Draft Assessment Methodology for Oregon's 2024 Integrated Report

Updates for Marine Waters

Oregon Department of Environmental Quality is proposing to adopt two new assessment methodologies into the Assessment Methodology for Oregon's 2024 Integrated Report. These will become two new chapters in *assessment methodologies for specific pollutants and parameters* section of the document. The full document is available online at: https://www.oregon.gov/deq/wq/Documents/wqaIR2024method.pdf.

The following supporting documents for the marine water assessment methodology updates can be found here;

- **Fact Sheet** - Assessing Ocean Acidification and Hypoxia Impacts in Oregon Marine Waters
- **Technical Support Document** - Draft Methodology for Assessing Ocean Acidification and Hypoxia Impacts in Oregon
- **Technical Workgroup Process Overview**

Assessment – Biocriteria Marine Waters – Ocean Acidification

PARAMETER	BENEFICIAL USE
Aragonite/Pteropod Shell Dissolution	Fish and Aquatic Life – Marine Waters

WATER QUALITY STANDARDS:

340-041-0011
Biocriteria
Waters of the State must be of sufficient quality to support aquatic species without detrimental changes in the resident biological communities.

ASSESSMENT METHODOLOGY: Ocean Acidification for Marine waters

The ocean absorbs about 30% of the carbon dioxide (CO_2) that is released into the atmosphere. As levels of atmospheric CO_2 increase from human activity the amount of carbon dioxide absorbed by the ocean also increases.[1] As excess CO_2 is absorbed by seawater, a series of chemical reactions result in changes in the carbonate chemistry, lowering the pH of ocean waters. This reduction in ocean pH, called ocean acidification, poses a threat to the integrity of marine species and food webs. Calcifying invertebrates appear to be particularly vulnerable.[2,3]

The goal of this methodology is to assess changing ocean conditions while also distinguishing between natural variability and long-term change using the existing biocriteria narrative water quality standards. Biological assessments provide direct measures of the cumulative response of the biological community to stressors and the beneficial use support status for aquatic life.[4] As with DEQ's implementation of the biocriteria water quality standard for freshwater, this methodology requires understanding natural background conditions in the absence of stressors (reference conditions).

The methodology applies a hybrid marine biocriteria assessment framework that allows for the assessment of biological and chemical metrics individually or in combination, depending on data availability. In this framework, biologically relevant numeric benchmarks are used to evaluate the degree of impact. The methodology does not by itself identify which pollutant should be addressed by point source or other controls through a Total Maximum Daily Load. U.S. Environmental Protection Agency guidance recommends listing waters with aquatic use impaired based directly on biological response as Category 5: 303(d) even if the pollutant is not known.

This is a new assessment methodology for use in the 2024 Integrated Report. An accompanying technical support document outlines the rationale, process, and approach DEQ is proposing to use to assess ocean acidification impacts for water quality assessment.

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[1] https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

[2] Barton, A., Hales, B., Waldbusser, G. G., Langdon, C., & Feely, R. A. (2012). The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. Limnology and Oceanography, 57(3), 698–710. https://doi.org/10.4319/lo.2012.57.3.0698

[3] Wootton, J. T., Pfister, C. A., & Forester, J. D. (2008). Dynamic patterns and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. Proceedings of the National Academy of Sciences, 105(48), 18848–18853. https://doi.org/10.1073/pnas.0810079105

[4] https://www.epa.gov/sites/default/files/2015-10/documents/2006irg-report.pdf

DATA EVALUATION:

With assistance from a group of technical experts, DEQ developed an ocean acidification biocriteria assessment framework by identifying clearly defined lines of evidence and indicators to assess biological impacts related to ocean acidification. This ocean acidification methodology will assess biological impacts to calcifying zooplankton (*Limacina helicina*) in Oregon's territorial waters in response to changes in ocean carbonate chemistry. Pteropods (*L. helicina,* and others) are pelagic sea snails that rely on the biomineral aragonite ($CaCO_3$) to form and maintain their shells. As a result, the degree of shell dissolution is closely linked with the saturation state of aragonite (Ω_{ar}) in the water column.[5] The strength of pteropods as a bioindicator for ocean acidification impact is based on global abundance and distribution, well documented stressor-specific sensitivity, ranging from evidence of exposure (e.g., shell dissolution), sublethal and lethal responses,[6,7,8] and role as an important prey group for ecologically and economically important fishes, birds, and whale in some parts of the Pacific Ocean.[9,10,11] This robust and well-defined relationship between pteropod shell dissolution and aragonite (Ω_{ar}) allow biological

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[5] Feely, R. A., Alin, S. R., Carter, B., Bednaršek, N., Hales, B., Chan, F., Hill, T. M., Gaylord, B., Sanford, E., Byrne, R. H., Sabine, C. L., Greeley, D., & Juranek, L. (2016). Chemical and biological impacts of ocean acidification along the west coast of North America. Estuarine, Coastal and Shelf Science, 183, 260–270. https://doi.org/10.1016/j.ecss.2016.08.043

[6] Lischka, S., Büdenbender, J., Boxhammer, T., & Riebesell, U. (2011). Impact of ocean acidification and elevated temperatures on early juveniles of the polar shelled pteropod Limacina helicina: mortality, shell degradation, and shell growth. Biogeosciences, 8(4), 919-932. https://doi.org/10.5194/bg-8-919-2011

[7] Bednaršek, N., Klinger, T., Harvey, C. J., Weisberg, S., McCabe, R. M., Feely, R. A., Newton, J., & Tolimieri, N. (2017). New ocean, new needs: Application of pteropod shell dissolution as a biological indicator for marine resource management. *Ecological Indicators*, *76*, 240–244. https://doi.org/10.1016/j.ecolind.2017.01.025

[8] Lischka, S., & Riebesell, U. (2012). Synergistic effects of ocean acidification and warming on overwintering pteropods in the Arctic. Global Change Biology, 18(12), 3517-3528. https://doi.org/10.1111/gcb.12020

[9] Armstrong, J. L., Boldt, J. L., Cross, A. D., Moss, J. H., Davis, N. D., Myers, K. W., Walker, R. V., Beauchamp, D. A., & Haldorson, L. J. (2005). Distribution, size, and interannual, seasonal and diel food habits of northern Gulf of Alaska juvenile pink salmon, *Oncorhynchus gorbuscha*. Deep Sea Research Part II: Topical Studies in Oceanography, 52(1), 247–265. https://doi.org/10.1016/j.dsr2.2004.09.019

[10] Aydin, K. Y., McFarlane, G. A., King, J. R., Megrey, B. A., & Myers, K. W. (2005). Linking oceanic food webs to coastal production and growth rates of Pacific salmon (Oncorhynchus spp.), using models on three scales. Deep Sea Research Part II: Topical Studies in Oceanography, 52(5), 757–780. https://doi.org/10.1016/j.dsr2.2004.12.017

[11] Karpenko, V., Volkov, A., & Koval, M. (2007). Diets of Pacific Salmon in the Sea of Okhotsk, Bearing Sea, and Northwest Pacific Ocean. North Pac Anadromous Fish Commission Bull, 4.

measurements of severe shell dissolution and chemical measurements of aragonite (Ω_{ar}) to be the basis for biological impact assessment.[8,12,13,14]

Data metrics and benchmarks

Aragonite saturation state (Ω_{ar}) will serve as the basis for the chemical metrics used in this assessment because it represents the best available science to measure OA stress to pteropods[15]. Procedures and core principles to quantify aragonite (Ω_{ar}) are outlined in McLaughlin et al. (2015), Dickson et al. (2007), and Dickson (2010).[16,17,18] These widely approved procedures describe the primary measurement parameters required to derive aragonite (Ω_{ar}), as well as the relative uncertainty associated with each combination of parameters.[18] As a derived value, uncertainty in aragonite (Ω_{ar}) calculation is a product of several sources of potential error, including independent measurements of multiple carbonate parameters as well as the thermodynamic constants used to relate carbonate species to one another. To address these and other sources of uncertainty, members of the California Current Acidification Network have suggested an uncertainty range of aragonite Ω_{ar} +/- 0.2 when linking changes in ocean chemistry to aragonite Ω changes in ecosystem function.[16]

Two benchmarks are needed within each data type to use the hybrid framework for Integrated Report categorical assessment. For each data type, a value is needed above which experts have confidence about biological impact based on a single data type (referred to as "independently applicable (IA)" benchmark), and one above which indicates biological impact, but requires confirmation multiple line of evidence (referred to here as a "combined line of evidence (CLOE)"

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[12] Bednaršek, N., Feely, R. A., Reum, J. C. P., Peterson, B., Menkel, J., Alin, S. R., & Hales, B. (2014). *Limacina helicina* shell dissolution as an indicator of declining habitat suitability owing to ocean acidification in the California Current Ecosystem. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1785), 20140123. https://doi.org/10.1098/rspb.2014.0123

[13] Bednaršek, N., Feely, R. A., Howes, E. L., Hunt, B. P. V., Kessouri, F., León, P., Lischka, S., Maas, A. E., McLaughlin, K., Nezlin, N. P., Sutula, M., & Weisberg, S. B. (2019). Systematic Review and Meta-Analysis Toward Synthesis of Thresholds of Ocean Acidification Impacts on Calcifying Pteropods and Interactions With Warming. *Frontiers in Marine Science*, *6*, 227. https://doi.org/10.3389/fmars.2019.00227

[14] Waldbusser, G. G., Hales, B., Langdon, C. J., Haley, B. A., Schrader, P., Brunner, E. L., Gray, M. W., Miller, C. A., & Gimenez, I. (2015). Saturation-state sensitivity of marine bivalve larvae to ocean acidification. *Nature Climate Change*, *5*(3), 273–280. https://doi.org/10.1038/nclimate2479

[15] Bednaršek, et al. (2019), "Systematic Review and Meta-Analysis." https://doi.org/10.3389/fmars.2019.00227

[16] McLaughlin, Karen, Stephen Weisberg, Andrew Dickson, Gretchen Hofmann, Jan Newton, Deborah Aseltine-Neilson, Alan Barton, Sue Cudd, Richard Feely, Ian Jefferds, Elizabeth Jewett, Teri King, Chris Langdon, Skyli McAfee, Diane Pleschner-Steele, and Bruce Steele. 2015. "Core Principles of the California Current Acidification Network: Linking Chemistry, Physics, and Ecological Effects." *Oceanography* 25(2):160–69. https://doi.org/10.5670/oceanog.2015.39

[17] Dickson, Andrew. 2010. "The Carbon Dioxide System in Seawater: Equilibrium Chemistry and Measurements." *Guide to Best Practices for Ocean Acidification Research and Data Reporting* 17–40.

[18] Dickson, Andrew Gilmore, Christopher L. Sabine, James Robert Christian, Charlene P. Bargeron, and North Pacific Marine Science Organization, eds. 2007. *Guide to Best Practices for Ocean CO2 Measurements*. Sidney, BC: North Pacific Marine Science Organization.

benchmark). Use of each benchmark will be determined based on data availability within an assessment unit during the assessment period. In cases where two lines of evidence are available for assessment DEQ will rely on the combined lines of evidence benchmark, whereas in instances where only a single line of evidence is available DEQ will employ the independently applicable benchmark for that data.

Aragonite saturation state Ω_{ar} thresholds for severe shell dissolution derived experimentally, through expert consensus, and through a field stress-response study range from 1.06 to 1.3, with the final recommended value of 1.2.[19,20] For the purposes of this assessment methodology DEQ proposes to adopt the uncertainty range of +/- 0.2 outlined in McLaughlin et al. (2015) to identify the two aragonite Ω_{ar} biological impact benchmarks for severe pteropod shell dissolution[18]. The lower end of the 0.2 range around Ω_{ar} =1.2 will define the IA benchmark and the upper end will define the CLOE benchmark. DEQ and the workgroup believe aragonite Ω_{ar} = 1.0 (1.2 - 0.2) is a suitable IA benchmark value that provides the certainty needed to determine impairment on chemical data alone, and aragonite Ω_{ar} = 1.4 (1.2 + 0.2) is a suitable "CLOE benchmark to indicate biological impact but require biological data confirmation to determine impairment. The application of these chemical benchmarks to the pteropod/aragonite relationship serves as the translation to derive corresponding severe shell dissolution benchmarks (**Figure 1**).

The biological metric for this assessment will be the percentage of individuals within a pteropod (*L. helicina)* sample with severe shell damage (Type II & Type III) based on detailed procedures outlined in Bednarsek et al. (2012).[21] DEQ selected 62% and 40% individuals with Type II/III dissolution as the IA and CLOE biological benchmarks, respectively. The rationale for this

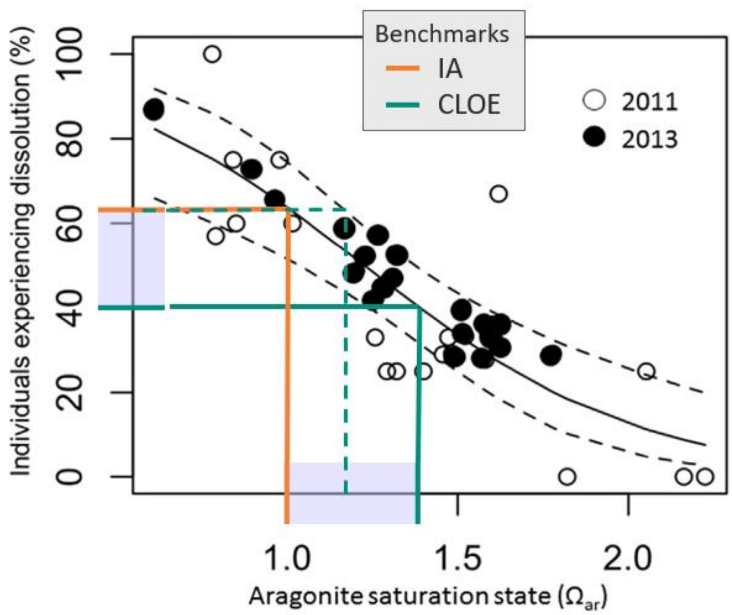

Figure 1: Figure from Feely et al. (2016) modified to show derivation of DEQ's proposed assessment benchmark values for OA.

[19] Bednaršek, et al. 2019. "Systematic Review and Meta-Analysis," https://doi.org/10.3389/fmars.2019.00227
[20] Bednaršek, et al. 2014. "*Limacina Helicina* Shell Dissolution," https://doi.org/10.1098/rspb.2014.0123
[21] Bednaršek, N., Tarling, G. A., Bakker, D. C., Fielding, S., Cohen, A., Kuzirian, A., McCorkle, D., Lézé, B., & Montagna, R. (2012). Description and quantification of pteropod shell dissolution: A sensitive bioindicator of ocean acidification. *Global Change Biology*, *18*(7), 2378–2388. https://doi.org/10.1111/j.1365-2486.2012.02668.x

choice is as follows. Utilizing the regression relationship of Ω_{ar} versus % individuals with Type II/III dissolution[22], 62% of individuals with dissolution represents the upper 95th confidence limit of an Ω_{ar} = 1.2 **(Figure 1** – dashed line), the threshold at which severe dissolution occurs.[23] According to Bednarsek et al. (2017, Fig 1d), a benchmark of 62% of individuals with Type II/III dissolution correlates to a mean survival probability of roughly 50%, which aligns with an acute (Lethal Concentration to 50% of the sample) effect, suggesting that 62% of individuals with Type II/III dissolution represents a severe effects/lethality threshold (**Figure 1**- orange line).[24] While the CLOE benchmark (40% individuals with combined Type II/ III dissolution) accounts for some natural variability in biological response, and therefore requires a second line of evidence from the chemical indicator to determine impairment (**Figure 1** – green line).

Natural background conditions

A critical piece of biocriteria assessment for the determination of aquatic life beneficial use impairment is establishing the natural background exceedance of the IA and CLOE benchmarks. Nearshore environments with seasonal upwelling (such as Oregon's territorial sea) intermittently become undersaturated with respect to aragonite (Ω_{ar} < 1) under naturally occurring conditions (Harris et al. 2013).[25] Thus, it is expected that chemical assessment benchmarks may be naturally exceeded with some frequency, and some percentage of pteropods would naturally be affected by Type II/III dissolution.

A well developed and routinely applied approach to determine OA natural background condition is to estimate the contribution of anthropogenic carbon (C_{anth}) to observational measurements to quantify the shift from pre-industrial times.[26]

For the biological indicator, DEQ is proposing to use the most recently published pre-industrial estimates of natural background percentage individuals with Type II/III dissolution in the nearshore (36-39%) as evidence that the CLOE benchmark (40%) is on the upper end of the range of natural background condition (**Figure 2**), and impact should be confirmed with the chemical indicator.[28] DEQ is proposing that published pre-industrial pteropod dissolution estimates in nearshore environments provide sufficient evidence that levels chosen for the IA and CLOE benchmarks represent a deviation from natural background conditions. For this

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22 Feely, et al., 2016. "Chemical and Biological Impacts," https://doi.org/10.1016/j.ecss.2016.08.043

23 Bednaršek, et al. 2019. "Systematic Review and Meta-Analysis," https://doi.org/10.3389/fmars.2019.00227

24 Bednaršek, N., Feely, R. A., Tolimieri, N., Hermann, A. J., Siedlecki, S. A., Waldbusser, G. G., McElhany, P., Alin, S. R., Klinger, T., Moore-Maley, B., & Pörtner, H. O. (2017). Exposure history determines pteropod vulnerability to ocean acidification along the US West Coast. Scientific Reports, 7(1), 4526. https://doi.org/10.1038/s41598-017-03934-z

25 Harris, Katherine E., Michael D. DeGrandpre, and Burke Hales. 2013. "Aragonite Saturation State Dynamics in a Coastal Upwelling Zone." *Geophysical Research Letters* 40(11):2720–25. doi: 10.1002/grl.50460

26 Feely, et al., 2016. "Chemical and Biological Impacts," https://doi.org/10.1016/j.ecss.2016.08.043

reason, biological IA and CLOE benchmark values will be evaluated directly to determine an excursion without additional comparison to natural background conditions.

Year	Location	Ω_{ar}, preind.	Ω_{ar}, current	% Ind. with severe dissolution, preind.
2011	nearshore	1.39	1.05	39
2013	nearshore	1.46	1.08	36
2011	offshore	2.21	1.51	8
2013	offshore	2.09	1.43	12

Figure 2: Adapted from Feely et al. (2016) reported on average current and estimated pre-industrial period aragonite saturation states and percentage of individuals affected by severe dissolution for nearshore and offshore regions of CCE calculated for years 2011 and 2013.

Unlike the biological indicator, which serves as an integrator of exposure time and frequency in the water column, chemical observational data represent a snapshot in time or a selected portion of the water column. Thus, for the chemical indicator, DEQ is proposing that observational data must not only be compared to benchmark values but also evaluated against estimated background conditions to determine an excursion. Documented biological impacts related to OA taking place from decreasing available aragonite occur in part because the stratified boundary (horizon) of undersaturated ($\Omega_{ar} < 1$) conditions is moving up the water column. Pre-industrial estimations of carbonate chemistry can be used to compare present day observations of Ω_{ar} in the vertical water column to those expected in the absence of anthropogenic carbon. Additionally, these pre-industrial estimates can be used to generate a depth horizon for a given Ω_{ar} value, where concentrations in the water column below the horizon are expected to occur under natural background conditions, and above which concentrations were not expected to occur (**Figure 3**). DEQ believes estimated pre-industrial depth horizons of chemical benchmarks represent one way to compare current observational data with natural background conditions to determine impairment. At each profile monitoring location, DEQ will employ the best available estimate of pre-industrial depth horizon to confirm the deviation from natural background condition. Sample results below the depth horizon will be excluded from the remaining categorical assessment steps (**Figure 3**). Remaining results above the pre-industrial depth horizon will be pooled by assessment unit, and DEQ will use existing precedent of a 10% exceedance rate with a 90% confidence rate according to the exact binomial test to determine impairment. Steps for model derived depth horizons and additional options DEQ may use to derive similar depth estimates are outline in the Technical Support Document.

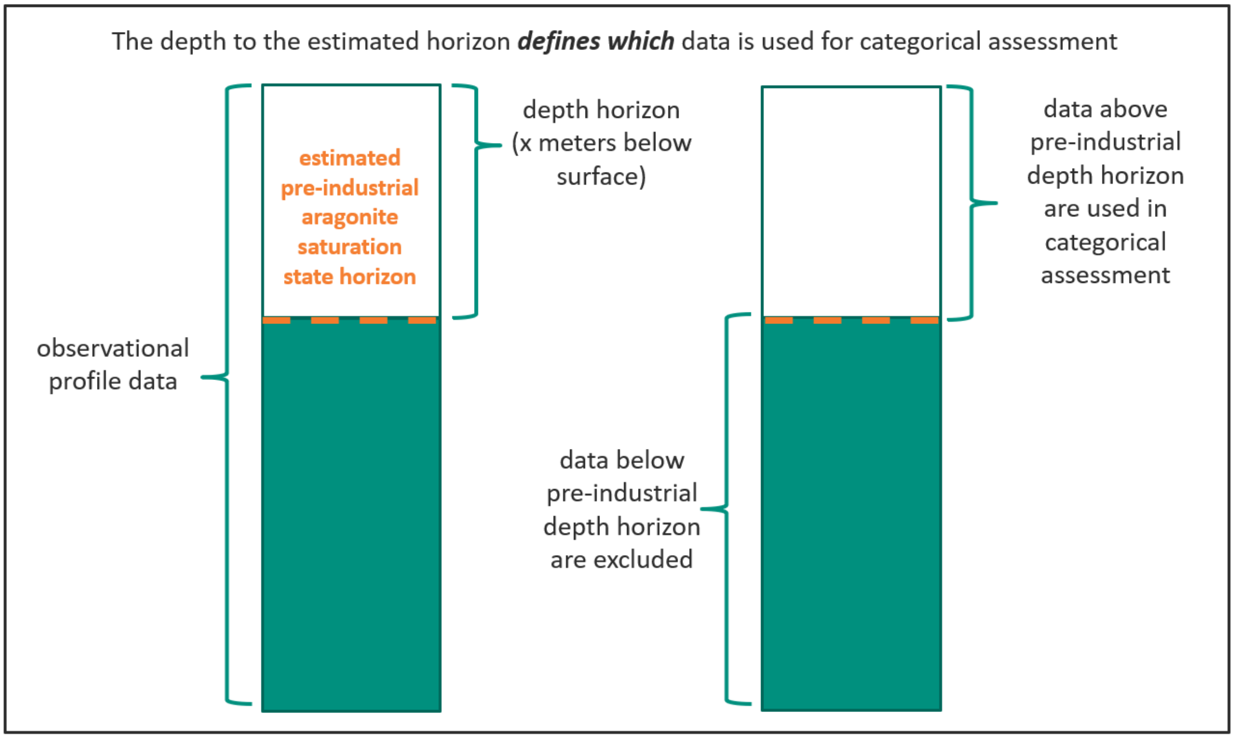

Figure 3. Pre-industrial aragonite saturation state horizon estimates will be used to define which data will be used in categorical assessment to determine impairment.

DATA REQUIREMENTS

Biological and chemical data for this assessment must be:

- Collected within the critical period and critical area
  - Critical period of April through the end of September is defined by the temporal overlap of (1) changes in ocean conditions in Oregon associated with seasonal upwelling and (2) the temporal window of data used to define the pteropod aragonite relationship.[27,28]
  - Critical area – defined by the spatial overlap of three considerations: (1) the boundaries of and/or relevance to Oregon's territorial waters, (2) likely pteropod habitats, and (3) applicability of pre-industrial calculations used to define natural background conditions in nearshore waters. This will be evaluated on a case-by-case basis.
- Biological data
  - Must have two or more representative samples. DEQ will use an average to compare to the appropriate assessment benchmark.

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[27] Bednaršek, et al., 2017. "Exposure History Determines," https://doi.org/10.1038/s41598-017-03934-z

[28] Bednaršek, et al. 2014. "*Limacina Helicina* Shell Dissolution," https://doi.org/10.1098/rspb.2014.0123

- Consistent with sampling procedures outlined during NOAA hydrographic cruises.[29,30]
- Biological samples used to calculate the assessment metric must contain at least 15 organisms.
- Calculations of the metric (% individuals with severe shell dissolution) are consistent with sample processing and the categorization scheme outlined in Bednarsek et al. (2012).[31]

- Chemical data
  - Each Assessment Unit must have five unique (different date/time) vertical profiles
  - Each profile must have vertical resolution sufficient to be representative of the water column.
  - Vertical profiles with Ω_{ar} derived from two of four possible carbonate measurements (seawater pH, partial pressure carbon dioxide (*p*CO2), total dissolved inorganic carbon (TCO2), or total alkalinity (TA)) combined with salinity, temperature, and depth.[32] DEQ will not employ algorithm-derived approaches internally to derive Ω_{ar} in the 2024 Integrated Report cycle, but will accept pre-calculated Ω_{ar} data derived via widely approved approaches so long as the associated calculation error rates are not greater than +/- 0.2 Ω_{ar} as described in McLaughlin et al. (2015).[34]
  - When not reported directly, DEQ will use the seacarb R package to calculate Ω_{ar}.
  - An approach to determine the best available representation of pre-industrial depth horizon to confirm the deviation from natural background condition.

Other approaches to assess biological integrity in marine waters

DEQ may consider alternative approaches to identifying biological impairment to marine communities. DEQ acknowledges that impairment determinations can be made based on overwhelming evidence where multiple sources of data and/or information indicate impairment. This may include the use of some combination of observational data, published literature, and best professional judgment when interpreting data and information submitted to the agency for assessment purposes. If this approach is taken, a detailed rationale will be included in the Integrated Report.

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[29] Bednaršek, et al., 2017. "Exposure History Determines," https://doi.org/10.1038/s41598-017-03934-z
[30] Bednaršek, et al., 2014. "*Limacina Helicina* Shell Dissolution," https://doi.org/10.1098/rspb.2014.0123
[31] Bednaršek, et al., 2012. "Description and quantification," https://doi.org/10.1111/j.1365-2486.2012.02668.x
[32] McLaughlin, et al., 2015. "Core Principles," https://doi.org/10.5670/oceanog.2015.39

Numeric data must be supported by supplementary materials outlining field and laboratory procedures as well as project plan that includes a purpose statement, the number of samples collected, and quality assurance and quality control protocols for collecting and analyzing samples.

ASSIGNMENT OF ASSESSMENT CATEGORY

For the 2024 IR DEQ will be assessing water bodies for impacts to biological response as a result of changing OA conditions and will therefore be evaluating Categories 5 and 3 using both data types. For the 2024 IR cycle, DEQ will not determine biocriteria attainment (Category 2) because there is uncertainty in the level of protection provided by the current CLOE benchmarks. The hybrid framework for OA biocriteria assessment **(Figure 4)** and flowchart for assigning assessment categories (**Figure 5**) outline how DEQ will assess data for categorical determination.

		Aragonite Saturation State (Ω_{ar})			
		No data	**> 1.4**	**≤ 1.4 (CLOE)**	**≤ 1.0 (IA)**
	No data	No assessment	Category 3 (insufficient data)	Category 3B (potential concern)	**Category 5** (IA - Chem)
% pteropods with severe shell dissolution	**< 40**	Category 3 (insufficient data)	Category 3 (insufficient data)		
	≥ 40 (CLOE)	Category 3B (potential concern)		**Category 5** (CLOE)	
	≥ 62 (IA)	**Category 5** (IA – Bio)			

Figure 4. Proposed framework for OA biocriteria assessment outlining categorical assignments based on biological and chemical data assessed individually or in combination. IA=Independently Applicable benchmark, CLOE = Combined Lines of Evidence benchmark.

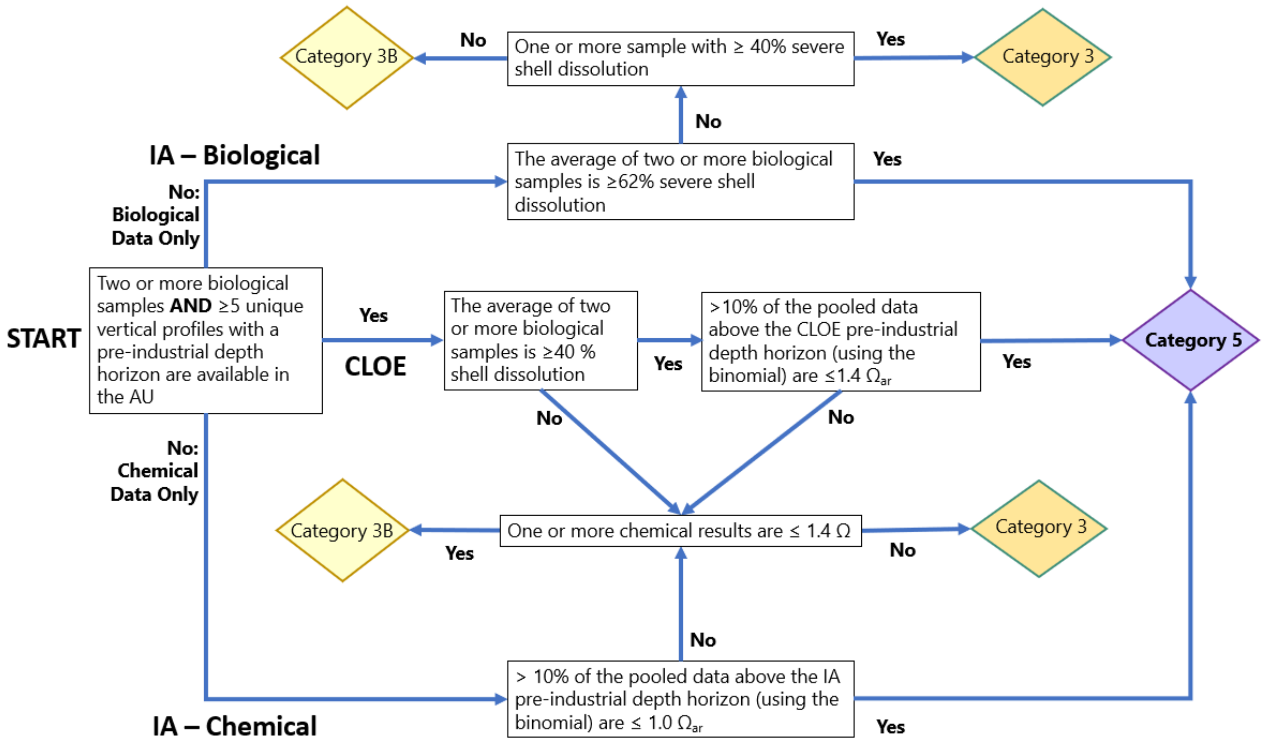

Figure 5. Flowchart for assigning assessment categories based on OA hybrid biocriteria assessment framework.

Category 5

Biological data - independently applicable

The average of two or more representative pteropod samples in an assessment unit that meet data requirements is greater than or equal to 62 % individuals with severe shell dissolution.

OR

Chemical data - independently applicable

- At least five unique (different date/time) vertical profiles representative of the water column collected in the critical assessment windows and data window
- Greater than 10% of all vertical profile results in an assessment unit above the estimated pre-industrial depth horizon of 1.0 Ω_{ar} are less than or equal to 1.0 Ω_{ar} according to the exact binomial test for conventional pollutants

OR

Combined line of evidence - biological data and chemical data

The average of two or more representative pteropod samples in an assessment unit that meet data requirements is greater than or equal to 40% pteropods with severe shell dissolution.

AND

- At least five unique (different date/time) vertical profiles representative of the water column collected in the critical assessment windows and data window
- Greater than 10% of all vertical profile data in an assessment unit above the estimated pre-industrial depth horizon of 1.4 Ω_{ar} are less than or equal to 1.4 Ω_{ar} according to the exact binomial test for conventional pollutants

Category 4

TMDLs needed to attain applicable water quality standards have been approved (Category 4A), other pollution control requirements are expected to address a pollutant and will attain water quality standards (Category 4B), or impairment is not caused by a pollutant (Category 4C).

Category 3B: insufficient data; potential concern

Water bodies with be placed in Category 3B: insufficient data; potential concern when:

Biological data only

Only a single pteropod sample is available in an assessment unit that meets data requirements with greater than or equal to 40% individuals with severe shell dissolution

OR

Chemical data only

When fewer than five unique (different date/time) vertical profiles representative of the water column are available in an assessment unit:

- One or more results is less than or equal to 1.4 Ω_{ar}.

When more than five unique (different date/time) vertical profiles representative of the water column are available in an assessment unit:

- Less than 10% of all vertical profile data in an assessment unit above the estimated pre-industrial depth horizon of 1.4 Ω_{ar} are less than or equal to 1.4 Ω_{ar} according to the exact binomial test for conventional pollutants **and** one or more results is less than or equal to 1.4 Ω_{ar}.

OR

Combined lines of evidence - biological data and chemical data

One line of evidence meets the conditions for Category 5, while the other line of evidence meets the conditions for Category 3.

Category 3: insufficient data

Water bodies will be placed in Category 3: insufficient data when:

Biological data only

Only a single pteropod sample is available in an assessment unit that meets data requirements, and it has less than 40% individuals with severe shell dissolution.

OR

Chemical data only

Fewer than five unique (different date/time) vertical profiles representative of the water column are available in an assessment unit above and all results are greater to 1.4 Ω_{ar}.

OR

Combined lines of evidence - biological data and chemical data

A single pteropod sample or an average of multiple samples is available in an assessment unit that meets data requirements, and it is less than 40% individuals with severe shell dissolution

AND

When all unique (different date/time) vertical profiles representative of the water column in an assessment unit above the estimated pre-industrial depth horizon of 1.4 Ω_{ar} are greater than 1.4 Ω_{ar}.

Category 2: attaining

DEQ will not be using OA impact benchmarks (outlined above) to determine attainment for the narrative biocriteria in the 2024 assessment.

DELISTING – NEW DATA

Without a pathway to attainment DEQ will evaluate potential delisting on a case-by-case basis.

Assessment – Marine Dissolved Oxygen

PARAMETER	BENEFICIAL USE
Dissolved Oxygen	Fish and Aquatic Life – Marine Waters

WATER QUALITY STANDARDS:

340-041-0016
Dissolved oxygen (excerpt for marine waters)
Dissolved oxygen (DO): No wastes may be discharged and no activities may be conducted that, either alone, or in combination with other wastes or activities, will cause violation of the following standards: The changes adopted by the Commission on Jan. 11, 1996, become effective July 1, 1996. Until that time, the requirements of this rule that were in effect on Jan. 10, 1996, apply:

(6) For ocean waters, no measurable reduction in dissolved oxygen concentration may be allowed"

From Table 15 of OAR-340-041-0016:

The only DO criterion that provides no additional risks is "no change from background". Waterbodies accorded this level of protection include marine waters and waters in Wilderness areas.

ASSESSMENT METHODOLOGY – Marine waters

Seasonal hypoxia (low oxygen conditions) is a natural feature in upwelling regions in the Eastern Pacific, such as Oregon's territorial sea, but recent research suggests that hypoxic events have been increasing in frequency, duration, and occurring in locations where they are not commonly observed.[33] These changes have raised concerns that biological impacts are taking place outside of natural ecosystem variability, and that aquatic life beneficial uses are not being fully supported in some areas. For this assessment, DEQ is proposing an approach that will allow the

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[33] Chan, F., Barth, J. A., Lubchenco, J., Kirincich, A., Weeks, H., Peterson, W. T., & Menge, B. A. (2008). Emergence of Anoxia in the California Current Large Marine Ecosystem. *Science*, *319*(5865), 920–920. https://doi.org/10.1126/science.1149016

agency to quantify measurable reduction of DO in Oregon's territorial sea for the purposes of interpreting Oregon's narrative marine DO criteria for aquatic life beneficial use support.

This is a new assessment methodology for use in the 2024 report. An accompanying Technical Support Document outlines the rationale, process, and approach DEQ is proposing to use to assess hypoxia impacts for water quality assessment.

DATA EVALUATION

For the 2024 report, DEQ is proposing to adopt a hybrid framework wherein two lines of evidence will be used to assess aquatic life beneficial use support. One line of evidence will rely on quantifying measurable reduction by comparing observational data with background conditions established either through long term observational data sets or modeled conditions. The second line of evidence will use established DO biological impact benchmarks to provide a biological lens to determine whether measurable reduction is likely affecting aquatic life beneficial use support.

Biologically relevant benchmark

Narrative criteria are descriptions of the conditions necessary for a waterbody to attain its designated use.[34] The dissolved oxygen thresholds summarized in Chan et. al. (2019) provide examples of biological responses to low dissolved oxygen conditions in marine environments.[35] Hypoxic conditions (dissolved oxygen levels of 1.4 ml/l (2.0mg/L; 62µmol/kg) or less) are reported to have biological impacts, ranging from changes in behavior, decreased metabolic fitness, to overall organism survival.[38,36] This value will be the numeric benchmark used to assess beneficial use support for fish and aquatic and by which the measurable reduction would be evaluated.

Quantifying change from background

In determining the degree of change that constitutes "measurable reduction" for the purposes of assessment, DEQ will rely on quantitative measurements of change relevant to the data and information available and may utilize multiple approaches as needed. DEQ will adapt

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[34] EPA 2002, Consolidated Assessment and Listing Methodology, First Edition, U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds https://www.epa.gov/sites/production/files/2015-09/documents/consolidated_assessment_and_listing_methodology_calm.pdf

[35] Chan, F., Barth, J. A., Kroeker, K. J., Lubchenco, J., & Menge, B. A. (2019). THE DYNAMICS AND IMPACT OF OCEAN ACIDIFICATION AND HYPOXIA: Insights from Sustained Investigations in the Northern California Current Large Marine Ecosystem. *Oceanography*, *32*(3), 62–71.

[36] Vaquer-Sunyer, Raquel, and Carlos M. Duarte. "Thresholds of Hypoxia for Marine Biodiversity." Proceedings of the National Academy of Sciences 105, no. 40 (October 7, 2008): 15452–57. https://doi.org/10.1073/pnas.0803833105.

methodologies outlined in published literature relevant to quantifying shifts in marine DO relevant to Oregon's territorial waters such as Pierce et al., (2012), Adams et al., (2013), and others.[37,38] DEQ will also consult with regional experts as needed to ensure adaptations to methodologies to satisfy the approach outlined in this document are appropriate based on data types and locations. Detailed summaries of the application of these methodologies will be provided in the assessment rationale at the AU-parameter level of reporting.

Establishing background condition for comparison purposes is a critical component of determining measurable reduction. Changing ocean conditions are typically evaluated on decadal rather than yearly or seasonal scales. Where available, DEQ will evaluate a measurable reduction based on observational datasets collected at consistent locations over multiple decades. In assessment units where this temporal coverage is not available, DEQ will rely on validated model output to quantify background conditions.

Chemical data metric

Oceanographic DO data is measured and reported in a variety of ways. For consistency with common reporting values, DEQ will convert marine DO measurements to ml/l. DEQ is proposing to use a daily statistic of the value DO representing the lower 10th percentile as the assessment metric from which to evaluate the frequency of exceedances of the biologically relevant benchmark. This daily summary statistic allows comparison of historical data to recent observational data. Additionally, the statistic characterizes the lowest values in the water column where measurable reduction has been documented to occur, while not basing the assessment on a daily minimum value which can be a subject to data quality concerns.

DATA REQUIREMENTS

Chemical data for this assessment must be:

- Collected within the critical period
  - DEQ will consider April through the end of September as the critical assessment window for marine DO.
- Observational data
  - Data must be collected under a project plan with widely approved sample collection methods.

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[37] Pierce, S. D., Barth, J. A., Shearman, R. K., & Erofeev, A. Y. (2012). Declining Oxygen in the Northeast Pacific. Journal of Physical Oceanography, 42(3), 495–501. https://doi.org/10.1175/JPO-D-11-0170.1

[38] Adams, K. A., Barth, J. A., & Chan, F. (2013). Temporal variability of near-bottom dissolved oxygen during upwelling off central Oregon. Journal of Geophysical Research: Oceans, 118(10), 4839–4854. https://doi.org/10.1002/jgrc.20361

    - Historical data will be evaluated for quality by consulting regional experts and published literature.
    - To calculate daily 10^{th} percentiles, a minimum vertical resolution sufficient to represent the water column.
- Model output
    - Validated in state waters.
    - Accounts for spatial and temporal variability in DO conditions.
    - DEQ may request guidance from technical workgroup members to interpret model performance for temporal, spatial and climatic variations.

Other approaches to assess biological integrity in marine waters

It is important to note that the two lines of evidence outlined in the hybrid framework are not the only lines of evidence DEQ will consider in marine DO narrative criteria assessment. DEQ acknowledges that impairment determinations can be made based overwhelming evidence where multiple sources of data and/or information indicate impairment. This may include the documented periods of prolonged anoxia tied to biological impact or the use of some combination of observational data, published literature, and best professional judgment to interpreting data and information submitted to the agency for assessment purposes. If this approach is taken, a detailed rationale will be included in the Integrated Report.

ASSIGNMENT OF ASSESSMENT CATEGORY

For the 2024 report, DEQ will be assessing water bodies for impacts to biological response as a result of increasing frequency and duration of nearshore hypoxic events and will therefore be evaluating Category 5 and 3. Without a clear understanding of what values levels of dissolved oxygen in marine waters equate to the beneficial use being fully supporting, DEQ will not be assessing for attainment. The hybrid framework for hypoxia in marine waters assessment (**Figure 6**) and flowchart for assigning assessment categories (**Figure 7**) outline how DEQ will assess data for categorical determination.

		Observational Data		
		≤ 1.4 ml/l	> 1.4 ml/l	No data
Background Conditions	Observational deviation from background	**Category 5** (combined lines of evidence)	Category 3B (potential concern)	No assessment
	Modeled deviation from background	**Category 5** (combined lines of evidence)	Category 3B (potential concern)	No assessment
	No evidence of deviation from background	Category 3B (potential concern)	Category 3 (insufficient data)	No assessment

Figure 6: Proposed framework for marine dissolved oxygen assessment outlining categorical assignments based on multiple lines of evidence. IA=Independently Applicable benchmark, CLOE = Combined Lines of Evidence benchmark.

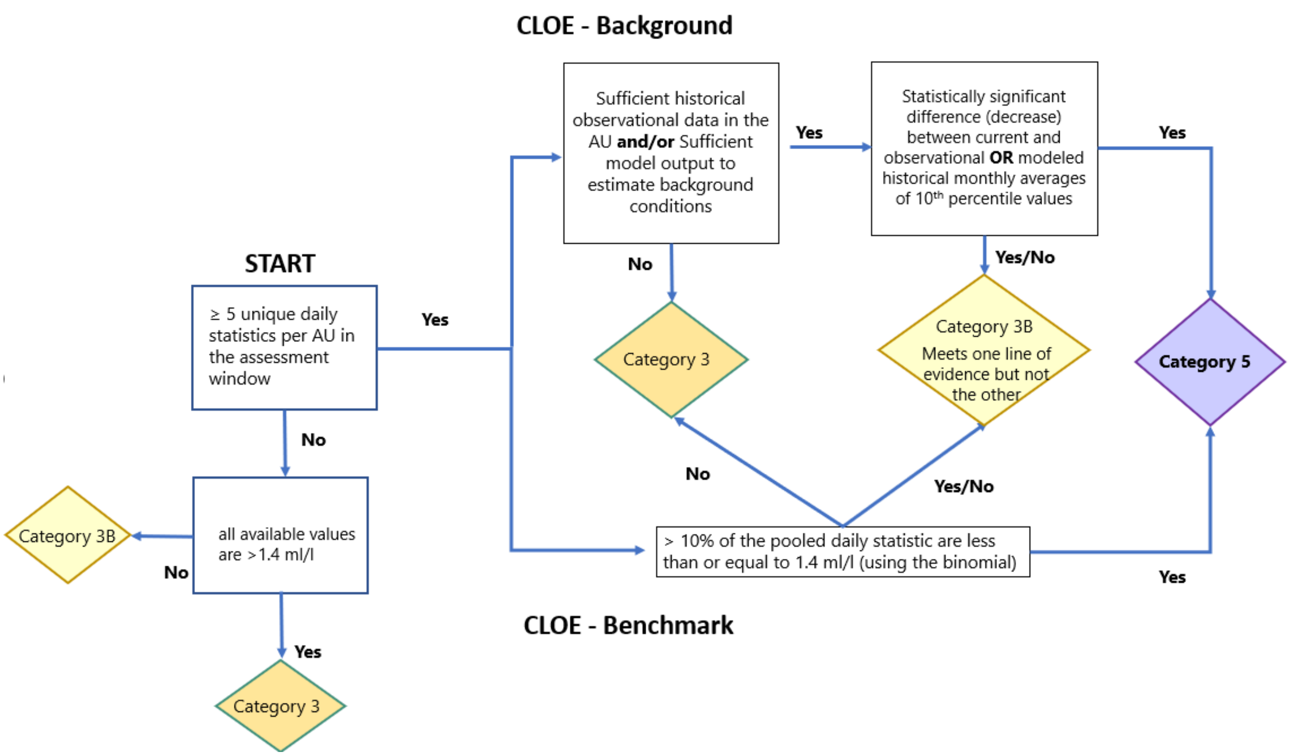

Figure 7: Flowchart for assigning categories based on the marine dissolved oxygen assessment framework.

Category 5

Within the critical assessment window, at least five unique daily statistics where greater than 10% are less ≤1.4 ml/l according to the exact binomial test for conventional pollutants.

AND

There is a statistically significant difference (decrease) in marine DO during the critical assessment window based on either observed or modeled historical conditions.

Category 4

TMDLs needed to attain applicable water quality standards have been approved (Category 4A), other pollution control requirements are expected to address pollutant and will attain water quality standards (Category 4B), or impairment is not caused by a pollutant (Category 4C).

Category 3B: insufficient data; potential concern

Water bodies will be placed in Category 3B: insufficient data; potential concern when one line of evidence does not indicate impairment (illustrated in Figure *7*).

Category 3: insufficient data

Water bodies will be placed in Category 3: insufficient data when both lines of evidence do not indicate impairment (illustrated in Figure *7*).

OR

Fewer than five unique daily statistics are available the critical assessment window and no values are less than 1.4 ml/l.

Category 2: attaining

DEQ will not be using hypoxia related benchmarks to determine attainment for the narrative marine dissolved oxygen criteria.

DELISTING – NEW DATA

Without a pathway to attainment DEQ will evaluate potential delisting on a case-by-case basis.