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Author/Year	Citation	Title	Data/Information	Relevant Statements from Article	EPA's Assessment of WQS
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	Unpublished account	Update on Hatchery Research and Use of State Funds to Improve Larval Performance at Whiskey Creek Shellfish Hatchery	-Update on hatchery research, pH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	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale:</u> -Hatchery population in Oregon, not sufficient to determine condition of natural populations in WA waters (i.e., lacks ecological complexity) -no *in situ* field data of natural populations in WA waters
Barton *et al.* 2012.	*Limnol. Oceanography*, 57(3) 2012, 698-710.	The Pacific Oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects	-Whiskey Creek 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	-Pacific oyster 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	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale:</u> -Hatchery population in Oregon, not sufficient to determine condition of natural populations in WA waters (i.e., lacks ecological complexity) -no *in situ* field data of natural populations in WA waters

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				-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 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	
Beesley, A.,	*Climate*	Effects of CO_2	-Laboratory study	-No impact on tissue structures was	Attainment Determination:

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Lowe, D.M., Pascoe, C.K., Widdicombe, S. 2008	*Research,* 37: 215-225	induced seawater acidification on the health of *Mytilus edulis*	of *Mytilus edulis*, a species present in Washington waters	observed, concluded that *M. edulis* possess strong physiological mechanisms by which they are able to protect body tissues against short-term exposure to highly acidified seawater -mechanisms come at an energetic cost, which can result in reduced growth during long-term exposures -Ocean acidification could reduce the general health status of this commercially and ecologically important marine species.	-No indication of non-attainment of any WA WQS <u>Rationale:</u> -Toxicity-focused lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
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*	-Laboratory study of *Littorina littorea*, a species present in Washington waters	-acidified seawater can have indirect biological effects by disrupting the capability of organisms to express induced defenses -.snails in this treatment compensated for a lack of morphological defense, by increasing their avoidance behavior -biological effects from ocean acidification may be complex and extend beyond simple direct effects	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> -lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
Bibby, R.,	*Aquatic*	Effects of Ocean	-Laboratory study	-Ocean acidification could have a	<u>Attainment Determination:</u>

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Widdicomb, S. Parry, H., Spicer, J., Pipe, R. 2008	*Biology*, 2:67-74	acidification on the immune response of the blue mussel *Mytilus edulis*	of *Mytilus edulis*, a species present in Washington waters	significant effect on cellular signaling pathways -may be disrupted by calcium carbonate shell dissolution.	-No indication of non-attainment of any WA WQS <u>Rationale</u> -lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
Bonfils, D. 2010	*abcNews,* April 22	Ocean acidification hits Northwest oyster farms	News article on hatcheries	-News article regarding hatcheries in Oregon	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> Hatcheries in Oregon insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity) -No *in situ* field data of natural populations in WA
Chan, K.Y.K., Grunbaum, D., O'Donnell, M.J.	*Journal of Experimental Biology,* 214:	Effects of ocean acidification induced	-Laboratory study of larval sand dollars collected in	-When exposed to elevated levels of pCO_2, morphological changes varied suggesting within-population variation in	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS

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2011	3857	morphological changes on larval swimming and feeding	East Sound, WA	sensitivity to changes -Possible that sand dollars collected in East Sound are acclimated to large diurnal pH fluctuations and upwelling events on WA coasts	Rationale-lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
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	-General information about the carbon cycle	-Mentions coastal upwelling zones off WA coast -Mentions high biological productivity fueled by nutrients	Attainment Determination: -No indication of non-attainment of any WA WQS Rationale -Model inappropriate for extrapolation to WA waters -No *in situ* field data of natural populations in WA
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	-Laboratory study on mollusk species found in Washington waters	-Noted a 28% decline in calcification of mollusks when exposed to pH levels estimated occur in 2100	Attainment Determination: -No indication of non-attainment of any WA WQS Rationale -lab study where chemical parameters are drastically manipulated; insufficient in

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					determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations
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*)	-Laboratory study conducted on *Haliotis kamtschatkana*, a species of abalone found in WA	-Larval survival decreased with elevated levels of CO_2 -Elevated levels had no effect on the proportion of surviving larvae that metamorphosed at the end of the experiment -Larval shell abnormalities developed at higher levels	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> -lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
Feely *et al.*, 2008.	*Science*, 320, no. 5882: 1490-1492	Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf (including supporting material)	-Discusses conditions on Pacific Continental Shelf, near CA-OR border -lowering of seawater pH by 0.1 since beginning of Industrial	-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	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale:</u> -Lowering of pH by 0.1 since Industrial Revolution does not specify a specific location, but is still within the

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			revolution -Upwelling near Oregon-California border, pH = 7.75	-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 -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%.	0.2 change allowed by WA WQS -lowest pH value still within allowable WQS range
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	-pH of open ocean surface waters decreased by 0.1 unit since beginning of Industrial era -Main Basin pH = 7.71-7.75 -Hood Canal Basin pH = 7.50-7.85 -Waters with pH < 7.75 enters Strait of Juan de Fuca -pH of deep waters flowing into Puget Sound over sill range from 7.64-7.78 -Outflowing surface waters at the sill have a pH of 7.75-7.81 -In shallow surface waters of Main Basin, South Sound and Hood Canal, pH ranged	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> -Lowering of pH by 0.1 in open ocean since Industrial Revolution does not specify a specific location, but is still within the 0.2 change allowed by WA WQS -all pH data in article is within the WQS range of 7.0-

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				from 7.77-8.25 -Below 50 m in Main Basin and South Sound pH was 7.71-7.91 -Deep waters of Hood Canal had pH of 7.32-7.75 -In southern part of Hood Canal Basin pH was < 7.4 -Data table shows pH range of 7.72-8.05 -pH decreases of 0.00-0.15 have been modeled for Puget Sound	8.5
Gazeau, F. 2007	*Geophysical Research Letters,* 34	Impact of Elevated CO_2 on Shellfish Calcification	-Laboratory study of *Mytilus edulis* and *Crassostrea gigas*, species found in WA	-calcification rates of the edible mussel (Mytilus edulis) and Pacific oyster (Crassostrea gigas) decline linearly with increasing pCO2 -dependency of calcification rates on pCO2 and [$CO3^{2-}$] values for both species	<u>- Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> -lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
Gazeau *et al.*, 2011.	*PloS ONE* 6 (8): 1-8	Effect of Carbonate Chemistry Alteration of the Early Embryonic Development of the Pacific Oyster	-Laboratory study of *Crassostrea gigas*, a species found in WA	-Studies have shown decreased growth rates and increased proportions of abnormal development under low pH conditions, they did not allow attribution to pH induced changes in physiology or changes due to a decrease in aragonite	<u>- Attainment Determination</u>: -No indication of non-attainment of any WA WQS <u>Rationale</u> -lab study where chemical

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		(*Crassostrea gigas)*		saturation state. -Developmental success and growth rates were not directly affected by changes in pH or aragonite saturation state, but were highly correlated with the availability of carbonate ions. -Studies suggest that the mechanisms used by these organisms to regulate calcification rates are not efficient enough to compensate for the low availability of carbonate ions under corrosive conditions. -Separating factors of pH, carbonate ion availability and seawater saturation state with respect to calcium carbonate in crucial as total alkalinity levels are not constant in the ocean and a similar decrease in pH does not lead to similar decline in calcium carbonate saturation state. -pH is not the main driver of the observed decreases in developmental success and growth rates.	parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
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.	-Laboratory study of *Mercenaria mercenaria*, a species found in WA	-Dissolution is an important size-dependent mortality factor for juvenile bivalves -Buffering against the metabolic acids that cause lowered saturation states may represent a potentially important management strategy to decrease dissolution mortality.	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> -lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural

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					populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
Hettinger, Annaliese, Sanford, Eric, Russell, Ann, Sato, Kirk, Hoey, Jennifer, Forsch, Margaux, Page, Heather and Brian Gaylord, in press	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, a species native to WA	-Larvae reared in a reduced pH environment experiences reduced shell growth rate and area -Juveniles exposed to a lower pH also experienced a lower growth rate -Focus on the impacts of reduced pH on a life stage may not capture the full impact	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> -lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
Juranek *et al.*, 2009.	*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	-no pH data, only aragonite saturation data -observations off of WA, OR and CA	-PNW coastal waters experience intense river inputs during the rainy winter months and the TA:DIC signature of the freshwater is often different than in the open ocean -There is a distinct seasonal cycle that is tightly coupled to upwelling dynamics near Newport -Within the ability to estimate anthropogenic CO_2 content (+/-50%), undersaturation over shelf/slope bottom	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> -Ambient WQ data for aragonite saturation -No data for which WA WQS exist

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				waters is likely a natural phenomena, but anthropogenic inputs have caused a shoaling	
Langston, 2011.	*Sightline Daily*, May 26, 2011.	Coming to a Shore Near You	-news article -mentions Puget Sound waters have a pH of 7.7 -mentions Hood Canal has pH of 7.4 -mentions global average drop from 8.2-8.1 since Industrial Revolution	-Corrosive waters of Hood Canal aren't the result of ocean acidification alone. Natural processes and other forms of pollution also contribute to low pH values. -About 24-49% of drop in pH in Hood Canal since pre-Industrial era is attributed to ocean acidification -Have Puget Sound organisms adapted to changes in pH, or are they too stressed to adapt? This is the big question scientists have to address. We don't know.	<u>Attainment Determination:</u> -No indication of non-attainment of any WA WQS <u>Rationale</u> -General information presented, no data -pH values mentioned are within the range of 7.0-8.5 for the WA WQS -
Langston, 2011.	*Sightline Daily,* June 22, 2011.	Trouble on the Half Shell	-news article	-It's absolutely clear that high carbon dioxide and baby oysters don't go well together…But it's really hard to do experiments when you're seeing these natural fluctuations and say "yes, this in fact is the thing that's causing the problem, " as opposed to something else that might happen to correlate with carbon dioxide.	<u>Attainment Determination</u>: -No indication of non-attainment of any WA WQS <u>Rationale</u> -General information presented, no data
Langston, 2011.	*Sightline Daily*, June 6, 2011.	The Puget Sound Shuffle	-news article	-no data presented	<u>Attainment Determination</u>: -No indication of non-attainment of any WA WQS <u>Rationale</u> -General information presented, no data
Lischka, S.,	*Biogeosciences,*	Impact of ocean	-Laboratory study	-Aragonitic shells are affected by ocean	<u>Attainment Determination:</u>

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Budenbender, J., Boxhammer, T., Riebesell, U. 2011	8(4):919-932	acidification and elevated temperatures on early juveniles of the polar shelled pteropod *Limacina helicina*: mortality, shell degradation, and shell growth	of *Limacina helicina*, a species found in WA	acidification and higher temperatures	-No indication of non-attainment of any WA WQS <u>Rationale</u> -lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
Moore, Stephanie, Runcie, Rosa, Stark, Kimberle, Newton, Jan and Ken Dzinbal, eds, 2012	Puget Sound Partnership, 2011 Overview	Puget Sound Marine Waters	-Overview of various topics in Puget Sound, including ocean acidification -Cites Feely, 2010, reviewed separately -pH in Hood Canal of less than 7.75, 7.35 and 7.06	-The lowest pH values in Hood Canal "appear to be the result of the combined influences of mixing of deep, CO_2 rich water from the Hood Canal basin along with strong production and respiration in surface waters in the eutrophic Lynch Cove region."	<u>Attainment Determination</u>: -No indication of non-attainment of any WA WQS <u>Rationale</u> -new pH data are still with the range of 7.0-8.5 within the WA WQS
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 -Individual speakers presented findings that have been reviewed	-Summarize hatchery mortality events	<u>Attainment Determination</u>: -No indication of non-attainment of any WA WQS <u>Rationale:</u> -Only pH data was non-site specific and mentioned a

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			separately under published articles		decrease in surface ocean pH of about 0.1 units, within the WA WQS range of a 0.2 change.
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 hard clams (*Mercenaria mercenaria*), Bay Scallops (*Argopecten irradians*), and Eastern Oysters (*Crassostrea virginica*)	-Laboratory study of species found in WA	-Increased levels of CO_2 resulted in declines in survivorship, delayed metamorphosis and slower growth rates -May result from their inability to adequately synthesize shell material -Could have profound impacts on food web	Attainment Determination: -No indication of non-attainment of any WA WQS Rationale -lab study where chemical parameters are drastically manipulated; insufficient in determining the chemical and associated biological condition of natural populations in WA waters (i.e., lacks ecological complexity). -No *in situ* field data of natural populations in WA
Welch, B.C. 2010	*Seattle Times,* June 15	Shellfish at risk: Puget Sound becoming acidified	-News article	-pH has been dropping in Puget Sound, shellfish have not been reproducing	Attainment Determination: -No indication of non-attainment of any WA WQS Rationale -No data presented -News article
Welch, C. 2009	June 15, 2009	Oysters in deep trouble: Is the Pacific Ocean's chemistry killing	-News article about hatchery mortality	-Discussion of recent hatchery mortality events	Attainment Determination: -No indication of non-attainment of any WA WQS

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		sealife?			Rationale -New article -No data presented
Wootton, T.J. 2009.		Dataset from Tatoosh Island 2000-2009	-Data including pH collected from 2000-2009 at Tatoosh Island, WA	-Raw data set	Attainment Determination: -No indication of non-attainment of any WA WQS Rationale -Data collected in Tribal waters -Due to unique collection location, more information in required before data can appropriately be extrapolated to State Waters
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	-pH decline is proceeding faster than previously predicted in some areas -pH had 0.24 unit range during a typical day due to daily variation in photosynthesis and respiration -pH fluctuated substantially over days and years -a general declining pH trend is apparent -declining pH reduces the performance of calcifying organisms -systematic changes in community structure are a function of mean annual pH -results point to "a need for more detailed investigation of the processes controlling ocean pH in higher latitudes and coastal habitats."	Attainment Determination: -No indication of non-attainment of any WA WQS Rationale -Data collected in Tribal waters -Due to unique collection location, more information in required before data can appropriately be extrapolated to State Waters

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				-"results highlight the urgent need for more spatially distributed and temporally intensive studies of ocean pH dynamics and their underlying causal mechanisms and consequences."	