EPA Evaluation of Ocean Acidification Information

Summary

On May 23, 2011, The Oregon Department of Environmental Quality (ODEQ) submitted their 2010 CWA 303(d) list of waters not meeting applicable water quality standards to the EPA. On March 15, 2012, the EPA partially approved and partially disapproved Oregon's 2010 list. The EPA approved the list that had been submitted, but found it to be incomplete. The EPA reviewed additional data and proposed the addition of waters to ODEQ's list. The EPA solicited comments on the proposed additions from March 15, 2012 through April 30, 2012. The Center for Biological Diversity (CBD) submitted comments, as well as additional references requesting that the EPA include all coastal waters as impaired on Oregon's list. The EPA responded to CBD's specific comments. The EPA also reviewed the articles submitted by CBD for sufficient data/information to evaluate Oregon's Water Quality Standards (WQS) that CBD asserted were not being attained, specifically marine pH criteria and narrative criteria related to aquatic life designated uses (see evaluation below and Appendix A for tables detailing each of the references submitted by CBD that were reviewed by the EPA). Appendix B includes more information on the history of the EPA's interaction with CBD on the issue of ocean acidification and Oregon's 2010 list.

While the EPA recognizes that ocean acidification has the potential to negatively impact aquatic life, based on the review of references submitted by CBD, and in accordance with the EPA's regulations and *Guidance for 2012 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act* (EPA, 2011) and *Integrated Reporting and Listing Decisions Related to Ocean Acidification* (EPA, 2010) the EPA has determined that, at this time, there is not sufficient evidence demonstrating non-attainment of Oregon's marine pH criteria and/or state-wide narrative criteria related to aquatic life designated uses to warrant listing any coastal waters as impaired or threatened related to these WQS (see detailed evaluation below).

Evaluation

While this evaluation addresses the issues and concerns generally raised by CBD in all of their communications with the EPA and ODEQ, it specifically responds to the letters submitted to ODEQ on June 10, 2009, during ODEQ's call for data, letters submitted on December 6, 2010 and May 2, 2011, during both of ODEQ's comment periods for the 2010 List, as well as comments submitted to the EPA on April 18, 2012, during the EPA's comment period. An additional letter was also received by the EPA on June 20, 2012, and at the discretion of the EPA, has been addressed here as well.

The EPA has conducted a thorough review of all of the comments and information submitted by the CBD in regards to Oregon's water quality standards (i.e., marine pH criteria and narrative criteria related to aquatic life designated uses) not being attained (i.e., impaired) or not being attained by the next listing cycle (i.e., threatened). The EPA presented guidance, in *Integrated*

Reporting and Listing Decisions Related to Ocean Acidification (EPA, 2010), which states that States should list waters for ocean acidification-related parameters if they are not meeting applicable water quality standards, when the data or information is available. (EPA, 2010) This evaluation addresses both non-site specific information and Oregon-specific data found in the articles.

Evaluation of non-site specific information

CBD has cited a number of news and scientific articles that provide non-site specific information (e.g., global modeling studies, laboratory studies, hatchery studies) that they assert show definitive evidence of waterbody impairments that would warrant listing all of Oregon's coastal waters. The EPA has found that the particular articles that were submitted do not provide sufficient data/information to assess or to demonstrate non-attainment of Oregon's WQS, which is further discussed below. See Appendix A, Table 1 for list of articles reviewed by the EPA and Appendix A, Table 2 for more information on those flagged as potentially appropriate to assess to Oregon's WQS.

Global Modeling Studies

The EPA supports the use of predictive modeling and other non-site specific data to make impairment decisions when extrapolation of such information to a wider geographic area is appropriate (EPA 2010). The EPA's review of the articles submitted by CBD revealed that many of the papers' authors themselves made reference to data gaps preventing definitive conclusions to be drawn about the degree to which ocean acidification impacts can be extrapolated to other locations. Many of the articles submitted by CBD reference the great spatial variability in the development of corrosive conditions as a result of differences in waterbody morphology and anthropogenic and natural inputs. Feely *et al.*, 2010, point out that ocean acidification does not occur in isolation, but instead occurs simultaneously with a variety of natural and anthropogenic processes, which can differ significantly by location. Barton *et al.*, 2012, noted that a significant shortcoming in understanding the effects of acidification on natural populations was the prediction of how carbonate conditions will vary in coastal and estuarine environments, and that before predictive models could be developed, high resolution monitoring of carbon dioxide chemistry was still needed. In Newport, Oregon, there is a distinct seasonal cycle relating to upwelling dynamics (Juranek *et al.*, 2009.) In Hood Canal, Washington, natural processes and pollution may contribute to low pH values (Langston, May 26, 2011.) Netarts Bay, Oregon is a lagoon-type estuary dominated by ocean inputs, while water exchange between the ocean and the four basins of Puget Sound is limited by bottom morphology at Admiralty Inlet (Barton, *et al.*, 2012 and Feely *et al.*, 2010). All of these variables make the extrapolation of data across a large geographic range for the purposes of determining non-attainment of water quality standards in local waterbodies, difficult and inappropriate in these circumstances.

Laboratory and Hatchery Studies

CBD also felt that results from submitted laboratory and hatchery studies should be extrapolated to Oregon's waters. Research suggests that spatial heterogeneity in natural variability is likely to affect the regional impact of ocean acidification on organisms (Friedrich *et al.* 2012) and that laboratory experiments suffered from a reduced ecological complexity (Honisch *et al.* 2012). Additionally, the conference proceedings from the Southern California Coastal Water Research Project (2010) concluded that there was a need for improved linkages between biological and oceanographic data, and recognized that "hatchery operators operate with tendencies that may obscure the relationship between water chemistry and recruitment." All of these variables make the extrapolation of data/information from the laboratory and hatchery studies submitted by CBD, for the purposes of determining non-attainment of water quality standards, difficult and inappropriate in these circumstances. More information is needed on the biological condition within the waterbody (e.g., *in situ* field studies documenting the health of aquatic life populations) or laboratory studies that are designed to account for natural variability and ecological complexity within a particular system.

Evaluation of Oregon specific data

CBD asserts that there are data within the articles that were submitted that indicate non-attainment of Oregon's pH water quality standard, as well as the Antidegradation standard and the Statewide Narrative criteria related to aquatic life designated uses. As discussed below, the EPA concluded that there was no existing and readily available data or information that showed that these water quality standards were not being met.

pH

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, there are basin specific criteria (OAR 340-041-0101 through 340-041-0350) which range from 6.5-9.0, depending upon the location. There was very little site specific pH data in the literature submitted by CBD. Barton *et al.*, 2012 reported pH in Netarts Bay as <7.6 to >8.2, with an instrument accuracy of +/- 0.2. In 2009 Barton, Cudd and Weigardt reported pH at an unknown location as ranging from 7.58-7.92. Feely *et al.,* 2008, documented pH near the Oregon/California border at 7.75. All of these pH data fall within the acceptable range of the Oregon water quality standards.

CBD commented that Oregon's pH water quality standard is "inadequate to protect the state's beneficial uses for aquatic life and fishing," (CBD, 2012) The 303(d) listing process does not review state water quality standards. State water quality standards are reviewed periodically by the State, such as during their Triennial Review process. Comments regarding the adequacy of the standards should be submitted to the State for inclusion in their review.

Antidegradation

In addition to reviewing the submitted articles for attainment with the pH criterion, the EPA also determined that there was no evidence of impairment based on Oregon's Antidegradation Standard (OAR 340-041-004.) CBD has identified no specific waterbodies that would need to be listed for antidegradation and has put forth no other evidence to support its comments regarding antidegradation, and has not provided a basis to justify such a listing.

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Statewide Narrative Criteria

The EPA reviewed CBD's submittals in regard to the Statewide Narrative Criteria (OAR 340-41-007). The relevant narrative criteria are as follows:

"(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;

The articles submitted are not sufficient in determining whether there is non-attainment of the Statewide Narrative Criteria. The majority of the studies that had information on marine organisms found in the Pacific Northwest were conducted in a laboratory. These particular lab-based studies alone are not sufficient to determine whether WQS are being met in State waters because water quality parameters are manipulated and therefore, may not represent the actual condition in the waterbody. They also do not provide sufficient information to account for the potential adaptation and acclimation of wild assemblages, so we are unable to apply those findings to an attainment decision in natural waterbodies. More information is needed on the biological condition within the waterbody (e.g., *in situ* field studies documenting the health of aquatic life populations). Also, there are no clear chemical thresholds at which dissolved carbon dioxide becomes deleterious to natural marine populations. No data or information was presented demonstrating impaired health of wild, natural populations in Oregon waters, therefore an impairment determination for the aquatic life designated uses cannot be made at this time.

While Barton *et al.*, 2012, determined that their hatchery study "validates previous laboratory-based acidification experiments in which carbonate chemistry was manipulated," they also concluded that "two significant shortcomings exist with regard to understanding acidification effects on natural populations of organisms in variable coastal and estuarine habitats: prediction of how carbonate conditions will vary in coastal and estuarine environments with increasing atmospheric CO_2 and a better understanding of the fundamental biology underlying the responses of multicellular organisms to acidification." They went on to say "[o]ur limited experience suggests that the multitude of forcing time scales still requires high-resolution monitoring of water CO_2 chemistry before we are fully capable of developing predictive models." Their paper included no data regarding the health of wild aquatic organisms. The only pH data presented indicated a pH in Netarts Bay of <7.6 and >8.2, both within the acceptable range of 7.0-8.5 for marine waters and 6.5-8.5 for estuarine waters.

Conclusion

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The EPA has concluded that there is insufficient evidence, at this time, demonstrating non-attainment of Oregon's marine pH criteria, antidegradation, or state-wide narratives related to aquatic life designated uses for impairments that could be related to ocean acidification to warrant an impaired or threatened water listing for any of Oregon's coastal waterbodies.

References:

Barton *et al.* Limnol. Oceanography, 57(3), 698-710. The Pacific Oyster, *Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects.* 2012.

Barton, Cudd and Weigardt. Unpublished account. Update on hatchery research and use of state funds to improve larval performance at Whiskey Creek Shellfish Hatchery. 2009?

CBD. *Comments on Proposed Decision to Add Waters to Oregon's 2010 Impaired Waters List.* Center for Biological Diversity, April 18, 2012.

EPA. *Integrated Reporting and Listing Decisions Related to Ocean Acidification.* Environmental Protection Agency, November 15, 2010.

EPA. *Guidance for 2020 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act.* US Environmental Protection Agency, March 21, 2011.

Feely *et al. Estuarine, Coastal and Shelf Science*, 88 (4): 442-449. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. 2010.

Feely *et al. Science*, 320, no. 5882: 1490-1492. Evidence for upwelling of corrosive "acidified" water onto the Continental Shelf . 2008.

Honisch *et al. Science* 335 (6072): 1058-1063. The Geological Record of Ocean Acidification. 2012.

Juranek *et al. Geophysical Research Letters* 36, no. 24: 1-6. A novel method for determination of aragonite saturation state on the continental shelf of Oregon using multi-parameter relationships with hydrographic data. 2009.

Langston. *Sightline Daily*, May 26, 2011. Coming to a shore near you. 2011.

ODEQ. *Response to Comments on Final Supplement to Oregon's 2010 Integrated Report.* Oregon Department of Environmental Quality, May 2011a.

ODEQ. *Response to Comments on Final Supplement to Oregon's 2010 Integrated Report* . Oregon Department of Environmental Quality, January 2011b.

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Southern California Coastal Water Project. Conference Proceedings. Ocean acidification effects on shellfish workshop: findings and recommendation. 2010.

Appendix A: EPA's Review of References Submitted by CBD

Table 1: CBD References Reviewed by the EPA.

Note: Studies were flagged as potentially appropriate in assessing non-attainment of Oregon's WQS, specifically marine pH and narrative criteria related to aquatic life designated uses, if they contained data/information collected from Oregon waters, or from waters where it is scientifically reasonable to extrapolate, and for parameters for which Oregon WQS exist. Table 2 provides EPA's assessment of flagged studies.

Author, year	Citation	Title	Subject	Potentially appropriate to assess to Oregon's WQS? (yes/no)
	Royal Society	Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide	CO_2 alters biogeochemical cycles, only feasible option to reverse is to reduce CO_2 emissions	NO
1990	Environmental Protection Agency	Biological Criteria: National Program Guidance for Surface Waters	Program Elements and Implementation of CWA, WQS	NO
2007	Intergovernmental Panel on Climate Change	Synthesis Report	Assessment of Intergovernmental Panel on Climate Change	NO
2008	Marine Ecology Progress Series, 373: 199-201	Special Issue: Effects of ocean acidification on marine ecosystems	Implications of Ocean Acidification, introduction to theme section	NO
2008		Monaco Declaration	Declaration of	NO

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			Ocean Acidification as a global issue	
2008	Antarctic Climate & Ecosystems Cooperative Research Centre	Position Analysis: CO_2 Emissions and climate change: Ocean impacts and adaptation issues	Science and oceanic effects of ocean acidification, policy	NO
2009	CBD Technical Series 46	Convention on Biological Diversity. Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity	Acidification and impacts on marine biodiversity	NO
2009	Environmental Protection Agency Federal Register 74: 17484	Ocean Acidification and Marine pH Water Quality Criteria	National Water Program Guidance for Biological Criteria for Surface Water	NO
2009	Interacademy Panel	Statement on Ocean Acidification	Oceans absorb CO_2 in the carbon cycle, CO_2 in water decreases pH and affects ecosystem	NO
2009	Ocean Carbon and Biogeochemistry	Responses to EPA notice of Data Availability From Ocean Carbon and Biochemistry program	Ocean Carbon and Biochemistry program comment on EPA questions	NO
2010	National Research Council	Ocean Acidification: A National Strategy to	Synthesis of ocean	NO

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		Meet the Challenges of a Changing Ocean Summary Report	acidification research on chemistry, organisms, and ecosystems	
2010	Environmental Protection Agency	Memo: Integrated reporting and listing decisions related to ocean acidification	EPA memorandum to include ocean acidification in CWA	NO
Abbasi, T., Abbasi, S.A. 2011	*Critical Reviews in Environmental Science and Technology*, 41	The Newest Threat to the Global Environment	General review article defining the mechanisms of ocean acidification	NO
Albright, R., Mason, B., Miller, M., & Langdon, C. 2010	*Rosenstiel School of Marine and Atmospheric Science, University of Miami*	Ocean acidification compromises recruitment success of the threatened Caribbean coral *Acropora palmata*	Ocean Acidification and its effects on fertilization and settlement of coral	NO
Anderson, A.J. 2006	*Global Biogeochemical Cycles,* 20	Coastal Ocean CO_2 - Carbonic Acid – Carbonate Sediment System of the Anthropocene	Carbon in ocean coast and sediment	NO
Anderson, K. Bows, A. 2011	*Philosophical Transactions of the Royal Society A,* 369: 20-44	Beyond ‘dangerous’ climate change: emission scenarios for a new world.	Outcomes of Climate Change	NO
Balch, W.M., P.E. Utegoff 2009	*Oceanography*, 22: 146-159	Potential Interaction Among Ocean Acidification	Acidification and properties of ocean water	NO

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Barry, J.P. 2005	*Journal of Geophysical Research*, 110	Utility of Deep Sea CO_2 Release Experiments in Understanding the Biology of a High-CO_2 Ocean: Effects of Hypercapnia on Deep Sea Meiofauna	Biology of high CO_2 Oceans and effects of high CO_2 in blood of sea organisms	NO
Barton, A., Cudd, S., Weigardt M. 2009?	Unpublished account	Update on Hatchery Research and Use of State Funds to improve Larval Performance at Whiskey Creek Shellfish Hatchery	Update on hatchery research, hatchery mortality events	Yes, with data
Barton, A., Hales, B., Waldbusser, G.G., Langdon, C., Feely, R.A., 2012	*Limnol. Oceanogr*	The Pacific Oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near term ocean acidification effects	Pacific Oysters are affected negatively to natural elevation in CO_2	Yes, with data
Beesley, A., Lowe, D.M., Pascoe, C.K., Widdicombe, S. 2008	*Climate Research*, 37: 215-225	Effects of CO_2 induced seawater acidification on the health of *Mytilus edulis*	Lab study on the impact of CO_2-acidified seawater (pH 7.8, 7.6, or 6.5, control = pH 8) on the health of *Mytilus edulis* was investigated during a 60 d	NO

			mesocosm experiment.	
Bibby, R., Harding, C.H., Rundle, S., Widdicombe, S., Spider, J. 2007	*Biol. Lett*, 3: 699-701	Ocean acidification disrupts induced defenses in the intertidal gastropod *Littorina littorea*	Complex effects of ocean acidification beyond direct, defenses of gastropod	NO
Bibby, R., Widdicomb, S. Parry, H., Spicer, J., Pipe, R. 2008	*Aquatic Biology*, 2:67-74	Effects of Ocean acidification on the immune response of the blue mussel *Mythilus edulis*	The effects of medium term (32 d) hypercapnia on the immune response of *Mytilus edulis* were investigated in mussels exposed to acidified (using CO_2) sea water	NO
Bindoff, N.L. 2007	Contribution of the Working Group I to the Fourth Assessment Report of the IPCC	Chapter 5: Observations: Oceanic Climate Change and Sea Level, Climate Change 2007: The Physical Science Basis	Climate Change and effect on change in sea level	NO
Bindoff, N.L., J Willebrand, V., Artale, A., Cazenavem J., Gregory, S., Gulev, K., Hanawa, C., Le Quere, S., Levitus, Y., Nojiri, C.K.,	Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.	Observations: Oceanic Climate Change and Sea Level. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental	Climate change and effect on ocean sea level, biogeochemistry, and salinity	NO

Shum, L.D., Talley, & A. Unnikrishnan. 2007		Panel on Climate Change.		
Bonfils, D. 2010	*abcNews*, April 22	Ocean acidification hits Northwest oyster farms	News article on hatcheries, no water quality data	NO
Brewer, P.G. 2009	Proceedings of the National Academy of Sciences 106: 12213	A Changing Ocean Seen with Clarity	Uptake of CO_2 in ocean and consequences	NO
Brewer, P.G., Hester, K. 2009	*Oceanography*, 22: 86-93	Ocean Acidification and the increasing transparency of the Ocean to Low Frequency Sound	Ocean acidification and decrease of soundwave dissipation	NO
Burns, W.C.G. 2008	*Saving Biological Diversity*, 187-202	Anthropogenic Carbon Dioxide Emission and Ocean Acidification: The Potential Impacts on Ocean Biodiversity	Ocean acidification and changes to ecosystems	NO
Byrne, R.H., Mecking, S., Feely, R.A., & Liu, X. 2009	Geophysical Research Letters, 37	Direct observations of basin wide acidification of the North Pacific Ocean	Transects from HI to AK to determine anthropogenic contribution to change in pH, no OR pH data	NO
Caldeira, K, Wickett, M.E. 2005	J. Geophys. Res., 110	Ocean Model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and the ocean	Model of atmospheric carbon dioxide emissions.	NO
Caldeira, K. &	*Nature*, 42 5: 365	Anthropogenic Carbon	Acidification from	NO

Wickett M.E. 2003		and Ocean pH	CO_2 emissions and ocean pH	
Caldiera, K. 2007	Geophysical Research Letters, 34	Comment on "Modern Age buildup of CO_2 and its effects on seawater acidity and salinity" by Hugo Loaiciga	Invalidation of Hugo Loaicigas assertions that Ocean Acidification is minimal	NO
Canadell, J.G., Quere, C.L., Raupach, M.R., Field, C.B., Buitenhuis, E.T., Ciais, P., Conway, T.J., Gillett, N. P., Houghton, J.T., Marland, G. 2007	*Proceedings of the National Academy of Science of the United States of Americ,* 104: 18866-18870	Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks	Growth of Atmospheric CO_2 from human sources, ocean CO_2 sinks	NO
Cao, L. Caldera, K. 2008	Geophys, Res, Lett, 35	Atmospheric CO_2 stabilization and ocean acidification	CO_2 and aragonite concentrations, stabilization of CO_2 to prevent dangerous anthropogenic interference with the climate system.	NO
Center for Biological Diversity, 2009		Request to designate ocean water segments as impaired or threatened under section 303(d) of the clean water act	Request to designate ocean as impaired	NO
Center for		Comments on draft	Comments on	Yes, but no

Biological Diversity, 2010		assessment of Oregon's marine waters.	Oregon integrated report	new data, includes references to articles already reviewed in this evaluation
Center for Biological Diversity, 2011		Comments on draft assessment of Washington's marine waters.	Comments on Washington integrated report	NO
Center for Biological Diversity, 2011		Request to [Makah to] designate ocean water segments as impaired or threatened under section 303(d) of the clean water act	Request to list Makah Nation waters as impaired	NO
Chan, K.Y.K., Grunbaum, D., O'Donnell, M.J. 2011	*Journal of Experimental Biology*, 214: 3857	Effects of ocean acidification induced morphological changes on larval swimming and feeding	Ocean acidification on planktonic larvae	NO
Chavez, F.P. 2007	U.S. Climate Change Science Program	Chapter 15: Coastal Oceans, North American Carbon Budget and Implications for the Global Carbon Cycle	Chapter in the First State of the Carbon Cycle Report, Coastal CO_2 and implications on carbon cycle	NO
Chen, M., Marquis, K.B., Averyt, B., Tignor, M., & Miller, H.L.	Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.	Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment	Report on Global Climate Change	NO

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2007		Report of the Intergovernmental Panel on Climate Change.		
Cohen, A.L., Holcomb, M. 2009	*Oceanography*, 22:118-127	Why Corals Care About Ocean Acidification: Uncovering the Mechanism	Effects of lower pH and calcification of coral	NO
Cohen, A.L., McCorkle, D.C., Putron, S., Gaetani, G.A., Rose, K.A. 2009	Geochem. Geophys. Geosyst., 10	Morphological and compositional changes in the skeletons of new coral recruits reared in acidified water: Insights into the biomineralization response to ocean acidification	Changes in coral due to acidification	NO
Cohen, F. 2010	*Seattle PI*, July 12	Scientists: Acidity in much of the Sound can be lethal Scientists.	Acidification in Puget Sound cause shellfish decline	NO
Comeau, S., Gorsky, G., Jeffree, R. Teyssie, J.L., Gattuso, J.P. 2009	*Biogeosciences Discuss.*, 6: 2523-2537	Key Arctic pelagic mollusk (*Limacina helicina*) threatened by ocean acidification	Mollusk threatened by acidification	NO
Cooley, S.R., Doney, S.C. 2009	Environmental Research Letters, 4	Anticipating ocean acidification's economic consequences for commercial fisheries	Analyzes economic impact of ocean acidification on US commercial fisheries	NO (cited Barton 2009 paper, which has been included in this evaluation)
Cooley, S.R., Kite-Powell, H.L., & Doney,	*Oceanography*, 22: 172-181	Ocean Acidification's Potential to Alter Global Marine	Acidification disrupts marine ecosystem services	NO

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S.C. 2009		Ecosystem Services		
Cooper, T. 2008	*Global Change Biology*, 14: 529-538	Declining coral calcification in massive Porites in two nearshore regions of the northern Great Barrier Reef	Calcification rates of Porites observed over 16 years have declined	NO
Cribb, J. 2008	ECOS 142: 18-21	Acid Oceans	Ocean Acidification and effects on Australian waters	NO
Crim, R. N., Sunday, J.M., Harley, C. 2011	*Journal of Experimental Marine Biology and Ecology*, 400(1-2): 272-277	Elevated seawater CO_2 concentrations impair larval development and reduce larval survival in endangered northern abalone (*Haliotis kamtschatkana*)	CO_2 impairs larval development of abalone	NO
Dashfield, S.L., Somerfield, P.J., Widdicombe, S., Austen, M.C., Nimmo, M. 2008	*Journal of Experimental Marine Biology and Ecology*, 365: 46-51	Impacts of ocean acidification and burrowing urchins on within-sediment pH profiles and sub tidal nematode communities.	Ocean acidification and impact on biogeochemical processes of sea urchins	NO
De'ath, G. Lough, J.M., Fabricius, K.E. 2009	323: 116-119	Declining Coral Calcification on the Great Barrier Reef	Reef-building corals are under increasing physiological stress from a changing climate and ocean absorption of increasing atmospheric	NO

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			carbon dioxide.	
Denman, K.L. 2007	Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.	2007: Couplings Between Changes in the Climate System and Biogeochemistry. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.	Report on global climate change, climate and biogeochemistry and carbon cycle	NO
Dickinson, G.H., Ivanina, A.V., Matoo, O.B., Protner, H.O., Lannig, G., Bock, C., Beniash, E., & Sokolova, I.M. 2011	*Journal of Experimental Biology, 214: Pt 15*	Interactive effects of salinity and elevated CO_2 levels on juvenile eastern oysters, *Crassostrea virginica*	Rising levels of atmospheric CO_2 lead to acidification of the ocean and alter seawater carbonate chemistry, which can negatively impact calcifying organisms, including mollusks.	NO
Doney, S.C., Balch, W.M., Fabry, V.J., Feely, R.A. $_2$009	*Oceanography*, 22: 16-25	Ocean Acidification: A critical Emerging Problem for the Ocean Sciences	Ocean Acidification overview	NO
Doney, S.C., Fabry, V.J., Feely, R.A., & Kleypas, J.A. 2009	Annual Review of Marine Science 1: 169-192	Ocean Acidification: The Other CO_2 Problem	Atmospheric CO_2 changes carbonate chemistry	NO

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Doney, S.C., Mahowald, N., Lima, I., Feeley, R.A., Mackenzie, F.T., Lamarque, J.F., Rasch, P. 2007	Proceedings of the National Academy of Sciences 104: 14580-14585	Impact of anthropogenic atmospheric nitrogen and sulfur deposition on ocean acidification and the inorganic carbon system	Biogeochemical impacts of anthropogenic nitrogen and sulfur, effect on carbon cycle	NO
Dore, J.E., Lukasb, R., Sadlerb, D.W., Church, M.J., Karlb, D.M. 2009	Proceedings of the National Academy of Sciences, 106: 12235-12240	Physical and biogeochemical modulation of ocean acidification in the central North Pacific	Physical and biogeochemical modulation of ocean acidification	NO
Fabry, V.J., McClintock, J.B., Mathis, J.T., & Grebmeier, J.M. 2009	*Oceanography*, 22: 160-171	Ocean Acidification at High Latitudes: The Bellweather	Acidification at high altitudes are under saturated with aragonite	NO
Fabry, V.J., Siebel, B.A., Feely, R.A., Orr, J.C. 2008	ICES Journal of Marine Science, 65: 414-432	Impacts of ocean acidification on marine fauna and ecosystem processes	Oceanic uptake of anthropogenic carbon dioxide (CO_2) is altering the seawater chemistry of the world's oceans with consequences for marine biota.	NO
Feely, R.A. 2004	*Science*, 305: 362-366	Impact of Anthropogenic CO_2 on the CaCO3 System in the Oceans	CO_2 and impact on calcium carbonate in oceans	NO
Feely, R.A. 2003	*PICES Scientific Report No. 24*	CO_2 in the North	Report, synthesis	NO

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		Pacific Ocean	of CO_2 data from north pacific ocean	
Feely, R.A. 2006		Carbon Dioxide and Our Ocean Legacy	Carbon dioxide and acidification	NO
Feely, R.A., Alin, S.R., Newton, J. Sabine, C.L., Warner, M., Devol, A., Krembs, C., Maloy, C. 2010	*Estuarine, Coastal and Shelf Science,* 88(4): 442-449	The Combined Effects of Ocean Acidification, Mixing, and Respiration of pH and Carbonate Saturation in an Urbanized Estuary	Study of pH levels in Puget Sound	NO
Feely, R.A., Doney, S.C., Cooley S.R. 2009	*Oceanography*, 22	Ocean Acidification: Present Conditions and Future Changes in a High CO_2 World	Anthropogenic CO_2 and change is seawater chemistry	NO
Feely, R.A., Sabine, C.L., Hernandez-Ayon, J.M., Ianson, D., Hales, B. 2008	*Science* , 320: 1490-92	Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf	Upwelling near CA-OR border	YES, data for OR near CA border presented
Findlay, H.S., Kendall, M.A., Spicer, J.I., Turley, C., Widdicombe, S. 2008	*Aquatic Biology,* 3: 51-62	Novel microcosm system for investigating the effects of elevated carbon dioxide and temperature on intertidal organisms	temperature- and pH-controlled microcosm system for the experimental investigation of intertidal organisms in elevated CO_2	NO
Fore, L. 2009	*Marine Pollution Bulletin,* 58: 1421-1423	Heeding a call to action for US coral	Coral Reefs are in danger and	NO

		reefs: The Untapped potential of the Clean Water Act	could be protected by CWA	
Forster, P., Ramaswamy, V., Artaxo, P., Bernsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, P., Prinn, R., Raga, G., Schultz, M., VanDorland, R. 2007	Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.	2007: Changes in Atmospheric Constituents on Radioactive Forcing. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.	Chemicals, gasses, and aerosols and the effect on global climate change	NO
Friedlingstein, P., Houghton, R.A., Marland,G., Hackler, J., Boden, T.A., Conway, T.J., Canadell, J.G., Raupach, M.R., Clais, P., Quere, C.L. 2010	*Nature Geoscience*, 3: 811-812	Update on CO_2 emissions	Atmospheric CO_2 emissions are increasing	NO
Friedrich *et al.*, 2012.	*Nature Climate Change* 2 (2): 1-5.	Detecting regional anthropogenic trends in ocean acidification against natural variability	Study of anthropogenic influence on ocean aragonite saturation state in North Pacific.	NO (cites Feely et al., 2008, which has been included in this evaluation)
Fussel, H.M. 2009	*Climatic Change*, 97: 469-482	An updated assessment of the risks from	Assessment of global climate	NO

		climate change based on research published since the IPCC Fourth Assessment Report	change and risks	
Gangsto, R., Gehlen, M., Schnieder, B., Bopp, L. Aumont, O., Joos, F. 2008	Biogeosciences Discuss, 5: 1655-1687	Modeling the marine aragonite cycle: changes under rising carbon dioxide and its role in shallow water	Model of aragonite, CaCO3, under rising CO_2 in shallow water	NO
Gattuso, F. 1998	*Global and Planetary Change,* 18: 37-46	Effect of Calcium Carbonate Saturation of Seawater on Coral Calcification	CaCO3 and coral calcification	NO
Gattuso, J.P., Hansen, L. 2009	*Oceanography*, 22: 190-201	European Project on Ocean Acidification: Objectives, Products, and Scientific Highlights	Research on the impacts and consequences of ocean acidification	NO
Gaylord, B. Hill. T.M., Sanford, E., Lenz, E., Jacobs, L., Sato, K., Russell, A., Hettinger, A. 2011	*The Journal of Experimental Biology*, 214(15): 2586-94	Functional impacts of ocean acidification in an ecologically critical foundation species.	Acidity effects on mussels, laboratory study	NO
Gazeau, F. 2007	*Geophysical Research Letters*, 34	Impact of Elevated CO_2 on Shellfish Calcification	Results of research on CO_2 and shellfish calcification	NO
Gazeau, F., Martin, S., Hansson, L., Gattuso, J.P. 011	*IMPRINT*, 2100: 5-14	Ocean acidification in the coastal ocean	Potential effects of ocean acidification on key coastal organisms, laboratory study	NO
Gazeau, F.,	PloS ONE 6 (8): 1-8	Effect of Carbonate	Laboratory study	NO

Gattuso, J., Greaves, M., Elderfield, H., Peene, J. Heip, C. and Middelburg, J. 2011		Chemistry Alteration of the Early Embryonic Development of the Pacific Oyster (*Crassostrea gigas)*	on effect of pH and aragonite saturation state on developmental success and growth rates	
German Advisory Council on Global Change 2006		The Future Oceans – Warming Up, Rising High, Turning Sour	Report on ocean acidification and CO_2 storage	NO
Gledhill, D.K. 2008	*Journal of Geophysical Research*, 113	Ocean Acidification of the Greater Caribbean Region 1996-2006	Ocean acidification in Caribbean and effects on local shellfish	NO
Gledhill, D.K., Wanninkhof, R. Eakin, C.M. 2009	*Oceanography*, 22:48-59	Observing Ocean Acidification from Space	Ocean Acidification with satellite observations	NO
Global Carbon Project, 2010	http://www.global carbonproject.org/index.htm	Carbon Budget 2009	Global Carbon Emissions	NO
Green, M.A., Waldbusser, A., Reiley, S., G.G., Emerson, S.L., O'Donnell, S. 2009	*Limnology and Oceanography*, 54(4): 1048-1059	Death by dissolution: Sediment saturation state as a mortality factor for juvenile bivalves.	Death by dissolution is an important size related mortality factor for juvenile bivalves	NO
Gruber, N., Sariento J.L., Stocker, T.F. 1996	*Global Biogeochemical Cycles*, 10: 809-837	An Improved Method for Detecting Anthropogenic CO_2 in the Oceans	Separating anthropogenic CO_2 and natural background dissolved carbon in water	NO
Gruber, Nicolas,	Sciencexpress, 1	Rapid Progression of	Model simulation	YES, CA/OR

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Hauri, Claudine, Lachkar, Zouhair, Loher, Damian, Frolicher, Thomas and Gian-Kasper Plattner, 2012		Ocean Acidification in the California Current System	to study potential development of ocean acidification in CA current	border,
Guinotte, J.M., Fabry, V.J. 2008	Ann, N.Y. Acad. Sci 1134: 320-342	Ocean Acidification and its potential effects on marine ecosystems.	Evidence suggests significant consequences for marine taxa that calcify	NO
Guionette, J.M. 2006	*Frontiers in Ecol. Environ,* 4: 141-146	Will Human-induced Changes in Seawater Chemistry Alter the Distribution of Deep-Sea Scleractinian Corals?	Reduced CaCO3 and aragonite may inhibit shell growth	NO
Hall-Spencer, J.M., Riccardo, R.M., Martin, S., Ransome, E., Fine, M., Turner, S.M., Rowley, S.J., Tedesco, D., Buia, M.C. 2008	*Nature*, 1-4	Volcanic carbon dioxide vents show ecosystem effects of ocean acidification	Natural CO_2 flux from volcanic vents show insight into ocean acidification effects	NO
Halpern, B. 2008	*Science*, 319: 948	Global Map of Human Impact on Marine Ecosystems	Aggregate map of anthropogenic impact on ocean ecosystems	NO
Hansen, J., Sato, M., Kharecha, P., Beerling, D., Masson-Delmotte, R.,	*Open Atmospheric Science Journal*, 2: 217-231	Target Atmospheric CO_2: Where Should Humanity aim?	To preserve the earth at optimal conditions, 350 ppm atmospheric CO_2 must be	NO

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Pagani, V., Raymo, M., Zachos, L.C. 2008			achieved.	
Harrould-Kolieb, E., Satvitts, J. 2008		Acid Test: Can We Save our Oceans fromCO_2?	Impact of CO_2 on ocean life and avenues of policy and technology to reduce CO_2 concentrations	NO
Haugan, P.M., Turley, C., & Poertner H-O. 2006	OSPAR Commission Report	Effects on the Marine Environment of Ocean Acidification Resulting from Elevated Levels of CO_2 in the Atmosphere	CO_2 lowers pH and $CaCO_3$ concentrations in water, negatively affecting calcifying organisms	NO
Hauri, C., Gruber, N. Plattner, G.K., Alin, S., Feely R.A., Hales, B., & Wheeler, P.A. 2009	*Oceanography*, 22: 60-71	Ocean Acidification in the California Current System	Study of corrosive upwelling events in CA current system	YES (uses data from Feely et al. 2008, reviewed in this evaluation)
Hester, K.C., Peltzer, E. T., Kirkwood, W.J., Brewer, P.G. 2008	Geophysical Research Letters, 35	Unanticipated consequences of ocean acidification: A noisier ocean at lower pH.	Ocean Acidification and sound absorbtion	NO
Hettinger, Annaliese, Sanford, Eric, Russell, Ann, Sato, Kirk, Hoey, Jennifer, Forsch,	Ecological Society of America, in press	Persistent carry-over effects of planktonic exposure to ocean acidification in the Olympia oyster	Laboratory study on Olympia oysters.	NO

Margaux, Page, Heather and Brian Gaylord, in press				
Hoegh-Guldberg 2007	*Science*, 318: 1737-1742	Coral Reefs under rapid Climate Change and Ocean Acidification	Warm, acidic seas impair coral calcification	NO
Honisch *et al*., 2012.	*Science* 335 (6072): 1058-1063.	The Geological Record of Ocean Acidification	Global review of geological records, no local data	NO
Hutchins, D.A., Mulholland, M.R., and Fu, F. 2009	*Oceanography*, 22:128- 145	Nutrient Cycles and Marine Microbes in an CO_2 enriched Ocean	Increased CO_2 may affect nitrogen cycle	NO
Intergovernmental Panel on Climate Change 2007	Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.	Climate Change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.	Comprehensive report on global climate change and effects, including ocean acidification	NO
Ishimatsu, Atsushi. 2004	*Journal of Oceanography*, 60(4)	Effects of CO_2 on Marine Fish: Larvae and Adults	CO_2 and its effects on fish egg and larvae	NO
Juranek, L.W., Feeley, R.A., Peterson,W.T., Alin, S.R., Hales, B., Lee, K., Sabine, C.L., Peterson, J. 2009	Geophysical Research Letters, 36	A novel method for determination of aragonite saturation state on the continental shelf of central Oregon using multi-parameter relationships with hydrographic data.	Observations of aragonite saturation states in OR, WA and CA, no WQS to compare to	NO
Kawaguchi, S.,	*Biology Letters*	Will krill fare well	Antarctic krill	NO

Kurihara, H., King, R., Hale, L., Berli, T., Robinson, J.P., Ishida, A., Wakita, M., Virtue, P., Nicol, S., Ishimatsu, A. 2010		under Southern Ocean Acidification?	experimentally exposed to various ppm of CO_2	
Kelly, R.P., Foley, M.M., Fisher, W.S., Feely, R.A., Halpern, B.S., Waldbusser, G.G., Caldwell, M.R. 2011	*Science*, 332: 1036	Mitigating Local Causes of Ocean Acidification with Existing Laws	Mitigating Local Causes of Ocean Acidification with Existing Laws	NO
Kleypas, J.A. 2006		Impacts of Ocean Acidification on Coral Reefs and other Marine Calcifiers	Rising CO_2 affects carbonate, which affects biological and geochemical processes	NO
Kleypas, J.A., Yates, K.K. 2009	*Oceanography*, 22	Coral Reefs and Ocean Acidification	Coral indicator of ocean acidification and ecosystem effects	NO
Kolbert, E. 2006	*The New Yorker, Nov. 11. 2006*	The Darkening Sea	Carbon emissions and effects on ocean	NO
Kroeker, K.J., Kordas, R.L., Crim, R.N., Signh, G.G. 2010	*Ecology Letters*, August 16	REVIEW AND SYNTHESIS: Meta-analysis reveals negative yet variable effects of ocean acidification on marine	Ocean acidification effect on marine organisms	NO

		organisms.		
Kuffner, I.B., Anderson, A.J., Jokiel, P.L., Rodgers, K.S., Mackenzie, F.T. 2008	*Nature Geoscience*, 1:114	Decreased abundance of crustose coralline algae due to ocean acidification	Coralline algae suffering from decreased CaCO3 concentrations in the water due to acidification	NO
Langdon, C. Broecker, M.J., Hammond, D.E., Gleen, E., Fitzsimmons, K., Nelson, S.G., Peng, T-H., Hajdas,I. Bonani, G. 2003	*Global Biogeochemical Cycles,* 17(1), 1011	Effect of elevated CO_2 on the community metabolism of an experimental coral reef	Effects of CO_2 on coral metabolism in coral in laboratory test	NO
Langdon, C., Atkinson, M.J. 2005	J. Geophys. Res., 110	Effect of elevated pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment	Study of coral in Hawaii	NO
Langston, J. 2011	*Sightline Daily*	The Acid Test, The Puget Sound Shuffle, Trouble on the Half Shell, Coming to a Shore Near You	News articles—discuss pH in Hood Canal, no OR data	NO
Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S.,	Proceedings of the National Academy of Sciences of the United of America, 105: 1786-1793	Tipping elements in the Earth's climate system	Critical points and policy regarding global climate change	NO

Schellnhuber, H.J. 2008				
Lischka, S., Budenbender, J., Boxhammer, T., Riebesell, U. 2011	*Biogeosciences*, 8(4):919-932	Impact of ocean acidification and elevated temperatures on early juveniles of the polar shelled pteropod *Limacina helicina*: mortality, shell degradation, and shell growth	Aragonitic shells are affected by ocean acidification and higher temperatures	NO
Lumsden, H., Bruckner, AW., & Dorr, G.	NOAA Technical Memorandum CRCP-3, Silver Spring MD, 365	The State of Deep Coral Ecosystems of the United States	Health of deep sea corals and ecosystems, threats	NO
Maier, C., Hegeman, J. Weinbauer, M.G., Gattuso, J.P. 2009	*Biogeosciences*, 6:1671-1680	Calcification of the cold-water coral *Lophelia pertusa* under ambient and reduced pH.	Calcification of corals may be first to be affected by acidification	NO
McMichael, A.J., Woodruff, R.E., Hales, S. 2006	Lancet, 367, 859-969	Climate Change and human health: present and future risks.	Effects of greenhouse gas and climate change	NO
McMullen, C.P., Jabbour, J. 2009	United Nations Environment Programme, Nairobi, Earthprint	Climate Change Science Compendium 2009	Explanation of ocean acidification	NO
McNeil, B.I., & Matear, R.J.	*Carbon Balance and Management*, 1:2	Projected Climate Change Impact on Oceanic Acidification	CO_2 decreases pH, higher temperatures decrease CO_2 sink in ocean	NO
McNeil, B.I., Matear, R.J. 2008	Proceedings of the National Academy of Sciences, 105: 18860-18864	Southern Ocean acidification: A tipping point at 450 ppm atmospheric CO_2	Seasonal fluctuation of carbonate ions and pH in Southern Ocean and observations	NO

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Meehl, G.A. 2007	Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.	2007: Global Climate Projections. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.	Projected changes in emissions and climate, projected effects on biogeochemical feedback loops and ocean acidification	NO
Miles, H. Widdicombe, S., Spicer, J.I., Hall-Spencer, J. 2007	*Marine Pollution Bulletin*, 54:89-96	Effects of anthropogenic seawater acidification on acid-base balance in the sea urchin *Psammechinus miliaris*	Artificial exposure of acidic seawater to urchins, effects and hypercapnia and mortality of urchins in experiment	NO
Miller, A.W. Reynolds, A.C., Sobrino, C., Riedel, G.F. 2009	PLoS ONE 4 (5): e5661	Shellfish Face Uncertain Future in High CO_2 World: Influence of Acidification on Oyster Larvae Calcification and Growth in Estuaries	Laboratory study on oysters	YES, but no new data presented (cites Feely et al. 2008, which has been reviewed in this evaluation)
Millero, F.J.,Woosley, R., DiTrolio, B., and Waters, J. 2009	*Oceanography*, 22: 72-85	Effect of Ocean Acidification on the Speciation of Metals in Seawater	pH will change the organic and inorganic speciation of metals and its effect on marine organisms	NO
Moore,	Puget Sound Partnership, 2011 Overview	Puget Sound Marine	Overview of	NO

Stephanie, Runcie, Rosa, Stark, Kimberle, Newton, Jan and Ken Dzinbal, eds, 2012		Waters	various topics in Puget Sound, including ocean acidification	
Morgan, LE, C-F Tsao, JM Guinotte. 2006	Marine Conservation Biology Institute, Bellevue, WA.	Status of Deep Sea Coral in US Waters, with Recommendations for their Conservation and Management	Health of corals in US waters	NO
Moy, A.D., Howard, W.R., Bray, S.G., Trull,T.W. 2009	*Nature Geoscience*	Reduced calcification in modern Southern Ocean planktonic foraminifera	Field data of reduced calcification in Southern Oceans	NO
Munday, P.L. Dixson, D.L., Donelson, J.M., Jones, G.P., Pratchett, M.S., Devitsina, G.V., Doving, K.B. 2009	Proceedings of the National Academy of Sciences 106: 1848-1852	Ocean acidification impairs olfactory discrimination and homing ability of a marine fish	Acidification reduces fish response to natural cues, reduces sustainability and diversity of fish species	NO
Munday, P.L., Dixson, D.L. 2010	Proceedings of the National Academy of Sciences, 107(29): 12930-34	Replenishment of fish populations is threatened by ocean acidification	Ocean acidification and impact on fish and fish larvae	NO
Murray, J.R. 2006	*Science*, 312: 543-547	Reefs of the Deep: The Biology and Geology of Cold-Water Coral Ecosystems	Impacts of ocean acidification on deep water coral	NO
Nellemann, C., Hain, S., & Alder J., 2008	United Nations Environment Programme	In Dead Water – Merging of Climate Change with pollution, over-harvest, and infestations in the	Ocean acidification and impact on marine biology and industry	NO

		world's fishing grounds		
Ocean Acidification Reference User Group, 2009	European Project on Ocean Acidification	Ocean Acidification: The Facts. A special introductory guide foe policy advisors and decision makers.	Reference guide to ocean acidification and impacts	NO
Orr, J.C. 2005	*Nature*, 407: 681-686	Anthropogenic Ocean Acidification over the Twenty-first Century and Its Impact on Calcifying Organisms	Twenty-first century ocean acidification is reducing carbonate ions in ocean	NO
Orr, J.C., Caldeira, V., Fabry, J.P., Gattuso, P., Haugen, P., Lehodey, S., Pantoja, H.O., Portner, U., Riebesell, T., Trull. E., Urban, M., & Broadgate, W. 2009	*Oceanography*, 22: 182-189	Research Priorities for Understanding Ocean Acidification: Summary From the Second Symposium on the Ocean in a High CO_2 World	Ocean acidification in context of human cause	NO
Parks, N. 2009	*Environmental Science and Technology*, 6118	Is regulation on ocean acidification on the horizon?	Update to CWA for marine pH	NO
Pelejero, C. and Calvo, E. 2010	*Trends in Ecology & Evolution*, 1-13	Paleo-perspectives on ocean acidification.	Ecological impacts of high CO_2 and observed impacts	NO
Portner, H.O., Langenbuch, M., & Reipschlager, A. 2004	*Journal of Oceanography*, 60: 705-718	Biological Impact of elevated ocean CO_2 Concentrations: Lessons from animal physiology and earth history	Impact of high CO_2 and animal biology	NO

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Portner, Hans O. 2005	*Journal of Geophysical Research*, 110(9)	Synergistic effects of temperature extremes, hypoxia, and increases in CO_2 on marine animals: From Earth History to global change	Combined effects of temperature, CO_2, and hypoxia on ecology , animal metabolism and mortality	NO
Quesne, W.J.F.L., Pinnegar, J.K. 2011	*Lowestoft Laboratory, Centre for Environment, Fisheries and Aquaculture Science*	The potential impacts of ocean acidification: scaling from physiology to fisheries	potential impact of ocean acidification on fisheries with particular emphasis on approaches to scaling from physiological responses to population- and ecosystem-level processes	NO
Raupach, M.R., Marland, G., Ciais, P., Quere, C.L., Canadell, G., Klepper, G., Field, C.B. 2007	Proceedings of the National Academy of Sciences of the United States of America, 104: 10288-10293	Global and regional drivers of accelerating CO_2 emissions	Drivers for increase of anthropogenic CO_2 emissions	NO
Richardson, K., Steffen, W., Schellnhuber, H.J., Alcamo, J., Barker, T., Leemans, R., Liverman, D. Munasinghe, M., Osman-Elasha,	Copenhagen 2009, 10-12 March	Synthesis Report from Climate Change: Global Risks, Challenges, and Decisions	Impacts, results, and the future of climate change	NO

B., Stern, N., & Waever, O. 2009				
Riebesell, U. 2000	*Nature*, 407: 364-367	Reduced Calcification of Marine Plankton in Response to Increased Atmospheric CO_2	CO_2 slows down calcification in corals	NO
Rosa, R., Seibel, B.A., 2008	Proceedings of the National Academy of Sciences 105: 20776-20780	Synergistic effects of climate related variables suggest future physiological impairment in a top oceanic predator.	Synergism between ocean acidification, global warming, and expanding hypoxia will compress the habitable depth range of the species jumbo squid	NO
Ruttimann, J. 2006	*Nature News Feature*, 978-980	Sick Seas	pH drop and acidified water dissolves carbonate skeletons of organisms	NO
Sabine, C.L. 2004	*Science*, 305: 367-371	The Oceanic Sink for Anthropogenic CO_2	The ocean has been absorbing CO_2 since the start of the industrial period	NO
Shirayama, Y. 2005	*Journal of Geophysical Research*, 110(9)	Effect of increased atmospheric CO_2 on shallow water marine benthos	Chronic effects of CO_2 in shallow waters	NO
Silverman, J., Lazar, B., Cao, L., Caldeira, K.	Geophysical Research Letters, 36	Coral reefs may start dissolving when atmospheric CO_2	CO_2 concentrations in the ocean impair	NO

Erez, J. 2009		doubles	calcification and dissolve coral reefs	
Simpson, S.D., Munday, P.L., Wittenrich, M.L., Manassa, R., Dixson, D.L., Gagliano, M., Yan, H.Y. 2011	*Biology Letters*, June 1	Ocean acidification erodes crucial auditory behavior in marine fish	Ocean acidification results in loss of hearing in fish, impairing natural responses and communication	NO
Southern California Coastal Water Research Project 2010	*Ocean acidification effects on shellfish workshop.*	Ocean acidification effects on shellfish workshop: Findings and recommendations	Discussion of hatchery mortality events, no WQS data	NO
Steinacher, F., Joos, Flolicher, T.L., Plattner, G.K., Doney, S.C. 2009	*Biogeosciences*, 6: 515-533	Imminent ocean acidification in the Arctic projected with the NCAR global couple carbon cycle-climate model	Simulated pH changes in the Arctic and retreating sea ice	NO
Stone, R.P., Shotwell, S.K. 2007	NOAA Technical Memorandum CRCP-3, Silver Spring MD, 365	State of the Deep Coral Ecosystems in the Alaska Region: Gulf of Alaska, Bering Sea and the Aleutian Islands. In: SE Lumsden, Hourigan TF, Bruckner AW and Dorr G The State of Deep Coral Ecosystems of the United States	Alaskan deep coral ecosystems	NO
Talmage, S.C., and Gobler, C.J. 2009	Stony Brook University, School of Marine and Atmospheric Sciences	The effects of elevated carbon dioxide concentrations on the metamorphosis, size, and survival of larval	Effects of elevated carbon dioxide concentrations on the metamorphosis,	NO

		hard clams (*Mercenaria mercenaria*), Bay Scallops (*Argopecten irradians*), and Eastern Oysters (*Crassostrea virginica*)	size, and survival of larval marine organisms	
Tans, P. 2009	*Oceanography*, 22: 26-35	An Accounting of the Observed Increase in Oceanic and Atmospheric CO_2 and an Outlook for the Future	Analysis and calculation of source of CO2 increase	NO
Turley, C. 2006	Avoiding Dangerous Climate Change	Chapter 8: Reviewing the Impact of Increased Atmospheric CO_2 on Oceanic pH and the Marine Ecosystem	Atmospheric CO_2 creates positive and negative feedback mechanisms, integration of net impact on marine ecosystem	NO
Turley, C. 2007	*Coral Reefs*, 26: 445-448	Corals in deep water: will the unseen hand of ocean acidification destroy cold-water ecosystems?	Disruption of natural conditions for deep water cold coral groups	NO
Turley, C. 2010	UNEP Emerging Issues	Environmental Consequences of Ocean Acidification: A threat to food security	Acidification, impact on food web and commercial aquaculture	NO
Turley, J.C., Blackford, S., Widdicombe, D., Lowe, P.D., & Rees, A.P. 2006		Reviewing the Impact on Increased Atmospheric CO_2 on Oceanic pH and the Marine Ecosystem	Basic overview of impacts of CO2 and acidification on several marine specie groups	NO

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US Geological Survey, 2000	http://www.usgs.gov/themes/factsheet/146-00/	Mercury in the Environment Fact Sheet 146-00	Effects of Mercury and fish	NO
Veron, J.E.N. 2009	*Marine Pollution Bulletin*, 58: 1428-1436	The coral reef crisis: The critical importance of <350 ppm CO_2	Optimal coral ecology, CO_2 and coral bleaching	NO
Waldbusser, G.G., Steenson, R.A., Green, M.A. 2011	*Journal of Shellfish Research*, 30(3): 659-669	Oyster Shell Dissolution Rates in Estuarine Waters: Effect of pH and Shell Legacy	Acidity and shell legacy and effect on dissolution of CaCO3 in oyster shells, laboratory study on eastern oysters and pH trends in Chesapeake Bay	NO
Walther, F.J., Sartoris, C., Bock, C., Portner, H.O. 2009	*Biogeosciences Discuss.*, 6: 2837-2861	Impact of anthropogenic ocean acidification on thermal tolerance of the spider crab *Hyas araneus*	Synergistic impacts of climate change, temperature and acidification on spider crabs	NO
Welch, B.C. 2010	*Seattle Times*, June 15	Shellfish at risk: Puget Sound becoming acidified	pH has been dropping in Puget Sound, shellfish have not been reproducing	NO
Welch, C. 2009	June 15, 2009	Oysters in deep trouble: Is the Pacific Ocean's chemistry killing sealife?	News article about hatchery mortality, no WQS data	NO
Widdicombe, H., Needham, R. 2007	*Marine Ecology Progress*, 341: 111-122	Impact of CO_2 induced seawater acidification on the burrowing activity of *Nereis virens* and sediment	Ocean acidification and effect on nutrient (nitrate, ammonium,	NO

		nutrient flux	nitrite, and phosphate) flux of sea worms.	
Widdicombe, S., Spicer, J.I. 2008	*Journal of Experimental Marine Biology and Ecology*, 366: 187-197	Predicting the impact of ocean acidification on benthic biodiversity: What can animal physiology tell us?	Impact of acidification on ocean floor biodiversity, resulting hypercapnia on marine organisms	NO
Wootton, J.T., Pfister, C.A., Forester, J.D. 2011		Comments on draft 2010 assessment of Washington's marine waters	Comments of WQ, 303(d)	NO
Wootton, T.J.		Dataset from Tatoosh Island 2000-2009	Data including pH.	NO
Wootton, T.J., Catherine , A.P., James, D.F. 2008	Proceedings of the National Academy of Sciences, 105(48): 18848-18853	Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset.	Ecological impact of declining pH	NO
Wootton, T.J., Pfister, C.A., & Forester, J.D. 2008	Proceedings of the National Academy of Sciences, 105(48): 18848-18853	Dynamic patterns and ecological impacts of declining ocean pH in a high resolution multiyear dataset.	8 year data set of atmospheric CO_2 concentrations and ocean pH at a north temperate coastal site	NO
Zeebe, R.E. 2008	*Science*, 321: 51-52	Carbon Emissions and Acidification	Ocean Acidification as a result from atmospheric CO_2	NO

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Table 2: Assessment summary of CBD references flagged as potentially having usable data/information to assess to Oregon's WQS.

Author, year	Citation	Title	Local Data	Relevant Statements from Article	Assessment of Water Quality Standards
Barton, Cudd and Weigardt, 2009???	Unpublished account	Update on Hatchery Research and Use of State Funds to Improve Larval Performance at Whiskey Creek Shellfish Hatchery	-Update on hatchery research, pH was recorded at an unknown location and ranged from 7.58-7.92.	-*Vibrio tubiashii* is a significant stress factor for shellfish larvae, but is not the underlying cause of catastrophic mortality events -Upwelling of nutrient rich, deep ocean water onto the continental shelf results in sharp decline I the performance of bivalve larvae (in the hatchery) -Upwelled water has a pH of 7.55-7.6 -Mass mortality events follow upwelling events by 24-48 hours -Trying to determine trends in pH data is somewhat suspect-pH is affected by biology and using it as a marked of upwelled water masses is therefore questionable. -Upwelling of deeper ocean water is directly linked to poor performance of larvae in the hatchery	-Hatchery population, no *in situ* field data of natural populations -Does not indicate non-attainment of pH standard, falls within marine 7.0-8.5 or estuary and fresh water site specific criteria of 6.5-9.0.
Barton *et al.* 2012.	*Limnol.*	The Pacific Oyster,	-Whiskey Creek	-Pacific oyster	Hatchery

	Oceanography, 57(3), 698-710.	*Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects	Hatchery, Netarts Bay, OR -pH <7.6 to >8.2 -surface ocean pH decreased by 0.1 unit since preindustrial period -accuracy of YSI electrode only +/- 0.2 pH units	introduced, limited naturally sustaining populations -Hatchery problems began in 2006 with *Vibrio tubiashii* outbreak -Netarts Bay-lagoon type estuary with dominated by ocean inputs, minimal freshwater input -pH is an imperfect variable for determining the corrosivity of ocean water -Bay subject to two major forcings of carbonate chemistry: upwelling state of adjacent ocean, diurnal metabolic variability within bay -Research has demonstrated the importance of environmental conditions related to climate and weather in controlling oyster recruitment -Hatchery conditions are not representative of wild conditions -Within cohort variability exists and allows some to grow without incident -Bay experiences large fluctuations in carbonate chemistry driven by	population, no *in situ* field data of natural populations -Does not indicate non-attainment of pH standard, falls within marine 7.0-8.5 or estuary and fresh water site specific criteria of 6.5-9.0.

				primarily natural mechanisms -Two significant shortcomings with regard to understanding acidification effects on natural populations in variable coastal and estuarine habitats: prediction of how carbonate conditions will vary in coastal and estuarine environments with increasing atmospheric CO_2 and a better understanding of the fundamental biology underlying the responses of multicellular organisms to acidification -Limited experience suggests the multitude of forcing time scales still requires high-resolution monitoring of water CO_2 chemistry before we are fully capable of developing predictive models -Correlative and suggestive nature of hatchery study highlights significance of variable carbonate chemistry on commercially important species, validates	

				previous lab based experiments	
Feely *et al.*, 2008.	*Science*, 320, no. 5882: 1490-1492	Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf (including supporting material)	-lowering of seawater pH by 0.1 since beginning of Industrial revolution -Upwelling near Oregon-California border, pH = 7.75	-Although seasonal upwelling of undersaturated waters is a natural phenomenon, ocean uptake of anthropogenic CO_2 has increased the areal extent of the affected area -much of the corrosive character of these waters is the natural result of respiration processes at intermediate depths below the euphotic zone -Region experiences seasonal periods of aragonite undersaturation, so important to understand how increased corrosiveness with impact indigenous species -Little is known about how intermittent exposure to corrosive waters might affect organisms -Comprehensive field studies of response to sporadic increases in CO_2 are lacking; further research under field conditions is warranted	-Only possible OR data indicates a pH near the Oregon-California border of 7.75, within the marine range of 7.0-8.5

				-Calculations of anthropogenic CO_2 in Northwestern Pacific have many sources of uncertainly including quality of density versus anthropogenic CO_2 fit, the similarity between coastal and open ocean waters, and the temporal stability of parameters such as the total alkalinity in the coastal region; estimates are good to within +/- 50%.	
Gruber, Nicolas, Hauri, Claudine, Lachkar, Zouhair, Loher, Damian, Frolicher, Thomas and Gian-Kasper Plattner, 2012	Sciencexpress, 1	Rapid Progression of Ocean Acidification in the California Current System	Data indicates pH along CA/OR border of 7.92,	-Model simulation to study potential development of ocean acidification in CA current -While the upwelling of waters with low pH and aragonite saturation is a naturally occurring event along the U.S. West Coast, models indicate that an increase in atmospheric CO_2 since pre-industrial times lowered the pH by 0.1 -Most predictions occur whether high or low CO_2 scenarios are used -While able to predict chemical changes in CA Current System with	Model predicts pH along CA/OR border of 7.92, well within WQS, no other data to compare to WQS

				some confidence, impacts on organisms and ecosystems remain highly uncertain -None of the organisms studied so far has a simple dose response -Organisms living in the CA Current System may have had a change to adapt to the naturally low and variable pH and aragonite saturation conditions, making them potentially less vulnerable to ocean acidification -The CA current system is moving rapidly toward conditions that are well outside the natural range -Ocean acidification will not be operating in isolation, but impact could be potentially worsened with synergistic effects of ocean warming and deoxygenation	
Hauri *et al.*, 2009.	*Oceanography* 22, no. 4: 60-71.	Ocean Acidification in the California Current System	-Used Feely et al. (2008) estimated pH data from CA near OR border in Regional Ocean Modeling System (ROMS) and simple	-Eastern boundary upwelling systems are naturally more acidic than most of the rest of the surface ocean -High variability in carbonate chemistry,	-methodology unclear for derived pH values; however, derived pH values are within OR's WQS range of 7.0-8.5.

			ecological-biogeochemical model in order to study pH changes in seasonal and wider spatial context.	largely driven by seasonal upwelling of waters with low pH and saturation states, and subsequent interactions of transport and biological production -Responses of marine organisms and ecosystems to permanently low pH conditions are not yet well investigated -We must improve our currently insufficient understanding of the consequences of ocean acidification for individual organisms, entire ecosystems, marine biogeochemical cycling and feedback to the climate system in order to inform policy-makers and provide a sound science basis for urgent decision regarding CO_2 mitigation -Meanwhile it is important to lower the pressure on marine ecosystems from other stressors such as pollution, coastal degradation and eutrophication to make these systems less	

				vulnerable to the changing marine chemical conditions association with increasing CO_2	

Appendix B: History

History of EPA's interaction with CBD on a national level

CBD petitioned EPA on December 17, 2007 to revise its recommended Clean Water Act Section 304(a)(1) national marine pH water quality criterion for the protection of aquatic life and also asked EPA to publish information and provide guidance on listing waters affected by ocean acidification. On April 15, 2009, EPA published a Federal Register Notice of Data Availability (NODA) soliciting scientific data and information on ocean acidification that may be useful to the EPA in its decision to re-evaluate and revise the marine pH water quality criterion.

After reviewing all of the information received, on April 15, 2010 EPA issued a memorandum detailing the decision not to revise the marine pH criterion. In the memorandum, EPA concluded that the comments received highlighted the uncertainties in the use of marine pH as the sole indicator for ocean acidification. The Agency received information from the National Oceanic and Atmospheric Administration (NOAA) that indicated that one general marine pH criterion would not suffice for all coastal regions, as there are significant regional differences in natural diurnal and seasonal pH, dissolved inorganic carbon (DIC), partial pressure of CO_2 and total alkalinity (TA) ranges and associated biological responses. In addition, based on the comments received, EPA noted that most coastal regions do not have the data to characterize diurnal and seasonal variability and that short term trends in carbon system parameters and pH cannot be determined.

On November 15, 2010, EPA issued a memorandum entitled "Integrated Reporting and Listing Decisions Related to Ocean Acidification," that recognized the seriousness of aquatic life impacts associated with ocean acidification and described how states could address ocean acidification, where information exists, during the 2012 303(d) listing cycle. *See EPA, 2010.* The memorandum recommends that states develop a methodology for how they will assess for ocean acidification and begin to solicit water quality data and information related to ocean acidification during the 2012 listing cycle.

History of CBD's comments on Oregon's 2010 List

CBD sent a letter to ODEQ on August 15, 2007, requesting that Oregon add ocean waters to the 2008 303(d) List of Impaired Waters due to carbon dioxide pollution and ocean acidification and that they also revise current water quality standards for pH. A second letter was sent on June 9, 2008 requesting the same listings and standard revision.

ODEQ did not submit a 303(d) List in 2008, but proceeded with the development of the 2010 List. ODEQ issued a public call for data from May 11-June 11, 2009. On June 10, 2009, CBD submitted a letter during the call for data which included 72 references on a variety of ocean acidification issues. Upon analyzing the references, ODEQ determined that "the submitted information did not contain any monitoring or sampling data from ocean waters within Oregon's jurisdiction. None of the submitted information was the type of data described in the Assessment Methodology as relevant for comparison to Oregon's pH standard. [CBD] did not submit any analytical data in the templates and formats that were provided and specified for use for submission of data in the public call for data." *See ODEQ, 2011b.*

The draft assessment was then made available for public comment and review from November 15-December 15, 2010. CBD submitted comments on December 6, 2010, stating that coastal waters should be listed for ocean acidification. A number of references were included with the comments. ODEQ noted in their January, 2011 Response to Comments that the waters discussed in these references, "are not within Oregon's jurisdiction and are not appropriate to include in Oregon's 305(b)/303(d) assessment. [CBD] also noted recent reports of low productivity in Oregon shellfish hatcheries, but did not provide any specific information that DEQ could review to determine if this warranted consideration in addition to pH data that were previously solicited and are available in DEQ's data repository." *See ODEQ, 2011b.*

A second public comment period for Oregon's 2010 draft assessment occurred from April 13, 2011 through May 3, 2011.   CBD submitted comments which asserted that new information showed impairments to aquatic life and that the pH criteria were inadequate. Additional references were included. ODEQ stated in its May 2011 Response to Comments that they applied their numeric pH criteria where data was available. ODEQ conducted a review of the journal articles CBD submitted with their comments, "but did not find any useable data that could have been processed with other chemical data for evaluating site conditions in Oregon." *See ODEQ, 2011a.*