SCIENTIFIC REVIEW AND REBUTTAL OF THE SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT (SCCWRP) EXPERT PANEL REPORT ON BRINE DISCHARGE MANAGEMENT

By:
Daniel P. Cartamil, Ph.D

Marine Biology Research Division
Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Dr.
La Jolla CA 92093-0204

Submitted to:

Poseidon Resources, Inc.
501 W. Broadway, Suite 2020
San Diego, CA 92101

Introduction:

In response to the pressures of a growing global population, climate change and dwindling water supplies, there has been increasing interest in desalination as an alternative to traditional water sources. In California, the State Department of Water Resources and regional water supply managers are advancing seawater desalination as a new source of potable water, where it is urgently needed as the current population of almost 38 million continues to grow, and groundwater and freshwater supplies have become depleted.

As part of the desalination process, large volumes of seawater are extracted and concentrated seawater is discharged that is approximately twice the salinity of the receiving waters. A growing field of science and industry is concerned with the mechanisms whereby this concentrate can be rapidly diluted to minimize environmental impacts (Mauguin & Corsin 2005, Voutchkov 2011). Nevertheless, there are concerns about the effects of concentrated brine discharge on marine life (Lattemann & Hoepner 2008), including the physiological effects of hyper-salinity toxicity.

Currently, there are no water quality objectives in the California Ocean Plan that apply specifically to desalination discharge. Rather, Regional Water Quality Control Boards have established permit requirements and applied variable effluent limits based upon the specific characteristics of the site in question. At present, the California State Water Resources Control Board (SWRCB) is re-examining the effects of brine discharge, and recently convened a panel of five experts to advise on best practices for brine disposal in support of the development of an amendment to the Ocean Plan. Their report (Southern California Coastal Water Research Project 2012; hereafter referred to as 'Panel Report') provides a partial review of existing literature, and covers many aspects of brine discharge management including environmental impacts, discharge site scenarios, modeling, and monitoring. The Panel Report also provides several recommendations relating to the regulatory framework for California desalination.

Among the recommendations set forth by the panel experts is a 'one-size-fits-all' solution for managing the discharge of brine from California's desalination facilities along the entire thousand-mile coastline. Specifically, the Panel Report recommends a statewide minimum dimension for regulatory mixing zones, wherein salinity increase would be restricted to 5% (approximately 1.7 parts per thousand, or ppt) above ambient concentrations at the edge of a 100 meter mixing zone in the receiving water (Page 45 of Panel Report). Such an approach may impose overly conservative and restrictive requirements that (depending on site-specific conditions) may not provide any tangible environmental benefit while potentially impacting the feasibility of implementing seawater desalination in areas where local conditions warrant consideration of alternative approaches. The arbitrary nature of the Panel's proposed salinity limit is further exposed by the hyper-salinity toxicity study commissioned by the State Water Board and conducted by Marine Pollution Studies Laboratory at Granite Canyon. This study found that all but two Ocean Plan species are unaffected by salinity concentrations below 40 ppt (approximately 20% above California coastal waters ambient salinity). However, the toxicity report itself is confounded by methodological flaws, and may not be a valid representation of the effect of hyper-saline conditions on local organisms. Appendix A consists of a review of the toxicity study conducted by Marine Pollution Studies Laboratory at Granite Canyon.

Given the urgent need for alternative water sources in California, it is imperative that such potentially restrictive regulatory measures be based upon an unbiased interpretation of well designed and rigorously conducted scientific studies. However, there are several problems with the Panel's review and interpretation of the existing scientific and industry literature - these problems extend to the conclusions and recommendations drawn in the Panel Report. The following paper presents a critical review of the cited literature and the introduction of several relevant topics that were not discussed in the Panel Report.

1) <u>Sub-par quality of the literature cited by the Panel Report</u>

Several studies have identified potential mechanisms by which desalination plants may have an impact on marine systems. However, many of the published review articles and case studies cite little or no peer-reviewed literature, and present little or no empirical data to support statements regarding environmental effects of desalination (Roberts et al. 2010). Additionally, most extant studies are poorly designed, non-replicable, and confounded by uncontrolled factors. Unfortunately, many of these flawed studies appear to have been influential in the Panel's decision making process while other salinity studies were omitted or given inconsequential consideration. Below, I present a critical review of the studies featured most prominently in the Panel's report, and provide a more realistic interpretation of their findings with respect to salinity toxicity.

Sea Grass Communities:

The Panel Report notes that "benthic infaunal communities and sea grasses are the most sensitive to the acute effects of concentrate discharge", and that "impacts to seagrasses can occur following increases of only 1-2 ppt in salinity". However, a critical review of the literature cited in the Panel Report does not support this conclusion. Talavera & Ruiz (2001) are cited as an example of a field study demonstrating deleterious effects of a 2 ppt salinity increase (from brine discharge) on the seagrass *Cympodocea nodosa*. However, this result is highly suspect for several reasons:

> 1) The authors characterized the discharge salinity field by measuring salinity at several sites on only *one* day in August 2000 – a day chosen for its particularly calm weather and wave conditions. These conditions facilitated sampling but also inhibited the normal mixing and dilution of plant effluent. The authors state that "it is very reasonable to think that the dilution of the brine was much less that the one that [sic] would take place in normal conditions of more wind and surf". In addition, sampling should be performed multiple times per site over several months in order to accurately characterize the salinity field and for the results to be statistically valid.

2) No systematic survey of seagrasses was conducted – rather, *Cympodocea* distribution was described qualitatively from photographs taken at several of the salinity sampling sites.

3) No peer-reviewed literature was cited in this paper.

4) The Panel Report concludes from their review of this study that "discharge from a Canary Island desalination plant was associated with the disappearance of the seagrass *Cympodocea nodosa* in the areas near the outfall; farther away the grass was in poor condition". This is in direct opposition to what the *authors themselves* state regarding brine discharge: "current effects on the marine biological communities are nonexistent."

The Panel Report also cites Gacia et al. (2007), which purports to examine effects of brine discharge on the seagrass *Posidonia oceanica.* These authors found that although there was no extensive decline of the surveyed *Posidonia* meadow over time, in some instances "seagrass showed reduced growth and necrotic tissue". However, the salient feature of this study was that the desalination plant source water consisted of groundwater "of agricultural origin", and was characterized by "high nutrient concentration, especially of nitrates, which reached 100 times the base level". In contrast, California seawater is characterized by very low (~1.0 µg atoms l^{-1}) nitrate levels (Petersen et al. 1986). In describing the effects of the discharge on *Posidonea*, the authors conclude (with respect to distinguishing between the effects of salinity and high nitrate levels): “from our present data we cannot establish the relative contribution of each of them”.

Sanchez-Lizaso et al. (2008) also attempted to evaluate brine discharge effects on *P. oceanica.* In laboratory studies, *P. oceanica* specimens transplanted from the wild were abruptly exposed to higher salinity regimes, and were reported to be sensitive to changes in salinity as small as 1 ppt. However, as was noted in the discussion, *P. oceanica* thrives in other areas of the Mediterranean where salinity is consistently up to 3 ppt greater than the concentrations found to initiate deleterious effects in the experimental study. This suggests that *P. oceanica* can physiologically adapt to constant conditions of higher salinities, but that *abrupt* transitions in ambient salinity lead to deleterious effects. A field study was also conducted, in which *P. oceanica* meadows were exposed to effluent from an active desalination plant. Although some deleterious effects were noted adjacent to the plant outfall, high source water nitrate levels confounded their results, as was the case in Gacia et al. (2007). The authors state: “The high nutrient concentrations of the brine may be the result of organic pollution not related to the desalination plant. This fact, together with other plant symptoms, such as the extremely high epiphyte abundance, the higher nitrogen and phosphorous concentration in tissues and the higher herbivore activity, leads us to think that, even without discarding a possible salinity stress, the main cause of the degradation of the meadow in the near field of the emissary is eutrophication”. Of note, the authors did not provide detailed, reproducible methodology for either the laboratory or field portions of the study.

The Panel Report also cites Latorre (2005), who purported to describe the environmental impact of brine disposal on *P. oceanica* off the Mediterranean coast of Spain. *No detailed experimental design or quantitative results were reported*, and thus no conclusions can be drawn from this work. The lack of validity of this study is highlighted by the fact that it was voluntarily withdrawn by the author, but accidentally published by the journal 'Desalination'; an erratum was published in a subsequent volume (Latorre 2006). Nevertheless, the Panel Report cites this paper as evidence that increases of 1-2 ppt salinity negatively impact seagrasses.

<u>Soft bottom benthic infauna, meiofauna and coral communities:</u>

Del Pilar Ruso (2007) conducted a study of the effects of hyper-saline brine discharge on soft bottom infaunal assemblages in the Mediterranean. As would be expected, some changes in infaunal community composition took place within the area directly adjacent to the outfall, and the zone of highest salinity concentration was dominated by more stress-resistant species, such as nematodes. This change in species composition was primarily noted in the immediate vicinity of (i.e., the closest sampling stations to) the outfall. Ambient salinity levels (control values outside of the study's survey transects) were not reported, making it difficult to assess the change in salinity necessary to trigger such re-structuring. Riera at el. (2011) reported similar results in a study of brine discharge effects on Canary Islands meiofauna. Specifically, they reported that meiofaunal community composition was altered by exposure to brine, and that the greatest degree of alteration was observed adjacent to the plant outfall. Although the authors only investigated changes in community composition up to a maximum of 30 meters distance from the outfall, the effects dissipated rapidly as brine mixed with receiving water and was diluted.

Such re-structuring of benthic community composition is expected. Graham (2005), in his evaluation of the potential environmental impacts of the Encina desalination project at Carlsbad, CA, postulated that, due to the negative buoyancy of the brine discharge, the benthic (i.e., bottom-dwelling) community within the mixing zone would likely be re-structured, becoming dominated by stress-tolerant species such as estuarine infauna (estuarine organisms are commonly exposed to severe salinity fluctuations) that would migrate or settle into the area. This phenomenon was first described several decades ago (Chesher 1975) and is an anticipated effect of brine exposure that should apply only to the immediate vicinity of an outfall where salinity values are highest, but would not be expected at distances of hundreds of meters (i.e., beyond the initial mixing zone).

With regard to coral communities, the Panel Report cites only one peer-reviewed journal article, Raventos et al. (2006). This study found no differences in coral community structure attributable to salinity toxicity effects from a Mediterranean desalination plant. The authors postulated that this may have been due both to the high natural variability inherent in coral community structure, as well as rapid dilution of the concentrate upon leaving the discharge pipe. This serves to highlight the need for consideration of site-specific biological and physical characteristics when assessing the potential effects of brine discharge.

2) <u>Applicability of these studies to local issues</u>

Based upon the aforementioned studies, the Panel Report makes the conceptual leap that the purported high salinity sensitivity of some sea grass habitats, such as *P. oceanica*, can be generalized to all situations. Notwithstanding the lack of scientific validity that characterizes many of these studies (as described above), it may be inappropriate to extrapolate their results to the California coastline. First, most of the cited studies were conducted in very distant locations (e.g., Canary islands, Mediterranean Sea) where salinity conditions can be quite different than those found in California coastal waters. Secondly, the sea grasses most commonly found in California [(eelgrass (genus *Zostera*) and surfgrass (genus *Phyllospadix*)] appear to be more tolerant of salinity fluctuations than *P. oceanica*.

Some salinity tolerance studies do exist for local sea grass species which were not cited in the Panel's report. Moore et al. (1996) studied the eelgrass *Zostera marina*, and concluded that salinity levels of 4-5 ppt above ambient resulted in only a 10% decrease in shoot growth. Green and Short (2003) reported that *Z. marina* can inhabit permanent salinity conditions over a *range* of almost 30 ppt. The surfgrass species in southern California waters most likely to be impacted by brine discharge is *Phyllospadix torreyi*. Drysdale & Barbour (1975) report that tolerance ranges of *P. torreyi* for salinity are relatively broad, although this has not been experimentally verified.

The Panel Report does not discuss the possible effects of salinity on giant kelp, *Macrocystis pyrifera*, which is perhaps the most conspicuous macroalgal species along the southern California coastline, forming dense beds that support a diverse assemblage of biota that are of economic and ecological importance. As is the case with most species, peer-reviewed literature detailing salinity effects on *M. pyrifera* is scarce. However, marine algae in general are characterized by high tolerance to salinity fluctuations (Kirst 1990). Laboratory studies conducted by Bay and Greenstein (1993) indicated that elevated salinity did not produce toxic effects on *M. pyrifera* spores collected in southern California waters. Specifically, exposure of giant kelp blades to elevated salinities of 38.5 ppt and 43 ppt did not affect either the spore generation rate or the length of the germination tube. Buschmann et al. (2004) reported that *M. pyrifera* in Chilean waters performed best (physiologically) at lower salinities of 27-30 ppt (in contrast to an average of 33.5 ppt at Carlsbad, CA), highlighting the plasticity with which this species can adapt to a broad range of salinity regimes.

In light of the paucity of salinity toxicity studies relating specifically to southern California biota, Graham (2005) argued that the salinity tolerances of Southern California Bight (SCB; the embayment encompassing the southern California coastline from Pt. Conception as far south as Cabo Colonet, Baja California) species could be deduced based upon their geographic distributions. SCB ocean salinity ranges between 33 and 34 ppt. However, salinity can vary, decreasing due to precipitation or increasing due to evaporation. Along coastal areas, salinities as high as 37 ppt occur in bays and other enclosed areas (Soule and Oguri 1974). Additionally, the SCB is a ‘transitional zone’ between more tropical fauna to the south and more temperate fauna to the north, and thus most SCB species have geographic distributions that extend beyond the SCB boundaries. For example, most of the species living in southern California also inhabit coastal waters along the southern coast of Baja California, Mexico. In addition to being warmer, these waters have higher salinities (34.5 ppt) that become even higher in shallow, enclosed areas (Hickey 1993). Further, a number of these same species [e.g., the California bat ray, *Myliobatis californica* (Bizzarro et al. 2009)] also live in the northern Gulf of California where salinity generally ranges from 35 to 36 ppt, but can be as high as 39-40 ppt in shallow areas (Brusca 1980). Thus, the natural geographic distributions of a number of SCB species extend into habitats where salinity (also temperature) is comparable to the salinity increase expected at a typical desalination plant (Graham was specifically referring to the Encina plant in Carlsbad, CA in his report). For this reason, Graham (2005) argued that SCB biota should be largely unaffected by desalination plant operation, with the obvious exception of those organisms living within the immediate vicinity of the outfall.

As is the case with almost any discharge from an industrial process, hypersaline brine exposure will undoubtedly have some effects on marine organisms. These effects, particularly the re-structuring of benthic communities within the mixing zone, are described or postulated for a range of taxa, and this report is not meant to dispute that fact. However, it is also true that the extant studies are far from comprehensive, often inconclusive, and that there is a notable paucity of studies describing salinity toxicity effects specifically on California species. Furthermore, results from studies conducted in distant locales that do not approximate California coastal water conditions are not necessarily relevant to California biota. For example, notwithstanding the scientific validity of the *P. oceanica* studies reviewed above, the rationale of applying findings for a highly sensitive sea grass such as *P. oceanica*, which has only been studied in the Mediterranean, to southern California waters where the dominant flora is a giant kelp species (*Macrocystis pyrifera*) with a broad salinity tolerance, is simply not logical.

3) <u>The area affected by brine discharge is extremely small relative to available continental shelf area in the Southern California Bight</u>

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The continental shelf off California is generally considered to extend offshore to a depth of approximately 200 meters. This is a highly productive zone which supports not only a diverse biota, but various commercial fisheries and recreational uses. Thus it is prudent to examine the extent to which it is adversely impacted by industrial activities, including desalination operations. The SCB itself is comprised of an area of 95,780 km^2, of which the continental shelf constitutes 11%, or 4895 km^2 (Emery 1960). By contrast, under modeled ‘historical average conditions’ at the Encina plant in Carlsbad (which could be considered a ‘typical’ California desalination plant scenario), the area of the benthos expected to experience salinity concentrations of 35 to 40 ppt is only approximately 0.15 km^2, an area that can be considered extremely small relative to the available shelf habitat (Graham 2005). This area will generally have similar biological characteristics to adjacent shelf habitat, particularly in the water column, while the benthic community composition in the mixing zone will likely be re-structured to become dominated by more salinity-tolerant species. Outside the mixing zone, community composition should remain largely unaffected.

4) <u>Site-specific conditions should be considered</u>

Site-specific physical conditions are critical factors influencing the degree to which brine discharge will affect marine life, as discussed in detail in the Panel Report (pages 15-27). Briefly, brine discharged into a high energy environment such as the surf zone will be diluted substantially faster and over a shorter distance than brine discharged into a low energy environment such as a bay. Ocean currents, tidal flux, wind speed, and bottom topography, including slope and rugosity, also play important roles in brine dilution. The dispersal mechanism (e.g., diffuser vs. passive mixing), velocity, trajectory, initial concentration, temperature and density of the brine, as well as the temperature and salinity of the receiving water, are all influential physical factors that must be considered.

Of equal importance are site-specific biological conditions. Several questions must be addressed in an assessment of environmental impacts, including but not limited to:

• Biota. What type of organisms live in the receiving waters? Are these organisms sessile or mobile (and therefore able to avoid high salinity conditions)? Are there endangered or salinity-sensitive species? What are the general salinity-tolerance characteristics of the region's biota? What are the available sources of information regarding the biology of the organisms, and how reliable are these sources? If reliable, are they applicable to local issues?

• Habitat types. What type of habitats exist in the receiving waters? Does the benthic habitat consist of soft bottom, rocky reef, rubble, or a combination of the above? Does the water column consist of open water or kelp forest? Is the habitat productive? Does it serve an exceptional biological (e.g., nursery area), commercial (e.g., fisheries activity) or recreational (e.g., tourism) function? What is the natural ecological variability of the habitat? Is the habitat an important source of, or sink for, larvae of resident organisms? Is the habitat or ecosystem already stressed by a pre-existing condition, such as pollution?

A representative example of site-specific response is that of the Tampa Bay, Florida desalination plant. With a production capacity of up to 25 mgd, it is currently the nation's largest desalination facility. The plant discharges into a semi-enclosed bay, which is generally thought to be an overly sensitive habitat to salinity increases. However, the hydrological characteristics and strong tidal flushing capacity of this bay are such that salinity buildup and concomitant toxicity are avoided, and various studies conducted within Tampa Bay have concluded that adverse environmental effects associated with this plant are minimal (TBW 2010).

In short, there are a large number of interacting physical and biological characteristics that determine the suitability of an area for optimal brine discharge dilution, and the ramifications of this discharge as concerns the area's biota. Thus, it is imperative to consider these site-specific conditions in the design, regulation, and monitoring phases of desalination plant operation, a conclusion that is reached in the Panel Report despite its contradictory recommendations.

5) <u>Sub-lethal effects and future monitoring:</u>

The Panel Report notes that 'very few peer-reviewed studies have evaluated sub-lethal effects of desalination discharges, either in the laboratory or in the field', including effects on biota in California waters. Such sub-lethal effects could include changes to an organism's reproductive capacity, growth and assimilation rates, and behavior. It will be many years, perhaps decades, before these sub-lethal effects are fully described for California species, and appropriate regulatory plans can be rationally considered. In addition, there is a paucity of studies employing robust Before-After, Control Impact (BACI) monitoring designs, which would substantially add to our understanding of desalination effects. The Panel Report does a commendable job of outlining monitoring strategies that would accurately assess the impacts of desalination brine upon receiving ecosystems over time in California waters (pages 40-43). It is notable that the Panel Report specifically states that "concentrate discharge sites can vary in terms of physical structure, hydrology, and biological communities. Consequently, any monitoring strategy should be site-specific, and a 'one-size-fits-all' approach will not be effective". Similarly, a one-size-fits-all *regulatory policy* that does not take into account site-specific considerations is illogical for California's desalination plants.

The SWRCB should encourage (or fund when appropriate) studies of sub-lethal effects and monitoring programs that employ BACI designs. Findings of such studies could then be integrated into an environmental desalination policy that is periodically revisited and evolves with the current state of scientific knowledge.

<u>Conclusions</u>:

The expert panel convened by SWRCB has reviewed the extant scientific and industry literature and, based upon their interpretation of this information, recommended a statewide minimum dimension for regulatory mixing zones of desalination plant discharge. Specifically, the Panel Report recommends that salinity increase be restricted to 5% (approximately 1.7 ppt) above ambient concentrations at the edge of a 100 meter mixing zone in the receiving water. Based upon a critical review of the Panel Report and the literature cited therein, I come to the following conclusions as pertains to the proposed regulatory mixing zone requirements:

• The literature cited in this report is generally inconclusive at best. Many of the studies are poorly designed, non-replicable, or plagued by confounding factors, and therefore of little scientific validity. Moreover, they were not conducted on local species, and thus the extrapolation of these results to California waters is scientifically unjustified. By extension, the recommended maximum allowable salinity increase of only 5% above ambient at the edge of the regulatory mixing zone is not justified by the information presented in the Panel Report and even appears to conflict with the Panel's conclusion that regulations should account for site-specific conditions.

• The most convincing scientific studies concern the effects of hyper-saline brine on benthic communities, which will likely experience some form of community re-structuring. These effects will have to be considered as a necessary cost of the desalination process, but appear to be localized to the immediate vicinity of the outfall. In addition, the benthic area that will experience biologically relevant salinity increases is extremely small relative to the available shelf habitat in the SCB. Given these facts, there does not appear to be a compelling justification for a regulatory mixing zone limit of only 100 m. This distance is not consistent with previous regulatory requirements, and appears to have been chosen arbitrarily.

• The physical and biological characteristics of California’s coastal waters are highly variable. This variability, in turn, directly influences the degree to which brine discharge will affect marine life. Therefore, site-specific conditions should be considered and incorporated into the regulatory framework governing proposed and existing desalination plants along the California coastline. A ‘one-size fits all’ regulatory plan, while convenient, is not scientifically defensible, and is not the appropriate measure to protect California’s marine environment.

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APPENDIX A: Review of Hyper-Salinity Toxicity Thresholds Study

In addition to the Panel Report reviewed in the preceding section, the Southern California Water Resources Control Board commissioned a study by the Marine Pollution Studies Laboratory at Granite Canyon to determine the tolerance of several Ocean Plan test species to varying concentrations of hyper-saline brine (Phillips et al. 2012). The results of this study could have important regulatory implications, as they will presumably be used in the development of an amendment to the CA Ocean Plan that addresses the impacts of desalination effluent upon marine life. As such, it is expected that the study should be rigorously conducted, and reported in such a way that can be readily understood and interpreted by the Board.

Nonetheless, this report is characterized by a lack of basic methodological considerations. There is insufficient background information and extensive use of jargon (e.g., ‘rangefinder’ versus ‘definitive’ tests) that is not explained and therefore extremely difficult to interpret by the layperson. Terms such as ‘lowest observable effect’ and ‘median effect concentrations’, which are the critical experimental parameters, are never explained – this also makes it difficult for readers to interpret the results. The experimental methodology is poorly presented and lacking in critical details. For example, the report states that ‘larval development tests’ were conducted in 20 mL vials, but does not explain what this test actually consists of, what is measured, or how the results are quantified.

The study purports to have tested various protocols at differing salinity levels. However, there is no mention of sample size, which is obviously a very important determinant of test accuracy. Judging from the report text and accompanying tables it appears that very few of the test salinities were actually replicated. This violates basic scientific protocol, and makes any realistic interpretation of the results impossible. Additionally, several of the testing protocols could result in increased toxicity that would mask or exacerbate the salinity effect that is being tested for. This includes a possible ion imbalance of the concentrated brine due to freezing, and toxicity caused by the addition of Nanopure (distilled) water to dilute the concentrated brine (as opposed to the use of seawater, which is how brine effluent would by diluted in actuality).

The lack of reported results is also problematic. At the very least, toxicity curves should have been presented. Without these data, it is difficult to assess the legitimacy of the study and understand the variance in results from one test salinity to another. The authors conducted copper, cadmium and zinc reference toxicity tests, but there is no mention as to what purpose these tests serve, and the results (shown in Figure 1) vary widely. Nevertheless, these results, the least important in the study as pertains to salinity toxicity, are the only ones the authors chose to present in graphical form. In addition, some of the reported results are simply not logical. For example, Table 1 shows that for the topsmelt survival test, the lowest observable effect was at a concentration of 65 ppt, while the EC50 (the salinity concentration at which 50% mortality is observed) is 63.4 ppt. These results likely stem from the lack of replication, and cast the shadow of doubt over the legitimacy of the conclusions.

In summary, this study appears to be flawed in several critical aspects, including the experimental design, analysis, and the reporting of the results. As presented, it would not pass a critical scientific peer review. Further, the final report is written in such a manner that it cannot be evaluated by anyone lacking expertise in the field of toxicity testing. I would recommend that the State Board take into consideration these aspects of the report, and conduct an independent review of its validity, before basing any important policy decisions on the results reported in it.

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CURRICULUM VITAE

Daniel P. Cartamil, Ph.D.

Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive
La Jolla, CA 92093-0204
Office: (858) 534-8044
Email: dcartamil@ucsd.edu

EDUCATION:

3/04-10/09 Scripps Institution of Oceanography – La Jolla, CA; Ph.D. in Marine Biology.

8/99-5/03 California State University – Long Beach, CA; Masters degree in Biology.

9/88-5/93 State University of New York – Oneonta, NY; Bachelors degree in Biology.

WORK EXPERIENCE:

10/09-present Scripps Institution of Oceanography, UC San Diego – Post-doctoral researcher.

3/04-10/09 Scripps Institution of Oceanography, UC San Diego – Research Assistant in the laboratory of Dr. Jeffrey Graham.

8/03-2/04 California State University, Long Beach – Part-time faculty.

9/99-5/02 California State University, Long Beach – Long Beach, CA. Teaching associate.

6/94-2/99 Frank Orth and Associates – Long Beach, CA (seasonal). Fisheries biologist for three seasons in Alaska and two in California.

6/93-3/94 Industrial Environmental Analysts – Sunrise Florida. Chemical extractions and nutrient analysis of industrial effluent samples. Director of Microbiology laboratory.

Desalination-specific Experience:

4/11-present RBF, Inc. – Marine biology consultant assessing environmental impact issues for construction of SWRO desalination plant at Oceanside, CA.

3/11-present Poseidon Resources, Inc. – Marine biology consultant assessing environmental impact issues for construction of SWRO desalination plants at Carlsbad and Huntington Beach, CA.

3/11 Watereuse Association Desalination Committee - Marine biology consultant reviewing Position Paper on impingement and entrainment impacts.

1/11 National Centre of Excellence in Desalination - Marine biology consultant reviewing proposals for SWRO impacts research in western Australia.

PEER-REVIEWED PUBLICATIONS:

A. Nosal, **D. Cartamil**, N. Wegner (*in press*). Demography and movement patterns of leopard sharks (*Triakis semifasciata*) aggregating near the head of a submarine canyon along the open coast of southern California, USA. Environmental Biology of Fishes.

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