August 12, 2016

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Re: Comment – CWA Section 305(b)/303(d) Integrated Report, Attn: Xueyuan Yu

On behalf of the Center for Biological Diversity (the Center), I submit this information to highlight that ocean-acidification threatened and impaired coastal and bay waters were omitted in the San Diego 2016 Water Quality Draft Integrated Report and 303(d) list.

Coastal and bay water across the San Diego region may already be experiencing the harmful effects of ocean acidification. There is strong scientific evidence showing that growth, survival, and behavioral changes in marine species are linked to ocean acidification. These effects can extend throughout the food webs, threatening coastal and estuarine ecosystems, fisheries, and human communities. The San Diego water board must analyze and list the water bodies that are threatened or impaired by increasing acidity.

Increasing concentrations of atmospheric carbon dioxide and the contribution of coastal pollution, sedimentation, and inadequate watershed management can substantially amplify the fluctuating pH conditions in San Diego waters making them more corrosive and highly vulnerable to ocean acidification. Some coastal and bay waters of San Diego may already experience conditions that impair the survival and growth of calcifying organisms such as oysters. Here, we present the most current scientific information on ocean acidification that the San Diego water board must consider for its water quality assessment. The San Diego water board should address ocean acidification in its 2016 Integrated Report (IR) and designate those coastal and bay waters impaired due to ocean acidification. Additionally, the San Diego water board must obtain all readily available data on ocean acidification and analyze it for its water quality assessment.

1. San Diego's duty to assess ocean acidification

a. Clean Water Act Background related to ocean acidification

San Diego may not ignore its duties under the Clean Water Act to solicit and consider ocean acidification data and information during its biennial water quality assessments. Not only the Clean Water Act section 303(d) mandates that states and regions must list waters that are not meeting water quality standards as impaired, but also EPA has directed states and regions to do so (EPA 2010a).

San Diego water board can address ocean acidification in regional waters through the Clean Water Act. Under the Clean Water Act and EPA's mandate, the San Diego water board has the

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authority and duty to identify waters impaired by ocean acidification. Impaired waters listing can help with local management, control local sources of pollution, and even address cross-border sources of pollution that contribute to acidification. It is not unique for water pollution to have sources that are not confined to one region or state, and the Clean Water Act has already grappled with downstream and cross-border pollution. See *e.g.*, *Arkansas v. Oklahoma,* 503 U.S. 91 (1992) (EPA has clear authority to require a discharge permit to comply with a downstream state's water quality standards); *Milwaukee v. Illinois.*, 451 U.S. 304 (1981) (Milwaukee's battle with Illinois over sewage discharges into Lake Michigan); *Gulf Restoration Network v. Jackson*, 2013 U.S. Dist. LEXIS 134811 (E.D. La. 2013) (concerning EPA authority to set water quality standards for multiple states whose runoff contributes to the Gulf of Mexico dead zone). There is also a precedent and guidance for addressing atmospheric deposition as a source of water pollution under section 303(d). [1]

EPA's (2010a) memorandum instructs that states should list waters not meeting water quality standards, including marine pH water quality standards, and should solicit existing and readily available information on ocean acidification using the current 303(d) listing framework. EPA also recommended that states:

(1) request and gather existing data related to ocean acidification, including temperature, salinity, dissolved oxygen, nitrate, total alkalinity, and pH;
(2) develop assessment methods for evaluating impacts of ocean acidification on marine waters based on existing pH and biological water quality criteria;
(3) track the progress of federal efforts to develop assessment and monitoring methods;
(4) develop bioassessment methods and/or biocriteria to reflect ocean acidification impacts;
(5) and include in their Integrated Report methodology a description of how they consider available ocean acidification data and information for assessment decisions.

In this letter we show that ocean acidification is already impacting San Diego's coastal and bay waters and its negative effects will only grow more severe with business as usual greenhouse emission scenarios. The Center urges the San Diego water board to analyze readily available data and assess its coastal and bay waters to identify threatened and impaired waters due to ocean acidification under section 303(d) of the Clean Water Act.

b. California's water quality standards applicable to ocean acidification

San Diego must analyze its coastal and bay waters as required by section 303(d) of the Clean Water Act because existing pollution controls are insufficient for waters to meet the state marine water quality objectives regarding pH [2]. San Diego must include all water bodies that fail "*any water quality objectives*" including numerical, narrative, and antidegradation criteria. Below is a

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[1] TMDLs Where Mercury Loadings Are Predominantly From Air Deposition September 2008 https://www.epa.gov/sites/production/files/2015-07/documents/document_mercury_tmdl_elements.pdf

[2] California Ocean Plan (2015). Water Quality Control Plan: Ocean Waters of California. State waters resources control board. California Environmental Protection Agency. 103 pp http://www.waterboards.ca.gov/water_issues/programs/ocean/docs/cop2015.pdf

summary of water quality objectives regarding pH for the state of California applicable to San Diego.

Numerical objectives
Based on the numerical water quality objectives for adequate aquatic life and seafood consumption, the pH of bay or estuary waters must fall between 6.5 and 8.5 units at all times. For ocean waters the pH must fall between 6.0 and 9.0 units[3]. The national recommended water quality criteria based on EPA standards requires that pH for saltwater aquatic life protection shall be between 6.5 to 8.5 units at any time. In addition, "the pH shall not be changed at any time more than 0.2 units from that which occurs naturally" (California Ocean Plan, Water Quality Objectives, Chemical Characteristics, Section II.D.2).

Antidegradation objectives
"Marine communities, including vertebrate, invertebrate, algae, and plant species, shall not be degraded (California Ocean Plan, Water Quality Objectives, Biological Characteristics, Section II.E.1). Based on the California Ocean Plan, degradation "shall be determined by comparison of the waste field and reference site(s) for characteristic species diversity, population density, contamination, growth anomalies, debility, or supplanting of normal species by undesirable plant and animal species. Degradation occurs if there are significant differences in any of three major biotic groups, namely, demersal fish, benthic invertebrates, or attached algae. Other groups may be evaluated where benthic species are not affected, or are not the only ones affected."

The Sand Diego water board must evaluate the attainment status of each of these standards with respect to ocean acidification. Moreover, if the water quality standards are not being attained, "*but the source-stressor is unknown (e.g., carbon deposition, nutrient enrichment, industrial discharge, natural background, etc), then EPA expects the segment to be listed*" (EPA 2010).

The San Diego water board must evaluate all readily available information about ocean acidification. There are increasingly important high-resolution data sets that contain information on ocean acidification (see below). San Diego must evaluate these data to determine baseline conditions and to assess its coastal, bay and estuarine waters for impairment by ocean acidification.

Increases of atmospheric carbon dioxide (CO_2), due to human activities, increases the uptake of CO_2 into the oceans making coastal and estuarine waters more acidic by decreasing the pH. There is strong scientific evidence that ocean acidification directly affect shellfish and other marine groups compromising growth, survival, reproduction, and metabolism. Ocean acidification can also amplify the toxicity of harmful algal blooms, impair fish behavior, and affect prey source and distribution of fish and marine mammals. San Diego must analyze coastal, bay and estuarine waters for changes in pH to determine whether they pose a risk to marine life.

[3] California Ocean Plan (2015). Water Quality Control Plan: Ocean Waters of California. State waters resources control board. California Envrionmental Protection Agency. 103 pp http://www.waterboards.ca.gov/water_issues/programs/ocean/docs/cop2015.pdf

Below we explain: how atmospheric CO_2 concentration drives ocean acidification; the scientific evidence supporting that ocean acidification is already harming marine life; how ocean acidification violates aquatic life standards even while attaining pH numeric standards; and we provide readily available data that must be considered in the 2016 Integral Report.

2. Relationship between CO_2 emissions and ocean acidification

Ocean acidification is directly related to the increase in atmospheric CO_2 emissions globally. Atmospheric CO_2 concentrations reached average levels of over 401 ppm globally on December of 2015 (NOAA National Climatic Data Center 2015) which is higher than at any point during the last 800,000 years (Lüthi et al. 2008). Over the past 200 years, the global oceans have absorbed approximately 25 % of the anthropogenic CO_2 released to the atmosphere from burning fossil fuels (Canadell et al. 2007, Feely et al. 2013, IPCC 2014). Anthropogenic CO_2 emissions from burning fossil fuels, cement production, and land used accounts for a total of 36 giga tones (Gt) of CO_2 per year in the past 10 years. Current emissions are about 40 $GtCO_2$ per year (Rogelj et al. 2016). Approximately 9 Gt of CO_2 per year (i.e., 26% of total emissions) entered the global oceans since 2004 (Le Quéré et al. 2015).

As the global oceans uptake the excess of CO_2, seawater chemistry profoundly changes and the oceans become more acidic (Orr et al. 2005, Fabry et al. 2008, Fabry 2009, Doney et al. 2009, Gattuso and Hansson 2011, Feely et al. 2013). The average pH of the global surface oceans has already decreased by 0.1 units (from 8.2 to 8.1 pH units) which represent a 30 % increase acidity and a 10% decrease in carbonate ion concentration in comparison with pre-industrial levels (Feely et al. 2004, Caldeira and Wickett 2005b, Orr et al. 2005, Cao and Caldeira 2008, Doney et al. 2009, Byrne et al. 2010). For some marine organisms this change already impairs their ability to grow shells. Long term monitoring and modeling studies of waters across the Pacific West Coast of the United States show a clear pH decline over the past decades (Beman et al. 2011, Friedrich et al. 2012). In fact, anthropogenic ocean acidification already exceeds the natural variability on regional scales and is detectable in several Pacific regions (Friedrich et al. 2012, McLaughlin et al. 2015, Takeshita et al. 2015).

Once anthropogenic CO_2 enters the oceans it is impossible to remove it, and the global oceans may require thousands of years to naturally return to a higher pH state (Solomon et al. 2009). Current CO_2 emission trajectories are tracking some of the worse emission scenarios (IPCC 2013) and rates of atmospheric CO_2 are forecast to reduce surface ocean pH by 0.3 to 0.5 units on average by 2100, and regional changes may be even more severe (Caldeira and Wickett 2005a, Orr et al. 2005, McNeil and Matear 2006, Steinacher et al. 2009, Doney et al. 2009). Changes in ocean chemistry due to increasing absorption of carbon dioxide concentration emitted by human activities is unprecedented in the geological record (Honisch et al. 2012). In fact, the oceans are becoming acidic at a rate faster than they have in the past ~300 millions year, a period that includes three major mass extinctions (Zeebe 2012, Hönisch et al. 2012). The current change in seawater chemistry is an order of magnitude faster than what occurred 55 million years ago during Paleocene-Eocene Thermal Maximum, which is considered to be the closest analogue to the present, when 96% of marine species went extinct (Zeebe 2012, Hönisch et al. 2012). While the atmospheric concentration of CO_2 is currently over 401 ppm, coastal and estuarine waters experience wide fluctuations of CO_2 concentrations that reach levels not expected until the end of the century (Feely et al. 2009).

3. Ocean acidification already affects marine life

a. Ocean acidification reduces calcium carbonate saturation

The uptake of anthropogenic CO_2 by the oceans not only reduces the pH of seawater, but also lowers the concentration of carbonate ion (CO_3^{-2}) and thus calcium carbonate ($CaCO_3$) saturation states - the amount of dissolved calcium carbonate available in seawater (Orr et al. 2005, Cao and Caldeira 2008, Doney et al. 2009). This relationship can be detected globally (Jiang et al. 2015) and regionally (Waldbusser et al. 2015a). Reduction of calcium carbonate saturation state due to decline in pH directly affects those species that produce shells and skeletons even when pH may be considered within normal ranges. This is because carbonate ions in seawater partially buffer the acidity created by decreasing pH. However, this neutralizing reaction depletes seawater of carbonate ions, making $CaCO_3$ less available for calcifying marine organisms to build shells and skeletons. Globally, the surface concentration of carbonate ions has decreased by more than 10% since the pre-industrial era (Caldeira and Wickett 2003, Orr et al. 2005, Feely et al. 2008).

Calcium carbonate saturation state is an important parameter that directly affects the ability of marine calcifying species of producing shells and skeletons (Ries 2010, Comeau et al. 2012, Feely et al. 2012, Jiang et al. 2015, Lebrato et al. 2016). In fact, calcium carbonate saturation states, instead of pH, is most commonly used to assess the effects of ocean acidification on marine organisms and determine the ability of organisms to produce shells and skeletons (Ries 2010, Albright and Langdon 2011, Bednaršek et al. 2012b, Waldbusser et al. 2015a). For example, decreasing carbonate saturation states is a better proxy to determine ocean acidification impairments in shelled mollusks (Fig. 1), which are directly linked with chronic and acute effects (Gazeau et al. 2013, Waldbusser et al. 2015a). Lower calcium carbonate saturation states is already affecting many marine organisms and altering ecosystem structure and function (Fabry et al. 2008, Nagelkerken and Connell 2015, Linares et al. 2015, Yang et al. 2016, Albright et al. 2016) and it is predicted to further decline in the near future (Cao and Caldeira 2008).

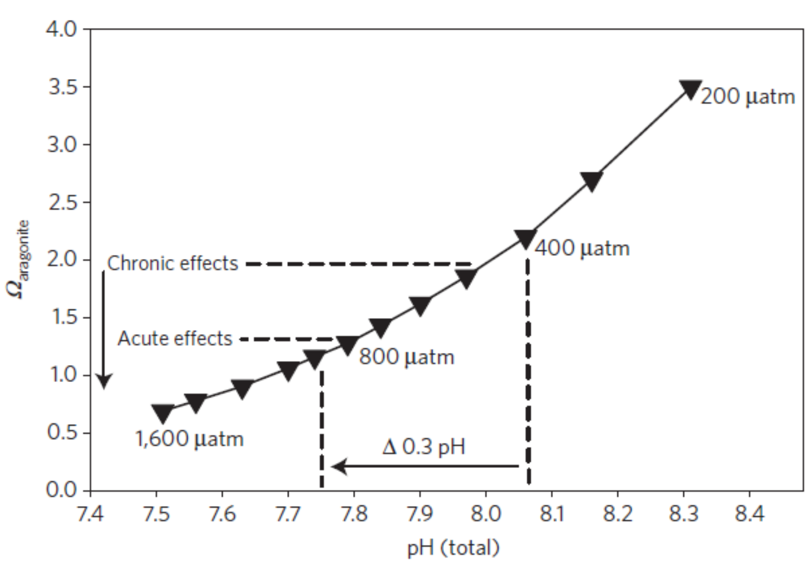

Figure 1 Calculated response of pH and aragonite saturation state to increasing *p*CO2 from 200 to 1,600 µatm (triangles) at typical upwelling conditions along the Oregon coast. Conditions calculated for total alkalinity = 2,300 µmol kg^{-1}, temperature = 13ºC, and salinity = 33. Symbols are values of pCO2 . Chronic and acute effects due to saturation state decreases from experiments have been noted for bivalve larvae. The Δ 0.3 pH was previously noted as

significant to many physiological processes in mollusks (Gazeau et al. 2013). *Figure and legend after (Waldbusser et al. 2015a).*

Calcifying organisms are particularly vulnerable to decreasing pH of seawater due to their dependence on carbonate ions concentrations and calcium carbonate saturation states. As the saturation state of $CaCO_3$ minerals reaches 1 (i.e., the equilibrium of a mineral to form or dissolve) calcification is depleted, stopped, and dissolution occurs (Gattuso and Hansson 2011). As such, the amount of the most common mineral forms of calcium carbonate in seawater (i.e., aragonite and calcite) determines the capacity of marine calcifiers to deposit (Ω>1) or dissolve (Ω<1) their calcium carbonate structures. This is because at lower pH, the amount of carbonate ions decreases making it less available for organisms to be used. Aragonite and calcite saturation states has already declined globally, although no uniformly (Jiang et al. 2015) and it is predicted to further decline by the end of the century (Cao and Caldeira 2008). Rates of change are one to two orders of magnitude larger than as estimated for the last glacial culmination (Friedrich et al. 2012).

b. San Diego 's coastal and bay waters are affected by ocean acidification

Ocean acidification is already affecting coastal and bay waters of the San Diego region by impairing the capacity of organisms to produce shells and skeletons, altering food webs, and affecting the dynamic of entire ecosystems such as kelp forests (Cooley and Doney 2009, Cheung et al. 2009, 2010, Brown et al. 2014, Ekstrom et al. 2015, Chan et al. 2016, Seijo et al. 2016). Small increases in acidity of coastal and estuarine waters can substantially reduce the ability of marine organisms to produce shells and skeletons. Microscopic algae and calcifying zooplankton are especially at risk and changes in their abundance and survivorship can result in cascading effects that ripple through the food web affecting other marine organisms from fishes to whales. But rising CO_2 in seawater can also directly affect marine fishes by affecting critical behavior such as orientation, predator avoidance, and the ability to locate food and suitable habitat.

San Diego's coastal waters are vulnerable to ocean acidification because two natural phenomena work in concert with anthropogenic CO_2 emissions: ocean currents and coastal upwelling. Acidification of California waters starts with surface oceanic currents carrying waters throughout the North Pacific from Asia to the West Coast. This water transport takes decades, absorbing atmospheric CO_2 produced through global human activity and accumulating CO_2 by natural respiration. Coastal upwelling along the state brings deep water rich in CO_2 and low in dissolved oxygen to the continental shelf driving chemical conditions that are harmful to marine life (Feely et al. 2004, 2008, 2009, Hauri et al. 2009, 2013, Gruber et al. 2012, Bednaršek et al. 2014). As these processes happen in a multi-decadal time frame, the effects of ocean acidification due the absorption of CO_2 across the North Pacific will become more severe overtime. That is, waters in transit to the West Coast will carry increasingly more anthropogenic CO_2 as they arrive to California and specifically to the San Diego region (Chan et al. 2016). Even if CO_2 emissions are totally halted today the West Coast states have already committed to increasing ocean acidification for the next three to four decades. Meanwhile, coastal upwelling is projected to intensify in response to stronger wings due to global warming, which will only increase the prevalence of waters of acidic and low oxygen conditions (Snyder et al. 2003, Sydeman et al. 2014).

Most importantly for local management, ocean acidification in coastal regions interacts with natural and anthropogenic processes that further reduce pH and carbonate saturation states (Feely et al. 2008, Wootton et al. 2008, Salisbury et al. 2008, Wootton and Pfister 2012, Takeshita et al. 2015). California coastal waters are relatively more acidic because oceanographic processes such as oceanic current and coastal upwelling (Feely et al. 2004, 2008, 2009, Hauri et al. 2009, 2013). However, surface waters already show undersaturation with respect to aragonite due to anthropogenic ocean acidification independently of upwelling pulses (Feely et al. 2008). In fact, without acidification, undersaturated waters would have been as much as 50 m deeper than they are today (Feely et al. 2008). In addition, recent declines in aragonite saturation states due to anthropogenic ocean acidification have been compounded by changes in the circulation of the California Current (Feely et al. 2012), likely connected to climate change (Bakun 1990, Snyder et al. 2003, Sydeman et al. 2014). Strong coastal upwelling occurs in the spring and summer bringing nutrients and even more CO_2 rich waters from the deep ocean due to ocean acidification (Feely et al. 2008). Upwelling in this region has been intensified in the past decades (Rykaczewski and Checkley 2008) and it is predicted to become stronger with more favorable winds due to climate change (Bakun 1990, Snyder et al. 2003, Sydeman et al. 2014). Models predict that by the mid-century, surface coastal waters in this region would remain undersaturated during the entire summer upwelling season and more than half of nearshore waters throughout the entire year (Gruber et al. 2012, Hauri et al. 2013).

Coastal and estuarine waters in California are influenced by local variability and ocean acidification can amplify these fluctuations. Daily and seasonal fluctuations in pH are due to changes in upwelling, respiration, salinity, temperature and several local factors such as river discharge, eutrophication, hypoxia, and chemical contamination that amplify the deleterious effects of anthropogenic ocean acidification in coastal and estuarine waters (Fabry et al. 2008, Kelly et al. 2011a, Cai et al. 2011, Waldbusser and Salisbury 2014). For example, ocean acidification combined with eutrophication can alter phytoplankton growth and succession affecting the entire base of food webs (Wu et al. 2014a, Flynn et al. 2015). Studies also show that under ocean acidification conditions heavy metal pollution can be more severe. In more acidic waters, sediments become more toxic as they easily bounds to heavy metals making them more available and thus more toxic for aquatic life (Roberts et al. 2013). For example, ocean acidification increases the toxicity effects of copper in some marine invertebrates (Campbell and Mangan 2014, Lewis et al. 2016).

Near and undersaturated coastal and bay waters in San Diego do not meet water quality objectives regardless of whether or not they attain current and inadequate pH numerical standards. The region and the state must act now to improve water quality in coastal, bay and estuarine areas because aragonite saturation state of some bodies of waters in San Diego are already suboptimal for oyster growth and reproduction (see below). The region and the states should also address factors that magnify the effects of acidification at local scale to increase the probability of calcifying species to deal with higher acidification in the near future.

c. Empirical and field studies show that marine calcifiers are highly vulnerable

Experiments have shown that ocean acidification has deleterious effects on many marine organisms (Feely et al. 2004, Cooley and Doney 2009, Hendriks et al. 2010, Kroeker et al. 2013, Waldbusser et al. 2015a, Yang et al. 2016) with long-term consequences for marine ecosystems (Hoegh-Guldberg 2007, Pandolfi et al. 2011, Couce et al. 2013, Nagelkerken and Connell 2015, Linares et al. 2015). Recent studies have confirmed this in the field, despite several confounding factors such as temperature and daily fluctuations (Albright et al. 2016). Calcifying organisms are clearly more vulnerable to the effects of ocean acidification than non-calcifying species (Kroeker et al. 2013) especially those that use aragonite as their calcium carbonate minerals (Ries 2010).

Most extant calcifying organisms use aragonite as the preferable crystal form of calcium carbonate to produce shells and skeletons and they are the most vulnerable to acidification (Ries 2010, Wittmann and Pörtner 2013). Since aragonite is more soluble than calcite, undersaturated conditions for aragonite will be reached before they are for calcite. Therefore, those organisms that use aragonite as the preferable form of calcium carbonate for calcification are the first to be affected as calcium carbonate plummets due to acidification. However, calcifying species have different thresholds for aragonite (i.e., the aragonite saturation state that prevents calcification and leads to dissolution is species specific), thus some marine calcifier species will be more vulnerable than others (Ries et al. 2009, Lebrato et al. 2016). Because marine calcifiers have different capacity to use the same concentration of calcium carbonate to secret shells and skeletons (Ries et al. 2009), certain species are highly sensitive to the same aragonite saturation conditions and suffer the effect of ocean acidification with greater intensity (Wittmann and Pörtner 2013). However, those species that are able to calcify and growth under acidic conditions may suffer physiological constrains that impairs fertilization, reproduction, settlement, and their capacity to resist diseases and other stressors (Pörtner 2008, Hofmann et al. 2010, Wittmann and Pörtner 2013, Bednaršek et al. 2016).

d. Shellfish in the San Diego region are vulnerable to ocean acidification

Among the marine species most vulnerable to ocean acidification in San Diego region are shelled mollusks. Studies have shown that most shelled mollusks are especially sensitive to small pH changes, in particular carbonate saturation states (Barton et al. 2012, Gazeau et al. 2013, Hettinger et al. 2013a) (Fig. 4). Shelled mollusks such as oysters are keystone species in coastal areas that provide great economic value and ecosystems services such as water filtration, coastal protection, and habitat (Newell 2004) and they are at risk due to corrosive waters.

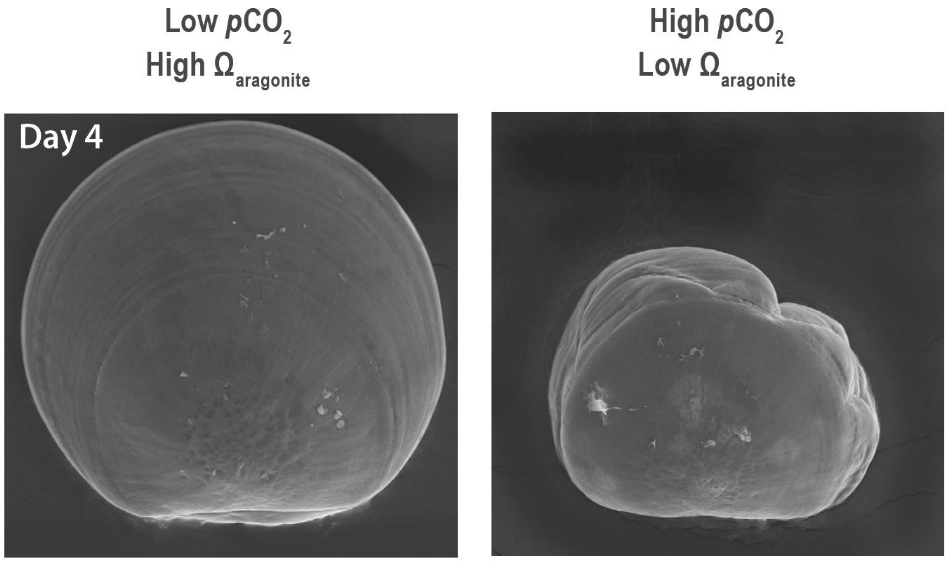

Figure 4. Pacific oyster larvae from the same spawn, raised by the Taylor Shellfish Hatchery in natural waters of Dabob Bay, WA, exhibiting favorable (left, $pCO_2 = 403$ ppm, $\Omega_{aragonite} = 1.64$, pH = 8.00) and unfavorable (right, $pCO_2 = 1418$ pp, $\Omega_{aragonite} = 0.47$, pH= 7.49) carbonate chemistry during the spawning period. Scanning Electron Microscopy images show representative larval shells from each condition at four days post–fertilization. *Figure and legend after Barton et al. 2015*

Ocean acidification has already affected oyster populations in estuarine waters of the U.S. Pacific Northwest (Barton et al. 2012, 2015, Timmins-Schiffman et al. 2012). Oyster production in the Pacific Northwest declined 22% between 2005 and 2009 because ocean acidification directly affected oyster seed production (Barton et al. 2012, 2015). In fact, Washington and Oregon alone experienced production declines of oyster seed hatcheries of up to 80% from 2006 to 2009 (Chan et al. 2016). In 2006, oyster larval production at the Whiskey Creek Hatchery (Netarts Bay, Oregon) substantially declined due to acidic water conditions leading to halted growth and oyster die offs (Barton et al. 2012).

Oysters and other marine bivalves show permanent negative effects due to ocean acidification when pH and aragonite saturation state declined below certain thresholds (Parker et al. 2009, 2012, Lannig et al. 2010, Barton et al. 2012, 2015, Hettinger et al. 2012, Gazeau et al. 2013, Waldbusser et al. 2015a, 2015b). Barton el al. (2012) first demonstrated that larval production and mid-stage growth of Pacific oyster (*Crassostrea gigas*) significantly declined as rearing water decreased **below 7.8 pH units** and below 1.7 in aragonite saturation state below. In waters with elevated CO_2 concentrations, oyster larvae showed difficulty with growth and development, drastically reducing oyster production (Barton et al. 2012). Even when larvae are able to develop under moderate aragonite saturation states, studies show they growth smaller (Waldbusser et al. 2015a) and very few develop to metamorphosis (Barton et al. 2012). Similarly, experimental studies with the Olympian oyster (*Ostrea lurida*), a foundation species of the Pacific Northwest, have shown that as pH declines to **7.8** units (well within the numerical standard pH criteria for the state of California), juvenile oysters exhibited a 41% decreased in shell growth rate, and negative effects persist even after oysters are returned to normal conditions (Hettinger et al. 2012, 2013b).

Ocean acidification can cost the shellfish industry million of dollars in economic losses and thousands of jobs. In fact, ocean acidification has already cost the oyster industry in the U.S. Pacific Northwest approximately $110 million dollars and compromised ~3,200 jobs (Washington State Blue Ribbon Panel on Ocean Acidification 2012, Barton et al. 2015). As the shellfish industry faces the increasing effects of ocean acidification, sales and job security will be drastically impacted affecting coastal communities, particularly in areas where fishing and coastal tourism provide the main economic support (Ekstrom et al. 2015, Chan et al. 2016). For example, a Canadian shellfish company reported losses of ~ $10 million during its scallop fisheries in 2014 because acidic waters (WCOAHP 2015a). The economic cost for the world could be over $100 billion USD with business as usual scenarios (Narita et al. 2012).

These findings in the Pacific Northwest are a wake-up call for action. Such negative effects of ocean acidification on shelled mollusk like oyster support the results from laboratory experiments. It is alarming that negative effects of ocean acidification are already seen under current and fluctuating pH conditions. As the ocean acidification trend continues, the shellfish industry that include oysters, mussels, scallops and crabs will be subject to substantial economic loses (Chan et al. 2016).

e. Ocean acidification affects crucial zooplankton groups such as pteropods

Ocean acidification in California waters affects crucial shelled organisms such as pelagic pteropods. Pteropods are small sea snails that use the aragonite form of calcium carbonate to secrete their spiral shells. Pteropods can be use as indicator for water impairment due to their striking vulnerability to ocean acidification. These mollusks are among the calcifier groups most sensitive to declines of aragonite saturation conditions because their delicate aragonite shells (Comeau et al. 2012, Lischka and Riebesell 2012, Bednaršek et al. 2016). In fact, in-life dissolution of pteropods-shells fossil can be used as an indicator of past ocean carbonate saturation conditions (Wall-Palmer et al. 2013). In the California Current Ecosystem, pteropods are already impacted by ocean acidification with reduction in abundance and signs of shell damages due to acidic waters (Bednaršek et al. 2014, Bednaršek and Ohman 2015). For example, sampling studies along the Washington-Oregon-California coast showed that on average, severe dissolution is found in 53 % of onshore pteropods and 24 % of offshore individuals due to undersaturated waters in the top 100 m with respect to aragonite (Bednaršek et al. 2014).

Field studies have demonstrated that pteropod's shell exhibit increasing dissolution as aragonite saturation declines below **1.3** (Bednaršek and Ohman 2015) and extensive dissolution (e.g., 30-50% shell surface area) in areas where aragonite saturation state is below 1.0 (Bednaršek et al. 2012a, Bednaršek and Ohman 2015). Values of **Ω** aragonite from 1.1 to 1.3 causes stress in pteropods and calcification is maintained at the expense of higher energy consumption (N. Bednaršek Per. Com.). At values below **Ω** aragonite = 1.1 extensive shell dissolution and irreparable damage is often observed (N. Bednaršek Per. Com.) (Fig 5). This highlights how aragonite saturation state is an important proxy to directly detect the impacts of ocean acidification on these organisms and how water quality standards must include this parameter.

Pteropods are so sensitive to acidic waters that their vertical distribution track changes in water chemistry in the southern California Current System (Bednaršek and Ohman 2015). As aragonite saturation horizon (Ω aragonite = 1.0) shoals (from >100 m to <75 m deep) pteropod abundance declines at depth below 100 m where waters are less saturated with respect to aragonite. In addition, severe shell dissolution is observed at depths where Ω aragonite equals 1.1 to 1.4 (Bednaršek and Ohman 2015). This dynamic in pteropod abundance due to change in sea water chemistry can directly affect those species that feed on them (Doubleday and Hopcroft 2015).

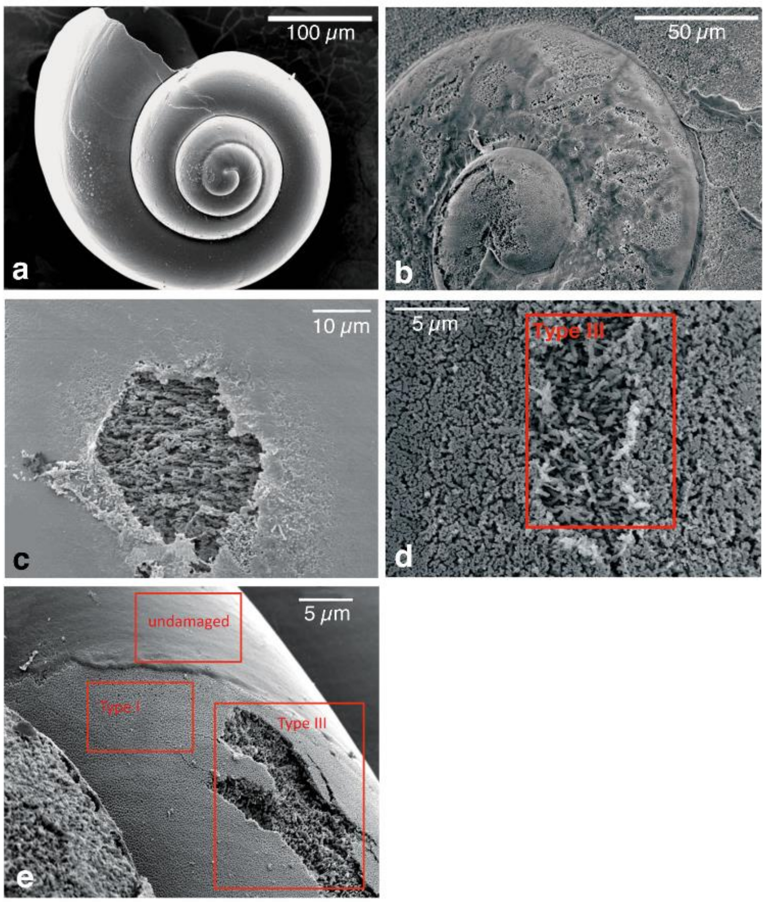

Figure 5 Scanning electornic micrographs illustrating types of shells dissolution in the thecosome pteropod Limacina helicina. (a) whole animal with no shell dissolution, (b) Type II dissolution; (c,d) Type III dissolution; (e) mixture of no dissolution, Type I and Type III on a single shell surface. As Ωarag decreases with ocean acidification, pteropods' biological condition deteriorates. Under low level of stress (Ω > 1.3) dissolution is insignificant and shell calcification is maintained. As Ω decreases, dissolution increases, calcification decreases and pteropod shells go through stress to damage to irreparable and ultimately leads to organism mortality. Below Ω < 1.1 moderate to extensive shell damage and decrease calcification occurs. Under undersaturated conditions (Ω <0.9) extensive severe dissolution and absence of calcification occurs. *Figure and legend modified after Bednaršek and Ohman (2015).*

Vertical distribution of pteropods is already affected by ocean acidification which may have important consequences for the species that feed on them. Pteropods are common prey for important commercial fishes such as anchovies, herring, jack mackerel, sablefish, and pink, chum, coho, and sockeye salmon (Brodeur et al. 1987, 2007, Armstrong et al. 2005, Aydin et al. 2005). In addition, zooplankton, squid, whales and even birds eat pteropods. Pteropods show vertical migrations to deeper waters during the day and feed in shallower waters at night to avoid predation. Ocean acidification can drastically constrain these vertical migrations by narrow the range of optimal carbonate saturation and thus calcification. For example, in the Pacific Northwest, diel migration for *L. helicina* is relatively shallow (100 m) because undersaturated waters with respect to aragonite (Mackas and Galbraith 2012). Thus, as pteropods are affected by ocean acidification through calcification and survivorship, ocean acidification indirectly affects species higher in the food web that depend on them as food source.

Pteropods are one of the most important species in oceanic marine food webs and their decline could threaten the functioning of entire coastal ecosystems and commercially important fisheries such as salmon (Doubleday and Hopcroft 2015). Pteropods are the main food sources for commercially and culturally important species such as Pacific salmon, herring, and squid (Doubleday and Hopcroft 2015). Therefore, temporal or spatial reduction in pteropod abundance will have drastic cascading effects on the species that rely on them as the main food source. For example, 30 % of the variability of pink salmon survival during spring-summer in Prince Williams Sound, southern Alaska, has been directly associated with changes in the abundance and distribution of the pteropod *Limacina helicina* (Doubleday and Hopcroft 2015).

f. Ocean acidification affects a variety of other marine organisms

Laboratory and mesocosm experiments shows that pH and calcium carbonate saturation state levels observed in coastal and estuarine waters of Sand Diego also impair calcification rates of other marine calcifiers such coccolithophorids, foraminifera, other mollusks, and sea urchins (Orr et al. 2005, Ries et al. 2009, Doney et al. 2009, Wittmann and Pörtner 2013, Haigh et al. 2015, Yang et al. 2016). Many calcifying species are directly affected by ocean acidification by decreasing calcification rates and compromising growth and survival. Overall calcifying organisms such as corals, echinoderms, and mollusks tend show higher sensitivity than crustaceans and fish species (Ries et al. 2009, Wittmann and Pörtner 2013) (Fig 6). For example, in experimental conditions, calcification rates in temperate corals, urchins, limpets, clams, scallops, and oysters decrease considerably as aragonite saturation state declines below 1.5 corresponding to very elevated pCO_2 (i.e., over 900 µatm) (see Ries et al. 2009). Studies also suggest that some species of juvenile fish of economical important coastal regions are highly sensitive to higher than normal pCO_2 concentrations and lower pH, exhibiting high mortality rates (Ishimatsu et al. 2004).

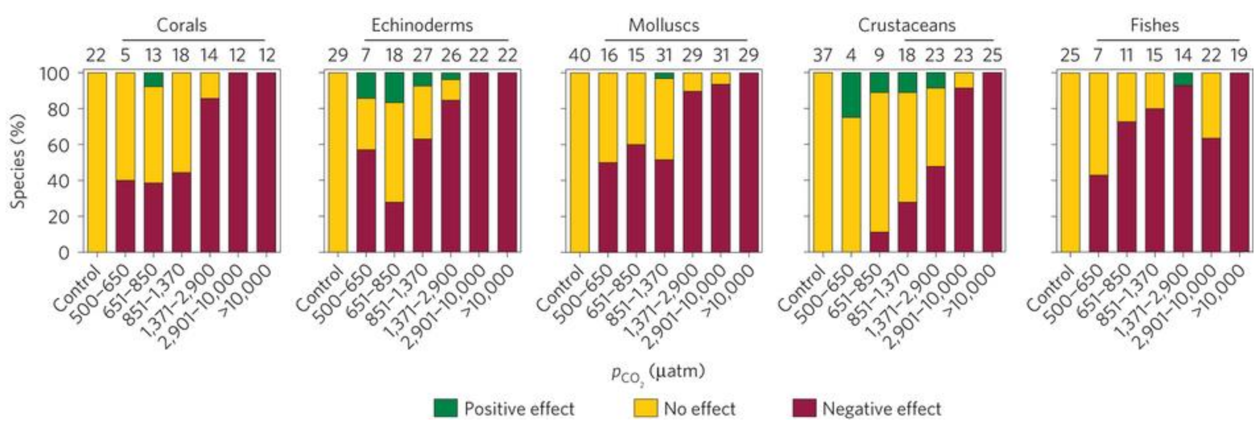

Figure 6 Fractions (%) of coral, echinoderm, mollusk, crustacean and fish species exhibiting negative, no or positive effects on performance indicators reflected as individual fitness in response to the respective p_{CO2} ranges (µatm). The numbers of species analyzed on each CO_2 range are on top of columns. Bars above columns denote count ratios significantly associated with p_{CO2} (according to Fisher's exact test, p<0.05, used to analyze species counts of pooled groups of negatively affected species versus not negatively affected species. *Figure and legend modified after Wittmann and Pörtner 2013.*

Ocean acidification will have negative impacts on calcification, survival, growth, reproduction and other physiological processes at the species level in the absence of evolutionary adaptation or acclimatization over the coming decades (Kroeker et al. 2013). These effects can accumulate through marine communities disrupting ecological process and energy fluxes (Nagelkerken and Connell 2015, Linares et al. 2015). Together, these studies forecast drastic changes in species composition with negative impacts through marine population and communities that ultimately affect ecosystem functionality and services.

g. Local stressors magnify anthropogenic ocean acidification

Local stressors can drastically magnify and contribute to acidification in Sand Diego coastal and estuarine waters. Local stressors such as eutrophication (Waldbusser et al. 2011, Cai et al. 2011), pollution (Biscéré et al. 2015, Flynn et al. 2015), sulfur dioxide deposition (Doney et al. 2007), hypoxia (Kemp et al. 2005, Melzner et al. 2012), river discharge (Salisbury et al. 2008), runoff from acidic fertilizers (Dentener et al. 2006), and harmful algal blooms (Wu et al. 2014b) can substantially contribute to ocean acidification in coastal waters (Duarte et al. 2013, Waldbusser and Salisbury 2014). Acidification can also be exacerbated by non-uniform changes in water circulation and biological processes, e.g., respiration (Feely et al. 2010) and precipitation runoff (Cooley and Doney 2009, Doney et al. 2009, Cheung et al. 2009). Non-atmospheric sources combined with anthropogenic ocean acidification can result in sudden negative ecosystem consequences when they coincide with physical processes such as upwelling that bring O_2 deprived, CO_2-enriched and low-pH waters to nearshore regions (Feely et al. 2009). For example, high mortality rate of oyster larvae from oyster hatcheries in the Pacific Northwest have been linked to the combination of multiple stressors in a lower pH environment (Barton et al. 2012, Timmins-Schiffman et al. 2012).

The US west coast Pacific had one of the worst harmful algal blooms recorded in 2015 with the highest concentrations of domoic acid yet observed[4] and ocean acidification may have increased their toxicity. These toxic algal blooms led managers to close down the entire West Coast recreational and crab fisheries from the southern Washington coast to Southern California[5]. The toxicity of harmful algal blooms increases with ocean acidification and eutrophication can alter phytoplankton growth and succession (Wu et al. 2014b, Flynn et al. 2015).This means that the water quality standard for toxic and other deleterious organic and inorganic substances for marine waters can be affected by both pH and pollution. For example, the toxicity of some harmful algal blooms can increase with ocean acidification (Sun et al. 2011) and with land-runoff and/or water column stratification (Hallegraeff 2010).

Harmful algal blooms can cause mass mortality of wildlife, shellfish harvesting closures, and tremendous risk to human health. Some species of *Pseudo-nitzschia*, a global distributed diatom genus, produce domoic acid, a neurotoxin that causes amnesic shellfish poisoning. Studies have shown that acidified conditions due to increasing pCO_2 can increase toxins concentration as much as five-fold in this harmful microalgae (Sun et al. 2011, Tatters et al. 2012). Toxicity levels

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[4] NOAA Fisheries mobilizes to gauge unprecedented West Coast toxic algal bloom, June 2015. http://www.nwfsc.noaa.gov/news/features/west_coast_algal_bloom/index.cfm

[5] South coast of Washington closed to crab fishing, June 2015. http://wdfw.wa.gov/news/jun0515a/

are positively correlated with mortality of shellfish, fish, marine mammals, and can cause deleterious effects in the central nervous system in humans known as paralytic shellfish poisoning (Tatters et al. 2012, 2013, Fu et al. 2012). For example, results from laboratory experiments indicate that levels of the toxin domoic acid and growth rate in the diatom *Pseudo-nitzschia multiseries* increases as pCO_2 in water increases from 220 to 730 ppm (Sun et al. 2011).

h. Ocean acidification can be partially addressed locally

Currently, several approaches can be used to prevent locally intensified ocean acidification. Recently, the West Coast Ocean Acidification and Hypoxia Science Panel working in partnership with the California Ocean Science Trust published a report highlighting major findings, recommendations, and actions that West Coast states, including British Columbia in Canada, can take now to address ocean acidification locally (Chan et al. 2016). This report suggested that the effectiveness of local actions will be higher in semi-enclosed water bodies such as estuaries and bays where local physical-chemical processes dominated over oceanic forcing (Chan et al. 2016). As such local actions will be paramount in San Diego since semi-enclosed water bodies such as estuaries and bays represent a substantial portion of marine waters in the region. The state of California has already a legal framework to address not only local stressors that amplify the effects of ocean acidification, but also reduce local and state level carbon dioxide emissions that primarily contribute to the problem.

Ocean acidification can have a localized impact and often act synergistically with other stressors. Marine species have a limited capacity to deal simultaneously with several stressors, and often the negative combined effects of ocean acidification with other local stressors are stronger than the sum of their parts. This is because ocean acidification in coastal areas can be intensified by the negative effects of local stressors (e.g., pollution, hypoxia, warming) (WCOAHP 2015b). Additional declines of pH, aragonite saturation states and dissolved oxygen associated with local stressors can suddenly push marine species across a critical threshold that drastically impairs their physiology and can cascade up through the food web affecting entire ecosystems (Nagelkerken and Connell 2015, Haigh et al. 2015). As marine species fare better dealing with one stressor instead of multiple stressors, the most practical, fast, and direct approach to deal with ocean acidification is to eliminate other local stressors and therefore increase the resilience of marine species to corrosive waters.

Under the Clean Water Act 303(d) implementation, Sand Diego has ample authority to address local sources that contribute to ocean acidification, including storm water runoff, sewage contamination, and management actions to build resilience. First, state government agencies are directed by the Clean Water Act to ensure that runoff and pollution (that contribute to acidification) are monitored, managed, and do not affect the functioning of aquatic ecosystems. For example, stormwater surge prevention, coastal and riparian buffers, wetlands, and waste water treatments are among the most effective methods to control runoff and associated pollutants (Kelly et al. 2011b). Moreover, effluent limitations could assist in preparedness or adaption for ocean acidification by reducing point sources impacts (Craig 2009). Second, controlling and preventing coastal erosion by increasing vegetation benefit coastal and estuarine ecosystems by reducing organic carbon, nutrient concentration and sediment loading and prevent habitat modification. Coastal and river watershed erosion facilitates the movement of fertilized and enriched waters from cultivated lands and contaminated watersheds further increasing acidification, euthrophication and hypoxia in coastal waters. Third, adequate land-use can reduce direct and indirect CO_2 emissions (e.g., due to deforestation), runoff, and erosion (Julius et al. 2008). Cities, town and counties can adopt policies to protect their own waters even without the state government (Kelly et al. 2011b). Finally, regulating emissions for pollutants such as nitrogen oxides and sulfur oxides from cars and power plants can diminish local drivers of ocean acidification (Kemp et al. 2005) as these pollutants can enter waters from the air close where they are produce (Doney et al. 2007). The Clean Water Act is meant to be complemented by and partnered with several other federal laws (e.g., Clean Air Act and Coastal Zone Management Act), state laws, and local ordinances that also provide legal mechanisms to protect coastal waters by controlling emissions, runoff, and land-use patterns through zoning and permitting (Craig 2009, 2016, Kelly et al. 2011b, Weisberg et al. 2016).[6]

Anthropogenic ocean acidification combined with local stressors that lower pH greatly magnifies the global ocean acidification problem and have drastic effects in coastal and estuarine waters affecting entire shellfish fisheries (Chan et al. 2016). Ocean acidification can be especially problematic in estuarine and coastal waters adjacent to urban areas drastically reducing water quality that impairs the survival and growth of marine species. By addressing local pollution, eutrophication, river runoff and shore line erosion (among others), the Sand Diego region will not only prevent the magnification of the ocean acidification problem, but also provide marine organisms with better capacity and more time to resist ocean acidification while we work globally to reduce atmospheric CO_2.

Although the primary solution to eliminate ocean acidification is to drastically curb CO_2 emissions globally, local management actions that directly address water quality by eliminating pollution, hypoxia, excess of land-based nutrient runoff, and sedimentation from land erosion will substantially ameliorate the likely stronger and synergistic deleterious effects of ocean acidification on marine species (Chan et al. 2016). Addressing local stressors may alone improve the health of coastal waters and protect coastal economies that depend on shellfish fisheries. Moreover, under the Clean Water Act, California has the authority to reduce atmospheric CO_2 that contributes to ocean acidification water quality violations. The Clean Water Act has a long history of being used to address water pollution from atmospheric deposition. For example, section 303(d) has been used to address cross-border pollution from atmospheric mercury, PCBs, and acid rain. California can do its part, as well as hold other states accountable for their contributions to ocean acidification.

4. Sand Diego must evaluate data related to ocean acidification parameters from several readily available sources

[6] Coastal Zone Act Reauthorization Amendments (CZARA) Section 6217 https://www.epa.gov/polluted-runoff-nonpoint-source-pollution/coastal-zone-act-reauthorization-amendments-czara-section

San Diego has a duty to evaluate ocean acidification parameters during its water quality assessment (EPA 2010a). San Diego water board must "*evaluate all exiting and readily available water quality-related data and information to develop the list*" 40 C.F.R. § 130.7(b)(5). Beyond reviewing the information submitted by the Center, San Diego must also evaluate pH and other monitoring data that is readily available and seek out additional ocean acidification data from state, federal, and academic research institutions. EPA's 2010 memo and Integrated Report Guidance discussed several sources, including the NOAA data (EPA 2010: 7-9; EPA Guidance 30-31). There are several sources for high resolution ocean acidification data that will be available in the near future.

The state must obtain and consider data being collected from the University of California San Diego, the National Oceanic and Atmospheric Administration, and other research institutions. They are conducting research surveys as well as have permanently moored instruments that are gathering information about ocean acidification. Finally, the Center urges the state to improve its own monitoring program so that it can detect ocean acidification related water quality problems at a higher temporal resolution.

The following are sources from which San Diego can obtain and evaluate data from:

- Natural Estuarine Research Reserve System
- Southern California Coastal ocean Observing System
- California Current Ecosystem Interdisciplinary Biogeochemical Moorings
- Carlsbad Aquafarm
- California Environmental Data Exchange Network
- NOAA Pacific Marine Environmental Laboratory Carbon Program
- NOAA National Ocean Data Center
- National Data Buoy Center

San Diego should obtain and evaluate data on all relevant parameters of ocean acidification (e.g., pH, pCO_2, calcium carbonate saturation) that are available from these and other sources including it its own water quality database. Coastal and estuarine ocean acidification parameters are not considered in the draft Integral Report. Thus, Sand Diego should seek, analyze, and discuss data on water quality parameters relevant to ocean acidification.

5. Current water quality criteria for pH are inadequate to address ocean acidification

Based on the scientific available information on the deleterious effect of ocean acidification on marine life in estuarine waters, California's water quality objectives regarding pH standards are inadequate, because negative effects can be observed at pH levels well within the current range that is considered normal. As such, California can and should develop new water quality standards for ocean acidification (either numerical or narrative) that better reflect natural variability and potential negative effects of acidification on vulnerable coastal and estuarine species. Current water quality criteria for pH were developed over four decades ago and are scientifically inadequate to address the effects of ocean acidification. The numerical criteria are not based in the most current science and are not ecological relevant for marine and estuarine species (Chan et al. 2016). California's current water good quality pH numerical standards for marine water uses may not be less than 6.0 or greater than 8.5 (or even 9.0) with less than 0.2 deviation within that range due to anthropogenic causes (see water quality objectives above). These thresholds are flawed with respect to ocean acidification applications (Chan et al. 2016). Several studies (see above) have shown biological impacts at pH levels well above 7.5 units. Moreover, this pH range represents up to two order of magnitude difference in acidity since the pH is in logarithm scale. Finally, a deviation of no more than 0.2 units from natural conditions is almost impossible to apply. This is because natural conditions are site specific and are difficult to determine without historical data.

New ecologically meaningful water quality criteria for ocean acidification must be developed and recent studies recommend more appropriate approaches (Weisberg et al. 2016). In addition, ocean acidification water criteria should be expanded to include other acidification parameters (e.g., pCO_2, aragonite saturation state, carbonate ions concentration) that may be more relevant than pH and may affect many marine species (Chan et al. 2016). For example, aragonite saturation state is more biologically relevant than pH for shell formation in calcifying organisms such as pteropods and oysters, and recent studies have already established chronic and acute thresholds that can be used (see above). In contrast, parameters such as pCO_2 instead of pH are more relevant for fish which can drastically impair their ability to avoid predators, find food, and identify suitable habitat.

Since the current numerical water quality criteria to analyze ocean acidification are inadequate, California should rely on their narrative and antidegradation standards to determine whether waters are impaired by ocean acidification. Biological criteria that better describe the effects of ocean acidification on marine organisms (e.g., growth, survival, reproductive success, behavior) that cascade up to populations and ecosystem are more useful. For example, the response of pteropods to ocean acidification may be a relevant biological criterion since they are among the most sensitive species to acidification and their decline will affect marine species that depend on them for food (see above). Thus, effective biological criteria should provide an early warning system before significant negative alterations due to ocean acidification have taken place. Since ocean acidification is predicted to worsen overtime, biological criteria will be fundamental to detect early negative effects and trigger management actions before significant ecosystem alteration happen.

Although EPA mandated states to list waters impaired by pH where data are available (EPA 2010b), substantive reform of the National Water Quality Standards for marine pH is urgently needed (EPA 2010c) since the current criteria is obsolete. Data collection can help determining pH natural variability in coastal waters and thus facilitate future regulatory revisions to allow the state and local governments to restrict pollutants[7]. The state of California and regional water boards should use existing laws to develop biological water quality standards for ocean acidification. For example, the state of California recently introduced a bill (AB 2139)[8] to actively address ocean acidification in coastal waters:

[7] EPA Ocean Acidification and Marine pH Water Quality Criteria. Notice of data availability. 74 FR 17484, April 15, 2009
[8] Assembly Bill, No. 2129 AB 2139, as amended, Williams. *Ocean Protection Council: ocean acidification.* *http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2139&utm_source=OAH+Subscri*

"This bill would require the [Ocean Protection] council to facilitate research and compile data on the causes and effects of ocean acidification and, no later than January 1, 2018, to adopt recommendations for further legislative and executive actions to address ocean acidification"

Water quality standards and impairment designations are only ecological meaningful compared to established baseline conditions, threshold for ecosystem change and ecosystems' vulnerability (Kelly et al. 2011b). Thus, the state and federal governments should support efforts to determine historical and current pH levels and natural fluctuations that because they are area-specific are often undefined. However, determining the baseline of naturally occurring pH range for a body of water does not necessarily requires long term monitoring programs. Natural temporal and spatial variability that occurs in a daily and seasonal basis due to variations in oceanic currents, water flow, river discharge, precipitation regime, temperature, remineralization and metabolic process such as respiration and photosynthesis can be calculated through several methods. For example, by reconstructing water chemistry conditions by analyzing sediment cores based on stable isotopes and by back-calculating pH and aragonite states for preindustrial pCO_2 levels with certain assumptions (see Evans et al. 2015 and Gray et al. 2012), natural baseline fluctuations for specific areas can be calculated. Specific water bodies can be listed as impaired based on biological indicators such as detrimental effects on oysters, pteropods or other calcifying organisms (Bradley et al. 2010).

More monitoring programs with high resolution and automatable equipment are needed to understand temporal and spatial fluctuation in the carbonate system parameter in waters cross San Diego and California. For example, more reliable, accurate, and self-calibrating pCO_2 and pH sensors such as MapCO2 used in the PMEL OA moorings network could be added in more sites throughout estuarine waters across the region and state to continuously monitor ocean acidification (as they do for temperature, and salinity). Therefore, based on the fact that current pH water quality standards are obsolete and inadequate for marine life, new quality standards should be immediately designed for coastal and estuarine/bay waters that take in consideration negative effects on sensitive species such as corals.

6. Conclusion

In conclusion, the Center urges the San Diego water board to thoroughly evaluate current studies on ocean acidification and data to identify waters that are currently harmful for marine life and that may not be meeting water quality standards including not only numeric but also narrative standards and designated uses, as threatened or impaired. The Center also requests that San Diego and California reevaluate obsolete and inadequate pH water quality standards that do not account for negative effects on marine life because they were designed for point source contaminated waters established more than four decades ago. Even though most pH values of coastal and estuarine/bay waters across San Diego may fall within the ranges attaining pH numeric standards for California, scientific evidence over the past decade clearly shows that these waters are becoming more acidic, directly compromising the growth and survival of

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important calcifying coastal and estuarine species such as oysters and pteropods, and indirectly fish species like salmon. It is imperative that San Diego takes concern and action now on ocean acidification to address this increasingly important water quality problem before it has devastating consequences on coastal, estuarine and bay ecosystems. Delaying action could make future management strategies substantially less effective and likely more costly. Minimizing or preventing additional local stressors on coastal ecosystems such as nutrient inputs associated with development and urbanization can ameliorate compounding threats of ocean acidification. In estuaries and bay waters natural factors including acidic freshwater inputs, restricted circulation, influence of coastal upwelling, and hypoxic conditions can amplify the effects of anthropogenic ocean acidification and nutrients inputs and predispose these ecologically and economically important habitat to corrosive waters. The actions that San Diego can take now based on the best available science would ameliorate the negative effects of ocean acidification. Inaction on ocean acidification will result in drastic biological, ecological and socioeconomic negative effects that will be more severe in coastal and estuarine environments compromising sensitive species, ecosystem services and the human populations that rely on them.

Please contact me if you require further information or have questions.

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