000	75
Geothermal	105,000	75
Solar & Geothermal	95,000	76

LITERATURE CITED

Anderson, W. 1970. A preliminary study of the relationships of saltponds and wildlife - South San Francisco Bay. Cal. Fish and Game 56 (4): 240-252.

Barlow, G. W. 1958. High salinity mortality of desert pupfish, Cyprinodon mecularius. Copeia, (3):231-232.

Black, G.F. 1980. Status of the desert pupfish, Cyprinondon macularius, (Baird and Girard), in California. Calif. Dept. Fish and Game, Inland Fish. Endang. Species Program, Spec. Publ. 80-1, 42 p.

__________, 1983. In Proceedings Aquatic Resources Management of the Colorado River System, November 14-16, 1981, Symposium, Las Vegas, Nevada. Ann Arbor Science, Woburn MA. Chapter 22; pgs 363-382.

Brocksen, R.W. and R.E. Cole 1972. Physiological responses of three species of fish to various salinities. Jour. Fish Res. Bd., Canada, 29 (4):399-405.

Chervinski, J. and Yashouv, A. 1971. Preliminary experiments on the growth of Tilapia aurea, Steindachnes (Pisces, Cichlidae) in seawater ponds. Bamidgeh, Bull. Fish Cult. Israel, 23(4):125-128.

Coleman, G.A. 1929. A biological survey of the Salton Sea. Calif. Fish and Game, 15(3): 218-227.

Evermann, B.W. 1916. Fishes of the Salton Sea. Copeia, 34:61-63.

Federal Register, Dec. 30, 1982. Proposed Rules, Endangered and threatened wildlife and plants; Review of vertebrate wildlife for listing as endangered or threatened species. U.S. Dept. Interior, Fish and Wildlife Service. Vol. 47, No. 251: pgs 58454-58459.

Frederickson, L.H. 1980. An evaluation of the role of feeding in waterfowl management in Southern California. (final rept.) U.S. Dept. Interior, Fish & Wildlife Service, Office of Migratory Bird Management, Wash. D.C. 173 p.

Garcia, J. 1981. Wildlife input related to the Salton Sea. Calif. Dept. Fish and Game, Region 5, Niland, Calif. Memorandum. November 1981. 2 p. + attachments.

Garrett, K. and J. Dunn 1981. Birds of Southern Calif. Status and distribution. Audubon Society, Los Angeles Chapter. 108 pp.

Goldsmith, M. 1976. Geothermal development and the Salton Sea. Calif. Inst. Techn., Pasadena, Calif. Memorandum 17.

Hanson, J. A. 1970, Salinity tolerances for Salton Sea fishes. Calif. Dept. Fish and Game, Inalnd Fish Admin. Rept., 70-2, 8 p.

Hely, A.G., Huges, G.H., and B. Irelan 1966. Hydrologic regimen of Salton Sea, California. U.S. Geol. Survey, Geol. Survey Prof. Paper 486-C, 32 p.

Hulquist, R. G. 1981. A summary of Salton Sea creel censuses, 1958, 1963 through 1967, and 1969. Calif. Dept. Fish and Game, Inland Fisheries, Region 5 Infor. Bull. 0004-3-1981, 46 p.

Jet Propulsion Lab, Calif. Inst. of Technology, 1981. Salton Sea solar pond project. Brochure, 13 p.

Kinne, O. and E.M. Kinne 1962. Rates of development in embryo's of a cyprinodont fish exposed to different temperature - salinity - oxygen combinations. Can. Jour. Zoo. Vol. 40: 231-253.

Kuhl, D.L. and L.C. Oglesby 1979. Reproduction and survival of the pileworm Nereis succinea in higher Salton Sea salinities. Biol. Bull., 157: 153-165.

Lasker, R. R.H. Tenaza, and L.L. Chamberlain, 1972. The response of Salton Sea fish eggs and larvae to salinity stress. Calif. Fish and Game. 58 (1): 58-66.

Layton, D. W. 1978. Water for long-term geothermal energy production in the Imperial Valley. Univ. California Lawrence Livermore Laboratory Dept., VERL-52576, Sept. 1978, 48 p.

Leitner, P. and G.S. Grant 1978. Observations on waterbird flight patterns at the Salton Sea, California, October 1976 - February 1977. Rept. Prepared for Lawrence Livermore Laboratory.

Matsui, M. 1981. The effects of introduced teleost species on social behavior of Cyprinodon macularius californiensis. Occidental College, Glendale, California, Thesis. 61 p.

McCaskie, G. 1970. Shorebird and waterbird use of the Salton Sea. Calif. Fish and Game, 56 (2): 87-95 p.

Schoenherr, A. A. 1979. Niche separation within a population of freshwater fishes in an irrigation drain near the Salton Sea, California. Bull. South. Calif. Acad. Sci. 78 (1): 46-55.

State of California, The Resources Agency, Dept. of Water Resources 1980. Streatching California's water supplies: increased use of Colorado River water in California. Southern District Report, 28 p.

________________, 1982. Report of interagency task force on increased use of Colorado River Water. 65 p.

________________, Energy Commission, 1981. Prepared for Occidental Geothermal Inc. final environmental impact report - Oxy geothermal power plant no. 1. 455 p.

________________, Fish & Game Commission 1982. Calif. Fish and Game Code. Under Policies of the California Fish & Game Commission. Pg. 421

________________, Water Resources Control Board 1969. Economic benefits derived from the waters of and lands surrounding the Salton Sea. Prepared by Development Research Associates, Los Angeles, Calif., 105 p.

Steinhart P. 1980. The city and the inland sea. Audubon 92(5): 98-125.

Thompson, W.F. and H.C. Bryant 1920. The mullet fisheries of Salton Sea. Calif. Fish and Game, 6 (2): 60-63.

U.S. Dept. Interior and the Resources Agency of California 1969. Salton Sea Project California, federal-state reconnaissance report. 160 p.

________________ 1974. Salton Sea Project California, Draft Environmental Statement 101 p.

U.S. Dept. Interior, Bureau of Land Management, Calif. Desert Dist. Indio Resource Area, 1982. Potential impacts resulting from leasing of the hydrocarbon resources of the Salton Sea, Riverside and Imperial Counties, Calif. Final environmental assessment #CA-066-2-4. 113 p.

U.S. Dept. Interior, 1980. The California desert conservation area, final environmental impact statement, and proposed plan. 245 p.

________, Fish and Wildlife Service 1970. Birds of the Salton Sea National Wildlife refuge. Refuge leaflet 186-193.

________, Bureau of Reclamation, Lower Colorado Region, September 1981. Water conservation opportunities Imperial Irrigation District, California. Salton Sea Operation Study, Draft Report, 58 p.

University of Calif. at Los Angeles, Environmental Science and Engineering, 1982. Resource use and wildlife issues in development of alternative energy technology in southern California deserts. Vol. II, Energy technology and the Salton Sea ecosystem.

Vittor, B.A., 1968. The effects of oxygen tension, salinity, temperature and crowding on the distribution, growth and survival of Balanus amphitrite Darwin in the Salton Sea, California. San Diego State College, California, Thesis. 151 p.

Walker, B. W. (editor) 1961. The ecology of the Salton Sea, California, in relation to the sportfishery. Calif. Dept. Fish and Game, Fish Bull. 113, 204 p.

Westec Services, 1981. Salton Sea anomaly, master environmental impact report. Prepared for County of Imperial. 458 p.