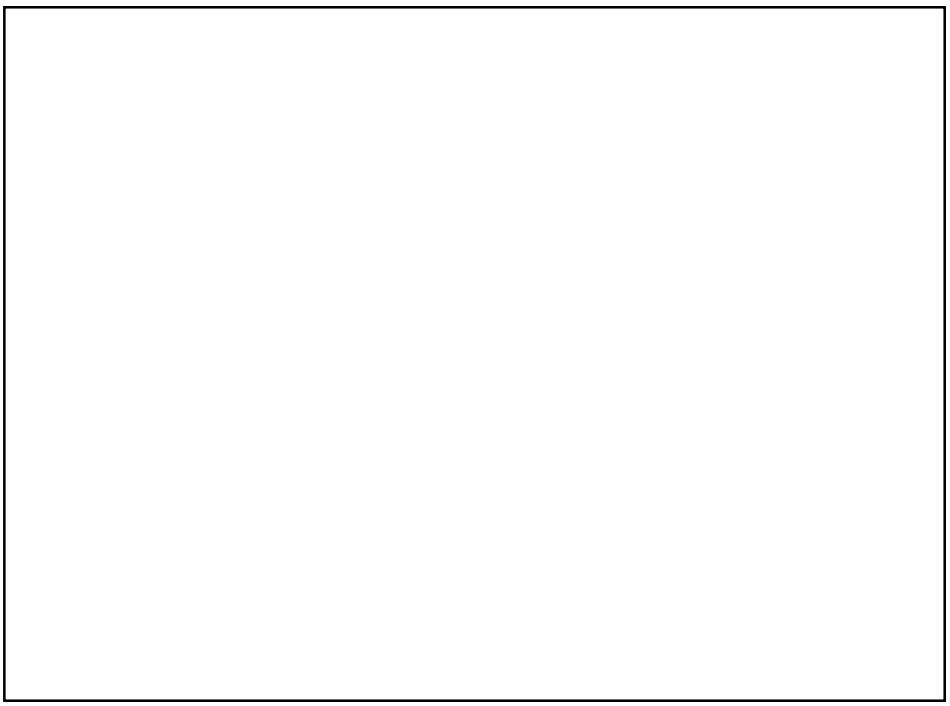
# Toxic Effects of Elevated Salinity and Desalination Waste Brine

Until recently, desalination of seawater has not been commonly used to produce potable water in Southern California. The high cost of water from desalination compared to the cost of water from other sources has limited the number of desalination projects. However, the recent drought prompted construction of several plants along the coast and plans for more (California Coastal Commission 1992).

Desalinated seawater is produced by either distillation or reverse osmosis. Distillation plants heat seawater to steam that is condensed to produce freshwater. Reverse osmosis plants filter seawater to remove large particles and pump the water at high pressure through membranes that remove the salt. Reverse osmosis is used by more than two-thirds of the plants in operation or planned in California (California Coastal Commission 1992). The by-product of freshwater production is brine with a salinity about twice that of seawater.

Waste brine is either discharged directly to the ocean or discharged through sewage outfalls. Because desalination plants have been in operation for a short time, little is known about the toxicity of waste brine. Brine from the Santa Barbara reverse osmosis desalination plant was toxic to kelp spores (ABC Labs, Inc. 1992). Furthermore, since most ocean discharges lower receiving water salinity rather than raise it, little work has been done on the effects of elevated salinity. The objectives of this study were to: 1) measure the toxic effects of increased salinity on marine species; and 2) determine the toxic effects of waste brine and the interactions between waste brine and sewage on toxicity.



**Examining the results of a toxicity test.**

## Materials and Methods

We tested the effects of increased salinity on spores of giant kelp (*Macrocystis pyrifera*) and an amphipod (*Rhepoxynius abronius*). The salinities tested were based on predictions from plume models for the Santa Barbara reverse osmosis desalination plant (Water Engineering & Modeling, Pasadena, CA). Salinity samples were pro-

duced by mixing hypersaline brine with laboratory seawater. Brine was produced by freezing and partially thawing laboratory seawater. Seawater was obtained from the Redondo Beach Edison Generating Station and filtered to 5 µm. The 48-hour kelp test used the methods of Hunt *et al*. (1991). Microscope slides with spores were preserved in glutaraldehyde for examination. The endpoints were germination success and germ tube growth. The 10-day amphipod survival test followed the guidelines of the American Society for Testing and Materials (ASTM 1991).

The interactions between elevated salinity and sewage were determined with a 48-hour sea urchin (*Strongylocentrotus purpuratus*) embryo development test according to methods Long *et al*. (1990); normal development was the endpoint. A 24-hour composite of secondary effluent from the El Estero treatment plant (Santa Barbara) was collected and tested within 24 h. The effluent was mixed with laboratory seawater and hypersaline brine to produce the desired combinations.

The original intent of the study was to test waste brine from the Santa Barbara reverse osmosis desalination plant, which can produce 6.7 million gallons per day (mgd) of freshwater and 12.5 mgd of brine. However, the plant ceased operation after the abundant rains of the past few years. The Diablo Canyon desalination plant was chosen as a substitute and their process was modified to simulate the Santa Barbara facility. The modifications included effluent chlorination. Four grab samples of brine and two grab samples of intake water were collected at the Diablo Canyon plant. The samples were diluted with laboratory seawater to produce a range of concentrations. The effect of the brine was determined with a sea urchin (*Strongylocentrotus purpuratus*) fertilization test according to methods in Dinnel *et al*. (1987). Residual chlorine was measured in the brine with the N,N-diethyl-p-phenylenediamine colorimetric technique (APHA 1989). Trace metals were measured in the intake water and brine by Coast-To-Coast Analytical Services, Inc. (San Jose, CA).

Brine controls were run for all tests, except the urchin embryo test, which used hypersaline brine prepared in the laboratory. Brine controls were a mixture of seawater, distilled water, and brine at the same concentration of brine in the salinity adjustments, but at the salinity of ambient seawater.

Reference toxicant analyses were performed with each of the bioassays. Copper was used for the kelp and sea urchin tests; cadmium was used for the amphipod test.

Levels of no effect (NOEC) were determined using an ANOVA and Dunnet's multiple range test (Zar 1984). Percent data were transformed to the arcsine before analysis. EC50s were calculated using the probit method.

## Results

Elevated salinity did not affect kelp spore germination or tube length or amphipod survival (Table 1). The highest average kelp spore germination occurred at the next to the highest salinity. The smallest germ tube length was observed at the highest salinity. However, the brine control was also fairly low.

El Estero wastewater at 5.6% effluent and ambient salinity (33.5 g/kg) had a significant effect on sea urchin development (NOEC=3.3%); at lower effluent concentrations, there were no effects on development (Table 2). Percent normal development was reduced substantially at a salinity of 36.5 g/kg in all samples including the salinity control. At the higher salinity, the proportion of normal embryos increased as the percent of sewage increased.

The desalination plant brine did not produce toxicity in the kelp germination and germ tube length tests, nor did it affect sea urchin fertilization (Table 3). Since the highest concentration of brine tested was 10%, the NOEC was 10% or greater. Concentrations of trace metals in desalination plant intake water and

## Table 1.

**Effects of elevated salinity on kelp spores (*Macroystis pyrifera)* and amphipods (*Rhepoxynius abronius*). Salinities were produced by mixing laboratory seawater with hypersaline brine. Brine controls were at ambient salinity, but contain the amount of brine in the salinity adjustments. SD=one standard deviation; P=probability; ns=not significantly different from control (ANOVA and Dunnett's test). The lab control or brine control were used for statistical comparisons depending on salinity.**

| TREATMENT | KELP SPORE GERMINATED (%) | | | KELP SPORE TUBE LENGTH (µm) | | | *RHEPOXYNIUS* SURVIVAL (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | P | Mean | SD | P | Mean | SD | P |
| Lab control (33.5 g/kg) | 85 | 4 | - | 15 | 1 | - | 99 | 2 | - |
| Brine control (38.5 g/kg) | 83 | 2 | ns | 14 | 2 | ns | - | - | - |
| Brine control (43 g/kg) | 81 | 3 | ns | 13 | 1 | ns | - | - | - |
| 34.5 g/kg salinity | 87 | 3 | ns | 14 | 1 | ns | 100 | 0 | ns |
| 35.5 g/kg salinity | 88 | 5 | ns | 15 | 1 | ns | 99 | 2 | ns |
| 36.5 g/kg salinity | 85 | 5 | ns | 15 | 1 | ns | 99 | 2 | ns |
| 38.5 g/kg salinity | 89 | 3 | ns | 15 | 0 | ns | 99 | 3 | ns |
| 43 g/kg salinity | 87 | 4 | ns | 12 | 0 | ns | - | - | - |

brine were similar to ambient seawater (Table 4). Residual chlorine levels in the brine were not elevated above the concentration of ambient seawater.

The NOEC for the Cd reference toxicant series for amphipods was 0.25 mg/L; the EC50 was 0.6 mg/L. The NOECs for the Cu reference toxicant series for kelp germ tube length were 32 µg/L and <5.6 µg/L; data were not sufficient to calculate EC50s. Samples for germination were not processed. The NOEC the Cu reference toxicant series for sea urchin sperm was 3.2 µg/L; the EC50 was 10.9 µg/L. All reference toxicant samples for the urchin embryo development test, including the controls, had poor development.

## Table 2.

**Effects of elevated slinity and El Estero sewage on sea urchin (*Strongylocentrotus purpuratus*) embryo development. SD=one standard deviation; P=probability; ns=not significantly different from control (ANOVA and Dunnett's test); s=significantly different from control (p<0.05).**

| TREATMENT | NORMAL (%) Mean | SD | P[a] |
|---|---|---|---|
| Lab control (33.5 g/kg) | 73 | 7 | |
| Salinity control (36.5 g/kg) | 18 | 10 | s |
| 33.5 g/kg, 1% sewage | 67 | 7 | ns |
| 33.5 g/kg, 1.8% sewage | 75 | 4 | ns |
| 33.5 g/kg, 3.3% sewage | 71 | 9 | ns |
| 33.5 g/kg, 5.6% sewage | 48 | 7 | s |
| 36.5 g/kg, 1% sewage | 19 | 2 | ns |
| 36.5 g/kg, 1.8% sewage | 22 | 6 | ns |
| 36.5 g/kg, 3.3% sewage | 23 | 6 | ns |
| 36.5 g/kg, 5.6% sewage | 32 | 9 | ns |

[a]Results of multiple comparison tests. Salinity control and 33.5 g/kg samples were tested against the lab control; 36.5 g/kg samples were compared to salinity control.

## Discussion

Desalination plant brine and elevated salinity did not produce toxic effects on amphipods, kelp spores, or sea urchin fertilization. There was a reduction in kelp spore germ tube length at 43 g/kg, but the same reduction occurred in the brine control indicating a chemical toxicity

## Table 3.

**Effects of desalination plant brine on kelp spores (*Macrocystis pyrifera*) and sea urchin (*Strongylocentrotus purpuratus*) fertilization. SD=one standard deviation; P=probability; ns=not significantly different from control (ANOVA and Dunnett's test); nt=not tested. The highest concentrations were tested first; if they were not significantly different from control (p>0.05), the lower concentrations were not tested.**

| TREATMENT | KELP SPORE GERMINATION(%) | | | KELP SPORE TUBE LENGTH (μm) | | | SEA URCHIN FERTILIZATION (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | P | Mean | SD | P | Mean | SD | P |
| Lab control | 77 | 8 | | 15 | 1 | | 85 | 6 | |
| Salinity control | 80 | 8 | ns | 15 | 2 | ns | 81 | 9 | ns |
| Seawater 1, 18% | 76 | 11 | ns | 14 | 1 | ns | 87 | 3 | ns |
| Seawater 2, 18% | 71 | 8 | ns | 16 | 1 | ns | 86 | 1 | ns |
| Brine 1, 2% | 72 | 9 | nt | 15 | 1 | nt | 87 | 4 | nt |
| Brine 1, 5% | 76 | 9 | nt | 15 | 1 | nt | 88 | 5 | nt |
| Brine 1, 10% | 75 | 6 | ns | 16 | 1 | ns | 84 | 11 | ns |
| Brine 2, 2% | 73 | 5 | nt | 15 | 1 | nt | 89 | 3 | nt |
| Brine 2, 5% | 74 | 12 | nt | 16 | 1 | nt | 83 | 5 | nt |
| Brine 2, 10% | 78 | 8 | ns | 15 | 1 | ns | 88 | 6 | ns |
| Brine 3, 2% | 68 | 13 | nt | 15 | 1 | nt | 83 | 4 | nt |
| Brine 3, 5% | 74 | 12 | nt | 16 | 2 | nt | 86 | 3 | nt |
| Brine 3, 10% | 81 | 8 | ns | 17 | 1 | ns | 83 | 6 | ns |
| Brine 4, 2% | 76 | 11 | nt | 15 | 1 | nt | 82 | 4 | nt |
| Brine 4, 5% | 78 | 6 | nt | 16 | 1 | nt | 79 | 8 | nt |
| Brine 4, 10% | 81 | 10 | ns | 17 | 1 | ns | 80 | 8 | ns |

## Table 4.

**Trace metal analyses of intake seawater and waste brine from the Diablo Canyon desalination plant.**

| CONTAMINANT | CONCENTRATION (mg/L) SEAWATER | BRINE |
|---|---|---|
| Arsenice | <0.005 | <0.005 |
| Cadmium | <0.001 | <0.001 |
| Chromium | <0.005 | 0.010 |
| Copper | 0.003 | 0.004 |
| Iron | 0.02 | 0.02 |
| Lead | 0.006 | 0.006 |
| Nickel | <0.01 | <0.01 |
| Silver | <0.01 | <0.01 |
| Zinc | 0.012 | 0.009 |

associated with the brine, rather than a salinity effect.

Sewage effluent had a significant effect on sea urchin development only at the highest concentration. Salinity also had a significant effect on urchin embryos. The 75% reduction in normal development with a 10% increase in salinity makes sea urchins among the most sensitive of marine embryos. The next most sensitive species is the scallop; embryo development decreased 40% following a 20% increase in salinity (Tettelback and Rhodes 1981).

The lack of successful reference toxicant exposure during the urchin embryo experiment raised questions about the sensitivity of the test. An additional urchin embryo test at a salinity of 36.5 g/kg produced a small response. But a severe response was produced at 38.5 g/kg confirming sea urchin sensitivity. Models of the Santa Barbara effluent plume predict that salinities greater than 35 g/kg outside the zone of initial dilution will occur less than 10% of the time (G. Bogle, Water Engineering & Modeling, Pasadena, CA,

personal communication). If the models are accurate, there should be little impact on urchin embryos in the field.

Since El Estero sewage effluent was toxic to sea urchins at ambient salinity, it was surprising that the effects were not more severe at higher salinities. Any interaction that may existed may have been obscured by the strong effect of salinity. Increased salinity may have altered the chemical speciation of toxicants in the sewage and reduced toxicity. Increased salinity can reduce the toxicity of some trace metals by increasing the complexation of the toxic, free ion form (Sprague 1985).

## Conclusions

Elevated salinity and sewage effluent had significant effects on sea urchin development. Sea urchins embryos proved to be among the most sensitive of marine species. The desalination waste brine was not toxic to amphipods, kelp spores, or sea urchin embryo at concentrations expected to occur in the field. Toxicity testing and field verification of model predictions should continue for the reverse osmosis and distillation desalination procedures currently in use. More work also needs to be done on the interactions between sewage effluent and desalination waste brine.

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