Via email and certified U.S. mail

March 31, 2021

Michael Regan, Administrator
U.S. Environmental Protection Agency
Office of the Administrator, 1101A
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460
Regan.michael@Epa.gov

Re: 60-Day Notice of Intent to Sue: Violations of the Clean Water Act; Failure to Identify Oregon Waters Impaired by Ocean Acidification

Dear Administrator Regan,

This letter serves as official notice of the Center for Biological Diversity's (the "Center") intent to file suit pursuant to section 303(d) of the Clean Water Act, 33 U.S.C. § 1313(d) against the United States Environmental Protection Agency ("EPA") for *violating its mandatory duty to identify Oregon coastal waters as impaired by ocean acidification*. EPA's failure to perform its non-discretionary duty to identify waters not meeting water quality standards constitutes a violation of the Clean Water Act.

EPA has ignored scientific evidence that ocean acidification is causing violations of Oregon's water quality standards at multiple locations. According to existing water quality standards, all Oregon waters must be of sufficient quality to support aquatic species without detrimental changes in the resident biological communities, and may not allow conditions that are harmful to aquatic life. OAR 340-041-0007, 0011. Numerous studies have documented corrosive water conditions in Oregon's coastal waters, and the damage these conditions are causing to local species and ecosystems. EPA must recognize and list coastal waters impaired by ocean acidification in order to begin the process of addressing local sources that contribute to the problem. If EPA does not revise Oregon's list of impaired waters within 60 days, we will pursue litigation over this matter.

The Clean Water Act and Oregon's Water Quality Standards

Congress enacted the Clean Water Act, 33 U.S.C. §§ 1251 *et seq*., with the express purpose of "restor[ing] and maintain[ing] the chemical, physical, and biological integrity of the Nation's waters." *Id*. § 1251(a). The goals of the Clean Water Act are to guarantee "water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation" and to promptly eliminate water pollution. *Id*. § 1251(a).

Towards those goals, the Clean Water Act requires each state to establish water quality standards for bodies of water within the state's boundaries. 33 U.S.C. § 1313(a)-(c); 40 C.F.R. § 130.3. To do so, a state first designates the use or uses of a particular body of water (e.g., recreation, shellfish production), see 40 C.F.R. § 131.10, and then designates water quality criteria necessary to protect that designated use. *Id*. § 131.11. These water quality standards include numeric criteria, narrative criteria, water body uses, and antidegradation requirements and should "provide water quality for the protection and propagation of fish, shellfish and wildlife and for recreation." 40 C.F.R. § 130.3.

Section 303(d) of the Clean Water Act then requires states to establish a list of impaired water bodies within their boundaries for which existing pollution controls "are not stringent enough" to ensure "any water quality standard applicable" will be met. 33 U.S.C. § 1313(d). States must "evaluate all existing and readily available water quality related data" to develop the list. 40 C.F.R. § 130.7(b)(5). The state's list of impaired waters must include all water bodies that fail to meet "any water quality standard," including numeric criteria, narrative criteria, water body uses, and antidegradation requirements. *Id*. § 130.7(b)(1),(3) & (d)(2). The list must also include waters that are threatened, waters currently attaining water quality standards but are not expected to meet applicable water quality standards before the next listing cycle. *Id*. § 130.7(b)(5)(iv).

In a memorandum to the states in 2010, EPA emphasized the importance of listing marine waters due to ocean acidification when those waters fail to meet *any* water quality standard, including narrative standards, and supported the use of predictive modeling and other non-site-specific data. EPA 2010 OA Memorandum: Integrated Reporting and Listing Decisions Related to Ocean Acidification.

Oregon's numerical pH criteria for marine waters (coastal and estuarine) are inadequate to address ocean acidification. Oregon's pH criterion states that for marine waters, the pH must fall between 7.0 and 8.5. OAR 340-041-0021. For estuarine and freshwaters, pH should fall within an even wider criteria from 6.5-9.0, depending upon location. OAR 340-041-0101, -0350. These criteria are extraordinarily broad and most coastal and estuarine waters attain such standards. However, strong scientific evidence shows deleterious effects for marine organisms well within these ranges. But while numerical pH criteria for marine and estuarine waters are inadequate to address the problem, several narrative criteria are relevant and can be used to identify waters impaired by ocean acidification.

Narrative criteria related to ocean acidification and aquatic life designated uses are listed below (emphasis added):

OAR 340-041-0011- Biocriteria:

Waters of the State must be of sufficient quality <u>to support aquatic species without detrimental changes in the resident biological communities</u>.

OAR 340-041-0007 - Statewide Narrative Criteria:

> (1) Notwithstanding the water quality standards contained in this Division, the highest and best practicable treatment and/or control of wastes, activities, and flows must in every case be provided so as to maintain dissolved oxygen and overall water quality at the highest possible levels and water temperatures, coliform bacteria concentrations, dissolved chemical substances, toxic materials, radioactivity, turbidities, color, odor, and other deleterious factors at the lowest possible levels.
>
> (10) The creation of tastes or odors or toxic or other conditions that are deleterious to fish or other aquatic life or affect the potability of drinking water or the palatability of fish or shellfish may not be allowed.

Oregon's antidegradation policy also requires that Oregon "protect, maintain, and enhance existing surface water quality to ensure the full protection of all existing beneficial uses." OAR 340-041-0004. Here, the existing beneficial uses include propagation of shellfish larvae in hatcheries, aquatic life uses, and shellfish harvest, among others.

If any of these narrative water quality standards are not met, Oregon must include those water bodies on its impaired waters list. Once a state develops its impaired waters list, the state must submit the list to EPA, and EPA must approve, disapprove, or partially disapprove the impaired waters list. 33 U.S.C. § 1313(d)(2). If EPA does not approve a state's list, then EPA must identify waters that should have been listed as impaired within 30 days. *Id*. § 1313(d)(2); 40 C.F.R. § 130.7(d)(2). EPA must solicit and consider public comment on such listings. 40 C.F.R. § 130.7(d)(2).

When a water body is listed as impaired pursuant to Clean Water Act Section 303(d), the state has the authority and duty to control pollutants from all sources that are causing the impairment. Specifically, the state or EPA must establish total maximum daily loads of pollutants that a water body can receive and still attain water quality standards. 33 U.S.C. § 1313(d). States then implement the maximum loads by incorporating them into the state's water quality management plan and controlling pollution from point and nonpoint sources. *Id*. § 1313(e); 40 C.F.R. §§ 130.6, 130.7(d)(2). The goal of section 303(d) is to ensure that our nation's waters attain water quality standards whatever the source of the pollution.

Oregon and EPA have ample authority to address local sources that contribute to ocean acidification. Although the primary solution to address ocean acidification is to drastically curb CO2 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 deleterious effects of ocean acidification on marine species (Chan et al. 2016). And by addressing local pollution sources, Oregon and EPA 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 CO2. Addressing local stressors can help improve the health of coastal waters and protect coastal economies that depend on shellfish fisheries.

The Best Available Science Indicates Oregon Coastal Waters Are Failing to Meet Narrative Criteria Due to Ocean Acidification

Oregon's territorial coastal waters are already experiencing the harmful effects of ocean acidification. Increasing concentrations of atmospheric carbon dioxide and the contribution of pollution, sedimentation, and inadequate watershed management amplify the fluctuating pH conditions in these waters and make them more corrosive. 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 web, threatening coastal and estuarine ecosystems, coastal fisheries, and humans.

Ocean acidification is impairing the capacity of organisms to produce shells and skeletons, altering food webs, and affecting the dynamic of entire coastal and estuarine ecosystems in Oregon (Hauri et al. 2009, Barton et al. 2012, Mackas and Galbraith 2012, Gruber et al. 2012, Lischka and Riebesell 2012, Hauri et al. 2013, Waldbusser and Salisbury 2014, Bednaršek et al. 2014, Ekstrom et al. 2015, Waldbusser et al. 2015a, Bednaršek and Ohman 2015, Barton et al. 2015, Chan et al. 2016, Bednaršek et al. 2016, Weisberg et al. 2016, Feely et al. 2016, Waldbusser et al. 2016, Feely et al. 2017, Bednaršek et al. 2017). 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 entire food web, affecting other marine organisms from fishes to whales. Increasing CO2 in seawater can also directly affect fishes by affecting critical behavior such as orientation, predator avoidance, and the ability to locate food and suitable habitat.

Oregon marine waters are vulnerable to ocean acidification because coastal upwelling amplifies the effect of anthropogenic CO2 deposition. Coastal upwelling along the Oregon coast brings deep and cold water rich in CO2 and low in oxygen to the continental shelf driving chemical conditions that are harmful to marine life (Feely et al. 2004, 2008, Hauri et al. 2009, Feely et al. 2009, Gruber et al. 2012, Hauri et al. 2013, Bednaršek et al. 2014). Because these processes happen in a multi-decadal time frame, the effects of ocean acidification due to anthropogenic CO2 deposition across the North Pacific will become more severe over time (Chan et al. 2016). Even if CO2 emissions are halted today, Oregon marine waters (and west coast waters in general) have already committed to increased ocean acidification for the next three to four decades. Although upwelling has always been present along the west coast of the U.S. due to the prevailing northerly winds, the corrosiveness of upwelled waters has increased significantly since pre-industrial times (Bednarsek et al., 2014) due to increased carbon emissions into the atmosphere from fossil fuel combustion and its impact on ocean waters. In addition, coastal upwelling is projected to intensify in response to stronger winds due to global warming, which will only increase the prevalence of water of acidic and low oxygen conditions (Snyder et al. 2003, Sydeman et al. 2014).

Numerous studies have documented the presence of coastal waters affected by ocean acidification. These studies, detailed in our comments submitted April 3, 2017 and attached as Exhibit A, demonstrate the degree to which ocean acidification is affecting Oregon's coastal waters and impacting the state's marine resources.

1. EPA Must Consider Aragonite Saturation State and Pteropod Dissolution In Assessing Whether Oregon's Coastal Waters Satisfy Narrative Criteria

EPA must consider aragonite saturation state when evaluating whether Oregon waters are meeting their narrative water quality standards. *See, e.g.*, OAR 340-041-0011 ("waters of the State must be of sufficient quality to support aquatic species without detrimental changes in the resident biological communities"); OAR 340-041-0007 ("the creation of. . . conditions that are deleterious to fish or other aquatic life . . . may not be allowed").

Aragonite is a carbonate mineral that is precipitated by pteropods and certain other organisms (e.g., corals, molluscs) to form their shells/skeletons/structures. Existing pH levels in Oregon coastal waters fall within the allowable range of state water quality standards, but pH levels well within this range are documented to cause extensive biological damage to a variety of organisms (Weisberg et al., 2016). Several studies have shown that the aragonite saturation state is a better early indicator of the impacts of ocean acidification than pH (Waldbusser et al, 2014; Waldbusser et al, 2015). Generally, in supersaturated conditions, where the aragonite saturation is greater than 1, pteropods and other shell building organisms exhibit no signs of shell dissolution (Weisberg et al., 2016). Waters with an aragonite saturation value of 1 or less are generally considered to be corrosive, i.e., water chemistry in which aragonitic shells dissolve rather than precipitate. Field studies (Bednarsek et al. 2014) and laboratory experiments (Busch et al., 2014) demonstrate that such reduced saturation states result in dissolution of organisms' shells. Recent research has determined a "shell dissolution threshold" of 1.1, above which signs of shell stress are not observed. At the threshold of 1.1, approximately 50% of pteropods are affected by dissolution. Below a saturation state of 0.8, dissolution becomes more severe (Bednarsek et al., 2017a, 2017b). Other research has documented saturation states of up to 1.7 being linked to commercial production failures of larval oysters (Barton et al., 2012).

The "shell dissolution threshold" of 1.1 -- at which 50% of pteropods are affected -- generally occurs around a pH of 7.80-7.85, which is well within the range of the Oregon water quality standards (Bednarsek et al., 2017a). This indicates that the approved numeric pH standard alone does not fully characterize the full range of measurable biological impacts on the State's designated uses. Aragonite saturation values of 1 or lower have been repeatedly observed in the marine waters of Washington and Oregon, in the coastal ocean (Feely et al., 2008, 2015; Harris et al., 2013), the estuarine water of Puget Sound and the Columbia River (Feely et al., 2010, 2016; Reum et al., 2014), while pH values remain well within the criteria. Due to regular upwelling events in Oregon, impacts to organisms along the coast due to aragonite saturation state <1 currently are indicative of the "tip of the iceberg" with predicted further decrease in aragonite saturation state from emissions that already occurred over the last 50 years.

Scientists also argue that pteropod shell dissolution should be used as an ecological indicator and early indicator of ocean acidification conditions. Using an ecosystem indicator screening framework for indicators of marine ecological integrity, shell dissolution scored very highly compared to other potential indicators (Bednarsek et al., 2017a). This suggests that it should be considered as an indicator of ecological integrity, which describes "the ability of a system to support and maintain a community of organisms and ecosystem functions within a natural range of variability, and to withstand or recover from disturbances." *Id*.

Pteropod dissolution may signal similar declines in the health and productivity of other taxa with similar biology, ecology and distribution, and therefore ecosystem level implications (Bednarsek et al., 2017a). The commercial and recreational shellfisheries are $48 million industries in Oregon, which have the potential for similar dissolution impacts, some of which are already being seen (Barton et al., 2012; Sylvia and Davis, 2016).

2. <u>The Best Available Science Shows that Undersaturated Waters Exist off the Coast of Oregon and Are Harming Biological Communities</u>

Recent studies have confirmed that wild and native Oregon species are being negatively impacted by ocean acidification within state waters. In 2014, Bednarsek et al. published a widely publicized study on the shell dissolution of pteropods off the coast of Washington, Oregon, and California. Pteropods are an important prey group for birds, whales, and ecologically and economically important fishes (Bednarsek et al., 2014). The study found that 53% of onshore and 24% of farther offshore pteropods had severe dissolution damage. The authors estimated that the incidence of severe pteropod shell dissolution owing to anthropogenic ocean acidification has doubled in near shore habitats since pre-industrial conditions across the study area and is on track to triple by 2050.

Data from Feely et al., 2015 demonstrate an aragonite saturation state of less than 1, which is corrosive to pteropods, in 73% of observations in state waters. Feely et al., 2015 recorded an increase in dissolution along sampling transects with the greatest dissolution found within closest proximity to the Oregon coast. This correlates with a decrease in aragonite saturation, a shoaling of the aragonite saturation horizon and an increase in the percent of the water column that is undersaturated, up to 100% at some stations.

Many additional field and lab studies demonstrate impacts to shellfish from corrosive conditions. A number of studies document a close positive correlation between the rate of calcification and the aragonite saturation state. As the aragonite saturation state decreases, so does the rate of calcification (Feely et al., 2012). Mollusks (such as mussels, clams, and oysters) have been shown to be sensitive to ocean acidification, and both early life stages and adults have shown reduced calcification, growth, and survival when exposed to corrosive conditions (e.g., aragonite saturation less than 1) (Nature Climate Change 10.1038). Hatchery and laboratory studies have shown that oyster larvae experience conditions detrimental to their development and growth at an aragonite saturation level of 1.7 (Waldbusser et al., 2013). Laboratory studies by Miller et al., 2016, demonstrate impacts on early stages of Dungeness crabs, including delays in hatching at a pH of 7.1, and significantly reduced zoeal survival at a pH of 7.5 and below. Bednarsek et al., 2016, recorded increased pteropod mortality with increased dissolution. Recent studies by both Bednarsek et al., 2016, and Lischka et al., 2011, document cumulative effects of decreased pH, deoxygenation and increased ocean temperatures which negatively impacted survivability of pteropods.

Violations of Oregon's Water Quality Standards

In 2014, after soliciting comments on proposed additions to its 2012 303(d) list, Oregon submitted its list of impaired waters to EPA. In its submission, Oregon did not list any waters as impaired due to ocean acidification and only responded to comments pertaining to ocean acidification and the pH numeric standard. On December 21, 2016, more than two years after DEQ's submission of Oregon's 2012 303(d) list, EPA partially approved and partially disapproved the list. EPA assessed all of the readily available data and information that Oregon failed to consider and proposed adding 332 waters to Oregon's list for a variety of parameters.

EPA did not propose the addition of marine waters due to impairments from ocean acidification. Instead, EPA solicited public comments specifically about ocean acidification and sought additional data during the public comment period, which was open from December 16, 2016 to April 3, 2017. The Center submitted comments during this time period, attached as Exhibit A. In December 2018 EPA revised its 2016 partial approval/partial disapproval action and identified a total of 999 water bodies for inclusion on Oregon's 2012 list. However, EPA approved Oregon's 2012 list without any listings of marine waters for aquatic life impairments due to ocean acidification.

In November 2020, EPA approved Oregon's 2018/2020 303(d) list. While still not listing any coastal waterbodies as impaired due to ocean acidification, the 2018/2020 list includes the entire territorial ocean as "category 3B," indicating the state and EPA found insufficient data to determine whether a designated use is supported, but that some data "indicate possible impairment."

Oregon's coastal waters are violating the state's narrative water quality standards that require waterbodies to support, and be free of conditions harmful to, aquatic life. OAR 340-041-0011 ("waters of the State must be of sufficient quality to support aquatic species without detrimental changes in the resident biological communities"); OAR 340-041-0007 ("the creation of. . . conditions that are deleterious to fish or other aquatic life . . . may not be allowed"). Scientific studies indicate undersaturated conditions within Oregon's coastal waters, Feely et al. 2015, Bednarsek et al. 2014, 2017, and the best available science demonstrates that a decreased aragonite saturation state results in detrimental effects on a multitude of species, including pteropods, mussels, and oysters. Weisberg et al., 2016. Numerous scientists have voiced their support in using aragonite saturation information to interpret Oregon's narrative standards that support aquatic life.

EPA's subsequent approval of Oregon's 2018/2020 303(d) list with all coastal waters categorized as "3B" (insufficient data) does not ameliorate the agency's failure to properly list them as impaired. Because state coastal waters show undersaturated aragonite conditions, and because of the documented impacts of undersaturated aragonite conditions on Oregon's marine species, EPA must immediately list all of Oregon's coastal waters as impaired due to ocean acidification. EPA's failure to do so violates the Clean Water Act. 33 U.S.C. § 1313(d); 40 C.F.R. § 130.7(b)(5).

Conclusion

For the above reasons, we urge EPA to identify all of Oregon's coastal waterbodies as impaired due to ocean acidification. EPA must consider all readily available data on the impacts of ocean acidification on Oregon's waters for its water quality assessment and consider the attainment status of all of Oregon's relevant water quality standards. By identifying coastal waterbodies as impaired, the state and EPA can then develop strategies to lessen the local sources of ocean acidification. If EPA does not do so, we will pursue litigation in federal court.

Please let us know if you have any questions.

Sincerely,

Emily Jeffers
Staff Attorney
Center for Biological Diversity
1212 Broadway, Suite 800
Oakland, CA 94612
(408) 348-6958
ejeffers@biologicaldiversity.org

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EXHIBIT A

Summited via email

April 3, 2017

Jill Fullagar
Impaired Waters Coordinator Watershed Unit,
Office of Water and Watersheds US EPA, Region 10
1200 Sixth Avenue, Suite 900 (OWW-192)
Seattle, WA 98101-3140
Email: fullagar.jill@epa.gov

Re: Request for Public Comment on Ocean Acidification Impacts in Oregon Marine Waters

Dear Jill Fullagar,

On behalf of the Center for Biological Diversity (The Center), I submit this letter regarding a request for public comments on data and information of ocean acidification impacts in Oregon's marine waters. In previous comments, the Center has provided significant information and supporting materials about the impacts of ocean acidification in Oregon's marine waters. As shown in the record for the proposed additions of the 2010 integrated report, on June 10, 2009, the Center submitted comments and scientific information requesting that EPA include coastal waters as impaired on Oregon's 303(d) list. On December 6, 2010, May 2, 2011, April 18, 2012, June 20, 2012, and in 2014, the Center submitted additional information and comments on ocean acidification for consideration in the Oregon water quality assessment. Since then, it has become more apparent that ocean acidification poses a serious threat to water quality with adverse effects to vulnerable marine and estuarine organisms. Here I discuss new studies and comment on previous studies on the impact of ocean acidification in Oregon's marine waters that EPA and the Oregon Department of Environmental Quality (ODEQ) should include and analyze for the 2012 and 2016 integrated report.

Specifically, the Center urges Oregon to list the following water bodies as threatened or impaired due to ocean acidification under its 303(d) Waster Quality Report:

a. NH-10 off Newport, OR (44.6°N, 124.3°W).
b. Oregon Inshore Surface Mooring at 7 m and 25 m deep (44.65828 ºN, -124.09525 ºW).
c. Oregon Shelf at 80 m deep (44.63708 ºN, -124.30595 ºW).
d. Oregon Shelf Surface Mooring at 7 m deep **(**44.63565 ºN, -124.30427 ºW).
e. Oregon Offshore at 580 m deep (44.3695 ºN, -124.95369 ºW)
f. Oregon Offshore Surface at 7 m deep (44.36485 ºN, 124.94343 ºW)

Additionally, Oregon must further obtain all readily available data on ocean acidification from sources listed in this letter (below) and analyze them for its water quality assessment.

Abel Valdivia, PhD, Ocean Scientist, Oceans Program . 1212 Broadway, Suite 800 . Oakland, CA 94612
Phone: 510-844-7100 x 303 . Fax: 919-932-0199 . Twitter@AbelValdivia . avaldivia@biologicaldiversity.org

1. Oregon's marine and estuarine pH standards

Oregon's numerical pH criteria for marine waters (coastal and estuarine) are inadequate to address ocean acidification. The Oregon Department of Environmental Quality (ODEQ) should analyze whether marine waters are impaired by ocean acidification based on designated aquatic life uses and the associated narrative criteria. Oregon's pH criterion states that for marine waters, the pH must fall between 7.0 and 8.5 (OAR 340-041-0021). For estuarine and freshwaters, pH should fall within an even wider criteria from 6.5-9.0, depending upon location (OAR 340-041-0101 – a 340-041-0350). These criteria are very wide and most coastal and estuarine waters attain such standard. However, strong scientific evidence shows deleterious effects within these ranges for marine organisms (see below), even though pH fall within the acceptable range of the Oregon water quality standards. Therefore, numerical pH criteria for marine and estuarine waters are inadequate to address the ocean acidification problem. The EPA and ODEQ must analyze whether marine and estuarine waters are impaired by ocean acidification based on the narrative criteria related to aquatic life designated uses found at OAR 340-41-007(1) and (11). These narrative criteria state that:

(1) Notwithstanding the water quality standards contained in this Division, the highest and best practicable treatment and/or control of wastes, activities, and flows must in every case be provided so as to maintain dissolved oxygen and overall water quality at the highest possible levels and water temperatures, coliform bacteria concentrations, dissolved chemical substances, toxic materials, radioactivity, turbidities, color, odor, and other deleterious factors at the lowest possible levels.

(11) The creation of tastes or odors or toxic or other conditions that are deleterious to fish or other aquatic life or affect the potability of drinking water or the palatability of fish or shellfish may not be allowed . . .

Coastal and estuarine waters throughout the Oregon coast may already be experiencing the harmful effects of ocean acidification. Increasing concentrations of atmospheric carbon dioxide and the contribution of pollution, sedimentation, and inadequate watershed management can substantially amplify the fluctuating pH conditions in these waters making them more corrosive.

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 web, threatening coastal and estuarine ecosystems, coastal fisheries, and humans. Here, we present a summary of the most current scientific information on ocean acidification across Oregon marine, coastal and estuarine waters that should be considered to determine water impairment related to ocean acidification in the 2016 Integrated Report.

2. Oregon's marine waters affected by ocean acidification should be listed

a. Oregon's marine, coastal and estuarine waters are affected by ocean acidification

Impaired waters by ocean acidification should be included in the 2016 integrated report. Based on the designated aquatic life uses and associated narrative criteria, marine, coastal, and estuarine water affected by ocean acidification are not "*at the highest possible level*" and can be considered "*deleterious to fish and other aquatic life*". Ocean acidification may already impairing the capacity of organisms to produce shells and skeletons, altering food webs, and affecting the dynamic of entire coastal and estuarine ecosystems in Oregon (Hauri et al. 2009, Barton et al. 2012, Mackas and Galbraith 2012, Gruber et al. 2012, Lischka and Riebesell 2012, Hauri et al. 2013, Waldbusser and Salisbury 2014, Bednaršek et al. 2014, Ekstrom et al. 2015, Waldbusser et al. 2015a, Bednaršek and Ohman 2015, Barton et al. 2015, Chan et al. 2016, Bednaršek et al. 2016, Weisberg et al. 2016, Feely et al. 2016, Waldbusser et al. 2016, Feely et al. 2017, Bednaršek et al. 2017). 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 entire food web, affecting other marine organisms from fishes to whales. Increasing CO_2 in seawater can also directly affect fishes by affecting critical behavior such as orientation, predator avoidance, and the ability to locate food and suitable habitat.

Oregon marine waters are vulnerable to ocean acidification because coastal upwelling amplifies the effect of anthropogenic CO_2 deposition. Coastal upwelling along the Oregon coast brings deep and cold water rich in CO_2 and low in oxygen to the continental shelf driving chemical conditions that are harmful to marine life (Feely et al. 2004, 2008, Hauri et al. 2009, Feely et al. 2009, Gruber et al. 2012, Hauri et al. 2013, Bednaršek et al. 2014). Because these processes happen in a multi-decadal time frame, the effects of ocean acidification due to anthropogenic CO_2 deposition across the North Pacific will become more severe overtime (Chan et al. 2016). Even if CO_2 emissions are halted today, Oregon marine waters (and west coast waters in general) have already committed to increased ocean acidification for the next three to four decades. In addition, coastal upwelling is projected to intensify in response to stronger winds due to global warming, which will only increase the prevalence of water of acidic and low oxygen conditions (Snyder et al. 2003, Sydeman et al. 2014).

In Oregon, ocean acidification in marine waters interacts with natural and anthropogenic processes that further reduce pH and carbonate saturation state (Feely et al. 2008, Salisbury et al. 2008, Hauri et al. 2009, Takeshita et al. 2015, Chan et al. 2016). Although, Oregon coastal waters are relatively more acidic because oceanic currents and coastal upwelling (Feely et al. 2004, 2008, Hauri et al. 2009, Feely et al. 2009, Hauri et al. 2013, McLaughlin et al. 2015, Turi et al. 2016), surface waters already show undersaturation with respect to aragonite due to anthropogenic ocean acidification independently of upwelling pulses (Feely et al. 2008, Carter et al. 2017). In fact, without acidification, undersaturated waters would have been as much as 50 m deeper than they are today (Feely et al. 2008).

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) and that directly affect Oregon marine waters. Strong coastal upwelling along the Oregon coast occurs in the spring and summer supplying even more CO_2-rich waters from the deep ocean (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 (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).

Oregon coastal waters are already experiencing harmful conditions as a result of ocean acidification (Feely et al. 2010) even though they fall within the numeric standard criteria for pH (7.0-8.5) in the state. Oregon are among the first states to pass a threshold that is consider sub-lethal to marine organisms such as bivalves (Ekstrom et al. 2015) (Fig. 1a). Although models show that by mid-century coastal waters will be close to undersaturation (Cao and Caldeira 2008); estuarine waters today are undersaturated with respect to aragonite (Feely et al. 2010). These near and undersaturated waters in Oregon do not meet water quality standards - including designated uses, regardless of whether or not they attain current and inadequate pH numeric standards. Such prediction for the middle of the century (only 35 years from now) has tremendous implications for coastal waters in Oregon. Thus, the state must act now to improve water quality in coastal areas because 1), aragonite saturation state of some coastal and estuarine waters in Oregon are already suboptimal for oyster growth and reproduction (see below), and 2) control of stressors that magnify the effects of acidification at local scale must be implemented now to increase the probability of calcifying species to deal with higher acidification in the near future.

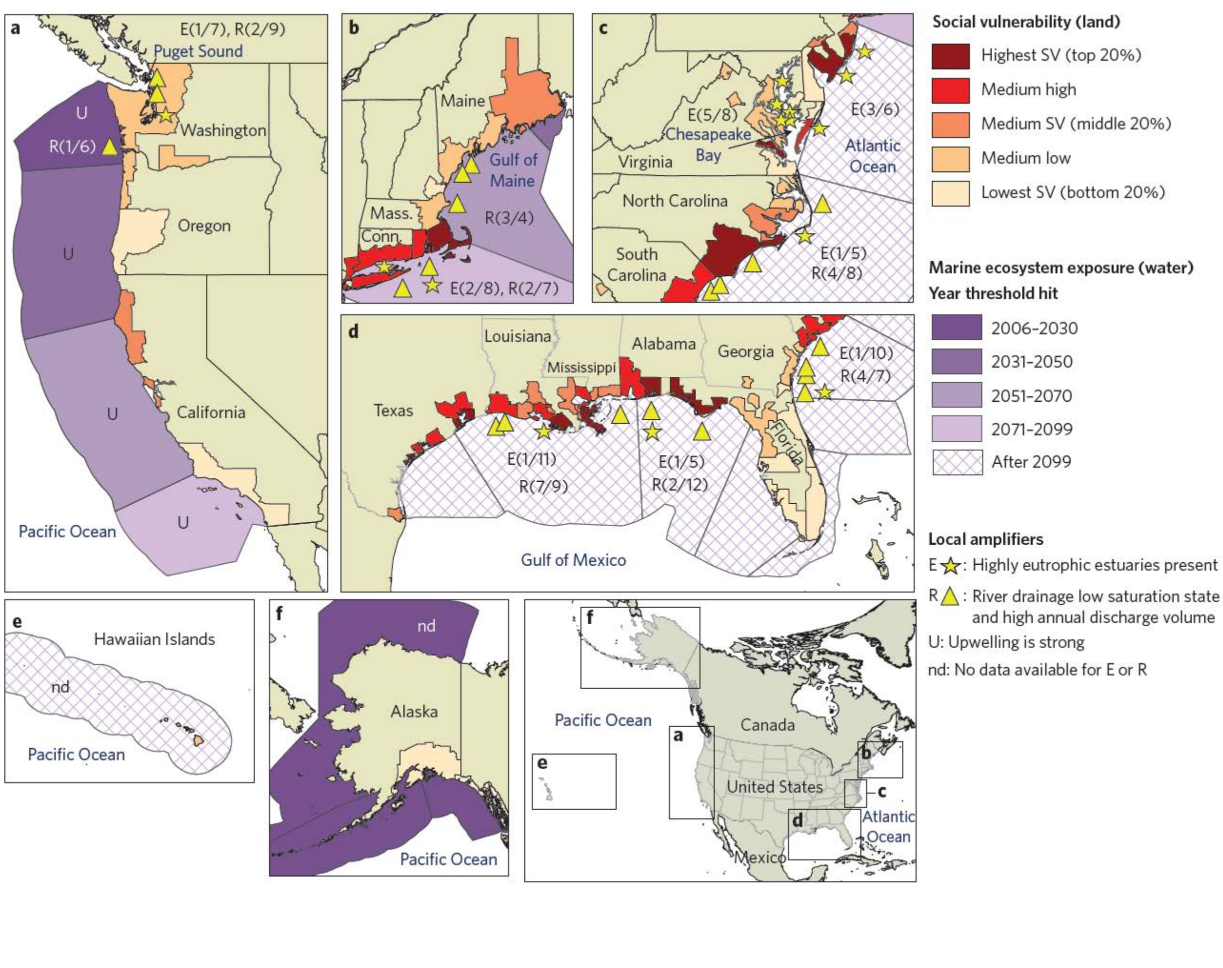


Figure 1. Vulnerability of coastal states to ocean acidification. **a-f**, Scores of relative social vulnerability are shown on land (by coastal county cluster) and the type and degree of severity of OA and local amplifiers to which coastal marine bioregions are exposed, mapped by ocean bioregion: US West Coast (**a**), Northeast (**b**), Chesapeake Bay (**c**), the Gulf of Mexico and the coast of Florida and Georgia (**d**), the Hawaii Islands (**e**), and Alaska (**f**). Social vulnerability (red tones) is represented with darker colors where it is relatively high. Exposure (purple tones) is indicated by the year at which sub-lethal thresholds for bivalve larvae are predicted to be reached, based on climate model projections using the RCP8.5 CO2 emission scenario. Exposure to this global OA pressure is higher in regions reaching this threshold sooner. Additionally, the presence and degree of exposure to local amplifiers of OA are indicated for each bioregion: E(x/y) marks bioregions in which highly eutrophic estuaries are documented, x is the number of estuaries scored as high, and y is the total number evaluated in each bioregion, locations of highly eutrophic estuaries are marked with a star; R(x/y) marks bioregions in which river water draining into the bioregion scored in the top quintile of an index designed to identify rivers with a very low saturation state and high annual discharge volume (calculated by authors from US Geological Survey data), x is the number of rivers scoring in the top quintile of those evaluated, and y is the total number evaluated in this study. Approximate locations of river outflows of those rivers scoring in the top quintile are marked with a yellow triangle, and U marks bioregions where upwelling is very strong in at least part of the bioregion. *Figure and legend after Ekstrom et al. (2015).*

Coastal and estuarine waters of Oregon are also influenced by local variability, and ocean acidification from coastal upwelling and atmospheric deposition can amplify these fluctuations. Daily and seasonal fluctuations in pH are due to changes in 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. 2011, 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).

b. Empirical and field studies show that marine calcifiers are highly vulnerable to ocean acidification in Oregon waters

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 that these adverse impact can be already detected in the field, despite several confounding factors such daily fluctuations in temperature, oxygen levels, salinity, and other variables (Yang et al. 2016, Albright et al. 2016, Bednaršek et al. 2016, Sunday et al. 2017). 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). 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).

c. Shellfish in the Oregon region are vulnerable to ocean acidification

Non-atmospheric sources combined with anthropogenic CO_2 deposition can result in 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). Acidification can also be exacerbated by non-uniform changes in water circulation and biological processes such as respiration (Feely et al. 2010)

Among the marine species most vulnerable to ocean acidification in marine waters of Oregon 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. 2). Shelled mollusks such as oysters are keystone species in estuarine areas that provide great economic value for local and regional economies, and ecosystems services such as water filtration, estuarine protection, and habitat (Newell 2004). With ocean acidification oysters are at risk due to corrosive waters.

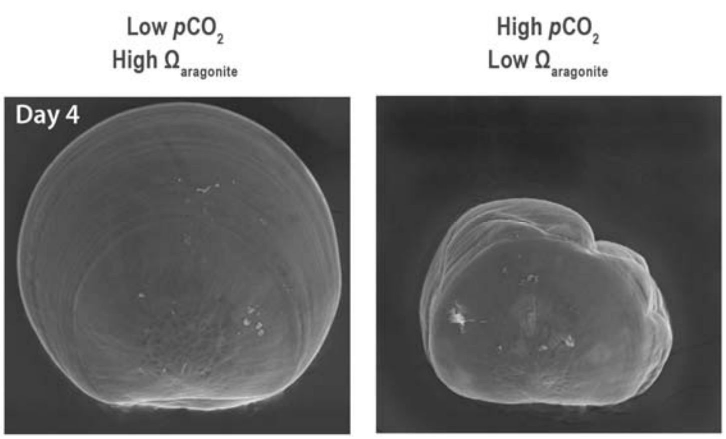


Figure 2 Pacific oyster larvae from the same spawn, raised by the Taylor Shellfish Hatchery in natural waters of Dabob Bay, WA, exhibiting favorable (left, pCO_2 = 403 ppm, $\Omega_{aragonite}$= 1.64, pH = 8.00) and unfavorable (right, pCO_2 = 1418 pp, $\Omega_{aragonite}$= 0.47, pH= 7.49) carbonate 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, Timmins-Schiffman et al. 2012, Barton et al. 2015). For example, 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 decline below certain thresholds (Parker et al. 2009, Lannig et al. 2010, Parker et al. 2012, Barton et al. 2012, Hettinger et al. 2012, Gazeau et al. 2013, Waldbusser et al. 2015a, Barton et al. 2015, Waldbusser et al. 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 at an oyster hatchery on the northern Oregon coast (Whiskey Creek Shellfish Hatchery in Netarts Bay) (Fig. 3). In waters with elevated CO_2 concentrations, oyster larvae have 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 Olympia 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 Oregon), 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).

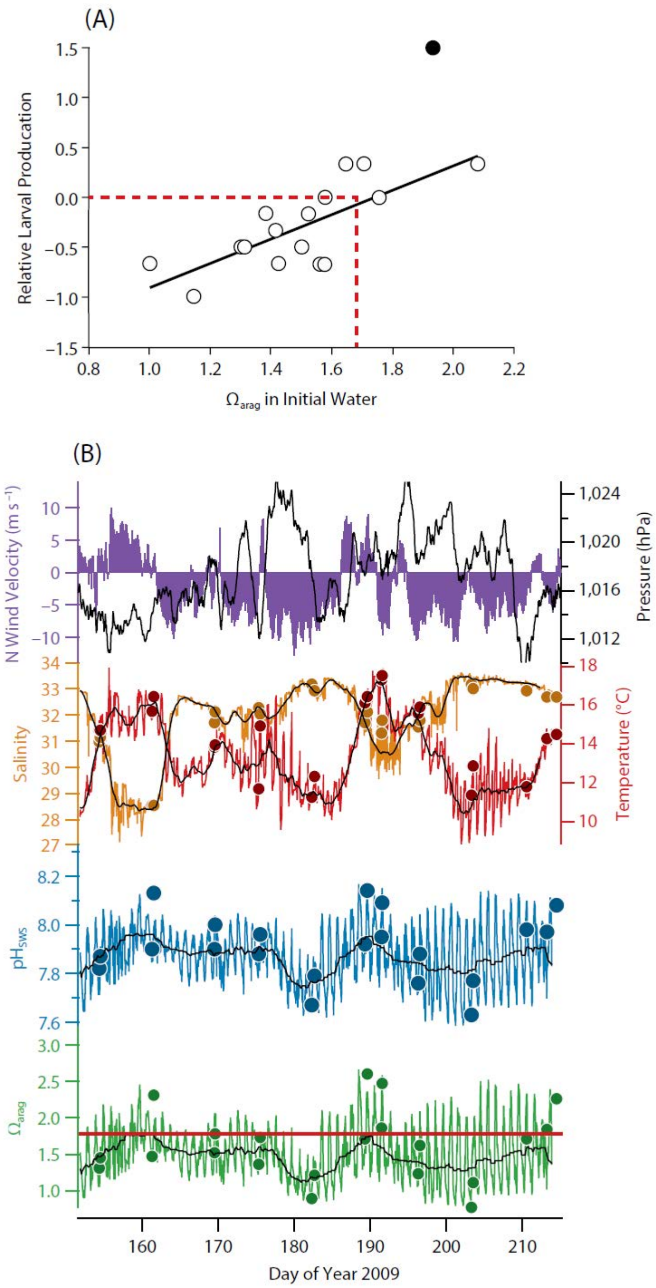


Figure 3 (A) Relative production of Pacific Oyster larvae at the Netarts Bay Whiskey Creek Shellfish Hatchery, Oregon as a function of aragonite saturation state (Ωarag). (B) Wind speed, atmospheric pressure, salinity, temperature, pH, and aragonite saturation state in Netarts Bay during summer 2009. The solid red line shows the threshold aragonite saturation state for no viable

commercial production. *After Barton et al. (2012, 2015)*

Ocean acidification can cost the shellfish industry millions 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).

These findings in the Pacific Northwest are a wake-up call for action to the state of Oregon. 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 along the Oregon coast that include oysters, mussels, scallops and crabs would be subject to substantial economic loses (Chan et al. 2016).

d. Ocean acidification affects crucial zooplankton groups such as pteropods

Ocean acidification in Oregon marine waters also affects important 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 used 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, which encompass marine waters of Oregon, pteropods are already impacted by ocean acidification with reduction in abundance and signs of shell damage due to relatively lower pH (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 (**Ω**) is below 1.0 (Bednaršek et al. 2012, 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. 4). 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 (Weisberg et al. 2016).

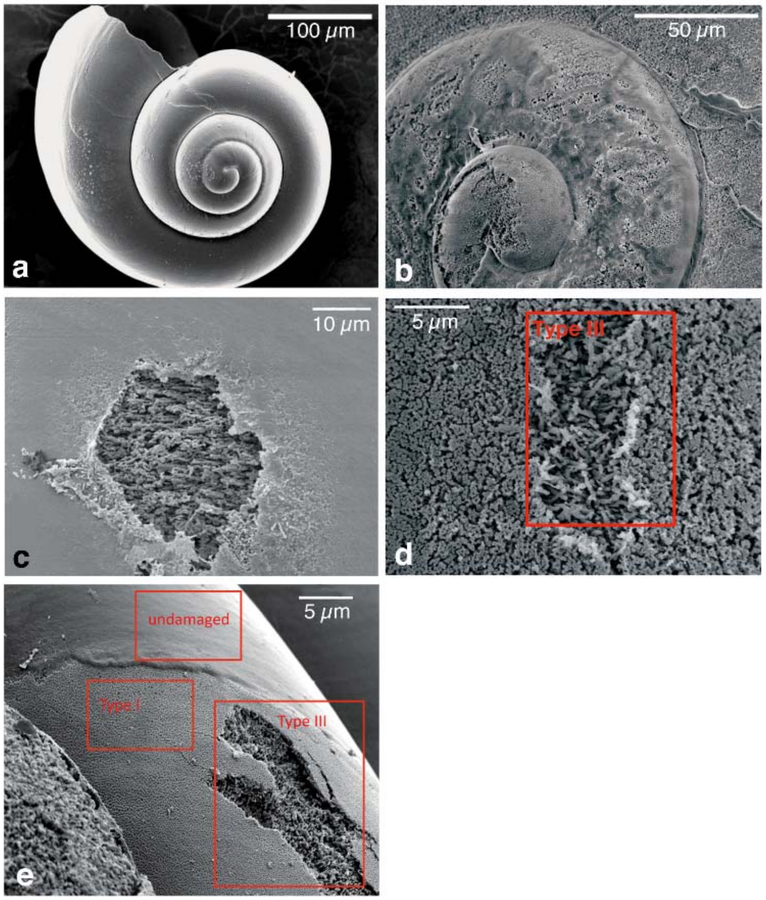


Figure 4 Scanning electronic micrographs illustrating types of shells dissolution in the thecosome pteropod *Limacina helicina*. (a) whole animal with no shell dissolution, (b) Type II dissolution; (c,d) Type III dissolution; (e) mixture of no dissolution, Type I and Type III on a single shell surface. 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).

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).

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 common prey for important commercial fishes such as anchovies, herring, jack mackerel, sablefish, and pink, chum, Coho, and sockeye salmon (Brodeur et al. 1987, Armstrong et al. 2005, Aydin et al. 2005, Brodeur et al. 2007). In addition, zooplankton, squid, whales and even birds can eat pteropods. 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).

Vertical distribution of pteropods is already affected by ocean acidification which may have important consequences for the species that feed on them. 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 narrowing 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.

e. Ocean acidification affects a variety of other marine organisms

Laboratory and mesocosm experiments show that pH and calcium carbonate saturation state levels observed in marine waters of Oregon affect calcification rates of 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 echinoderms and mollusks tend to show higher sensitivity than crustaceans and fish species (Ries et al. 2009, Wittmann and Pörtner 2013) (Fig. 5). 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 elevated pCO_2 (i.e., over 900 µatm) (Ries et al. 2009). Studies also suggest that some species of juvenile fish of economic importance in coastal regions are highly sensitive to higher than normal pCO_2 concentrations and lower pH, exhibiting high mortality rates (Ishimatsu et al. 2004).

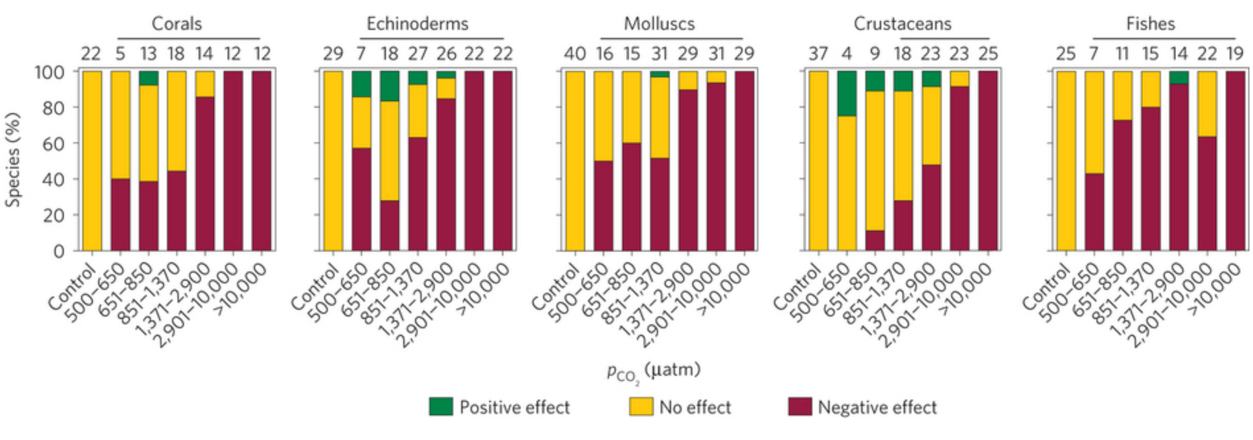


Figure 5 Fractions (%) of coral, echinoderm, mollusk, crustacean and fish species exhibiting negative, no or positive effects on performance indicators reflected as individual fitness in response to the respective p_{CO2} ranges (µatm). The numbers of species analyzed on each CO_2 range are on top of 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 populations and communities that ultimately affect ecosystem functionality and services.

f. Local stressors in coastal and estuarine waters magnify anthropogenic ocean acidification

Local stressors can magnify and contribute to acidification in Oregon's 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). Precipitation runoff can also increase acidification in coastal and estuarine waters (Cooley and Doney 2009, Doney et al. 2009, Cheung et al. 2009).

Ocean acidification can magnify the negative effects of toxic algal blooms. 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 commonly found in marine waters of Oregon, produce domoic acid, a neurotoxin that causes amnesic shellfish poisoning. Studies have shown that acidified conditions due to increasing pCO_2 can increase toxin concentrations as much as five-fold in this harmful microalgae (Sun et al. 2011, Tatters et al. 2012). Toxicity levels have been 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, Fu et al. 2012, Tatters et al. 2013). 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).

During spring and summer in the Pacific Northwest where relatively warmer waters, coastal upwelling, and increase freshwater runoff occur, coastal toxic algal blooms along the coast of California, Oregon, and Washington may becoming more common and intense. The Pacific Northwest (including Oregon) had one of the worst harmful algal blooms recorded in 2015 with the highest concentrations of domoic acid yet observed (NOAA Fisheries 2015). It is likely that ocean acidification and coastal runoff may have increased their toxicity. 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).These toxic algal blooms led managers to close down the entire west coast recreational and commercial crab fisheries from the southern Washington coast to Southern California (Ayres 2015). 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 suggests that coastal waters could be impaired with ocean acidification by failing water quality standards for toxic and other deleterious organic and inorganic substances, which were indirectly and partially driven by low water pH.

g. 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 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 Oregon since semi-enclosed water bodies such as estuaries and small bays represent a substantial portion of marine waters in the state. Oregon 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 acts 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, and runoff) (WCOAHP 2015b). Additional declines of pH, aragonite saturation state, 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 in the short term is to eliminate other local stressors and therefore increase the resilience of marine species to corrosive waters.

Under the Clean Water Act, Oregon has ample authority to address local sources that contribute to ocean acidification, including storm water runoff, sewage contamination, and management actions to build resilience. Anthropogenic ocean acidification combined with local stressors that lower pH greatly magnifies the acidification problem with drastic effects in local economies (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 estuary erosion (among others), the state of Oregon 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 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, Oregon has the authority to reduce atmospheric CO_2 that contributes to water quality violations due to ocean acidification. The Clean Water Act has a long history of being used to address water pollution from atmospheric deposition. For example, section 303(d) of the Clean Water Act has been used to address cross-border pollution from atmospheric mercury, PCBs, and acid rain. Oregon can do its part, as well as hold adjacent states accountable for their contributions to ocean acidification.

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

The estuarine/marine habitat pH criteria for Oregon marine and estuarine waters are inadequate to protect aquatic life. Based on the best available scientific information on the deleterious effect of ocean acidification on marine life, these pH standards are inadequate, because negative biological effects can be observed at pH levels well within the current range that is considered normal. Thus, the state of Oregon in conjunction with the EPA should develop new water quality standards for ocean acidification (either numerical or narrative) that better reflect the 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). These thresholds, while providing guidance, are insufficient 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 ambient is difficult to apply. The state and regional water boards must take steps to define historical ambient pH levels for its waters.

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 (Ishimatsu et al. 2004, Dixson et al. 2010, Ferrari et al. 2012).

4. Oregon's water bodies impaired by ocean acidification

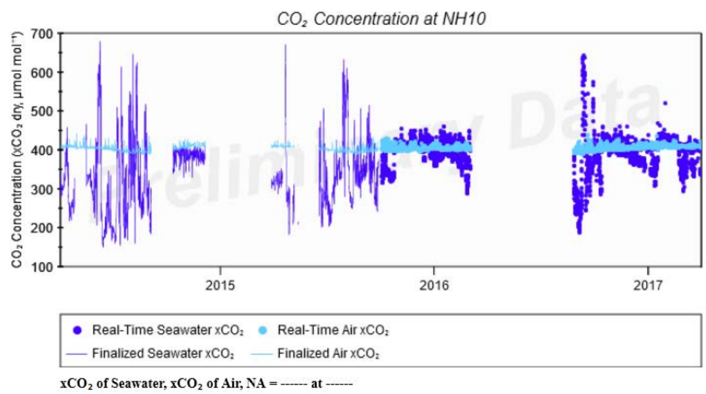
This section is an analysis of a series of water bodies across Oregon that may be already impaired by ocean acidification.

a. **NH-10 off Newport, OR** (44.6°N, 124.3°W).

Station description: The Newport Hydrographic (NH-10) mooring is located in the northern California Current Ecosystem along the central Oregon coast, about 12 miles to the west of Newport and anchor on the inner shelf at 85 m. This region supports economically important ground-fish and crab fisheries due to diverse and productive benthic and near shore ecosystems. The area around the mooring experiences a highly-variable biogeochemistry because river freshwater input and strong seasonal upwelling[1]. The combination of upwelling and high productivity can lead to bottom water hypoxia.[2]

Impairment: Although the recoded pH values since April 2014 fall within the normal pH criteria (7.0-8.5) for marine waters of Oregon (Fig. 6), these waters may be impaired by ocean acidification based on the narrative criteria. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the complete set of ocean acidification parameters for this mooring from April to September 2014 can be found at: http://cdiac.ornl.gov/ftp/oceans/Moorings/NH10_124W_44N/NH10_124W_44N_Apr2014_Sep2014.csv



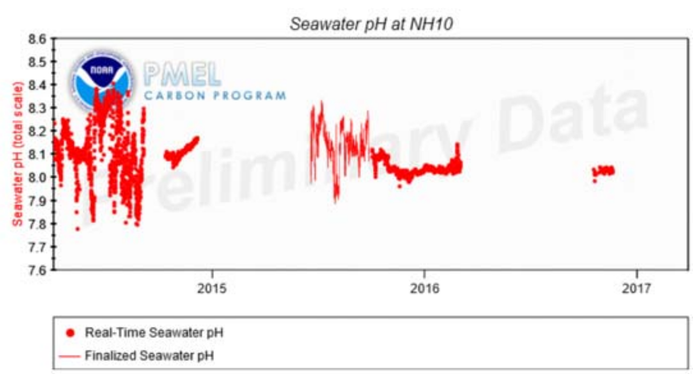


Figure 6 Real time data for pCO_2 and pH at NH10 from April 2014 to present. Note that significant gaps are present in the records. Current graphs can be found at: https://www.pmel.noaa.gov/co2/story/NH-10

[1] PMEL 2017, NH-10 Description https://www.pmel.noaa.gov/co2/story/NH-10
[2] PMEL 2017, NH-10 Description https://www.pmel.noaa.gov/co2/story/NH-10

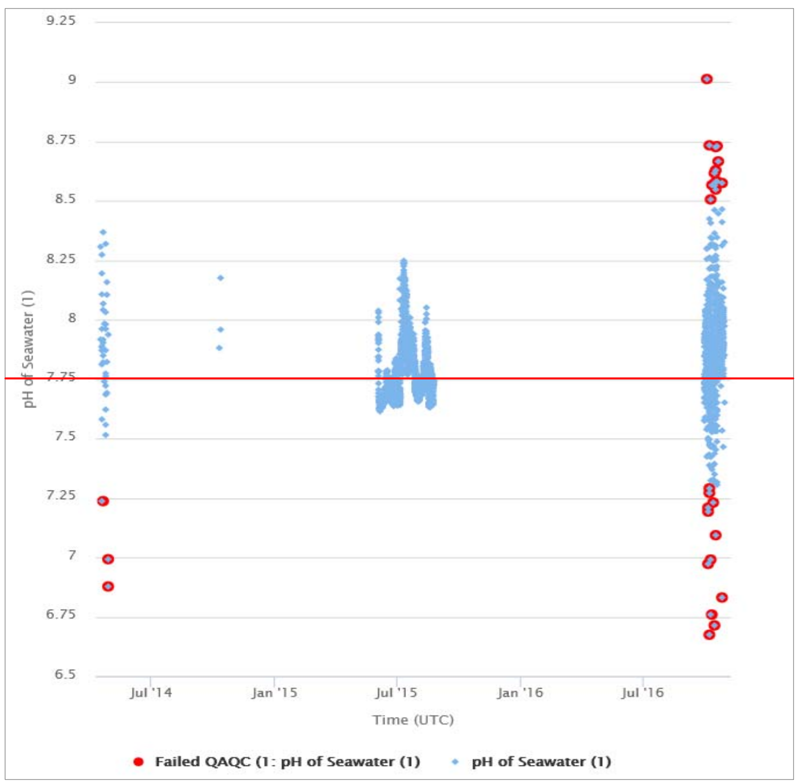
b. **Coastal Endurance Oregon Inshore Surface Mooring** - Seafloor Multi-Function Node (44.65828 ºN, -124.09525 ºW).

Station description: The Oregon Inshore Surface Mooring (CE01ISSM) site with the Seafloor Multi-Function Node is part of the Coastal Endurance Array anchored at ~25 m deep and located at about 1.73 miles west Agate Beach, Newport, Oregon. The mooring uses a CE01ISSM-MFD35-06-PHSEND000 to measure pH at 25 m deep. This area is highly productive with a dynamic upwelling environment.[3]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from April 15, 2014 to October 29, 2016 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE01ISSM-MFD35-06-PHSEND000

Figure 7 Real time data for pH at the Coastal Endurance Oregon Inshore Surface Mooring Seafloor Multi-Function Node (44.65828 ºN, -124.09525 ºW) from April 15, 2014 to October 29, 2016 using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graphs can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE01ISSM-MFD35-06-PHSEND000.



[3] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

c. **Coastal Endurance Oregon Inshore Surface Mooring** – Near Surface Instrument Frame (44.65975 ºN, -124.09504 ºW).

Station description: The Oregon Inshore Surface Mooring (CE01ISSM) site with the Seafloor Multi-Function Node is part of the Coastal Endurance Array anchored at ~7 m deep and located at about 1.73 miles west of Agate Beach, Newport, Oregon. The mooring uses a CE01ISSM-MFD35-06-PHSEND000 to measure pH at 7 m deep. This area is highly productive with a dynamic upwelling environment.[4]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from September 15, 2014 to October 29, 2016 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE01ISSM-RID16-06-PHSEND000

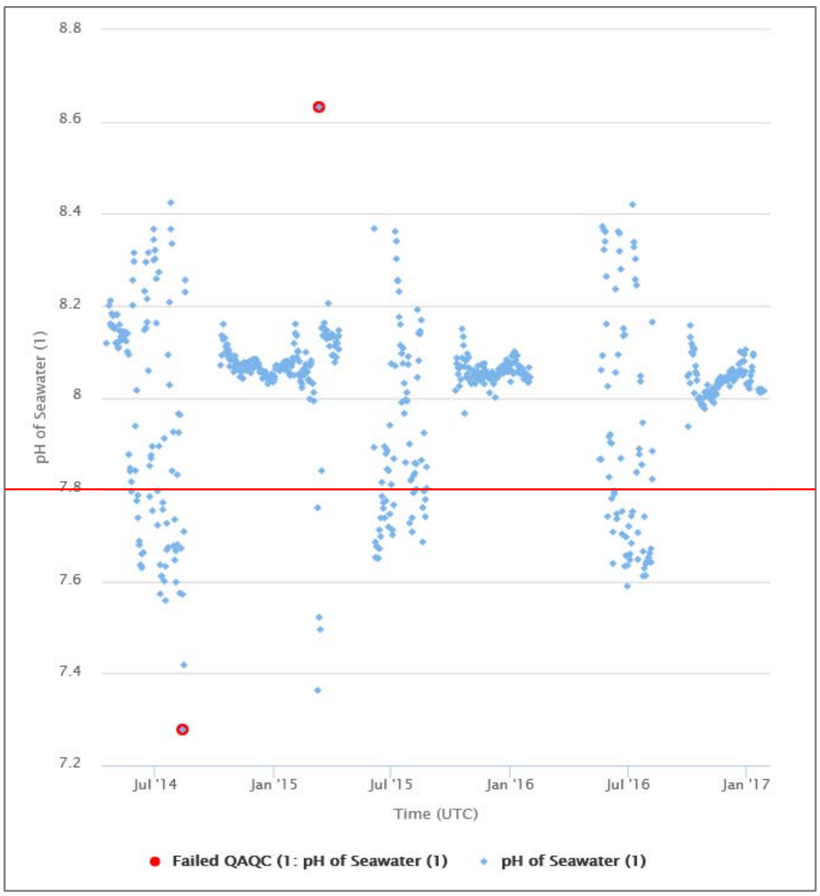


Figure 8 Real time data for pH at the Coastal Endurance Oregon Inshore – Near Surface Instrument Frame (44.65975 ºN, -124.09504 ºW) from April 15, 2014 to October 29, 2016 using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE01ISSM-RID16-06-PHSEND000

[4] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

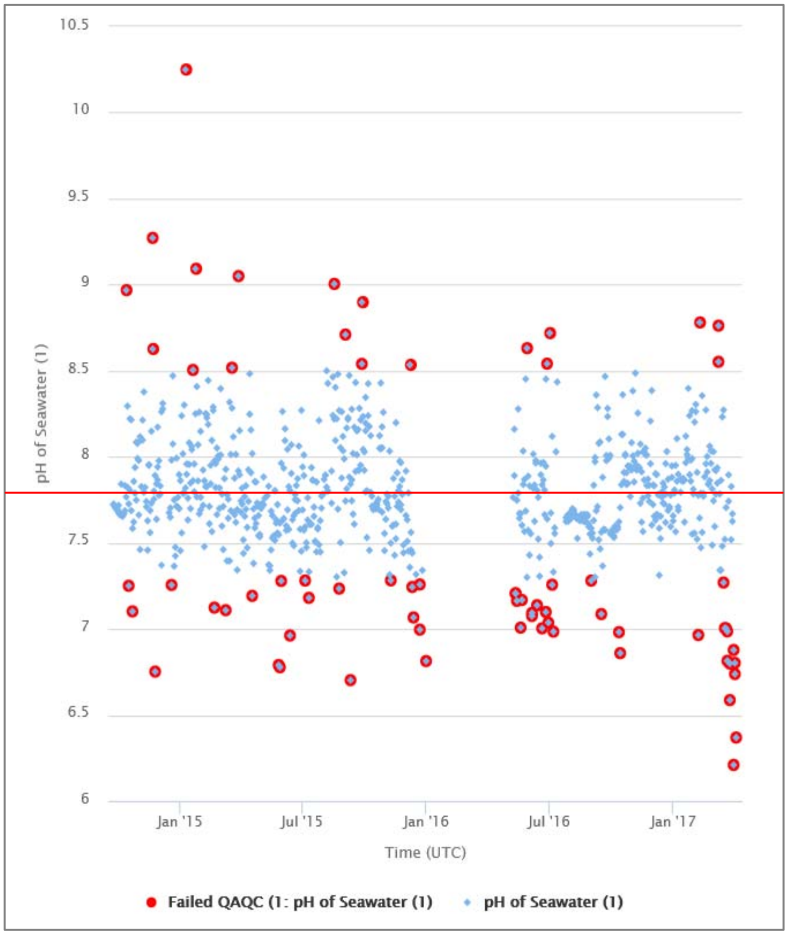
d. **Coastal Endurance Oregon Shelf Cabled Benthic Experiment Package -** Low-Power JBox (LJ01D) (44.63708 ºN, -124.30595 ºW).

Station description: The Oregon Shelf Cabled Benthic Experiment Package **(CE02SHBP)** site with the Low-Power JBox (LJ01D) node is part of the Coastal Endurance Array anchored at ~80 m deep and located at about 12 miles west of Newport, Oregon. The mooring uses a CE02SHBP-LJ01D-10-PHSEND103 to measure pH at 80 m deep. This area is highly productive with a dynamic upwelling environment.[5]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from September 25, 2014 to April 3, 2017 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE02SHBP-LJ01D-10-PHSEND103#CE02SHBP-LJ01D-10-PHSEND103/streamed_phsen-data-record

Figure 9 Real time data for pH at the Coastal Endurance Oregon Shelf Cabled Benthic Experiment Package - Low-Power JBox (LJ01D) (44.63708 ºN, -124.30595 ºW) using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE02SHBP-LJ01D-10-PHSEND103#CE02SHBP-LJ01D-10-PHSEND103/streamed_phsen-data-record



5 Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

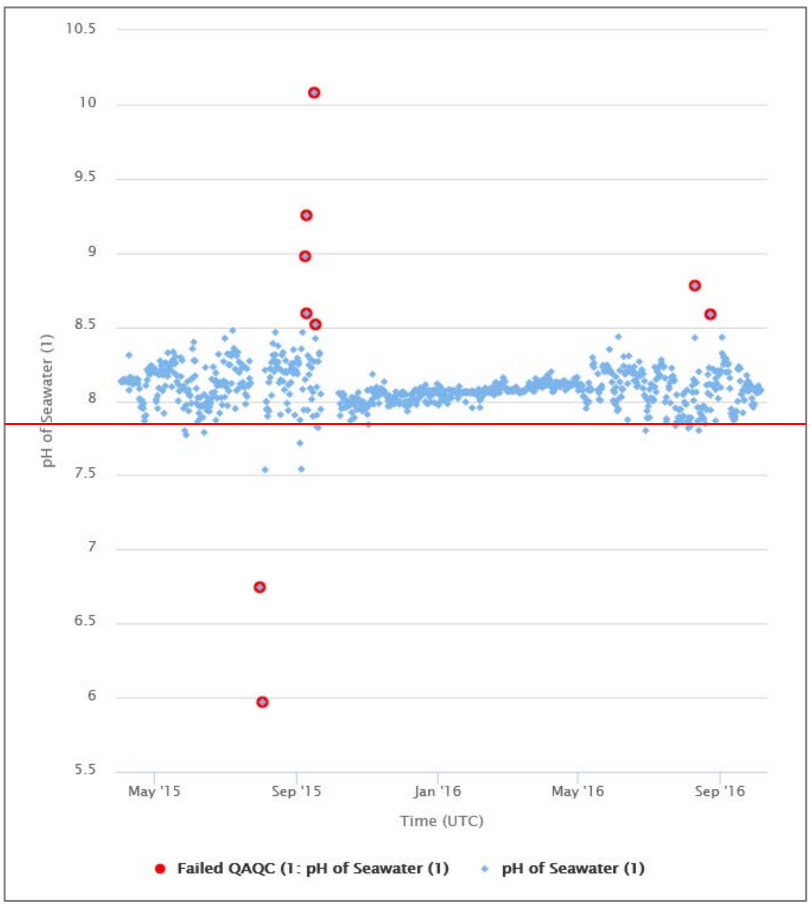
e. **Coastal Endurance Oregon Shelf Surface Mooring -** Near Surface Instrument Frame (44.63565 ºN, -124.30427 ºW).

Station description: The Coastal Endurance Oregon Shelf Surface Mooring (CE02SHSM) site with the Near Surface Instrument Frame node is part of the Coastal Endurance Array anchored at ~7 m deep and located at about 12 miles west of Newport, Oregon. The mooring uses a CE02SHSM-RID26-06-PHSEND000 instrument to measure pH at 7 m deep. This area is highly productive with a dynamic upwelling environment.[6]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from April 2, 2015 to October 6, 2016 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE02SHSM-RID26-06-PHSEND000#CE02SHSM-RID26-06-PHSEND000/telemetered_phsen-abcdef-dcl-instrument

Figure 10 Real time data for pH Coastal Endurance Oregon Shelf Surface Mooring - Near Surface Instrument Frame (44.63565 ºN, -124.30427 ºW) using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE02SHBP-LJ01D-10-PHSEND103#CE02SHBP-LJ01D-10-PHSEND103/streamed_phsen-data-record



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[6] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

f. **Coastal Endurance Oregon** Offshore Cabled Benthic Experiment Package - Low-Power JBox (LJ01C) (44.3695 ºN, -124.95369 ºW)

Station description: The Coastal Endurance Oregon Offshore Cabled Benthic Experiment Package (CE04OSBP) site with the Low-Power JBox (LJ01C) node is part of the Coastal Endurance Array anchored at ~580 m deep and located at about 12 miles west of Newport, Oregon. The mooring uses a CE04OSBP-LJ01C-10-PHSEND107 instrument to measure pH at 580 m deep. This area is highly productive with a dynamic upwelling environment.[7]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from August 25, 2014 to April 3, 2017 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE04OSBP-LJ01C-10-PHSEND107#CE04OSBP-LJ01C-10-PHSEND107/streamed_phsen-data-record

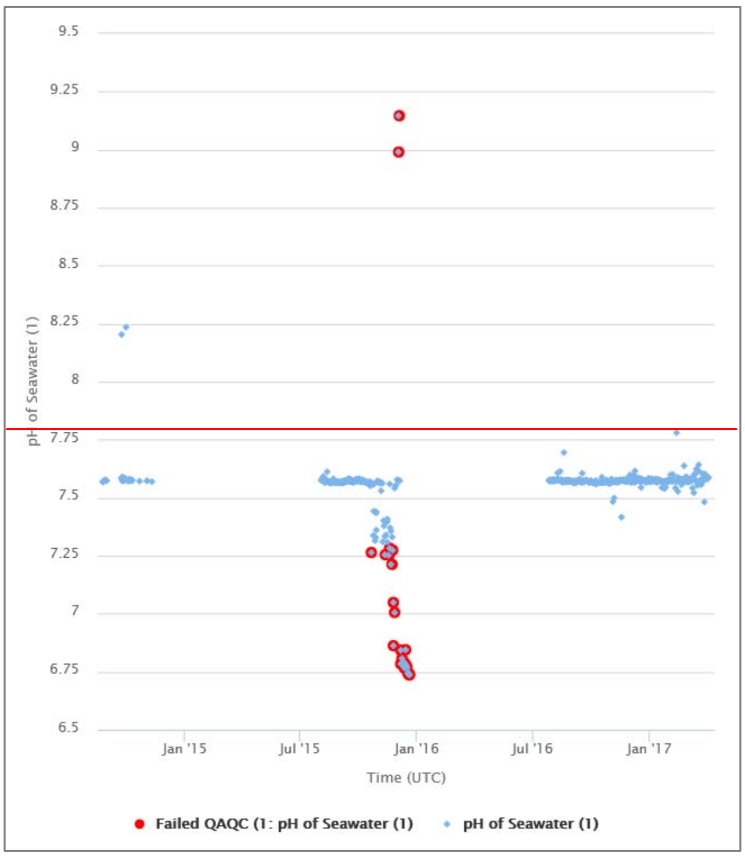


Figure 11 Real time data for pH Coastal Endurance Oregon Offshore Cabled Benthic Experiment Package - Low-Power JBox (LJ01C) (44.3695 ºN, -124.95369 ºW) using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE04OSBP-LJ01C-10-PHSEND107#CE04OSBP-LJ01C-10-PHSEND107/streamed_phsen-data-record

[7] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

g. **Coastal Endurance Oregon Offshore Surface Mooring -** Near Surface Instrument Frame (44.36485 ºN, 124.94343 ºW)

Station description: The Coastal Endurance Oregon Offshore Surface Mooring (CE04OSSM) site with the Near Surface Instrument Frame node is part of the Coastal Endurance Array anchored at ~7 m deep and located at about 42 miles west of Yachats, Oregon. The mooring uses a CE04OSSM-RID26-06-PHSEND000 instrument to measure pH at 7 m deep. This area is highly productive with a dynamic upwelling environment.[8]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from April 7, 2015 to March 19, 2017 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE04OSSM-RID26-06-PHSEND000#CE04OSSM-RID26-06-PHSEND000/telemetered_phsen-abcdef-dcl-instrument

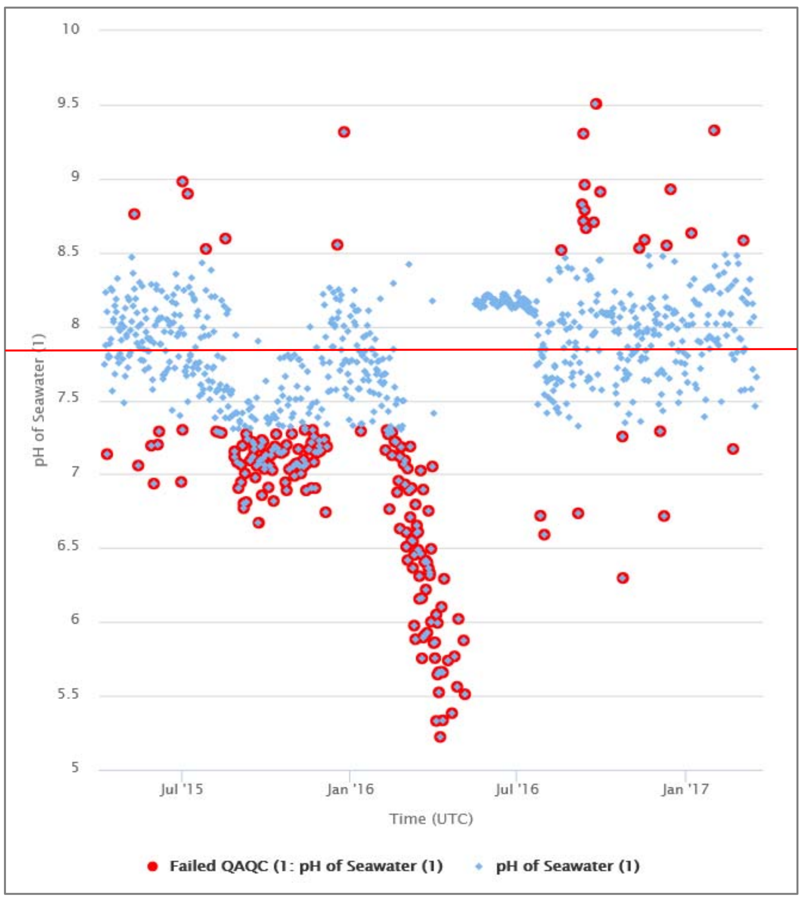


Figure 12 Real time data for pH Coastal Endurance Oregon Offshore Surface Mooring - Near Surface Instrument Frame (44.36485 ºN, 124.94343 ºW) using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE04OSSM-RID26-06-PHSEND000#CE04OSSM-RID26-06-PHSEND000/telemetered_phsen-abcdef-dcl-instrument

[8] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

5. **Oregon must evaluate data related to ocean acidification parameters from several readily available sources**

Oregon has a duty to evaluate ocean acidification parameters during its water quality assessment (EPA 2010). Oregon 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, Oregon 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 Oregon State, the University of Washington, National Oceanic and Atmospheric Administration, the ocean Observatories Initiative, and other research institutions. These institutions are conducting research surveys as well as have permanently moored instruments that are gathering information about ocean acidification. For example, much of these data, including measurements of CO_2, dissolved oxygen, turbidity, temperature, and salinity dating back to 2005, have been archived and are available to Oregon. Data relevant to ocean acidification in Oregon has also been transmitted to and made available by the Pacific Marine Environmental Laboratory. 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 additional sources from which Oregon can obtain and evaluate data from:

- NOAA Pacific Marine Environmental Laboratory Carbon Program
- Oregon State University, College of Earth, Ocean and Atmospheric Sciences
- Ocean Observatories Initiative
- NOAA National Ocean Data Center
- National Data Buoy Center
- University of Washington's Oceanic Remote Chemical Analyzer (ORCA) Group
- Northwest Association of Networked Ocean Observing Systems (NANOOS)
- Integrated Ocean Observing System
- Global Ocean Acidification Observing Network

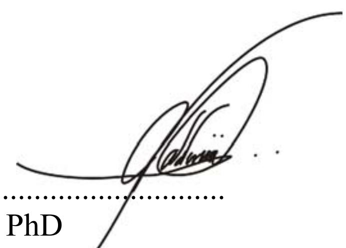
Oregon should obtain and evaluate data on all relevant parameters of ocean acidification that are available from these and other sources including it its own water quality database. Coastal and estuarine ocean acidification parameters were not considered for the most part in the last Integral Report. Thus Oregon should seek, analyze, and discuss data on water quality parameters relevant to ocean acidification.

6. Conclusion

The Center urges the state of Oregon and the EPA to include ocean acidification as water quality issue and to include water quality objectives for pH that avoid harmful biological impacts in the upcoming integrated report. Even though most pH values of marine waters in Oregon may fall within the ranges attaining pH numeric standards for the state, some water bodies are too acidic which harm calcifying organisms such as oysters. Scientific evidence over the past decade clearly shows that marine waters of Oregon are becoming more acidic, negatively affecting the growth and survival of important calcifying coastal and estuarine species. It is imperative that Oregon and the EPA take concern and action now on ocean acidification to address this increasingly important water quality problem before it has devastating consequences on coastal and estuarine 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 coastal development and urbanization can ameliorate the compounding threats of ocean acidification. In estuarine waters, natural factors such as freshwater inputs, restricted circulation, and hypoxic conditions can amplify the effects of anthropogenic carbon dioxide deposition and nutrients inputs and predispose these ecologically and economically important habitat to corrosive waters. The actions that Oregon 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.

Sincerely,



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Abel Valdivia, PhD
Ocean Scientist | Oceans Program
CENTER *for* BIOLOGICAL DIVERSITY
1212 Broadway, Oakland, CA 94612
Email: avaldivia@biologicaldiversity.org
Office: 510-844-7103

7. **Literature cited***

*All references were sent in a CD with a hard copy of this letter and associated data.

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July 25, 2018

Department of Environmental Quality
Attn: Josh Emerson
700 NE Multnomah Street, Suite 600,
Portland, OR 97232-4100
IntegratedReport@deq.state.or.us

Re: Data Submission for 2018 Oregon 303(d) List and Integrated Report

Oregon must identify waters threatened and impaired by ocean acidification for its 2018 Integrated Report and Clean Water Act 303(d) List of Impaired Waters. Ocean acidification has already caused detrimental effects on Oregon's shellfish and pteropods, and these threats to aquatic life are worsening over time. Oregon must act promptly to take steps to manage and mitigate the impacts of ocean acidification.

Oregon's duties to list waters threatened or impaired by ocean acidification

Oregon must obtain and evaluate data on ocean acidification. EPA instructs states to list waters not meeting water quality standards, including marine pH water quality standards, and to solicit existing and readily available information on ocean acidification using the current 303(d) listing framework. (Environmental Protection Agency 2010). Not only must the state consider this submission, Oregon also has an independent duty to evaluate ocean acidification during its water quality assessment (*Id.*). The Clean Water Act provides that states must "evaluate all existing and readily available water quality-related data and information to develop the list." 40 C.F.R. § 130.7(b)(5); see also *Sierra Club v. Leavitt*, 488 F.3d 904 (11th Cir. 2007).

For its 303(d) list, Oregon must consider all water quality standards; including designated uses, narrative, numeric, and antidegradation standards. 40 C.F.R. § 130.7(b)(3). Oregon's marine pH criteria allowing a pH range of 7.0 to 8.5 units, OR 340-041-0021, is inadequate because the best available science demonstrates that pH within that range has harmful effects on aquatic life (Chan et al. 2016). Oregon must analyze whether marine and estuarine waters are impaired by ocean acidification based on the narrative criteria related to aquatic life designated uses found at OAR 340-41-007(1) and (10), biocriteria at OAR 340-41-0011, total dissolved gas criteria at OAR 340-41-0031, as well as antidegradation policy that protects existing uses. These criteria state that:

> Notwithstanding the water quality standards contained in this Division, the highest and best practicable treatment and/or control of wastes, activities, and flows must in every case be provided so as to maintain dissolved oxygen and overall water quality at the highest possible levels and water temperatures, coliform bacteria concentrations,

> dissolved chemical substances, toxic materials, radioactivity, turbidities, color, odor, and other deleterious factors at the lowest possible levels.
>
> The creation of tastes or odors or toxic or other conditions that are deleterious to fish or other aquatic life or affect the potability of drinking water or the palatability of fish or shellfish may not be allowed.
>
> Waters of the State must be of sufficient quality to support aquatic species without detrimental changes in the resident biological communities.
>
> Waters will be free from dissolved gases, such as carbon dioxide[,] hydrogen sulfide, or other gases, in sufficient quantities to cause objectionable odors or to be deleterious to fish or other aquatic life, navigation, recreation, or other reasonable uses made of such water.

Oregon's antidegration policy also requires that Oregon "protect, maintain, and enhance existing surface water quality to ensure the full protection of all existing beneficial uses." Here, the existing uses include use in shellfish hatcheries, aquatic life uses, and shellfish harvest, among other things.

Here, Oregon must list water bodies as impaired for ocean acidification that have an aragonite saturation state ($\Omega_{ar)}$ below 1.7 or pH below 7.8 units because these conditions are known to harm aquatic life. New ecologically meaningful water quality criteria include the use of biological indicators (Weisberg et al. 2016). Specifically, pteropods are a useful biological indicator for ocean acidification impairments (Bednaršek, Klinger, et al. 2017). The threshold for oyster rearing is Ω_{ar} 1.7 (Barton et al. 2015; Barton et al. 2012), and the threshold for pteropod shell dissolution is Ω_{ar} ~ 1.1 to 1.2 (corresponding to 7.8 to 7.85 pH) (Weisberg et al. 2016). Oregon must consider these thresholds for aquatic life impairments. Additionally, Oregon must identify waters that are threatened with impairment.

High-quality federal data demonstrate that Oregon's waters are impaired

In EPA's partial denial of Oregon's 2012 List, it issued a call for comment on existing studies and any additional data on ocean acidification (EPA 2016). In its notice, EPA described that numerous lab and field studies showed impacts to shellfish and pteropods under corrosive conditions, and EPA acknowledged that data showed corrosive conditions off the Oregon coast (Id.). Specifically, "EPA reviewed NOAA data (Feely et al., 2014a; Feely et al., 2014b; Feely et al., 2015) and found the data demonstrate an aragonite saturation state of less than 1, which is corrosive to pteropods, in 73% of observations in Oregon state waters." EPA noted that the "2014 Bednarsek study found that 24% of offshore pteropods and 53% of onshore pteropods (delineated by the 200 meter isobaths) had severe dissolution damage." EPA acknowledged that the scientific information showed that aquatic life impairments occur at aragonite saturation states of less than 1.0; and that such conditions occur in Oregon state waters. These datasets show violations of Oregon's water quality standards, and they are enclosed with this letter.

Data from the 2016 NOAA West Coast Ocean Acidification cruise is also enclosed and further demonstrates that Oregon's marine waters are impaired with aragonite saturation and pH values below thresholds that are known to impair aquatic life (Alin 2017). See the charts below of the measured pH off the Oregon coast in 2016 and 2013 that show numerous observations of pH below 7.8 units (in red), which has been shown to have deleterious effects on Pacific oyster, Olympia oyster, and pteropods (Barton et al. 2012; Hettinger et al. 2012; Hettinger et al. 2013; Weisberg et al. 2016; Bednaršek et al. 2014; Barton et al. 2015).

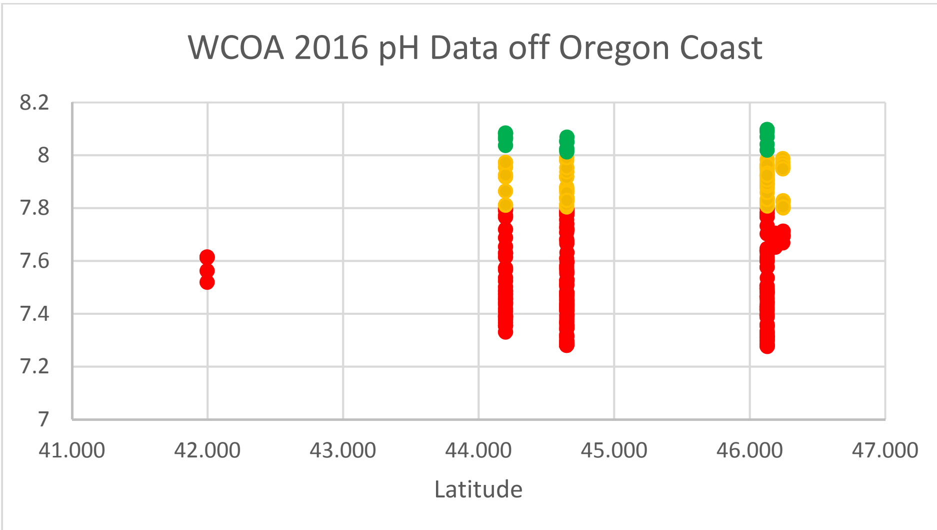

Figure 1. West Coast Ocean Acidification Survey 2016 pH data, red indicates pH at or below 7.8. Source: Alin et al. 2017

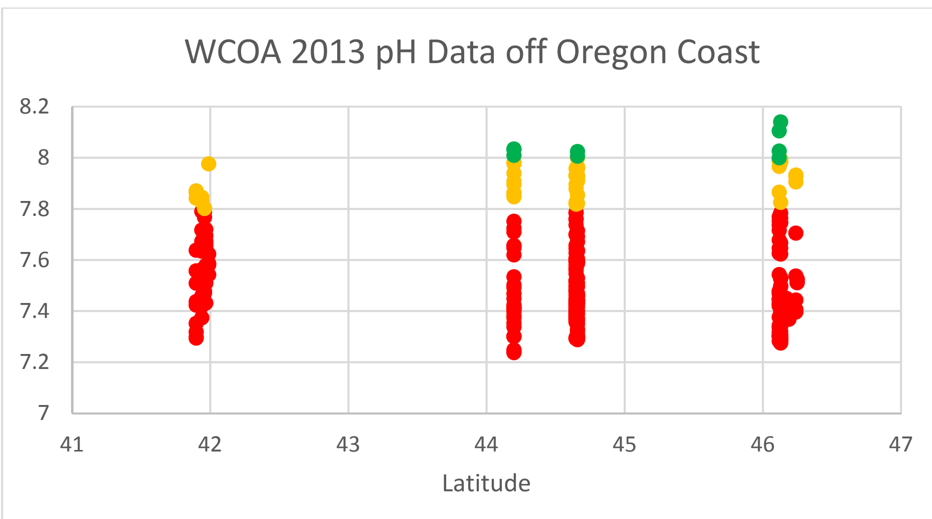

Figure 2. West Coast Ocean Acidification Survey 2013 pH data, red indicates pH at or below 7.8. Source: Feely et al. 2015

The 2013 cruise data recorded the lowest pH values near the mouth of the Columbia River and south near Oregon coast (Feely et al. 2018). Observations from that year off Newport, Oregon had low pH below 7.75 and Ω_{ar} below 1.0 from offshore to the coast (Feely et al. 2016). The most undersaturated waters were close to the coast where anthropogenic CO_2 has caused corrosive waters to shoal about 30 to 50 meters so they upwell on the coast (Id.).The combined cruises in 2007, 2011, 2012 and 2013 revealed that acidified waters that are corrosive to aquatic life reached shallow waters in most areas between Cape Mendocino, California to Heceta Head, Oregon (Feely et al. 2016). The cruise researchers reported "excellent consistency" between intertidal, nearshore, and offshore data (Id.). The 2016 cruise data corroborates these findings.

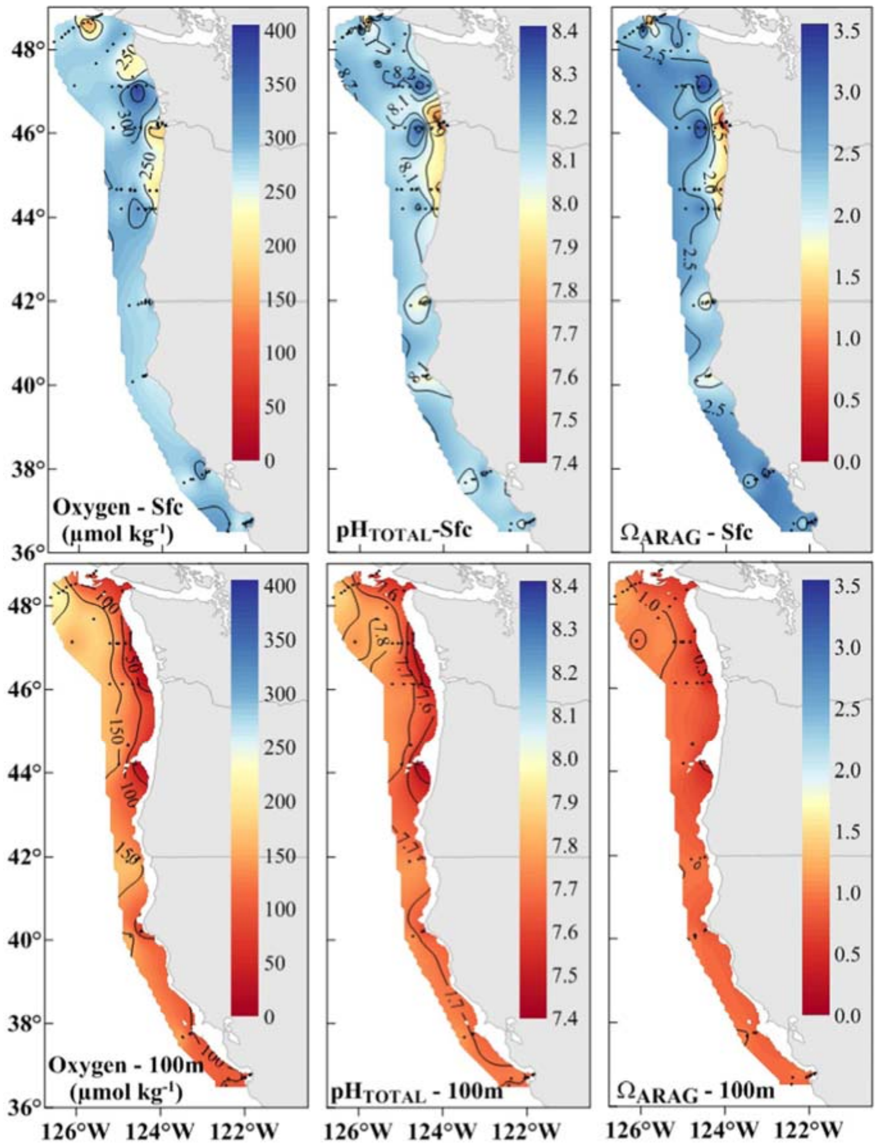

Fig. 3. Distributions of dissolved oxygen in μmol kg−1, in situ pHT, and aragonite saturation state at the surface (top panel) and 100 m (bottom panel) for the 2013 West Coast cruise (5–26 August 2013). Source: Feely 2018.

Coastal monitoring confirms the data from cruises showing that the nearshore is the most vulnerable to ocean acidification (Chan et al. 2017a). Chan et al. observed that there were hotspots over numerous years and that the nearshore, intertidal monitoring of pH corresponded with offshore pH (Id.). Minimum pH was 7.43 and 18 percent of the observations had pH below 7.8; which is a biological threshold for aquatic life impairments (Id.). In the table below see that the sites in Oregon waters had the highest frequency of pH at 7.8 or below and Ω_{ar} at 1.0 or below (Id.). The coastal monitoring study concluded that conditions in Oregon waters are already harmful to aquatic life:

> Our estimates of Ωarag-pH indicate that conditions corrosive to aragonite already blanket nearshore coastal habitats across large portions of the CCLME (Fig. 5). Corrosive conditions were evident for all sites. At one of the most acidified sites (SH, 44.25°N), up to 16% percent of Ωarag-pH fell below 1. Additionally, studies to date indicate that biological impacts can occur well before thermodynamic solubility is reached. Across the network, up to 63% of estimates of Ωarag-pH already fall below 1.7, a threshold associated with commercial production failures for larval oysters in the system.

This study shows that Oregon's waters are impaired with pH and aragonite saturation measurements reaching harmful levels a concerning percentage of the time during this long-term monitoring series. Enclosed with this letter is a coastal pH monitoring dataset and the supplementary materials, moreover Oregon must obtain and analyze the full data set.

Site	Site code	Station Coordinates	start year	end year	pH frequency ≤7.8	pH lower 5th percentile	pH min	pH mean	pH CV	pH # observations	Current $\Omega_{arag\text{-}pH}$ frequency ≤1.7	Current $\Omega_{arag\text{-}pH}$ frequency ≤1.0	Pre-industrial $\Omega_{arag\text{-}pH}$ frequency ≤1.7	Pre-industrial $\Omega_{arag\text{-}pH}$ frequency ≤1.0	Future $\Omega_{arag\text{-}pH}$ frequency ≤1.7	Future $\Omega_{arag\text{-}pH}$ frequency ≤1.0
Fogarty Creek	FC	44.84°N, 124.06°W	2011	2013	18.1%	7.71	7.54	7.99	0.022	49810	48.9%	11.7%	35.5%	3.5%	55.8%	28.6%
Strawberry Hill	SH	44.25°N, 124.12°W	2011	2013	16.3%	7.69	7.43	8.00	0.023	42203	46.9%	10.8%	30.9%	5.0%	52.9%	23.4%
Cape Arago	CA	43.31°N, 124.40°W	2013	2013	12.7%	7.70	7.44	8.03	0.023	8451	37.3%	9.3%	24.8%	4.0%	45.5%	18.5%
Cape Blanco	CB	42.84°N, 124.57°W	2012	2013	7.1%	7.72	7.56	8.01	0.017	19937	47.4%	3.6%	21.0%	0.8%	57.9%	12.7%
Cape Mendocino	CM	40.34°N, 124.36°W	2011	2013	0.3%	7.89	7.76	8.02	0.011	15398	33.6%	0.0%	3.9%	0.0%	61.1%	2.1%
Kibesilah Hill	KH	39.60°N, 123.79°W	2012	2013	0.3%	7.87	7.73	8.02	0.013	9185	44.1%	0.1%	18.9%	0.1%	74.2%	12.7%
Van Damme State Park	VD	39.28°N, 123.80°W	2011	2013	2.4%	7.82	7.58	7.98	0.012	35488	55.5%	0.4%	11.0%	0.0%	69.6%	6.5%
Bodega Head	BH	38.32°N, 123.07°W	2011	2013	5.6%	7.79	7.54	8.00	0.017	62321	42.8%	1.5%	15.5%	0.3%	57.3%	11.1%
Terrace Point	TP	36.95°N, 122.06°W	2011	2013	0.2%	7.96	7.66	8.15	0.015	47022	4.6%	0.0%	0.9%	0.0%	10.0%	0.4%
Hopkins	HP	36.62°N, 121.91°W	2011	2013	0.5%	7.91	7.60	8.12	0.018	40545	9.9%	0.0%	0.7%	0.0%	22.5%	0.4%
Soberanes	SB	36.45°N, 121.93°W	2013	2013	5.5%	7.79	7.50	7.97	0.016	23534	52.3%	0.9%	13.8%	0.3%	68.5%	8.2%
Lompoc Landing	LL	34.72°N, 120.61°W	2011	2011	0.7%	7.87	7.77	8.08	0.017	2877	23.5%	0.0%	2.5%	0.0%	34.5%	0.9%

Table 1. Coordinates, deployment time windows, and summary statistics of pH and Ωarag-pH from the intertidal ocean acidification observing network (Chan et al. 2017b).

Oregon must evaluate these data against the various water quality standards, including narrative aquatic life criteria, biocriteria, total dissolved gas criteria, and the antidegradation policy. Much of these federal data include parameters for pH, pCO_2, aragonite saturation state or can be used to calculate these conditions.

Damage to pteropods off the Oregon coast establishes aquatic life impairments

The science showing that conditions of ocean acidification observed off the Oregon coast are harmful to aquatic life has support in the best available scientific evidence. Aragonite saturation state showed a strong negative correlation to severe pteropod dissolution (Feely et al. 2016). As described in this letter, data demonstrate that Oregon's coastal waters often experience conditions of Ω_{ar} at or below 1.2, the biological threshold for impairment and survival of pteropods. Importantly, pteropod damage was observed to be ~22% higher in nearshore regions (Id.). On the map below of Oregon, the red hotspots represent the high percentages of severely dissolved pteropods observed during the surveys.

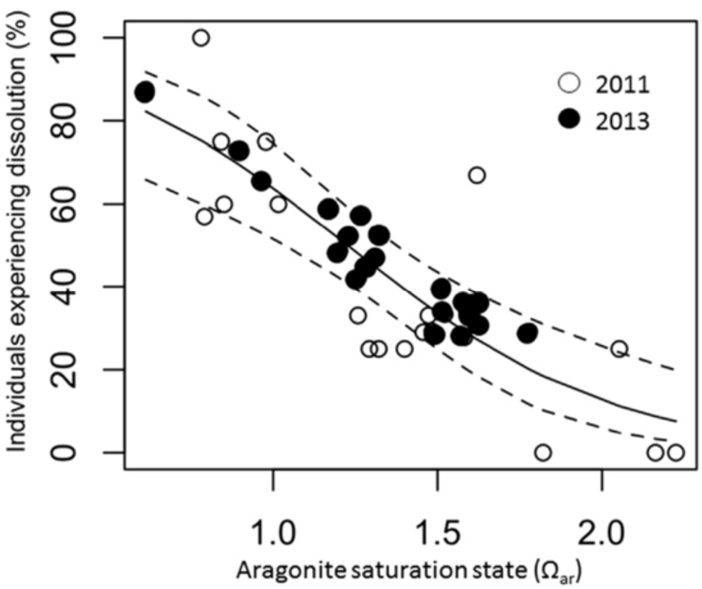

Figure 4. Percentage of individuals affected by severe dissolution as a function of aragonite saturation state (integrated over the upper100 m) for the 2011 (open circles) and 2013 (closed circles) data. The dashed lines show the 95% confidence interval for the logarithmic function. Source: Feely et al. 2016.

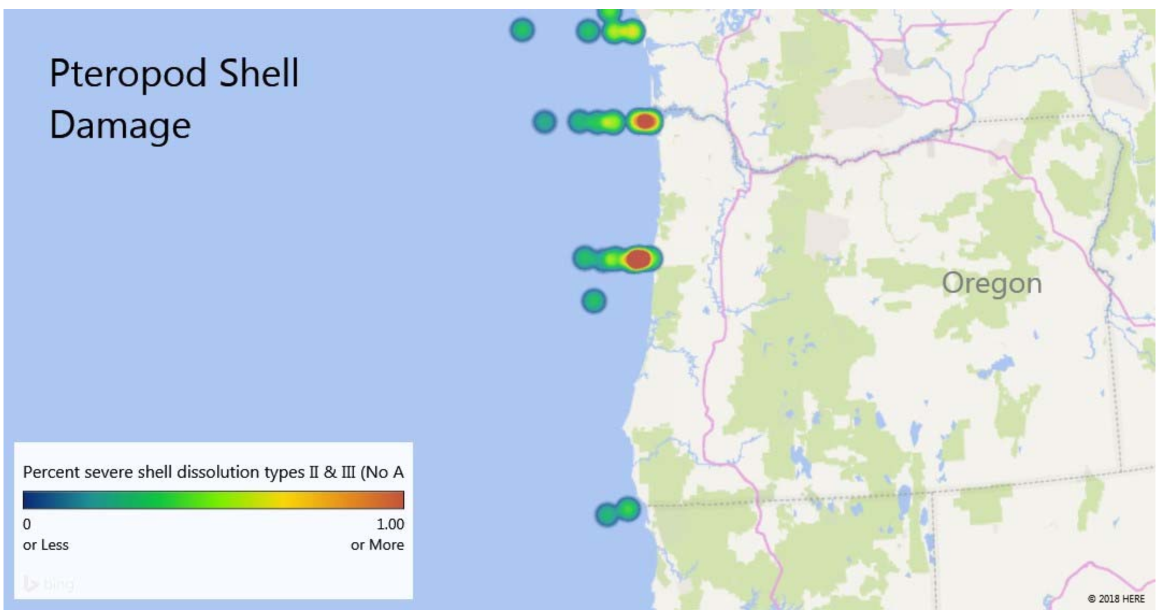

Figure 5. Map of pteropod shell dissolution. Red indicates 100% of pteropods had severe shell dissolution, and the gradient from blue to red indicates the percentage of severe shell dissolution observed in situ from surveys in 2011 and 2013. Source: Bednaršek 2016

Anthropogenic pollution was responsible for lowering average seawater Ω_{ar} from 1.46 to 1.08 in 2013, and increased the percentage of pteropods affected by dissolution by 20% in nearshore waters (Feely et al. 2016). Researchers note that these observations show that anthropogenic pollution is already having an impact on *Limacina helicina* (Id.). Shell dissolution is harmful to pteropods reducing survival and swimming abilities, enhancing predation, and increasing energetic requirements (Id.). Pteropods may also face survival pressures that cause local extinctions (Bednaršek et al. 2016).

Pteropods are already at their physiological limit off the Oregon coast (Bednaršek, Feely, et al. 2017). Bednaršek et al. recorded corrosive conditions in much of the water column, specifically near the Columbia River and along the central Oregon coast (Id.). The threshold for high survival of pteropods is Ω_{ar} ~1.2, and survival probability decreased 47% with declining Ω_{ar} (Id.). The aragonite saturation state in Oregon's waters is often at or below this threshold during certain seasons (Feely et al. 2018; Chan et al. 2017a; Bednaršek, Feely, et al. 2017). Pteropods were unable to acclimatize to the conditions despite previous exposure. The researchers concluded that pteropods in this region are limited by their habitat conditions, and this is corroborated by the observed decline in *L. helicina* in the North Pacific (Bednaršek, Feely, et al. 2017). The Bednaršek study connects the individual responses of pteropods to ocean acidification to population level effects.

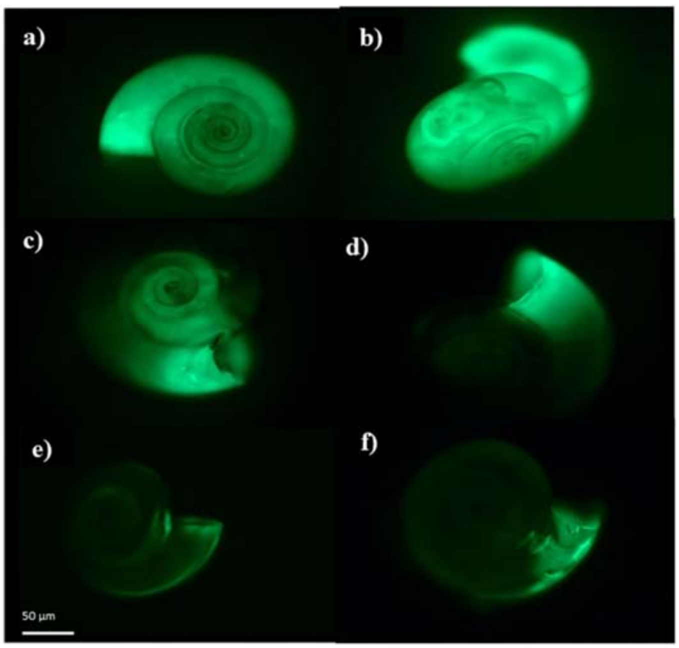

Figure 6. Calcification patterns in L. helicina depicted as the proportional fluorescent glow of incorporated calcein dye under the epifluorescence microscope. The greatest extent of fluorescent glow indicates the most active calcification activity and was present in pteropods collected from Cluster Groups 3 and 4 (with $\Omega ar \geq 1.2$; a and b) and occurs over the entire shell, from the protoconch to the growing edge. At lower Ωar (Cluster Group 2; $0.8 < \Omega ar < 1.2$) calcification extent is reduced to more distal parts of the shell (c and d), while overall decline in calcification occurs in pteropods from the Cluster Group 1 ($\Omega ar < 0.8$; e and f) with only parts of the growing edge still showing evidence of calcification activity. Pteropods were exposed to calcein dye for 18–20 hours; the images were taken at the same magnification (10 ×) and the scale bar (50 μm) indicates the size of the animal.

These data of the severe damage to pteropods, which are a fundamental part of the marine food web, clearly indicate that Oregon's waters are impaired for aquatic life uses. These waters exceed the acceptable narrative and biocriteria for aquatic life uses and must be listed as impaired.

Ocean acidification on the Oregon coast has impaired shellfish growth and survival

Coastal waters from the Oregon border to central Oregon should be listed as impaired by ocean acidification, including Netarts Bay. Seawater off the Oregon coast has been harmful to aquatic life since at least 2008, and ocean acidification has already resulted in major oyster seed production declines (Barton et al. 2015; Barton et al. 2012; Feely et al. 2012; Washington Marine Resources Advisory Council 2017). In 2008, shellfish hatcheries in the Pacific Northwest experienced a severe mass mortality event of oyster larvae, and production at Whiskey Creek was 25% of normal (Barton et al. 2015). Whiskey Creek uses seawater from Netarts Bay, and the seawater directly from the Bay killed the oyster larvae (Id. at 155). Whiskey Creek has an existing use of Netarts Bay water, and Netarts Bay has a designated use for shellfish harvesting.

Monitoring in 2009 showed that aragonite saturation state was linked to the survival and growth of the larvae, and that Ω_{ar} greater than 1.7 was the minimum threshold for commercial oyster larvae production at Whiskey Creek (Barton et al. 2015; Barton et al. 2012). Optimal oyster rearing requires much higher saturation states, and since 2007 the growing season has had to end early because of corrosive conditions in September and October due to ocean acidification (Barton et al. 2015). Oregon must evaluate the monitoring data from Netarts Bay at Whiskey Creek Hatchery, which is readily available to the state since Oregon funded the monitoring. An example of the Ω_{ar} data and information about the monitoring asset is available at the following link, although the online public dataset here appears to be incomplete (http://www.ipacoa.org/Explorer?action=oiw:fixed_platform:WCSH_Whiskey1:observations:H1_OmegaAragSat).

Monitoring seawater off the Oregon coast establishes that the conditions are already at or below pH and aragonite saturation levels that have been shown to impair shellfish growth and survival. A broad range of shellfish are threatened and impaired by these conditions. Pacific oysters, Olympia oysters, California mussels, and other shellfish are adversely affected by ocean acidification (Hettinger et al. 2012; Hettinger et al. 2013; Waldbusser & Hales 2014; Waldbusser et al. 2015; Barton et al. 2015; Gray et al. 2017). Ocean acidification and resulting lowered aragonite saturation can cause delayed development, reduced feeding success, shell damage, and reduced fitness and recruitment of bivalves (Id.).

Oregon must list its coastal seawaters from the Columbia River mouth to Yaquina Bay -- including but not limited to Netarts Bay -- as impaired because they routinely have conditions that are harmful to shellfish, including Ω_{ar} of less than 1.7. This violates Oregon's water quality standards for aquatic life uses.

Additional supporting data for ocean acidification threatened and impaired waters

Oregon must list several water bodies as impaired that are already experiencing water quality conditions that are harmful to aquatic life. Specifically, Oregon should list seawaters shoreward of these monitoring sites as impaired that have with highly credible water quality data demonstrating that conditions are unsuitable for aquatic life uses and existing uses, such as shellfish rearing.

a. NH-10 off Newport, OR (44.6°N, 124.3°W).
b. Oregon Inshore Surface Mooring at 7 m and 25 m deep (44.65828 ºN, -124.09525 ºW).
c. Oregon Shelf at 80 m deep (44.63708 ºN, -124.30595 ºW).
d. Oregon Shelf Surface Mooring at 7 m deep **(**44.63565 ºN, -124.30427 ºW).
e. Oregon Offshore at 580 m deep (44.3695 ºN, -124.95369 ºW)

f. Oregon Offshore Surface at 7 m deep (44.36485 ºN, 124.94343 ºW)

See Appendix A for data and information supporting a threatened or impaired listing for these sites. As discussed previously, there is substantial corroborating evidence that intertidal and nearshore waters express similar, if not more deleterious, pH and aragonite saturation conditions (Chan et al. 2017a; Feely et al. 2016). In 2017, we submitted data demonstrating these impairments to EPA in response to EPA's partial denial of Oregon's 2012 303(d) List and call for data on ocean acidification. Oregon must fully analyze these data and information are attached here as Appendix A for its 2018 Integrated Report and 303(d) List. Additionally, the Center's prior submissions to Oregon are incorporated herein by reference.

Beyond reviewing the information submitted by the Center, Oregon must also evaluate pH, biological information, and other monitoring data that is available to it and seek out ocean acidification data from state, federal, and academic research institutions. EPA's 2010 memo and Integrated Report Guidance discussed several sources, including the National Oceanic and Atmospheric Administration data (EPA 2010: 7-9; EPA Guidance 30-31). Key sources that Oregon must evaluate as readily available information are described in Attachment A.

Conclusion

In conclusion, Oregon must thoroughly evaluate ocean acidification data and identify undersaturated waters and others that are not meeting water quality standards as threatened or impaired. It is imperative that the state take action now on ocean acidification to address this important water quality problem that has already had devastating consequences on its shellfish hatcheries and threatens to seriously damage Oregon's marine ecosystems.

Sincerely,

/s/ Miyoko Sakashita
Miyoko Sakashita
miyoko@biologicaldiversity.org

Center for Biological Diversity
1212 Broadway #800
Oakland, CA 94612

***** Supporting data and sources enclosed in a CD sent via US mail.

Enclosed:
Appendix A.
Sources

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Data Sets

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