APPENDIX G

A REVIEW OF THE POTENTIAL BIOLOGICAL RESPONSE TO SALINITY CHANGES IN THE SALTON SEA

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1.0 INTRODUCTION

Salinity levels in the Salton Sea currently exceed that of seawater. Because it is in a closed basin with low rainfall and high evaporation, the natural tendency of the sea is toward increasing salinity (USDI and RAC 1974, Walker 1961). Increasing salinity has led to concern over the perpetuation of socially and economically important values of the sea, particularly the sport fishery, and concern for the salinity effects of various energy and water development projects (USDI and RAC 1974). Currently, salinity varies in the sea from 38-41 *o/oo* depending on location and meteorological conditions (i.e. rainfall, air temperature, wind speed, and freshwater inflow from irrigation) (Matsui 1988, personal communication). Salinity is expected to exceed 50 *o/oo* by the year 2000 (ESE 1982). Future salinity will vary considerably, dependent on decisions made regarding water use, energy and other development in the basin (Dritschilo and Pluym 1984).

Experiments with Salton Sea fish eggs and larvae led researchers to conclude that salinities in excess of 40 *o/oo* adversely affect development of embryos and larvae of *Bairdiella* and sargo (Lasker et al. 1972, May 1975, May 1976). Recent observations indicate that in spite of salinities as high as 41 *o/oo* successful reproduction of these species is still occurring (CDFG 1987). The fact that salinities are approaching potentially harmful levels has led to interest in reassessing our knowledge of the possible response of Salton Sea biota to increasing levels of salinity. The objectives of this report are to review the literature on salinity effects on fish and to provide an opinion on the likely effects of increasing salinity on Salton Sea fishes and lower trophic levels. We also identify what we consider to be important data gaps and outline studies required to provide the needed information.

2.0 STATUS OF PRESENT KNOWLEDGE

2.1 Fishes of the Salton Sea

Since its latest formation in the early 1900's, the Salton Sea has supported changing fish communities. Some of the current fish fauna of the Sea are listed in Table 1.

The corvina, bairdiella, and sargo are introduced from the Gulf of California (Walker 1961). The corvina and bairdiella are in the family Scianidae, a salt-tolerant group including croakers, seatrout and drum with distribution in nearshore and estuarine temperate and sub-tropical waters. Tilapia is an introduced cichlid (mouth-brooder) from Africa. It may be a hybrid but is probably close to *Tilapia mossambica* (Glen Black, 1988). They probably entered the Sea through irrigation canals following their introduction in the Coachella Valley. They have a 25-30 day reproductive cycle in warm water and generation times can be as short as 60 days (Bardach et al. 1972). They can reach a size of 3.5 pounds in the Salton Sea (G. Black, CDFG, personal communication). Tilapia are an important sportfish and are also currently the major food of corvina. They are somewhat limited by low winter temperatures which can cause large die-offs. The threadfin shad are a freshwater species which cannot reproduce in the Sea. Apparently all recruitment is through the irrigation canals. These are a potentially important food source for the Sea's sportfish though they are no longer very abundant.

The desert pupfish is the only species which may be considered native to the Sea. They can be quite abundant in nearshore areas and tributary streams. The pupfish may be among the last to disappear under conditions of increasing salinity. Walker (1961) reports they are abundant in hypersaline pools behind wave built sand bars and have been observed to spawn in these pools at salinities in excess of 70 *o/oo*. Black (1980) noted that pupfish were no longer abundant in these pools and may now be extinct in nearshore

Table 1. Selected fishes currently inhabiting the Salton Sea, California.[1]

Species name	Common name	Status
Cynoscion xanthulus	orangemouth corvina	popular gamefish
Bairdiella icistius	bairdiella	sportfish; forage for adult corvina
Tilapia mossambica	tilapia	sportfish; major forage for corvina, has replaced bairdiella in importance
Anisotremus davidsoni	sargo	gamefish; forage for corvina
Cyprinodon macularis	desert pupfish	California endangered species, Federally endangered species
Gillichthys mirabilis	longjaw mudsucker	forage for adult corvina; bait
Dorosoma petenense	threadfin shad	potential forage; cannot reproduce in Sea, declining
Gambusia affinis	mosquitofish	forage for corvina when available
Poecilia sp.	molly	

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[1] Nomenclature in this table and throughout report follows Robins et al. 1980.

areas of the lake. They are found in some tributary creeks (notably San Felipe and Salt Creek) though in low numbers. Present low abundance of the pupfish is believed to be related to interference from introduced species such as the sailfin molly (G. Black 1988).

2.2 Response of fishes to salinity changes

Fishes in saline waters must maintain the proper concentration of salts in the body fluid and prevent excessive loss of water (see Parry 1966, Conte 1969 for basic physiology of osmoregulation). This requires various adaptive mechanisms and the expenditure of energy since the osmotic concentration in fishes is less than that of sea water. Osmoregulatory mechanisms include drinking water and excretion or secretion of accumulating salts. These mechanisms are aided by limited skin permeability of marine adapted fish.

Fish vary in their ability to osmoregulate in high salinity waters. The highest salinity at which living fish have been reported is the occurrence of *Cyprinodon variegatus* at 142.4 *o/oo* (Simpson and Gunter, 1956). Some species can tolerate a wide range of salinities (euryhaline) by tolerating a certain degree of change in the body fluids or well developed osmoregulatory mechanisms.

Fish can acclimate to salinity changes through behavioral and physiological means. The time required for acclimation ranges from hours to days and varies by species (Parry 1966). The upper limits are set by physiological constraints of the individual organism.

Some fish which generally have a narrow tolerance range for salinity can be acclimated by very gradual changes to salinity well outside that range. *Tilapia mossambica*, a freshwater species, has been acclimated to salinity as high as 69 *o/oo* (Parry 1966). In general, because of less ability to osmoregulate, fish eggs and larvae are usually more restricted in the conditions of salinity which can be tolerated (Parry 1966). However, actual data for this lifestage are very limited.

Slow changes in salinity can be expected to select individuals and strains with increased salt tolerance. This adaptation would of course depend on the rate of change in the environment, the generation time of the organism, and the degree of variability in the population for traits which influence salinity tolerance. (Are there salt tolerant genes in the genetic pool)? Selection potential is a difficult parameter to forecast and little data exists. Theoretical approaches are possible. Heuts (1947) found that the rate of development of eggs of *Gasterosteus aculeatus* in different salinities depended on the race of the female parent. The potential can, to some degree, be evaluated using bioassay studies. However, individuals have to be brought through several generations to see if salt tolerance breeds true-is inherited.

2.3 Salinity tolerance studies for Salton Sea fishes.

Lasker et al. (1972) studied tolerance of eggs and larvae of *Bairdiella* and sargo. Hanson (1970) studied tolerance of the young of *Bairdiella*, corvina, and sargo. No studies for eggs and larvae of corvina and no studies of *Tilapia* from the Salton Sea could be located.

2.3.1 Eggs and Larvae

Lasker et al. (1972) measured the response of eggs and larvae of *Bairdiella* and sargo to high salinities. These experiments produced rather mixed results and must be regarded as inconclusive. The experiments suffered from a lack of well developed protocols and incorporated several confounding variables. These included use of antibiotics in some experiments, use of hormone induced ovulation in others, different methods for collection and fertilization of eggs. In addition no consideration was given to the possible interaction of temperature and salinity and its effect on survival. All tests were conducted at 21°C. The effect of salinity increase may be greater or less at different temperatures (Heuts 1947, Alderdice and Forrester 1968). Temperature and salinity may also interact with other factors such as parasitism (Moles and Pella 1984) and concentrations of toxic substances (Bryant et al. 1984) to influence mortality.

Lasker et al. (1972) do not report dissolved oxygen concentrations in their experiments. Since oxygen is less soluble in higher salinity waters this may have influenced their results. The study also did not report pH. During the evaporation of seawater pH increases, reaching a peak at about 70 *o/oo* and thereafter decreasing (Copeland, 1967). This may also influence the survival of eggs and larvae. The actual pH of Salton Sea water may be quite different, being influenced by biological processes in the Sea.

Finally, there is some evidence that the salinity exposure of the parent fish and that to which the eggs are first exposed result in adjustments in the eggs that persist throughout the lives of fish hatched from those eggs (Kinne 1962). Although not clearly stated in Lasker et al. (1972), it appears that all eggs were obtained from fish acclimated to Salton Sea water of about 37 *o/oo*. The effect of higher acclimation salinities on survival of eggs and larvae exposed to different salinities was not addressed.

Lack of standardization in the experimental techniques led, not surprisingly, to inconclusive results. In the *Bairdiella* experiments survival at 35 *o/oo* (presumably a control) ranged from 0.0 to 50.5%; at 40 *o/oo* from 0.0 to 52.5%; at 45 *o/oo* from 0.0 to 47.0%; and at 50 *o/oo* from 0.0 to 16.4%. In any given experiment, mortality did tend to increase at higher salinities. Use of antibiotics seemed to result in poor survival at all salinities.

The sargo experiments were also inconclusive. Survival for fish in 35 *o/oo* salinity ranged from 0 to 90%. In one experiment, survival was 90% at a salinity of 35 *o/oo*, dropped to 8% at 45 *o/oo* and was 0% at all higher salinities. In another experiment survival was 13% at 35 *o/oo*, 10.6% at 40 *o/oo* and then increased in salinities of 45, 50 and 55 *o/oo* to 36%, 41% and 51% respectively.

May (1975, 1976) had greater success at keeping *Bairdiella* alive in the lab and found diminished reproductive success of *Bairdiella* at 40 *o/oo*.

2.3.2 Young

Hanson (1970) conducted 96-hour shock bioassays and an 8-day bioassay following acclimation to higher salinities (for *Bairdiella* only) on young-of-year fish. Acclimation salinities and acclimation schedules are not reported. There was only one replicate for each test and only combined results are reported. Concentrations of dissolved oxygen and pH were not reported.

Survival of young-of-year *Bairdiella* was 100% at 52.5 *o/oo* and dropped to 40% at 55 *o/oo*. Survival of yearling *Bairdiella* was 100% at 45.0 and fell to 60% at 52.5 *o/oo* (intermediate salinities were not tested), however, these fish could be acclimated to 58 *o/oo*.

Young-of-year corvina experienced 100% survival at salinities less than or equal to 52.5 *o/oo* although survival remained above 90% at salinities up to 57.5 *o/oo*.

Results for sargo were ambiguous but indicate that sargo may be less tolerant of high salinities than the other two species.

2.4 Known salinity distribution of selected Salton Sea biota.

In the absence of definitive studies on the tolerance of Salton Sea fishes to salinity increases and in the absence of any studies on the salinity tolerance of some of the Seas' other biota it may be possible to derive some expectations for changing community composition based on the known distribution of these or related biota in environments of differing salinity.

Distribution data may provide only a conservative estimate of the salinity range tolerated by a species. Naiman et al. (1975) found that though Death Valley pupfish (*Cyprinodon milleri (=salinus*) could tolerate salinities of 88 *o/oo*, they were rarely found in nature at salinities over 45 *o/oo*, perhaps due to limited reproduction.

Corvina

No distribution data for *Cynoscion xanthulus* related to salinity were found, however, several reports for related species were found. Edwards (1976) found juvenile white seabass, *Cynoscion nobilis*, in a lagoon on the Pacific Coast of Mexico where dry season average monthly salinity was measured as high as 60 *o/oo* but where lower salinity water was usually available (~35 *o/oo*). The actual salinity at the time and location of collection of these fish is not reported. Spotted seatrout, *Cynoscion nebulosus*, were captured in water with salinity as high as 57 *o/oo* in the Upper Laguna Madre, Texas (Hellier 1962). The age of these fish (i.e. young-of-year, juvenile, adult) is not reported. Breuer (1957) reports that *Cynoscion nebulosus* in Baffin Bay, Texas are conspicuous by their absence when salinities reach 55 parts per thousand, though he presents no data to support this statement. In contrast, Simmons (1957) found limited numbers of *C. nebulosus* adults in salinities of 25 *o/oo* to 75 *o/oo* and temperatures of 4°C to 33°C in upper Laguna Madre, Texas. He also found that smaller individuals were present in all months though combinations of high salinity and high temperatures limited their numbers. Simmons indicates that *C. nebulosus* did not spawn in waters above 45 *o/oo* though he presents no supporting data. He does remark that they were very sensitive to crowding from other fish.

Bairdiella

Hellier (1962) took specimens of silver perch (*Bairdiella chrysura*) in salinities as high as 56.8 *o/oo* at a temperature of 31°C in the upper Laguna Madre, Texas. Simmons (1957) found silver perch in the same location only in salinities of 45 *o/oo* or less.

Sargo

No reports on the salinity distribution of *Anisotremus* were located.

Pupfish

Deacon and Minckley (1974) report that *Cyprinodon atrorus* tolerates 95 *o/oo* salinity in Cuatro Ciengas basin, Mexico and *Cyprinodon sp.* survive 78 *o/oo* salinity in Cottonball Marsh, Death Valley, California. Simmons (1957) found the killifish (*Cyprinodon variegatus*) very commonly in waters from 5 to 75 *o/oo* at all temperatures in the upper Laguna Madre, Texas. Simpson and Gunter (1956) collected over 2000 specimens of *C. variegatus* in a salinity of 142.4 *o/oo*. Renfro (1966) successfully hatched eggs of *C. variegatus* in the laboratory in salinity peaking at 110 *o/oo* with temperatures ranging from 17.4°C to 27.5°C. Barlow (1958) found that young fry of *C. macularius* continue to develop at a salinity of 90 *o/oo* but that adults died at lower salinities. Kinne (1962) found successful hatching in salinities up to 70 *o/oo* for this species while adults could tolerate salinities of 80-85 *o/oo*.

Tilapia

Fishes of the genus Tilapia are highly variable in their tolerance of salinity and individual species may themselves be quite plastic in their response. Hammer (1987) cites reports that *T. mossambica* from Lake Ihotry, Madagascar have an upper tolerance of 20-30 *o/oo*. *T. mossambica* introduced to Indian waters survived direct transfers from freshwater tanks to 50% and 100% seawater. After acclimation they could tolerate salinities of 65 *o/oo* (Ramamurthi, cited in Hammer 1987). Bardach et al. (1972) indicate that *T. mossambica* can breed in seawater (we assume this is 35 *o/oo* salinity) though it is not reported whether this is the upper limit. It is also not clear whether the authors observed breeding behavior at these salinities or the successful production of young; the distinction is important. Gerking and Lee (1980) found that while mating behaviors by both sexes of Amargosa pupfish (*Cyprinodon nevadensis*) and females lay a few eggs in salinities as high as 43 *o/oo*, both egg production and egg viability fell to very low levels above 20 *o/oo* salinity.

2.5 Trophic Considerations

Increases in the salinity of the Salton Sea could effect fishes indirectly well before reproductive failure or mortality of adult fish occurs. Biologically, the sea is a relatively simple system. Food webs are short and lack diversity (Walker 1961). In such a system, changes in the lower trophic levels, can dramatically effect abundance of top predators such as corvina. For example, the major source of food for corvina has been Bairdiella. Bairdiella depend almost entirely on the benthic worm, *Nereis* (= *Neanthes*). Adult corvina may tolerate salinities as high as 75 *o/oo* and adult Bairdiella as high as 58 *o/oo*. If reproductive success of *Nereis* is threatened at 50 *o/oo*, both these species will disappear at salinities over 50 *o/oo* (in fact, reproductive failure of Bairdiella will likely occur first). In such a scenario, corvina may be able to switch to an alternate prey source such as Tilapia. Such a switch is apparently happening in the Sea now (G. Black, CDFG, personal communication). Because of behavioral or distributional characteristics of predator and prey, switching may not always be possible (Hagar 1984, Kitchell and Crowder 1986, Jude et al. 1988). In simple food chains the fate of the top predator is governed by the weakest link in the chain.

More important trophic links may be found in the Seas plankton community. Though considered relatively unimportant to the Seas top predators (Walker 1961), trophic relations of the early life stages of these species may be critical and may cause changes well before salinity reaches critical levels for the fish. Although adult corvina feed heavily on Bairdiella and other fish prey, the juveniles must subsist for their first year on copepods, barnacle nauplii, other zooplankton and *Nereis*. These trophic interactions must be considered in anticipating the likely effects of increased salinity yet they are extremely difficult to quantify and difficult to predict in any rigorous way.

In general increasing salinity, results in the decline of species numbers, but abundance of remaining species may be great (Carpelan 1967, Copeland 1967, Hammer 1987). In hypersaline waters nutrients are also concentrated by evaporation and may lead to high levels of productivity (Copeland and Nixon 1974, Hammer 1987). In plankton, species differ in their tolerance to salinity with some preferring fresher waters, some preferring high salinity and some having a very wide range of tolerance. The pattern is consistent for phytoplankton, zooplankton and other invertebrates. Under conditions of increasing salinity we would expect some species to disappear and some to increase therefore leading to changes in community composition over time, but an overall trend to fewer species (Table 2). These changes would necessitate modified food webs. Carpelan (1964) found that the distribution of algae in supersaline ponds limited the distribution *Artemia* (brine shrimp) feeding on it in spite of suitable salinities for *Artemia*.

Table 2. Numbers of species of major groups of plants and animals found in waters of different salinity in World athalassic saline waters. (data from Hammer 1987).

	Salinity (*o/oo*)								
Group	30	40	50	60	70	80	90	100	100+
Bacillariophyta	23	-	14	-	-	-	-	14	12
Chlorophyta	19	-	14	-	-	-	-	13	5
Chrysophyta	1	-	1	-	-	-	-	0	0
Cryptophyta	0	-	1	-	-	-	-	0	0
Cyanophyta	19		10	-	-	-	-	5	4
Euglenophyta	1	-	0	-	-	-	-	0	0
Pyrrophyta	3	-	3	-	-	-	-	1	0
Rotifera	20	8	6	4	3	2	2	0	
Anostraca	15	11	7	5	5	5	5	5	
Cladocera	14	11	6	5	3	1	1	1	
Copepoda	26	20	19	19	14	11	10	8	
Protozoa	48	-	30	-	-	-	-	26	
Insecta	14	7	7	6	5	4	2	2	
Mollusca	2	2	2	2	2	2	1	1	
Ostracoda	28	22	18	18	17	14	14	13	

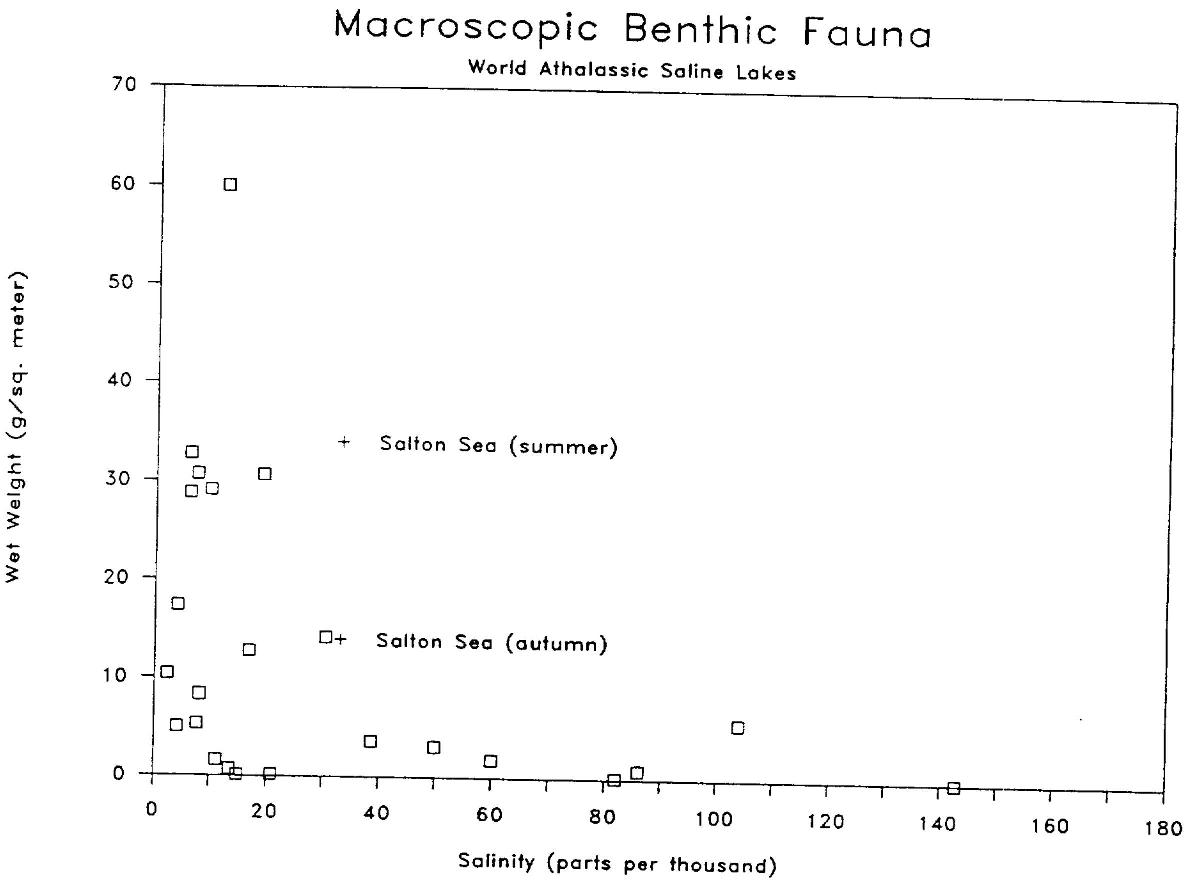
Walker (1961) describes four major planktonic animals of the Salton Sea: rotifer, *Brachionus plicatilis*; barnacle, *Balanus amphitrite;* cyclopoid copepod, *Cyclops dimorphus*; and nereid worm, *Nereis succinea* (pileworm). *Brachionus plicatilis* is the most ubiquitous rotifer in saline lakes (Hammer 1987). Hammer documents its occurrence on every continent except Antarctica in waters from 3 *o/oo* to 250 *o/oo* salinity. It lives in Mono

Lake, California in salinity to 90 *o/oo* and appears to be tolerant of the dominance of various anions as well as a wide spectrum of salinity. *Balanus amphitrite saltonensis* was described by Rogers (1949) as a subspecies of the cosmopolitan complex found only in the Salton Sea. Recent biochemical investigations indicate that there is no significant genetic differentiation of *B. a. saltonensis* from *B. a. amphitrite* populations sampled over a wide geographic range (Flowerdew 1985). Simmons (1957) found *B. amphitrite* in salinities of 25 to 75 *o/oo* though he remarks it was more abundant in waters of lower salinities. He also found the polychaet worms, *Nereis pelagica occidentalis* and *Polydora ligni*, withstanding salinities of 75 *o/oo.* Oglesby (1988) found reproduction of *Nereis succinea* was threatened at 45-50 *o/oo.* Little is known of the salinity tolerance of *Cyclops dimorphus.* It is a freshwater form thought to have entered the Salton Sea via the lower Colorado River. Other members of *Cyclops* occur in salinities from less than 13 *o/oo* to over 100 *o/oo* (Hammer 1987). Three of the four *Cyclops* species reported in Hammer have distributions in salinities less than 30 *o/oo.*

Nereis are a very important layer in the trophic structure of the Salton Sea. They provide one of the few links between primary production in the plankton and higher trophic levels (Walker 1961). Hammer (1987) lists the abundance and biomass of benthic organisms from saline lakes of the world. This data is plotted in Figure 1. by salinity of these lakes. The data indicates that lakes with salinities in the range of 0-30 *o/oo* can be very productive for benthic organisms but that over 30 *o/oo* salinity lakes are not as productive. The reasons are probably variable and no firm conclusions can be drawn. Walker (1961) provides some data which allow us to compare the Salton Sea to these other lakes. By his estimates the standing crop of *Nereis* varies between 14 g/m^2 in the autumn to 34 g/m^2 in the summer. This is well above estimates for other saline lakes and does not account for any of the biota besides *Nereis.*

Declines of a pileworm standing crop to levels approaching those of other saline lakes would certainly have a devastating effect on fish populations dependent on this production. Though we cannot say for certain at what level this would occur, it should happen before pileworm reproduction is

Figure 1: Standing crop (S/m² wet weight) of macroscopic benthic fauna from some athalassic saline lakes of the world.



threatened at 45 *o/oo*.

Dritschilo and Pluym (1984) put together a sophisticated ecotoxicological model of the Salton Sea. The model is an elaboration of a Ricker (1954) type recruitment model elaborated into a leslie matrix and tied to trophic considerations. Unfortunately the data to calibrate or validate the model are not available and the model incorporates a number of assumptions and toxicological relationships that are questionable. The model is presented more as a conceptual approach than an actual predictive tool although simulations are presented.

3.0 DATA GAPS AND RECOMMENDED STUDIES.

Important data gaps are listed below in what we believe to be priority ranking. Studies relate to identification of impacts. We recognize that some of these studies may involve long time periods and extensive expenditures. We do not contend that all of these studies are necessary before any meaningful management actions are taken.

1. Salinity tolerances for Sargo and Corvina (studies ongoing).
2. Monitoring pileworm standing crop, production and salt tolerance.
3. Tilapia studies including food web, reproduction and salt tolerance.
4. Monitor other trophic levels.
5. Expand salt tolerance studies to look at synergistic and cumulative effects (some studies proposed).
6. Study in situe hypersaline lagoons for ecological responses and tolerances.
7. Expand tolerance studies to assess adaptation and selection potential.

Conducting some or all of these studies would greatly improve our confidence in forecasting population and ecosystem responses to future conditions of salinity. As discussed, given the simplicity of the food webs any major shift in the trophic structure is likely to lead to effects on recreationally important species.

Studies related to mitigation assuming unavoidable salinity increases:

1. Research potential for Corvina/Sargo hatchery-artificial propagation.
2. Research potential for the introduction of alternative salt tolerant prey base (hypersaline lagoon pileworms and possibly shrimp).

These studies would provide some insurance for avoiding catastrophic loss of the fishery resources and establish contingency strategies if predicted salinity tolerances for target species are overestimated or if food webs collapse.

The California Department of Fish and Game has funded the Vantuna Research Group at Occidental College for studies of the Salton Sea. These studies have two main objectives: identification of major spawning and nursery areas and determination of levels of salinity that may be detrimental to reproduction of sargo and corvina in the Salton Sea. These studies are scheduled, for completion in 1990. Dose-response studies for selenium have been proposed but have not yet been funded.

Salinity levels detrimental to reproduction of sargo and corvina will be determined by laboratory bioassay techniques. These studies will consider the effects of acclimation salinities and will control for temperature, oxygen, and pH effects.

4.0 IMPACT ANALYSIS

Based on the preceding review of the literature we have proposed the following generalized model for changes in the Salton Sea biota in response to levels of salinity increasing from present levels. The analysis presented should be construed as professional opinion. Our crystal ball in this case is not very clear. Our ability to predict future biological conditions even given rigorous empirical data is lackluster and wrought with error. Dynamic ecological systems do not behave according to simple sets of linear relationships. Relationships are non-linear and change over time as different factors become limiting. If you could mathematically define such relationships (a quantitative model) there would be multiple correct solutions (possible futures). Ecosystem responses are not necessarily deterministic but incorporate elements of chaos and uncertainty. With imperfect knowledge we proceed to assess the biological ramifications of increased salinity.

Existence in saline waters usually requires some degree of osmotic regulation. Though most organisms in the Salton Sea are adapted for life in saline waters, osmoregulation requires the expenditure of an organisms energy. As conditions depart from optimum, greater expenditures are necessary for osmoregulation. These expenditures compete for other physiological demands such as growth, reproduction, resistance to disease and parasitism and other environmental stresses such as temperature extremes and toxic substances. Studies by Brocksen and Cole (1972) indicate that in short term studies (two weeks with two week acclimation period) Bairdiella and sargo experience reduced growth efficiency and increased maintenance requirements as salinity departs from optimum (37 and 33 *o/oo* respectively). They also found that respiration increased and food assimilation decreased for yearling corvina as salinities departed from 37 *o/oo*. As salinity increases toward an organisms upper tolerance level (the point at which death occurs) the risk of death due to these other factors also increases.

As an example, Tilapia currently experience episodes of mortality due to cold temperatures in the winter though not all the fish die every year (G. Black, CDFG, personal communication). As salinity increases, at some level we may expect to see greater susceptibility to this temperature stress and higher levels of mortality associated with it. This is also true for other fish in the Sea (i.e. bairdiella, corvina, sargo, and Tilapia) which experience high mortalities during the summer. This mortality has occurred regularly since these fish were first introduced to the Sea. The cause is not well known but is believed to be associated with high winds and mixing of the water column with high levels of hydrogen sulfide (produced in the sediments), and presumably low dissolved oxygen, mixed into surface waters. This is also a rather localized occurrence and does not effect all the fish. Under conditions of increasing salinity, these other environmental stresses may become increasingly damaging in a synergistic manner.

We have defined four circumstances under which a species existence in the Sea may become threatened due to increases in salinity:

1. The level at which other factors interact with salinity to cause excessive mortality,
2. The loss of primary food supply due to exceedance of salinity tolerance for that organism,
3. Reproductive failure,
4. Direct mortality due to exceedance of salinity tolerance.

We have almost no information on factors 1 and 2. Further increases in salinity can only increase the level of risk for those species which currently experience mortality related to environmental stress. Changes in the trophic structure of the sea are probably ongoing and the risk of these changes reaching a magnitude that exceeds the level of environmental variability and leads to significant restructuring of trophic relationships, also increases with increasing salinity. For some species the salinities at which factors 3 and 4 become important have been examined, though there is also a degree of uncertainty there. Often the ranges are vague and even where they are not, the importance and limits of selective forces are unknown. As conditions depart further from the present the number of possible events expands and our ability to accurately predict them diminishes dramatically.

In any case, we have provided an assessment indicating some of the more important shifts which are likely to occur as salinity increases (Table 3). As discussed previously, our assessment is soft and should be viewed as professional opinion. The assessment assumes that no new species are introduced, that corvina may be sustained in the Sea past the point of reproductive failure by artificial propagation, and that no significant reproduction by any species occurs in areas outside the Sea (i.e. irrigation canals).

Table 3. **Hypothetical chronology for salinity effects on Salton Sea Biota.**

Salinity	Event	Probability
40	Increased importance of environmental stress on all fish.	high
	Reproductive failure of Bairdiella, sargo, and tilapia due to excessive salinity.	moderate
	Declining abundance of primary forage for corvina due to above with resulting lower growth rates, decreased reproduction and higher mortality.	moderate
	Declining productivity (standing crop) of *Nereis* reduces food for Bairdiella, young corvina.	moderate
	Changes in lower trophic levels effecting recruitment success of corvina and other fish	low
45	Reproductive failure of Bairdiella, sargo,	high
	Loss of reproduction of tilapia due to excessive salinity.	moderate
	Reproduction of pileworm threatened	moderate
	Declining productivity (standing crop) of *Nereis* reduces food for Bairdiella, young corvina.	moderate
	Direct mortality to young and/or adult Bairdiella and sargo due to excessive salinity	moderate
	Declining abundance of primary forage for corvina due to above with resulting lower growth rates, decreased reproduction and higher mortality.	moderate
	Loss of recruitment of corvina due to reproductive failure at upper salinity tolerance.	moderate
	Changes in lower trophic levels effecting recruitment success of corvina.	low-moderate

Table 3. Continued.

Salinity	Event	Probability
50	Reproduction of Bairdiella and sargo no longer possible.	high
	Loss of reproduction of pileworm.	high
	Declining productivity (standing crop) of *Nereis* reduces food for Bairdiella, young corvina.	high
	Exceedance of upper salinity tolerance for adult sargo.	high
	Total loss of sargo.	high
	Total loss of Bairdiella.	high
	Loss of recruitment of corvina due to reproductive failure at upper salinity tolerance.	high
	Loss of forage for corvina, corvina fall to low numbers.	high
	Loss of corvina sport fishery.	high
	Reproductive failure for Tilapia.	moderate-high
	Total loss of food source for Bairdiella.	moderate
	Exceedance of upper salinity tolerance for adult Bairdiella.	moderate
55	Conditions intolerable for adult corvina due to lack of forage, corvina at very low numbers.	extreme
	Reproductive failure of Tilapia	high
	Total loss of corvina.	moderate
	Conditions intolerable for adult corvina due to high salinity for adults.	low-moderate

Table 3. Continued.

Salinity	Event	Probability
60	Tilapia success is highly variable from year to year due to interaction of salinity and other environmental factors.	extreme
	Corvina at very low numbers due to lack of forage, environmental stress, no reproduction.	extreme
	Total loss of corvina.	high
65	Total loss of corvina.	extreme
70	Tilapia adults can no longer tolerate high salinities (regardless of other environmental factors).	high
	Reproductive failure of desert pupfish.	high
	Loss of barnacle.	high
	Phytoplankton and zooplankton communities have lost some species, perhaps gained a few new ones. Species diversity is lower. No fish from previous community remain, with possible exception of desert pupfish.	high

5.0 MANAGEMENT/POLICY SUGGESTIONS

Briefly we have outlined some measures that may assist decision makers on the difficult choices they have before them.

As there is a great deal of uncertainty regarding the actual versus the predicted responses of the Salton Sea communities to increase salinity, we strongly urge that a monitoring program be put in place that focuses on the target species as well as other important trophic elements (pileworms, zooplankton, tilapia). This would allow us to assess whether our predicted responses are accurate and allow the calibration and validation of predictive models. In other words, any set acceptable salinity level should be tied to population monitoring as an insurance for our murky soothsaying abilities.

We suggest the development of an interim plan that includes the development of artificial propagation methods and facilities. This is possible right now. Also, the development of a strategy, should food webs begin to fail, that may include the introduction of alternative more salt tolerant species. In most cases we would be opposed to the introduction of new species into an aquatic ecosystem as they are already overburdened with transplants and exotic species that have extirpated or greatly reduced native species. The Salton Sea is special. It is a manmade body of water with, in part, a manmade ecosystem. We believe the introduction of new species should be done only as a fall back position but that the necessary research and planning be conducted now.

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