Marine Water Condition Index

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Cover photo: Aerial photograph of Dana Passage, August 23, 2010.

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Washington State Department of Ecology

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Abstract

The Washington State Department of Ecology (Ecology) developed the Marine Water Condition Index (MWCI) to communicate changes in water quality to a broad audience. In 2011 the MWCI was adopted as a dashboard indicator of Puget Sound health by the Puget Sound Partnership Leadership Council. We designed the index to detect subtle changes in ambient water quality that occur on large spatial and temporal scales. The goal of the index is to provide a framework that links changes in local water quality and physical conditions to a larger context of oceanic water quality and natural variability. This report describes the formulation and communication strategy of the index.

The MWCI reports shifting baseline conditions and trends in Ecology's long-term marine flight monitoring data using 12 water quality variables. Variables consist of both oceanographic state parameters and proxies for estuarine eutrophication.

We structured the MWCI in a modular fashion to communicate complex environmental data to a variety of users using different levels of information detail and communication aids.

The index is based on four stand-alone modules; each module relates to a narrowly defined aspect of marine water quality. The modules help narrow down likely causes of changing water quality.

1. Are nutrients changing from historic baseline conditions?
2. Are changes in ambient nutrients related to oceanic processes?
3. Are the nutrient balance and algal biomass changing from historic baseline conditions?
4. Do physical conditions affect the availability of oxygen and renewal of water?

We show that the MWCI responds to degradations in water quality from 1999 to 2008 and that eutrophication along the urban corridor plays a role in water quality throughout Puget Sound. The index also suggests that ocean influences alone cannot explain the observed increase in nutrient concentrations.

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Introduction

An index is a communication tool used for reporting complex information in an accessible numerical format. Environmental indices foster awareness, provide a broad overview of environmental quality, and have been applied across a wide range of habitats (Orians et al., 2000). Indices cannot substitute for scientific investigations aimed at determining the causality of changing environmental conditions, nor can indices replace an environmental assessment for setting regulatory standards.

The purpose of our new water quality index is to communicate environmental conditions effectively to a broad audience and provide a starting point for more in-depth dialogue and prioritization efforts between scientists, natural resource managers, and the public.

We wrote this report as a reference document for scientists, resource managers, and readers wanting to better understand or reproduce the index.

The Marine Water Condition Index (MWCI)

In this report, we describe the Marine Water Condition Index (MWCI). The index communicates shifting baseline conditions in marine eutrophication in context of the physical environment, natural variability, and large-scale oceanographic influences. The index focuses on changes in nutrients, eutrophication, the oxygen budget, and environmental conditions of the lower trophic level of the pelagic ecosystem. While it also accounts for ocean influences, it is by no means an index for the entire marine environment.

We applied the MWCI to Ecology's long-term monitoring data from 1999 to 2008, a period including both positive and negative sea-surface temperature anomalies. The period is well suited to test the index due to consistent methods, high data quality, and good data coverage from water depths of 0-50 meters. Beginning in 2012, MWCI updates will be available on the web: Ecology's Marine Water Monitoring Group, www.ecy.wa.gov/programs/eap/mar_wat/mwm_intr.html.

The MWCI formulation addresses the large spatial and temporal variability, spatial gradients, and dynamics of ambient estuarine environments by selecting seasonal and site-specific baseline conditions. Specifically, the index communicates how often values fall above or below expected baseline conditions over time.

The goal of the MWCI is to:

1. Provide a numeric score to inform scientists, natural resource managers, and the public about changes in marine water conditions.
2. Provide maximum insight into the data aggregation process to foster transparency, information value, and improved communication among diverse user groups.

We built the MWCI around four major modules that affect eutrophication (Figure 1):

1. Ambient nutrient levels.
2. Estuarine enrichment of nutrients.
3. Impact of nutrients.
4. Ventilation (the renewal of water and oxygen through estuarine processes).

A modular index structure provides insight into specific aspects of water quality and thereby achieves better insight into the environmental conditions and numerical aggregation process.

An intermediate index, the Eutrophication Index, includes modules 1- 3 and summarizes conditions specific to nutrients. The individual modules of the Eutrophication Index communicate the increasing likelihood of human eutrophication by taking ocean nutrient sources into account. The Ventilation module on the other hand considers estuarine physical conditions and communicates how physical conditions affect or mask the oxygen budget.

The MWCI draws on a 10-year subset (1999-2008) of historical data collected by Ecology's long-term monitoring program through the Puget Sound Ecosystem Monitoring Program (PSEMP)[1] and the Puget Sound Water Quality Authority (PSWQA, 1988).

To communicate the MWCI and its modular structure, we designed a reporting scheme using varying levels of numeric detail and temporal and spatial resolution. In addition, we present information side-by-side with published climatic and oceanographic indices to place the MWCI score in context with large-scale climatic fluctuations. The reporting scheme allows users to explore the underlying structure of environmental information across the entire range of information.

[1] Previously, the Puget Sound Assessment and Monitoring Program (PSAMP).

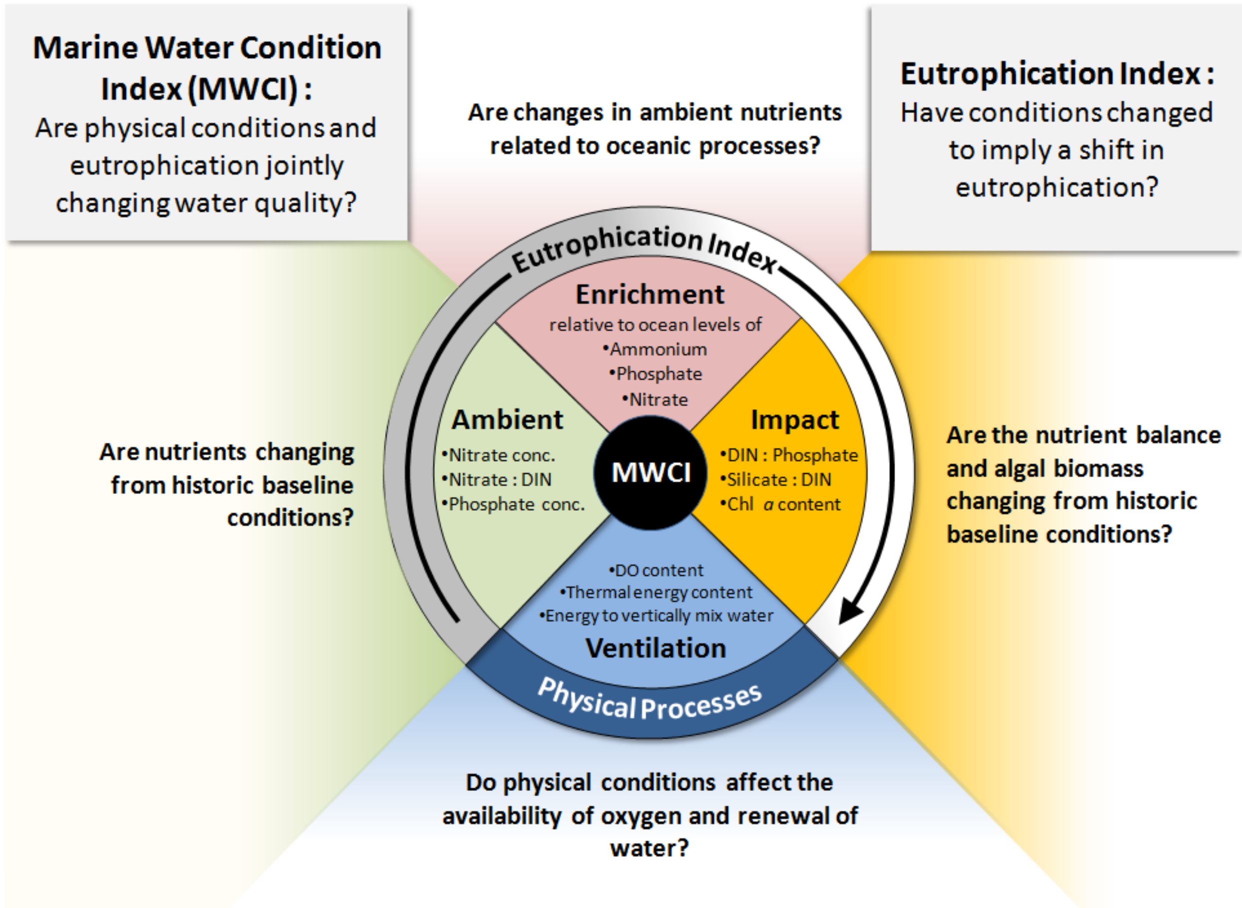

Figure 1. Four modules and two indices forming the Marine Water Condition Index (MWCI).

The MWCI summarizes information from four modules: Ambient, Enrichment, Impact, and Ventilation. Each module represents three variables.

Modules fall into two categories:

1. Those related to eutrophication: Ambient (changes in nutrient levels), Enrichment (changes in nutrients compared to oceanic concentrations), Impact (changes in the balance of nutrients and algal biomass). These three modules combine to form a subset, the Eutrophication Index. The Eutrophication index assesses nutrient conditions in order to identify possible shifts in the state of eutrophication.

2. Those related to physical processes: Ventilation (changes in physical conditions that affect oxygen levels and replenishment of water) addresses key physical conditions that are influencing eutrophication.

All four module scores (nutrient and algal biomass conditions plus physical information) form the overall MWCI and communicate changes in eutrophication in the larger context of estuarine and oceanic processes. The focus question underlying each module illustrates the information gain of a modular reporting structure.

DIN: dissolved inorganic nitrogen
Chl a: chlorophyll a
DO: dissolved oxygen

The MWCI replaces two previous marine water indices used by Ecology: *Water Quality of Concern* and *Sensitivity to Eutrophication*. The replacement of previous indices with the MWCI allows us to:

- Explore a more comprehensive suite of variables.
- Use a formulation that detects change against baseline conditions throughout Ecology's diverse and variable sampling station network.

Uses and Limitations of the MWCI

The MWCI in relation to Ecology's other activities

To meet requirements under section 303(d) of the Clean Water Act, Ecology conducts a marine water quality assessment on approximately a four-year cycle. Through this assessment, water bodies are categorized based on whether they meet federal water quality standards for specific parameters (dissolved oxygen, temperature, and pH in Clean Water Act Section 303 (d)).

This assessment approach is independent of the MWCI. The MWCI does not include state or federal water quality standards. The MWCI assesses water conditions relative to historical baseline conditions to account for the seasonal, tidal, and spatial variability found in Puget Sound. For more detail about Ecology's Clean Water Act Section 303(d) water quality assessment process, refer to: www.ecy.wa.gov/programs/wq/303d/index.html.

Ecology's Environmental Assessment Program produces three indices using a reporting scale between 0 and 100 (Puget Sound Partnership, 2010). The three indices seek to communicate environmental change across different eco-regions: freshwater (Hallock, 2002), marine sediment (Long et al., 2005), and marine water bodies (this report). Because of the large difference in focus, all three indices are formulated very differently. The difference limits the combination of the three indices to purely communication purposes.

- *Freshwater:* Ecology's freshwater quality index (WQI) and the MWCI differ with respect to the use of water quality standards. The WQI uses existing freshwater quality standards for parameters with applicable standards and the distribution of historical data for parameters without standards (Hallock, 2002). The WQI communicates Ecology's routine stream monitoring data of temperature, pH, fecal coliform bacteria, dissolved oxygen, total suspended sediment, turbidity, total phosphorus, and total nitrogen.
- *Marine sediment:* The sediment triad index is based on sediment chemistry, toxicity, and invertebrate community structure data and is currently being revised.
- *Marine water bodies:* MWCI complements Ecology's two existing indices but reports the inter-annual variability and long-term trend of marine conditions in relation to historically established baseline conditions. These conditions are empirically formulated for each location.

All three indices, however, can detect and communicate environmental change using approaches best suited for the particular environment and index formulation. For more information on Ecology's indices, visit Ecology's, Environmental Assessment Program at: www.ecy.wa.gov/programs/eap/index.html

Uses and advantages of the MWCI

Following are uses and advantages of the MWCI:

- **Detecting change beyond natural variability.** The MWCI's formulation has merit for an estuarine environment where geographical gradients, strong tidal dynamics, and vertical differences create high variability in the dataset. The MWCI relies on site-specific objectives (baseline conditions for each monitoring station) and therefore can respond sensitively to change at any point in the sampling network. This omits the formulation of eco-regions such as those formulated for the freshwater quality index (Hallock, 2002).

- **Comparing changes for locations with different ranges and amounts of data.** Water quality variables at some of Ecology's monitoring stations fluctuate with tides and weather conditions while others are very stable and consistent throughout the year.

  Some stations have non-normal data distributions with substantially different data ranges, as well as data gaps. This implies that a given amount of change that might be statistically significant at one station may be insignificant at another location. Using conventional water quality criteria alone may not distinguish significant changes. These potential issues are resolved with the formulation of the MWCI where we base index scores on median data values at each individual station and measure if more values begin to fall above or below the median over time.

- **Detecting changes separate from seasonal variability.** To overcome the strong seasonality in variables, the MWCI uses a de-seasonalized dataset. Ten-year monthly medians representing a time averaged seasonal cycle are subtracted from each station's dataset. The result is a dataset emphasizing variability. Scores for each sampling event fall into one of two categories; (1) above or equal to historical baseline conditions, or (2) below historical baseline conditions. The index then reports on the changes in the frequency of both categories over the period of a year.

  By using de-seasonalized datasets, the large number of site-specific objectives shares the same numerical baseline of zero. The number zero represents the expected 10-year baseline (median value) for a particular de-seasonalized variable.

- **Detecting changes on appropriate time scales.** The MWCI aggregates information over a period of years to decades, therefore, effectively reporting long-term changes occurring on annual to decadal time-scales. The index does not resolve changes that occur within the period of a year.

- **Setting environmental targets.** The selection of MWCI targets (ecosystem recovery/ improvement) relative to baseline conditions can be done independently of the index formulation. This translates into site-specific improvement targets that are independent of gradients and seasonal variation.

- **Comparing data across independent monitoring programs.** The MWCI uses a data structure that makes data comparison across monitoring programs easier because the focus is strictly on the variation and anomalies in relation to a baseline.

Limitations of the MWCI

Following are limitations of the MWCI:

- **Needs historic reference data.** The MWCI requires a well-established historic baseline over a period of at least a decade to account for varying environmental marine conditions (such as the Pacific Decadal Oscillation).
- **Toxic chemicals not included.** The MWCI uses non-toxic variables that are an integral part of the ecosystem (e.g., nitrate, chlorophyll-a, temperature, salinity, oxygen). Chemicals of concern may pose a severe threat that is not reported by the index. See: www.ecy.wa.gov/programs/wq/pstoxics/index.html. The MWCI is therefore only one of the Puget Sound Partnership's 20 dashboard indicators (www.psp.wa.gov/pm_dashboard.php).
- **Microbial species composition and abundance not included.** A fundamental aspect of ecosystem functioning is mediated through microbial process and the microbial food web. Changes in the estuarine microbial community have profound effects on biogeochemical processes, the entire aquatic food web, and water quality for humans. The MWCI does not include any species information. However, the index tracks nutrient ratios that provide a first insight into large changes in the microbial community.
- **Extent of variability at locations not captured.** While the MWCI detects shifts in the median tendencies in the datasets, it does not report on increases in the variance or magnitude of excursions.
- **Vertical extent of Puget Sound not fully captured.** The MWCI reports on the upper 50 meters of the water column, a limitation that was imposed by Ecology's historical sampling methods. Changes in the hypoxic condition below this depth are therefore not communicated. Until 2001, the depth of sampling was limited to the length of cable on the profiling instrument. After 2001, a new cable allowed sampling to near-bottom. The depth horizon of the MWCI can be expanded in the future, if a new reference frame is chosen.
- **Sampling biased toward daytime and calm weather conditions**. This limitation is an effect of using a floatplane for sample collection.

Strategies of the MWCI

Indices can follow fundamentally different approaches: those based on using water quality standards and those based on reference baseline conditions. Most indices use water quality standards to detect alarming changes in water quality relevant to water use and public health issues at specific locations. Indices that reference baseline conditions, on the other hand, are designed to track environmental change and are well suited for spatially complex and temporally variable environments.

The goal of the MWCI is to highlight environmental change. Its communication strategy is to:

- Clearly communicate the data without loss of information.
- Use a statistical framework so that only significant and meaningful changes are communicated.
- Effectively engage scientists, natural resource managers, and the public in exploring the causes of shifting baseline conditions.
- Provide a tool to help managers prioritize resources to address the most pressing environmental problems.
- Encourage all users to explore the underlying datasets.

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The Structure and Formulation of the MWCI

Methodology

Information for the MWCI is based on naturally occurring variables that are indicative of nutrient conditions, eutrophication, dissolved oxygen, and physical processes of estuarine and ocean waters (Nixon, 1995; Paerl et al., 2006). These variables are well-established and are used routinely in national and international monitoring programs (Orians et al., 2000; Newton et al., 2002). We measure variables at established (core) monitoring stations of Ecology's long-term monitoring program (Figure 2). We selected Ecology's ambient monitoring stations because of the wealth and consistency of data and their mid-basin or mid-channel locations. Ambient stations have an improved environmental signal-to-noise ratio over near-shore stations.

The MWCI is based on data that are of high quality and consistent methods. Ecology has been collecting monthly environmental data from Washington's inland marine water bodies and estuaries (Figure 2) since the 1970s (www.ecy.wa.gov/apps/eap/marinewq/mwdataset.asp). Due to method changes we limited our time-averaged seasonal cycle to the period from 1999 to 2008. We required a sufficient sampling frequency during 1999-2008 to establish a statistical baseline and some stations were excluded due to data gaps. Several long-term stations that Ecology continues to sample have therefore not been included in the MWCI (e.g., Hood Canal, Skagit Bay, Port Townsend harbor).

Establishing site-specific monthly baseline conditions allow us to place current observations into historic context to determine if:

- Conditions are changing from year to year.
- Observed changes are statistically significant over time.
- Observations represent an increase or decrease from baseline conditions.

The MWCI tracks a very large dataset: multiple variables (n=12), multiple depths (max 100 samples per station), and 12 sampling times per year at 27 stations. To summarize the large amount of data with the least information loss, we performed several steps of data reduction:

1. Summarized variables over depth using either statistics (medians from different depths) or standard oceanographic methods.
2. Removed seasonal variability by subtracting historical baseline conditions from each variable.
3. Reduced monthly information for each variable into yearly index scores using a frequency term.
4. Grouped individual variables into modules that represent environmental concepts.
5. Aggregated modules into higher index scores to simplify the environmental message to the public.

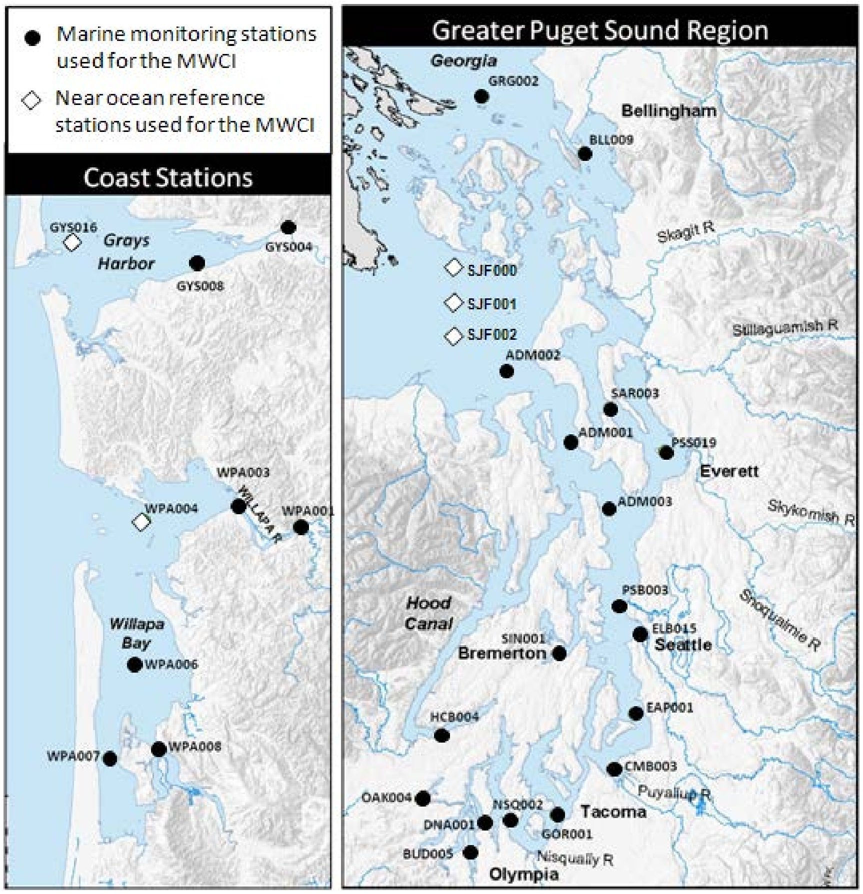

Figure 2. Ecology's 27 long-term monitoring stations used in the MWCI.

Selection of Ecology's long-term marine monitoring stations used in the calculation of the MWCI:

Stations are positioned at mid-channel and mid-basin locations to represent ambient water conditions and are sampled in monthly intervals using a float plane. Discrete water quality variables (0, 10, 30 m samples) and continuous water column profile information (0.5 m depth intervals) are collected using a Sea-Bird CTD package with *in-situ* sensors.

Stations in the Strait of Juan de Fuca (open diamonds) are part of the Joint Effort to Monitor the Strait (JEMS) project and are used as ocean reference stations for the Greater Puget Sound Region stations. Only nutrient and salinity variables are included in the MWCI.

The ocean reference stations (open diamonds) for the coast stations (GYS016 and WPA004) include the entire suite of variables for the MWCI.

Reducing vertical and seasonal variability

We rely on 12 variables (Table 1) plus salinity as a conservative ocean tracer. Variables are directly measured or inferred from:

- Physical, chemical, and optical state variables: pressure, temperature, conductivity, dissolved oxygen, and *in-situ* fluorescence.
- Analytically determined variables collected at discrete depths (0, 10, and 30 m): macro-nutrients (phosphate, nitrate, nitrite, ammonium, and silicate), oxygen, and chlorophyll-a.

To reduce the variability in individual CTD casts, physical, chemical, and optical state variables were depth integrated. To reduce variability in analytical determined variables we took medians from all three sampling depths (Table 1).

Table 1. Water quality variables used alone or in combination for the MWCI and their units.

Variables	Units
Physical	
Thermal energy content Salinity Dissolved oxygen content Energy required for vertical mixing (-ΔPE)	Depth integrated thermal energy (GJ/m^2) Concentration (psu) Depth integrated oxygen (kg/m^2) Inferred from vertical density structure (kJ/m^2)
Chemical	
Phosphate Nitrate Ammonium Silicate DIN (nitrate + nitrite + ammonium)	Median concentration [uM] from three depths: 0, 10, and 30 m
Nitrate:DIN Silicate:DIN DIN:Phosphate	Ratios based on median concentration from three depths: 0, 10, and 30 m
Biological	
In-situ Chlorophyll-a concentration	Depth integrated chlorophyll-a inferred from calibrated *in-situ* fluorescence (mg/m^2)

DIN: Dissolved inorganic nitrogen

Variables are measured using standard oceanographic protocols (UNESCO, 1994).

To reduce the large number of individual observations for each profile (every 0.5 m), we performed a depth integration or aggregation (0-50 m) on all variables. This approach reduces variability in the dataset and makes the MWCI more robust against patchiness.

Although some detail is lost during depth integration, relevant information for vertical mixing and oxygen transport are maintained in a physical term called potential energy required for vertical mixing (-ΔPE). This physical parameter uses information about the density structure for the water column segment (0-50 m) and represents the effect of stratification on vertical oxygen exchange between the surface and deeper waters.

To reduce vertical variability, water quality variables are depth integrated as follows:

1. Variables collected by continuous vertical sensor profiles are integrated over 50 meters (or maximum water depth if shallower) as follows:
    a. Temperature (°C) - thermal energy content (GJ/m^2) (IOC, SCOR, and IAPSO, 2010) is used to present the heat content over the sampling interval.
    b. Dissolved oxygen (mg/l) dissolved oxygen content (kg/m^2 water surface) is used to present the dissolved oxygen content over the sampling interval.
    c. *In-situ* fluorescence (calibrated with discrete chlorophyll-a samples) – chlorophyll-a content (mg/m^2 water surface) is used to present the algal biomass over the sampling interval.
    d. Density stratification - Potential energy (kJ/m^2) (Lewis, 1996) is used to represent the energy required to mix a stratified water body.

    Comment: Salinity (psu) - Salt is not depth integrated and only used as a conservative ocean tracer taken at the same depths as the nutrient samples.

2. Samples collected from discrete depths (0, 10, and 30 m) are combined, and the median value for all three depths is calculated to reduce vertical variability.

3. Variables from both continuous sensors and discrete samples (dissolved oxygen, *in-situ* chlorophyll-a) are compared, and sensor data are adjusted and then integrated over depth.

Establishing baseline water conditions

The MWCI uses de-seasonalized data over a 10-year period, 1999-2008. This baseline period was chosen because:

- There is consistency in methods for all 12 variables.
- It is a time period with relatively neutral Pacific Decadal Oscillation (positive and negative anomalies balance).
- The data record is of sufficient length to ensure statistically defensible baseline estimates (n>6).

Site-specific and seasonal-specific objectives (monthly) provide an important temporal reference framework for the MWCI. These objectives were empirically derived from Ecology's monitoring record and based on monthly summary statistics (120 months) and depth-aggregated variables (12 variables, 0-50 m). All data included in this baseline were carefully reviewed for quality by a team of reviewers.

We produced baseline conditions for each location and month of the year to generate a 10-year (median) seasonal cycle. When we subtract these baseline conditions from each new dataset, we remove the seasonal component. After subtracting the baseline, data falling exactly within the baseline becomes "zero". Larger values result in value > zero, smaller values result in values <0. The variability of data around the zero point (baseline) is detected by the index as specific variability and trends. The objective of the MWCI is to report on the relative change of the environment to the baseline. The numerical objective is therefore "zero".

Inter-annual changes that are otherwise masked are now emphasized. The MWCI therefore evaluates changes in the data distribution from a de-seasonalized data record and has eliminated the need to create eco-regions with specific water quality standards. The de-seasonalized data lends itself well for non-parametric statistical tests, and the variation of variables can be reduced to two categories falling within or beyond the baseline (Table 2; a binomial approach).

Table 2. Variation in the variables and their effect on lowering the MWCI score.

Exceeding the site-specific baseline	Not reaching the site-specific baseline
Chlorophyll-a concentration	Silicate:DIN ratio
Energy required for vertical mixing	DIN:phosphate ratio
Thermal energy content	Nitrate:DIN ratio
Nutrient concentrations	Dissolved oxygen content
Enrichment of nutrients in relation to near-ocean reference	

DIN: Dissolved inorganic nitrogen

Mathematical formulation of the four MWCI modules

The MWCI uses a mathematical formulation that explores the frequency with which data are different from expected baseline conditions. Data can either pass or fail an evaluation (test). The formulation is a binomial approach exploring changes in the median data distribution of each variable over the period of one year. The analysis then aggregates information from one year using monthly sampling events.

To arrive at a numerical index score between 0 and 100 for each variable and reporting period (t= 1 year), we use the ratio of data that fall within the objective range (meeting objectives) divided by the number of total sampling events during the reporting period (t) (n≤12 months). We adopted the formulation from the Canadian National Water Quality Index using only the "frequency term F2" (CCME Water Quality Index 1.0, Technical Report, 2001). The variable score V(i) is calculated as:

$$\mathrm{V(i)} = \left(\frac{\text{number of tests meeting historical objectives (t)}}{\text{number of sampling events (t)}}\right) \mathrm{x}100 - 50$$

Since baseline conditions represent median values under conditions of no change, 50% of the values will fall short of the objective (baseline) and fail. This results in a baseline score of 50 on a scale of 0-100. To illustrate that this condition is the baseline and that we are tracking change relative to this baseline, we decided to express scores on a scale between -50 and +50. After subtraction, zero becomes the baseline. The shift in scale (but preservation of range 100) underscores the difference of the MWCI to Ecology's sediment, freshwater, and previous marine indices.

The MWCI combines variable score V(i-k) into module scores (M_i) by averaging (arithmetic mean) the three variable scores for each module. As a result, all variables are weighed equally:

$$M(i)=(V(i) + V(j) + V(k))*1/3$$

Numerical aggregation of modules into the Eutrophication and Water Quality Indices

Each of the four modules (M) (Figure 3) – Ambient, Enrichment, Impact, and Ventilation – can be interpreted as a stand-alone module consisting of only three variables that track one aspect of eutrophication. We then combine and equally weight each module into the higher-level indices by simply using the arithmetic mean. We generate two indices each year. The Eutrophication Index communicates an average value for each of three modules – Ambient, Enrichment, and Impact – with each module contributing 33% of the score, and each variable being 11% of the total score. We calculate the index as:

$$\text{Eutrophication Index} = (\text{M (Ambient)} + \text{M (Enrichment)} + \text{M (Impact)}) * 1/3$$

The MWCI includes all four modules with each module (M) contributing 25% of the score, and each variable weighing 8.33% of the overall score, including the Ventilation module. We calculate the index as:

$$MWCI = (M\ (Ambient) + M\ (Enrichment) + M\ (Impact) + M\ (Ventilation)) * 1/4$$

We provide a numerical example of the different steps to calculate de-seasonalized datasets and module and index scores in Appendix B, Table B-1.

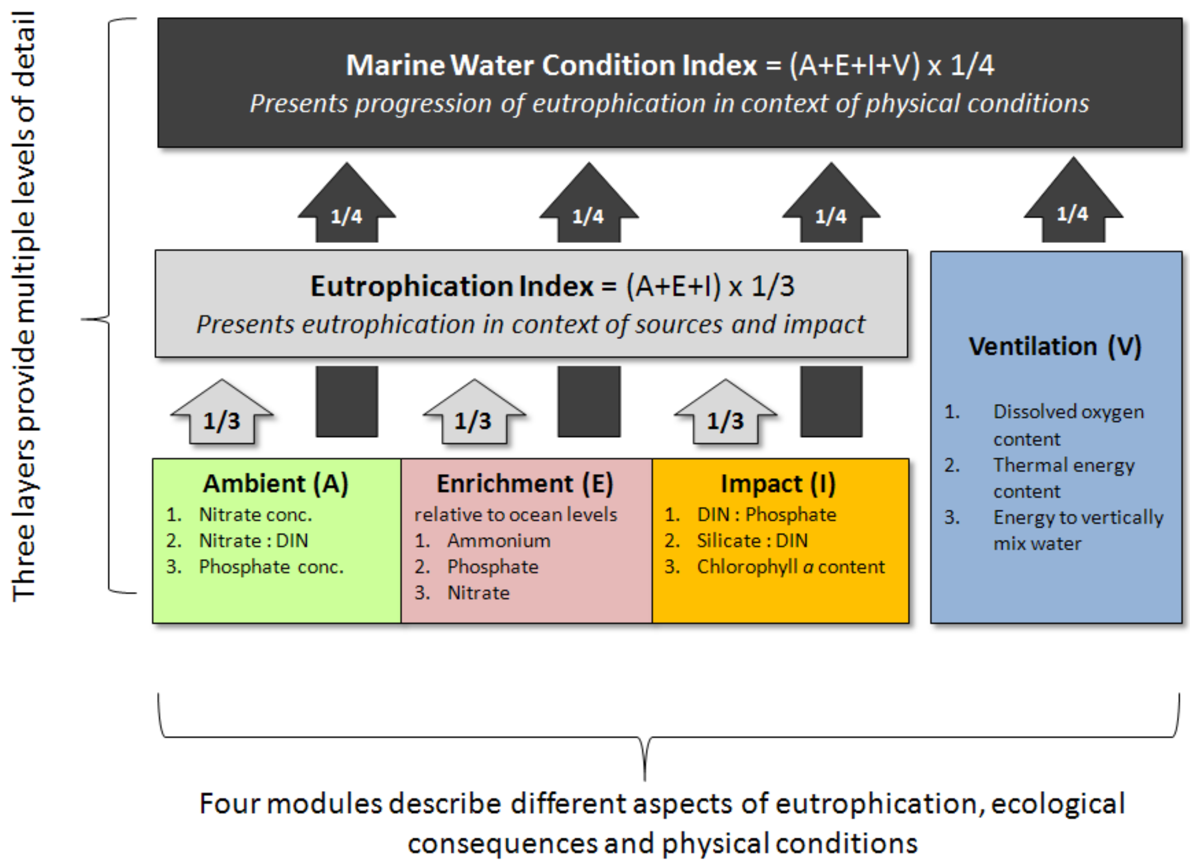

Figure 3. Aggregation of scores within the MWCI modular structure.

The MWCI has a modular structure to provide transparency into the data patterns of the 12 variables that form the index, with all variables weighted equally. Each module consists of three variables. The Eutrophication Index is calculated by adding the three nutrient-related modules and dividing by 3. The MWCI is calculated by adding the scores of the four modules and dividing by 4. The aggregation of data into two higher order indices (MWCI and Eutrophication Index) allows users the ability to assess nutrient-related eutrophication impacts separately or in combination with dissolved oxygen and physical conditions. DIN: Dissolved inorganic nitrogen.

Concepts Behind the Four MWCI Modules

The MWCI focuses on the change and variability of nutrient conditions, eutrophication, dissolved oxygen, and physical state variables relevant for ecosystem structure and functioning. Inherent to the index is a modular structure (Figure 1).

Four modules provide insight into the numerical drivers of the index. Three modules focus on a narrowly defined aspect of eutrophication in the environment: the Ambient module for the ambient nutrient conditions, the Enrichment module for the enrichment of nutrients in regional water bodies, and the Impact module for the potential impact of a nutrient imbalance. A fourth module, Ventilation, represents the important physical processes of an estuary.

We discuss each module in this section in context of the broader ecological function.

Ambient

Focus question for the Ambient module: Are nutrients changing from historic baseline conditions?

We compare three variables: nitrate, phosphate, and the ratio of nitrate to dissolved inorganic nitrogen (nitrate:DIN) to time-specific and site-specific baseline conditions (1999-2008).

Principle: While the macronutrients nitrate and phosphate are critical in supporting growth of algae, excessive nutrient concentrations can promote symptoms of eutrophication (Bachmann et al., 2006). In the marine ocean environment, nitrogen is considered the dominant growth-limiting factor for phytoplankton (Howarth and Marino, 2006). After an initial spring bloom, nitrogen availability quickly declines if vertical mixing, upwelling, or rivers do not resupply nutrients. To sustain algal growth, microbial nitrogen regeneration or atmospheric nitrogen fixation by cyanobacteria (blue green algae) become alternative sources of nitrogen.

The ratio of nitrate to DIN approximates the character of nitrogen that is available to phytoplankton, quickly recycled or provided via long-term biogeochemical cycles in the oceans interior fueling phytoplankton productivity (Dugdale and Goering, 1967). In a qualitative sense, the ratio also describes the quality of nitrogen for phytoplankton; low ratios are more readily taken up by cells.

When nitrogen availability is not limiting (e.g., under severe eutrophication), growth limitation for phytoplankton can shift from nitrogen to phosphate, silicate, light, and other growth controlling factors (Thingstad and Sagshaug, 1990; Correll, 1998).

Enrichment

Focus question for the Enrichment module: Are changes in ambient nutrients related to oceanic processes?

Three variables are included in the Enrichment module: nitrate, phosphate, and ammonium. In addition, salt is used as a conservative tracer to estimate ocean water dilution with freshwater.

Principle: Nutrient concentrations in the Strait of Juan de Fuca are typically higher than in Puget Sound during the productive season (Table 6). Therefore, changes in water exchange across Admiralty Reach can fundamentally affect the ambient nutrient conditions in Puget Sound.

Salt is a conservative marine tracer that can provide insight into the dilution of seawater with freshwater and addition or removal of nutrients. As ocean water enters Puget Sound, it undergoes many processes, including benthic, near-shore, and human-influenced interactions, that modify the oceanic nutrient-to-salt ratio. We term this modification *positive or negative enrichment*. Nutrient concentrations can increase by mixing with nutrient-rich freshwater from streams/rivers, or concentrations can become diluted with nutrient-poor rainwater. Enrichment in the water column can also develop from nutrient uptake by phytoplankton and subsequent sinking or removal of particles (export = negative enrichment) and decomposition of organic material (remineralization = positive enrichment) releasing nutrients into the water, as well as nutrients leaching from the benthos (positive enrichment). Salt provides a reliable tracer for ocean inputs and allows an integrated quantification of the net change of oceanic nutrient conditions in the estuarine context.

The relative influence of ocean nutrients can be conservatively accounted for using a dilution line (Giannelli et al., 2001). The line originates at nutrient and salt concentrations of zero and has a slope that is defined by the ratio of nutrients-to-salt found at an ocean reference station. Data that fall on the dilution line are diluted conservatively and are not enriched (positive or negative). The difference between measured and expected concentrations at any given salinity in the estuary defines the enrichment. We calculate the dilution line for each monthly sampling period according to:

$$\text{Enrichment (t)} = N_{i,t} - \frac{N_{0,t}}{S_{0,t}} x\, S_{i,t} \qquad (1)$$

Where (N) is the nutrient concentration in a specific month (t) collected at either a specific station (i) or reference station (o) and ($S_,$) is salinity.

We use three near-ocean reference sites: the Strait of Juan de Fuca (JEMS[2]) and stations closest to the ocean for Grays Harbor and Willapa Bay.

- In the Strait of Juan de Fuca, the depth horizon (30-80 m) is less variable and less affected by water leaving the Salish Sea (Thomson et al., 2007). We selected a depth interval that also matched the sill depth at Admiralty Reach (<70 m) which restricts the flow of water from the Straits[3] into Puget Sound to certain depths. Monthly ocean reference concentrations were calculated by averaging nutrient and salt values over a 30-80 m depth interval at three stations: SJF000, SJF001, SJF002 (see map and station key in Figure 2). The monthly inter-annual variability of the JEMS stations is lower than in Puget Sound, justifying the substitution of data. We substitute occasional data gaps due to severe weather with 10-year monthly median values.
- For the coastal bays, we selected WPA004 (Willapa Bay) and GYS016 (Grays Harbor) (Figure 2). Data gaps for these stations do not exist.

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[2] Joint Effort to Monitor the Strait.
[3] Strait of Juan de Fuca and Strait of Georgia.

Impact

Focus question for the Impact module: Are the nutrient balance and algal biomass changing from historic baseline conditions?

We use three variables in the module to describe the likelihood of impact. To approximate the potential for shifts in phytoplankton species composition, we report the ratios of dissolved inorganic nitrogen to phosphate (DIN:phosphate) and silicate to dissolved inorganic nitrogen (silicate:DIN). We use chlorophyll-a concentration as a proxy for overall algal biomass.

Principle: Diatoms typically dominate in Washington's marine waters (Horner, 2002) and have an excessive cell density relative to water. This density is much larger than in other phytoplankton species. Their silica-based structures are heavier than water and sink, thereby promoting vertical transport of organic material that sinks significantly faster than other species (Smetacek, 1985). This process provides benthic communities and microbial food webs with energy. Thus, species composition (diatoms vs. other species) affects biogeochemical pathways of organic material cycling in the estuary (Dortch et al., 2001).

Furthermore, phytoplankton species composition and abundance are impacted by shifts in nutrient ratios (Egge and Aksnes, 1992). Eutrophication alters natural nutrient ratios (Hecky and Kilham, 1988) since nitrogen and phosphate are introduced in quantities disproportionate to other growth factors (e.g., silicate). A shift from a diatom-dominated community to non-silicified species (e.g., flagellates) can occur if silicate is limiting. This can occur in eutrophic water with high nitrogen and phosphate concentrations but low silicate concentrations (Egge and Aksnes, 1992; Harashima, 2007).

As diatoms are replaced by other species, slower-sinking organic material has more time to be recycled within the water column. Effectively this reduces the energy transport to benthic communities and maintains high nutrient concentrations in the water column resulting in additional algal growth. At the same time, oxygen is consumed in mid-water regions by the microbial food web. Near-surface oxygen super-saturation along with hypoxia at depth (Tyler et al., 2009) are a typical result of eutrophication. The ratio of silicate to DIN is therefore an important proxy for the potential for export production and oxygen drawdown at depth (Harashima, 2007).

In other words, a shift from a diatom-dominated to a flagellate-dominated community alters (1) export production due to a slowed sinking rate (Hutchins et al., 1998) and (2) consequently the depth of the majority of oxygen drawdown (consumption).

Phytoplankton species composition is also strongly affected by the DIN to phosphorus (N:P) ratio (Hodgkiss and Ho, 1997). The N:P ratio promotes cyanobacteria at low ratios and flagellates at high ratios (Anderson et al., 2002). High abundances of nitrogen-fixing species additionally are capable of incorporating atmospheric nitrogen that affects the N:P ratio and are reported to have members that can produce severe cell toxins (Carmichael, 1992).

Ventilation

Focus question for the Ventilation module: Do physical conditions affect the availability of oxygen and renewal of water?

Because the Ventilation module is a suite of three physical variables, we report it separately from the Eutrophication Index. The overwhelming dependency of oxygen concentrations on physical factors in deep estuaries and fjords (Shen et al., 2008) motivated us to use three key physical variables to approximate conditions of the oxygen budget: oxygen content, thermal energy, and energy required for vertical mixing (mixing energy) (Lewis 1996). The Ventilation module is included in the overarching MWCI.

Principle: Dissolved oxygen is a critical state variable profoundly affecting chemical, biological, and ecological processes in the environment. *In-situ* dissolved oxygen concentrations are a product of competing physical and biological processes. These processes include solubility, transport, biological oxygen production (photosynthesis), biological demand (respiration), and chemical oxygen consumption (Walker, 1980). The solubility of oxygen in water is temperature-dependant and is higher in colder water. The effect of salt is smaller (Mel'nichenko, 2008). The cold temperature state of marine water is an important condition for Pacific Northwest food webs.

Atmospheric oxygen is supplied to deeper water by vertical mixing (convection) and is horizontally re-distributed by currents and tides (advection) over larger distances. We call the exchange of water masses and oxygen "ventilation" (e.g., Blanke et al., 2002). Sources of oxygen in aquatic environments are confined to regions near the surface where oxygen exchange with the atmosphere and primary productivity are the highest. This highlights the importance of the physical processes (e.g., vertical mixing, tides, and currents) in establishing oxygen levels *at depth*.

Oxygen consumption occurs everywhere in the water column through the process of respiration (Giorgio and Duarte, 2002). The rate of respiration is closely tied to temperature, increases exponentially in warmer water, and requires organic material. Dissolved oxygen concentrations decline when local oxygen demand exceeds local oxygen supply (e.g., during periods with warmer water and sufficient organic material availability). These conditions typically occur in Puget Sound in late summer (Devol et al., 2007). Water bodies with low circulation accumulate organic material (high microbial oxygen demand) and thus are the most vulnerable to chronically low oxygen concentrations (hypoxia).

Advection of water from distant sources can drastically improve conditions or sometimes decrease dissolved oxygen levels even further. The latter case occurs when transported water is already low in oxygen (e.g., upwelled hypoxic water from the ocean or from hypoxic regions such as Hood Canal). Mixing over sills improves oxygen conditions by aerating the water masses via vertical mixing. Strong vertical mixing typically occurs in Admiralty Reach and in the Tacoma Narrows. If a water body is isolated by bathymetry (shallow sills) and has a density structure that restricts vertical mixing, dissolved oxygen and water quality tends to be chronically lower (e.g., Hood Canal) and vulnerable to human pollution (Newton, 2006).

We combine dissolved oxygen content, thermal energy, and mixing energy to generate a score. The score provides information on the variability of the ventilation process and its associated influence on water quality and oxygen levels.

- *Dissolved oxygen content:* We calculate the oxygen content of the water column by integrating oxygen concentrations over the depth interval from 0 to 50 m.
- *Thermal energy:* Temperature critically affects chemical and biological oxygen consumption (respiration). Temperature can therefore be used as a proxy for the overall oxygen demand of the system. We calculate thermal energy content (better suited for depth integration) by integrating the specific heat content of seawater over 0-50 m (IOC, SCOR, and IAPSO, 2010).
- *Mixing Energy:* The ease with which water can vertically mix is critical for local oxygen supply. Water masses with very different density signatures remain physically separated unless density barriers are overcome by mixing (e.g., wind, tides), a process requiring energy (e.g., Fischer, 1976). Physical oceanographers routinely calculate the amount of energy that is required for vertical mixing, using the difference in potential energy between the observed and a theoretically well-mixed water column. The term *mixing energy* is referred to as $-\Delta PE$ (Lewis, 1996).

The Eutrophication Index

The Eutrophication Index answers the question: Have conditions changed to imply a shift in eutrophication?

A strong potential for eutrophication is indicated in three lines of evidence (Harashima, 2007):

- Increased ambient nutrient concentrations.
- Enrichment of nutrients relative to ocean water.
- A nutrient disequilibrium between silicate and nitrogen and phosphate are present.

The Eutrophication Index (EUI) combines scores of three modules that are specific to nutrient increases and eutrophication: Ambient, Enrichment, and Impact. The EUI is more sensitive to nitrogen because out of the total number of variables (9), there are five nitrogen and three phosphate terms. This is consistent with the greater importance of nitrogen as a growth-limiting factor. The progression of eutrophication typically follows a path of increasing nutrient concentration (Ambient), nutrients increasing above expected oceanic background levels (Enrichment), to a nutrient ratio imbalance and increased phytoplankton biomass (Impact). The focus of the EI summarizes all three aspects and communicates the potential of eutrophication when all three lines of evidence are falling in line.

The overall Eutrophication Index score reflects the likelihood of eutrophication above oceanic background influences and its ecological consequences as a whole. The EUI does not take changes in physical conditions into account that might explain some of the observations such as reduced oxygen. Each module by itself and the module combination helps to narrow down and communicate the cause and potential implications of changing nutrient conditions. Exploring the individual module score therefore permits users to see how each component (Ambient, Enrichment, or Impact) contributes to the score of eutrophication and its symptoms (Cloern, 2001).

Example: Elliott Bay

The Eutrophication Index shows no significant downward trend in Elliott Bay and conditions relax in 2006 to 2008. However, Ambient module scores in Elliott Bay are decreasing (Figure A-11) which suggests an increase in nutrients. In addition, the Impact module correlates negatively with the Pacific Decadal Oscillation (PDO) suggesting that Elliott Bay responds to climate variability with warmer sea surface temperatures negatively affecting nutrient ratios and algal biomass.

Trends in Puget Sound's Central Basin adjacent to Elliott Bay provide additional context. Here we find a significant decrease in the Eutrophication Index and significant decreases in the Ambient and Enrichment modules. This suggests that in the Central Basin nutrient concentrations are rising above ocean background concentrations. However, a negative correlation of the Eutrophication Index and the Ambient and Enrichment modules with the Upwelling Index (a product from NOAA PFEL[4]) also exists (Figure A-6). (See the section in this report entitled, *Coastal Upwelling Indices*, for a detailed explanation of the Upwelling Index.) This information cautions that influences from upwelling need to be considered in the declining water conditions. A more in-depth study is indicated to determine the causality in nutrient increases and enrichment in this area.

For scientists, more information can be obtained to further narrow down the observation. A negative correlation of the Eutrophication Index with the Upwelling Index (Figure A-6) indicates that trends of increased upwelling from 1999 to 2008 and the Eutrophication Index coincide. Heat maps showing monthly anomalies provide more detail. For example, silicate: DIN ratios (Table A-8) have been decreasing, confirming an underlying increase in eutrophication specific to nitrogen sources, thereby potentially excluding increased upwelling as a likely factor.

We can therefore communicate on several levels that nutrient conditions in Elliott Bay and Puget Sound's Central Basin are increasing. The increase is likely due to interplay between increased upwelling from 1999 to 2008 and regional enrichment affecting Central Basin and Elliott Bay eutrophication. As indices do not provide causality, further studies looking into specific details are warranted.

The MWCI

The level of the MWCI combines information on eutrophication trends in the context of local and larger scale physical conditions that affect the supply of oxygen and renewal of water masses. The MWCI combines all four modules (Ambient, Enrichment, Impact, and Ventilation) into one aggregated number.

The MWCI explores: Are physical conditions and eutrophication jointly changing water quality?

[4] National Oceanic and Atmospheric Administration Pacific Fisheries Environmental Laboratory

Example: If eutrophication potential is high, and ventilation of water masses and oxygen is low, environmental problems will be severe and the score will be low. If eutrophication potential is high, but ventilation supports higher oxygen supply, then conditions can potentially worsen if physical processes become unfavorable. The MWCI therefore takes the potential impact of the physical environment on water quality into account and provides extra room for the MWCI score to decline. As physical conditions are often linked to large-scale physical oceanic and climatic variability, the interplay of large-scale patterns with local water quality issues is captured in this overarching index**.**

Environmental Information Embedded in the Baseline Conditions

Baseline conditions carry important information about persistent environmental gradients, and the seasonality within Washington's inshore marine water bodies as illustrated in the following summaries.

We estimated site-specific baseline conditions using generalized monthly conditions (medians) at 27 stations during 1999-2008. This fixed historical reference frame allows us to define a suite of site-specific and season-specific baseline conditions that reflect the spatial (e.g., horizontal and vertical salinity gradients) and temporal complexity (e.g., tides, seasonality) of the estuarine environment. We thereby avoid the need to define specific water quality objectives for the MWCI for the extremely heterogeneous environment.

The comprehensive lists of site-specific monthly baseline values for all 12 variables are found in Tables 3-14. The tables are sorted according to highest yearly median values. This allows an exploration of the persistent geographical and seasonal gradient for each index variable within Ecology's monitoring network. The number of data points we used to establish the baseline values is shown in Appendix A, Tables A-13 to A-16.

Table 3. Site-specific objectives (baseline conditions) listed for each month for the thermal energy content variable (GJ/m^2) used in the Ventilation module.

Explanation: We sorted the table to reflect persistent environmental gradients. Seasonal range and maximum depth considered by the MWCI are included. In cases where stations are shallow, we selected a depth equal to the minimum low tide water line.

Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Median**	**Range**	**Depth (m)**
GOR001	1.82	1.66	1.65	1.74	1.90	2.22	2.48	2.64	2.64	2.48	2.22	1.96	**2.09**	**0.99**	**50**
NSQ002	1.76	1.66	1.64	1.78	1.91	2.31	2.57	2.69	2.74	2.59	2.23	1.93	**2.08**	**1.09**	**50**
HCB004	2.01	1.95	1.94	1.97	2.02	2.10	2.23	2.16	2.09	2.13	2.12	2.06	**2.08**	**0.29**	**50**
CMB003	1.84	1.67	1.64	1.69	1.80	2.09	2.28	2.43	2.47	2.40	2.23	1.99	**2.04**	**0.83**	**50**
EAP001	1.83	1.66	1.65	1.71	1.83	2.13	2.38	2.50	2.44	2.47	2.19	1.93	**2.03**	**0.85**	**50**
ELB015	1.86	1.67	1.64	1.70	1.92	2.04	2.35	2.48	2.52	2.44	2.17	1.97	**2.01**	**0.88**	**50**
PSS019	1.77	1.69	1.67	1.72	1.85	2.01	2.20	2.35	2.31	2.26	2.23	1.98	**1.99**	**0.67**	**50**
ADM003	1.71	1.63	1.63	1.70	1.88	2.11	2.33	2.46	2.46	2.36	2.10	1.88	**1.99**	**0.83**	**50**
SAR003	1.81	1.72	1.69	1.70	1.81	1.99	2.16	2.23	2.28	2.29	2.20	1.97	**1.98**	**0.61**	**50**
ADM001	1.65	1.60	1.62	1.69	1.84	2.07	2.26	2.42	2.34	2.21	2.00	1.81	**1.92**	**0.82**	**50**
GRG002	1.57	1.52	1.54	1.69	1.81	1.97	2.26	2.36	2.20	2.07	1.87	1.75	**1.84**	**0.84**	**50**
ADM002	1.55	1.54	1.59	1.62	1.77	1.84	1.94	1.99	2.01	1.90	1.81	1.68	**1.79**	**0.47**	**50**
DNA001	1.23	1.14	1.14	1.25	1.41	1.66	1.85	1.93	1.96	1.76	1.57	1.31	**1.49**	**0.82**	**35**
PSB003	1.03	0.95	0.92	0.98	1.08	1.25	1.41	1.45	1.46	1.36	1.26	1.11	**1.18**	**0.54**	**29**
WPA006	0.38	0.38	0.43	0.54	0.65	0.78	0.87	0.85	0.77	0.66	0.47	0.33	**0.59**	**0.54**	**13**
SIN001	0.46	0.44	0.45	0.51	0.56	0.65	0.77	0.77	0.76	0.68	0.56	0.50	**0.56**	**0.33**	**14**
GYS004	0.34	0.33	0.34	0.44	0.61	0.71	0.78	0.81	0.75	0.58	0.42	0.31	**0.51**	**0.50**	**12**
BUD005	0.33	0.33	0.34	0.38	0.44	0.51	0.60	0.61	0.60	0.53	0.45	0.39	**0.44**	**0.27**	**11**
OAK004	0.27	0.28	0.33	0.37	0.48	0.57	0.67	0.67	0.61	0.48	0.40	0.31	**0.44**	**0.40**	**10**
WPA001	0.25	0.24	0.28	0.32	0.48	0.57	0.66	0.63	0.58	0.43	0.30	0.24	**0.38**	**0.41**	**9**
BLL009	0.27	0.27	0.29	0.32	0.37	0.45	0.52	0.50	0.45	0.39	0.33	0.30	**0.35**	**0.25**	**10**
WPA007	0.18	0.18	0.21	0.28	0.34	0.41	0.44	0.45	0.41	0.34	0.23	0.15	**0.31**	**0.30**	**7**
WPA004	0.20	0.20	0.22	0.26	0.30	0.35	0.39	0.38	0.36	0.30	0.24	0.18	**0.28**	**0.21**	**7**
GYS016	0.20	0.21	0.21	0.23	0.29	0.32	0.33	0.36	0.30	0.28	0.27	0.21	**0.27**	**0.17**	**7**
WPA008	0.15	0.15	0.18	0.23	0.30	0.35	0.39	0.38	0.35	0.28	0.19	0.12	**0.26**	**0.26**	**6**
WPA003	0.16	0.16	0.18	0.22	0.29	0.34	0.38	0.36	0.33	0.25	0.19	0.15	**0.24**	**0.24**	**6**
GYS008	0.10	0.09	0.10	0.12	0.16	0.20	0.22	0.20	0.19	0.15	0.11	0.08	**0.13**	**0.14**	**4**

Table 4. Site-specific objectives listed for each month for the energy required for the vertical mixing variable (-ΔPE, kJ/m^2) used in the Ventilation module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
SAR003	-6.53	-6.29	-5.77	-5.42	-5.02	-7.71	-5.99	-4.00	-3.87	-2.41	-6.40	-9.72	**-5.88**	**7.31**	**50**
PSS019	-5.16	-5.50	-4.83	-6.43	-5.84	-8.21	-6.68	-3.68	-3.05	-4.09	-5.05	-4.62	**-5.11**	**5.16**	**50**
HCB004	-5.53	-6.04	-3.76	-5.21	-5.89	-4.90	-6.26	-4.86	-4.42	-3.36	-2.13	-5.53	**-5.06**	**4.14**	**50**
ADM003	-2.22	-1.06	-1.60	-1.95	-2.86	-3.68	-2.62	-2.09	-1.29	-2.55	-0.57	-0.42	**-2.02**	**3.26**	**50**
GRG002	-1.33	-0.64	-0.61	-1.05	-3.32	-4.93	-5.24	-4.49	-1.56	-2.48	-1.31	-1.32	**-1.44**	**4.62**	**50**
ADM002	-1.09	-1.05	-0.25	-0.90	-1.71	-2.57	-1.44	-1.41	-1.83	-1.47	-0.79	-1.40	**-1.40**	**2.33**	**50**
CMB003	-1.25	-1.15	-1.07	-1.79	-2.09	-2.49	-1.99	-1.45	-1.55	-1.28	-0.93	-0.94	**-1.36**	**1.56**	**50**
ADM001	-0.49	-0.50	-0.57	-1.54	-2.09	-1.16	-1.30	-1.33	-0.97	-1.38	-0.50	-0.18	**-1.07**	**1.90**	**50**
ELB015	-0.77	-0.91	-1.14	-1.10	-1.36	-2.22	-1.32	-1.06	-0.98	-0.94	-0.68	-0.93	**-1.02**	**1.54**	**50**
GYS004	-1.60	-1.14	-0.41	-1.31	-0.96	-0.40	-0.55	-0.55	-0.22	-1.05	-1.41	-1.48	**-1.01**	**1.39**	**12**
EAP001	-0.45	-0.55	-0.61	-0.83	-1.03	-1.55	-1.24	-1.19	-0.97	-0.92	-0.39	-0.79	**-0.88**	**1.16**	**50**
NSQ002	-0.66	-0.85	-0.78	-0.81	-0.56	-1.08	-0.86	-0.75	-0.73	-0.44	-0.29	-1.01	**-0.76**	**0.79**	**50**
GOR001	-0.26	-0.50	-0.57	-0.59	-0.64	-0.65	-0.64	-0.42	-0.43	-0.39	-0.26	-1.26	**-0.53**	**1.00**	**50**
DNA001	-0.55	-0.43	-0.29	-0.38	-0.11	-0.16	-0.35	-0.39	-0.24	-0.06	-0.07	-0.60	**-0.32**	**0.54**	**35**
PSB003	-0.40	-0.28	-0.20	-0.37	-0.36	-0.43	-0.31	-0.18	-0.20	-0.12	-0.09	-0.34	**-0.29**	**0.33**	**29**
WPA001	-0.28	-0.20	-0.15	-0.27	-0.16	-0.18	-0.21	-0.07	-0.05	-0.20	-0.25	-0.16	**-0.19**	**0.23**	**9**
SIN001	-0.07	-0.06	-0.06	-0.07	-0.06	-0.08	-0.13	-0.11	-0.08	-0.03	-0.03	-0.05	**-0.07**	**0.10**	**14**
OAK004	-0.08	-0.13	-0.08	-0.12	-0.07	-0.06	-0.05	-0.04	-0.01	-0.02	-0.03	-0.15	**-0.06**	**0.14**	**10**
BUD005	-0.02	-0.08	-0.06	-0.08	-0.08	-0.04	-0.12	-0.09	-0.06	-0.03	-0.03	-0.05	**-0.06**	**0.09**	**11**
BLL009	-0.05	-0.01	-0.04	-0.07	-0.07	-0.17	-0.19	-0.10	-0.09	-0.05	-0.03	-0.02	**-0.06**	**0.18**	**10**
WPA003	-0.11	-0.06	-0.07	-0.06	-0.09	-0.01	-0.06	-0.01	-0.01	-0.01	-0.03	-0.14	**-0.06**	**0.13**	**6**
WPA006	-0.04	-0.04	-0.05	-0.01	-0.02	-0.01	-0.01	-0.02	-0.02	0.00	-0.05	-0.06	**-0.02**	**0.05**	**13**
GYS016	-0.03	-0.04	-0.07	-0.09	-0.02	0.00	-0.01	-0.01	0.00	0.00	0.00	-0.13	**-0.01**	**0.13**	**7**
WPA004	-0.01	-0.02	-0.12	-0.04	-0.01	0.00	-0.02	0.00	-0.01	0.00	-0.01	-0.02	**-0.01**	**0.12**	**7**
WPA008	-0.02	-0.01	-0.02	-0.01	-0.02	-0.01	-0.01	0.00	0.00	0.00	-0.01	-0.01	**-0.01**	**0.02**	**6**
GYS008	-0.01	-0.03	-0.01	-0.01	-0.02	0.00	-0.01	0.00	0.00	0.00	-0.02	-0.04	**-0.01**	**0.04**	**4**
WPA007	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	**0.00**	**0.01**	**7**

Table 5. Site-specific objectives listed for each month for the dissolved oxygen content variable (kg/m^2) used in the Ventilation module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
NSQ002	0.39	0.39	0.43	0.49	0.50	0.44	0.42	0.39	0.36	0.32	0.31	0.35	**0.39**	**0.19**	**50**
EAP001	0.39	0.40	0.41	0.46	0.48	0.43	0.39	0.37	0.33	0.32	0.31	0.37	**0.39**	**0.17**	**50**
GOR001	0.38	0.39	0.43	0.46	0.49	0.43	0.40	0.38	0.35	0.31	0.30	0.35	**0.39**	**0.19**	**50**
PSS019	0.39	0.41	0.42	0.42	0.43	0.41	0.38	0.35	0.28	0.26	0.30	0.32	**0.39**	**0.17**	**50**
CMB003	0.38	0.40	0.41	0.43	0.46	0.40	0.39	0.35	0.31	0.30	0.29	0.34	**0.39**	**0.17**	**50**
ADM003	0.40	0.41	0.43	0.44	0.44	0.41	0.36	0.36	0.34	0.31	0.31	0.31	**0.38**	**0.13**	**50**
ELB015	0.37	0.40	0.41	0.43	0.44	0.43	0.39	0.35	0.31	0.29	0.30	0.35	**0.38**	**0.15**	**50**
ADM001	0.40	0.41	0.42	0.43	0.44	0.39	0.37	0.35	0.31	0.31	0.32	0.32	**0.38**	**0.13**	**50**
SAR003	0.38	0.39	0.40	0.40	0.39	0.39	0.37	0.33	0.29	0.25	0.28	0.33	**0.37**	**0.16**	**50**
GRG002	0.39	0.40	0.41	0.43	0.41	0.38	0.34	0.31	0.29	0.30	0.32	0.33	**0.36**	**0.14**	**50**
ADM002	0.39	0.39	0.38	0.36	0.36	0.32	0.29	0.29	0.26	0.25	0.30	0.29	**0.31**	**0.14**	**50**
DNA001	0.27	0.29	0.31	0.34	0.36	0.31	0.30	0.27	0.26	0.23	0.22	0.25	**0.28**	**0.13**	**35**
PSB003	0.22	0.23	0.25	0.25	0.27	0.26	0.24	0.23	0.21	0.17	0.18	0.20	**0.23**	**0.10**	**29**
HCB004	0.22	0.25	0.24	0.25	0.22	0.21	0.18	0.15	0.10	0.13	0.18	0.18	**0.19**	**0.15**	**50**
SIN001	0.10	0.11	0.12	0.14	0.14	0.13	0.13	0.12	0.11	0.09	0.09	0.10	**0.11**	**0.06**	**14**
WPA006	0.12	0.12	0.12	0.12	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.12	**0.11**	**0.03**	**13**
GYS004	0.13	0.12	0.11	0.11	0.11	0.10	0.09	0.08	0.08	0.10	0.10	0.11	**0.11**	**0.05**	**12**
BUD005	0.08	0.09	0.09	0.11	0.12	0.10	0.10	0.09	0.08	0.08	0.07	0.08	**0.09**	**0.05**	**11**
OAK004	0.08	0.08	0.09	0.09	0.10	0.09	0.09	0.09	0.08	0.06	0.07	0.08	**0.08**	**0.04**	**10**
BLL009	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.07	0.07	0.07	**0.08**	**0.02**	**10**
WPA001	0.08	0.09	0.09	0.08	0.07	0.07	0.06	0.05	0.05	0.06	0.07	0.07	**0.07**	**0.03**	**9**
WPA004	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	**0.06**	**0.01**	**7**
WPA007	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.06	**0.05**	**0.02**	**7**
GYS016	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.06	**0.05**	**0.02**	**7**
WPA003	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05	**0.04**	**0.02**	**6**
WPA008	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.05	0.05	**0.04**	**0.02**	**6**
GYS008	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.03	**0.03**	**0.01**	**4**

Table 6. Site-specific objectives listed for each month for the nitrate concentration variable (uM) used in the Ambient module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
ADM002	27.35	27.54	25.12	23.94	19.56	21.07	21.45	22.53	22.47	26.58	26.40	28.39	**24.53**	**8.83**	**50**
PSB003	29.63	29.86	27.14	23.43	15.86	13.14	11.99	15.30	18.00	22.45	25.04	28.04	**22.94**	**17.87**	**29**
CMB003	29.12	29.73	27.98	24.79	17.74	14.68	14.22	16.83	18.01	21.05	25.74	28.26	**22.92**	**15.51**	**50**
GRG002	27.40	27.54	25.59	21.18	17.05	13.40	10.86	12.63	20.45	23.79	26.32	27.84	**22.49**	**16.98**	**50**
HCB004	28.62	26.71	25.56	19.78	18.23	18.24	15.81	16.59	21.97	24.64	26.78	22.97	**22.47**	**12.81**	**50**
ELB015	29.65	30.33	29.30	22.76	16.94	14.42	14.00	16.12	17.14	21.83	25.63	28.57	**22.29**	**16.32**	**50**
EAP001	30.22	29.28	27.89	21.46	15.18	12.34	10.88	12.77	16.13	21.45	24.57	28.29	**21.46**	**19.34**	**50**
ADM001	27.75	28.51	24.95	19.79	13.78	16.22	14.85	15.44	18.40	22.91	25.20	27.49	**21.35**	**14.74**	**50**
GYS004	32.17	34.55	28.80	23.14	17.45	13.61	10.94	12.76	15.21	16.36	26.91	26.56	**20.30**	**23.61**	**12**
GOR001	29.81	29.84	27.64	21.30	13.90	12.19	12.38	12.47	13.59	19.23	23.45	29.78	**20.26**	**17.65**	**50**
ADM003	28.66	29.14	25.98	21.07	16.12	13.78	9.91	12.75	14.16	19.42	24.83	27.36	**20.24**	**19.23**	**50**
PSS019	29.67	28.47	19.54	20.91	13.71	15.94	10.26	13.07	19.03	23.11	24.68	27.68	**20.23**	**19.41**	**50**
SAR003	27.96	27.77	20.89	23.72	19.23	14.66	10.40	15.14	17.29	11.55	22.86	27.35	**20.06**	**17.56**	**50**
WPA001	46.52	39.22	26.46	37.37	10.11	3.84	1.74	4.19	5.78	10.96	27.78	35.16	**18.71**	**44.78**	**9**
NSQ002	30.02	29.92	27.00	18.69	10.70	8.74	9.15	10.38	9.76	15.10	21.83	27.70	**16.89**	**21.29**	**50**
DNA001	30.50	30.20	26.13	16.66	8.37	7.84	7.79	7.76	8.92	14.12	21.19	27.03	**15.39**	**22.73**	**35**
SIN001	29.33	29.53	24.17	14.77	6.21	4.76	4.95	6.69	7.84	15.86	22.60	26.42	**15.32**	**24.77**	**14**
BUD005	29.02	29.78	25.21	16.00	4.90	4.10	0.42	0.43	1.68	11.19	20.03	26.55	**13.60**	**29.36**	**11**
GYS008	23.18	21.92	15.61	14.40	8.85	6.42	4.77	7.62	9.66	12.88	13.11	23.90	**13.00**	**19.13**	**4**
BLL009	28.90	27.89	22.86	9.88	7.67	4.23	4.76	4.98	7.54	15.91	26.38	28.77	**12.89**	**24.67**	**10**
OAK004	27.14	25.74	20.01	13.65	0.36	0.83	0.48	0.42	3.98	9.56	19.27	25.48	**11.61**	**26.78**	**10**
GYS016	11.57	12.29	5.88	3.60	2.04	4.05	7.83	4.67	9.83	7.68	7.74	11.87	**7.71**	**10.26**	**7**
WPA003	27.43	18.76	13.47	8.94	2.72	0.34	0.20	1.01	2.94	5.17	13.32	13.86	**7.05**	**27.23**	**6**
WPA004	12.29	11.18	6.07	2.18	0.66	0.71	0.47	0.69	3.84	4.56	8.64	8.20	**4.20**	**11.82**	**7**
WPA006	13.61	9.68	3.79	0.19	0.23	0.17	0.07	0.20	1.74	2.95	7.94	4.92	**2.34**	**13.54**	**13**
WPA008	17.36	10.34	3.51	1.61	0.47	0.12	0.28	0.46	0.67	1.58	9.74	8.89	**1.59**	**17.24**	**6**
WPA007	14.72	9.86	0.65	0.14	0.27	0.11	0.21	0.25	0.51	1.82	7.72	3.28	**0.58**	**14.61**	**7**

Table 7. Site-specific objectives listed for each month for the phosphate concentration variable (uM) used in the Ambient module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
HCB004	2.99	2.67	2.62	2.32	2.31	2.64	2.46	2.92	2.91	3.47	2.88	2.66	**2.67**	**1.15**	**50**
PSB003	2.68	2.62	2.43	2.06	1.60	1.59	1.66	1.76	2.09	2.35	2.50	2.59	**2.22**	**1.09**	**29**
CMB003	2.52	2.45	2.43	2.12	1.83	1.69	1.64	1.91	2.10	2.29	2.53	2.69	**2.21**	**1.05**	**50**
ELB015	2.65	2.65	2.40	2.03	1.65	1.51	1.66	1.89	2.07	2.33	2.47	2.60	**2.20**	**1.14**	**50**
GOR001	2.72	2.65	2.44	1.79	1.70	1.76	1.65	1.95	2.03	2.36	2.54	2.61	**2.19**	**1.07**	**50**
NSQ002	2.74	2.68	2.43	1.66	1.33	1.61	1.61	1.95	1.99	2.39	2.59	2.70	**2.19**	**1.40**	**50**
ADM002	2.26	2.30	2.18	2.00	1.79	1.94	2.01	2.15	2.17	2.40	2.37	2.46	**2.17**	**0.67**	**50**
BUD005	2.71	2.49	2.16	1.65	0.98	1.92	1.76	2.00	2.13	2.29	2.66	2.81	**2.15**	**1.84**	**11**
DNA001	2.76	2.67	2.29	1.59	1.17	1.58	1.60	1.93	2.00	2.45	2.64	2.75	**2.15**	**1.59**	**35**
OAK004	2.48	2.16	1.85	1.34	0.69	1.27	1.75	2.10	2.29	2.59	2.44	2.71	**2.13**	**2.03**	**10**
ADM001	2.44	2.44	2.23	1.70	1.53	1.67	1.59	1.79	2.03	2.33	2.38	2.52	**2.13**	**0.99**	**50**
EAP001	2.69	2.58	2.47	1.94	1.58	1.50	1.47	1.58	1.87	2.28	2.44	2.62	**2.11**	**1.22**	**50**
GRG002	2.43	2.34	2.10	1.86	1.72	1.42	1.21	1.50	1.94	2.20	2.40	2.42	**2.02**	**1.22**	**50**
SIN001	2.73	2.57	2.18	1.45	1.10	1.61	1.87	1.80	1.87	2.18	2.58	2.74	**2.02**	**1.64**	**14**
ADM003	2.56	2.50	2.14	1.90	1.52	1.33	1.35	1.57	1.83	2.13	2.42	2.49	**2.01**	**1.23**	**50**
PSS019	2.52	2.31	1.41	1.96	1.57	1.66	1.35	1.54	2.00	2.10	2.52	2.51	**1.98**	**1.17**	**50**
SAR003	2.25	2.45	1.73	2.12	1.82	1.75	1.34	1.66	1.67	2.07	2.33	2.52	**1.94**	**1.17**	**50**
BLL009	2.23	2.29	1.82	0.98	0.99	0.66	0.75	1.07	1.58	1.83	2.36	2.41	**1.70**	**1.75**	**10**
WPA007	0.95	0.71	0.33	0.32	0.54	0.74	1.10	1.49	1.53	1.19	1.12	0.90	**0.92**	**1.22**	**7**
GYS016	0.86	0.80	0.60	0.40	0.53	0.72	1.02	1.22	1.32	1.11	0.97	0.80	**0.83**	**0.92**	**7**
WPA006	0.93	0.77	0.33	0.18	0.45	0.59	0.73	1.18	1.14	0.93	1.08	0.85	**0.81**	**1.00**	**13**
WPA004	0.79	0.74	0.38	0.29	0.35	0.45	0.64	0.91	1.02	0.83	0.97	0.76	**0.75**	**0.74**	**7**
WPA008	0.74	0.59	0.30	0.20	0.43	0.66	0.94	1.36	1.49	1.17	1.03	0.75	**0.74**	**1.29**	**6**
GYS008	0.59	0.55	0.61	0.48	0.60	0.68	0.73	1.15	1.42	1.21	0.95	0.64	**0.66**	**0.93**	**4**
WPA003	0.62	0.53	0.40	0.33	0.34	0.50	0.64	1.09	1.15	1.05	0.84	0.70	**0.63**	**0.82**	**6**
GYS004	0.37	0.25	0.34	0.36	0.32	0.38	0.47	0.79	0.95	0.78	0.54	0.55	**0.43**	**0.70**	**12**
WPA001	0.25	0.29	0.25	0.25	0.18	0.28	0.29	0.68	0.89	0.84	0.61	0.43	**0.29**	**0.71**	**9**

Table 8. Site-specific objectives listed for each month for the ratio of nitrate to dissolved inorganic nitrogen used in the Ambient module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
GRG002	0.997	0.991	0.984	0.943	0.904	0.936	0.947	0.921	0.967	0.978	0.975	0.993	**0.97**	**0.09**	**50**
HCB004	0.993	0.982	0.971	0.950	0.892	0.933	0.925	0.952	0.982	0.985	0.965	0.978	**0.97**	**0.10**	**50**
EAP001	0.996	0.996	0.979	0.956	0.898	0.817	0.845	0.918	0.936	0.975	0.981	0.995	**0.97**	**0.18**	**50**
SAR003	0.992	0.994	0.941	0.971	0.936	0.846	0.858	0.963	0.966	0.909	0.957	0.995	**0.96**	**0.15**	**50**
PSS019	0.993	0.988	0.933	0.951	0.875	0.854	0.857	0.926	0.966	0.966	0.984	0.992	**0.96**	**0.14**	**50**
PSB003	0.990	0.993	0.963	0.950	0.875	0.823	0.828	0.916	0.932	0.966	0.983	0.992	**0.96**	**0.17**	**29**
ELB015	0.996	0.993	0.979	0.955	0.892	0.841	0.843	0.911	0.905	0.958	0.986	0.987	**0.96**	**0.15**	**50**
ADM002	0.992	0.993	0.977	0.949	0.919	0.923	0.920	0.927	0.937	0.963	0.979	0.988	**0.96**	**0.07**	**50**
ADM003	0.994	0.995	0.966	0.952	0.866	0.838	0.835	0.886	0.899	0.946	0.987	0.988	**0.95**	**0.16**	**50**
ADM001	0.990	0.994	0.967	0.939	0.897	0.868	0.889	0.909	0.920	0.950	0.977	0.989	**0.94**	**0.13**	**50**
CMB003	0.987	0.982	0.963	0.950	0.875	0.811	0.843	0.879	0.883	0.933	0.959	0.982	**0.94**	**0.18**	**50**
GOR001	0.993	0.991	0.970	0.948	0.894	0.811	0.852	0.864	0.857	0.875	0.942	0.991	**0.92**	**0.18**	**50**
GYS004	0.925	0.958	0.938	0.896	0.925	0.908	0.763	0.729	0.715	0.748	0.891	0.899	**0.90**	**0.24**	**12**
NSQ002	0.991	0.981	0.961	0.922	0.863	0.786	0.760	0.811	0.796	0.823	0.898	0.965	**0.88**	**0.23**	**50**
BLL009	0.967	0.978	0.967	0.869	0.841	0.723	0.788	0.763	0.794	0.860	0.938	0.971	**0.86**	**0.26**	**10**
DNA001	0.981	0.980	0.951	0.904	0.851	0.729	0.745	0.763	0.787	0.805	0.872	0.944	**0.86**	**0.25**	**35**
WPA001	0.946	0.925	0.931	0.912	0.872	0.715	0.521	0.455	0.480	0.541	0.834	0.892	**0.85**	**0.49**	**9**
GYS016	0.908	0.918	0.835	0.795	0.593	0.828	0.815	0.661	0.837	0.694	0.792	0.845	**0.82**	**0.33**	**7**
SIN001	0.921	0.922	0.920	0.889	0.701	0.596	0.737	0.681	0.694	0.765	0.845	0.855	**0.81**	**0.33**	**14**
GYS008	0.911	0.919	0.883	0.880	0.809	0.750	0.768	0.634	0.699	0.683	0.769	0.898	**0.79**	**0.29**	**4**
WPA004	0.913	0.928	0.893	0.781	0.487	0.730	0.430	0.407	0.708	0.821	0.787	0.789	**0.78**	**0.52**	**7**
BUD005	0.941	0.957	0.930	0.889	0.690	0.484	0.268	0.201	0.482	0.751	0.807	0.900	**0.78**	**0.76**	**11**
OAK004	0.910	0.932	0.911	0.870	0.593	0.381	0.495	0.517	0.617	0.609	0.741	0.833	**0.68**	**0.55**	**10**
WPA003	0.901	0.896	0.865	0.852	0.603	0.381	0.266	0.406	0.427	0.523	0.708	0.815	**0.66**	**0.64**	**6**
WPA006	0.867	0.922	0.863	0.583	0.371	0.622	0.417	0.303	0.575	0.666	0.748	0.741	**0.64**	**0.62**	**13**
WPA008	0.860	0.905	0.829	0.807	0.394	0.398	0.302	0.307	0.378	0.412	0.705	0.804	**0.56**	**0.60**	**6**
WPA007	0.842	0.906	0.692	0.422	0.410	0.341	0.302	0.236	0.421	0.436	0.672	0.675	**0.43**	**0.67**	**7**

Table 9. Site-specific objectives listed for each month for the nitrate enrichment variable (uM) used in the Enrichment module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
GYS004	30.12	34.41	27.84	20.80	17.42	10.35	6.74	9.71	10.01	13.67	21.21	20.19	18.81	27.67	12
WPA001	42.67	36.63	22.42	29.50	11.12	3.75	0.82	2.23	2.99	8.02	22.69	31.69	16.77	41.85	9
GYS008	16.34	14.93	11.93	12.19	6.38	1.23	-0.95	4.19	1.40	9.10	7.61	16.03	8.35	17.29	4
WPA003	12.67	11.61	10.36	5.43	0.18	-0.54	-0.29	0.53	-1.20	0.62	7.01	6.56	3.02	13.86	6
WPA008	4.37	3.93	1.29	0.37	-0.11	-0.63	-0.26	-0.50	-1.98	-2.71	1.15	2.48	0.13	7.08	6
GYS016	-0.06	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	7
WPA004	-0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.04	0.00	0.12	7
ADM002	2.29	1.26	0.13	-0.10	-2.03	-1.93	-2.58	-1.73	-2.97	-0.53	-0.43	-0.43	-0.48	5.26	50
PSS019	5.85	5.31	0.38	-0.93	-4.87	-6.18	-8.99	-8.69	-6.80	-0.04	-0.66	2.34	-0.80	14.84	50
WPA007	-0.57	0.56	-2.17	-1.60	-0.70	-0.64	-0.40	-0.58	-2.17	-2.63	-1.03	-4.34	-0.87	4.90	7
WPA006	-0.86	0.88	-1.95	-1.28	-0.74	-0.69	-0.27	-1.47	-2.04	-2.25	-0.81	-2.98	-1.07	3.86	13
GRG002	0.84	1.81	2.02	-1.62	-4.29	-6.59	-6.01	-5.39	-3.19	-1.50	0.66	1.21	-1.56	8.60	50
CMB003	4.10	5.88	4.60	3.39	-3.01	-6.66	-8.58	-5.72	-5.19	-4.25	-0.43	2.34	-1.72	14.45	50
ELB015	4.52	4.83	5.62	1.76	-2.99	-6.88	-9.12	-6.08	-5.45	-4.03	-0.88	3.43	-1.93	14.74	50
HCB004	3.32	-3.28	0.97	-1.97	-1.78	-3.84	-6.81	-5.07	-7.54	-1.53	0.95	-1.96	-1.97	10.86	50
PSB003	4.36	4.96	3.80	0.89	-3.69	-8.27	-10.63	-8.22	-5.27	-3.10	-1.19	1.40	-2.15	15.59	29
ADM003	3.95	4.69	1.61	-0.73	-3.47	-8.59	-12.60	-10.24	-10.43	-5.53	-1.95	1.25	-2.71	17.29	50
EAP001	4.88	5.11	3.64	0.68	-4.55	-9.16	-11.84	-8.36	-8.35	-4.28	-1.71	2.41	-3.00	16.96	50
ADM001	2.91	2.95	1.12	-2.29	-5.49	-6.20	-8.06	-5.48	-5.99	-3.72	-1.17	-0.54	-3.00	11.01	50
SAR003	6.07	4.26	-2.50	2.19	-1.62	-6.66	-11.19	-7.08	-11.07	-12.98	-3.97	1.94	-3.24	19.05	50
GOR001	4.89	5.71	3.39	-0.77	-6.65	-10.79	-9.33	-9.69	-10.77	-6.59	-2.50	4.67	-4.54	16.50	50
NSQ002	4.79	5.15	3.26	-3.62	-10.47	-14.25	-12.43	-11.58	-14.47	-10.22	-4.00	2.15	-7.11	19.62	50
DNA001	5.90	5.83	2.35	-3.13	-12.08	-14.69	-14.19	-14.30	-15.40	-11.60	-4.49	2.20	-8.04	21.30	35
SIN001	4.81	4.88	0.37	-5.59	-14.02	-18.03	-16.71	-14.83	-16.92	-10.67	-3.12	0.83	-8.13	22.92	14
BLL009	4.73	3.01	0.36	-8.30	-10.79	-16.98	-15.92	-15.36	-14.45	-8.50	0.37	3.14	-8.40	21.71	10
OAK004	7.21	6.76	1.63	-5.12	-17.50	-19.16	-20.82	-20.39	-20.67	-15.03	-3.48	2.44	-10.08	28.04	10
BUD005	5.16	6.95	2.79	-3.93	-16.56	-18.01	-21.43	-20.82	-21.67	-14.89	-6.27	-0.42	-10.58	28.62	11

Table 10. Site-specific objectives listed for each month for the phosphate enrichment variable (uM) used in the Enrichment module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
HCB004	0.89	0.10	0.63	0.48	0.41	0.54	0.82	1.10	1.62	1.25	0.89	0.73	0.78	1.52	50
WPA007	0.16	0.10	-0.04	0.06	0.24	0.26	0.42	0.58	0.56	0.50	0.26	0.20	0.25	0.61	7
OAK004	0.75	0.57	0.26	-0.36	-0.95	-0.56	-0.16	0.18	0.22	0.41	0.50	0.81	0.24	1.76	10
GYS004	0.14	0.12	0.25	0.19	0.25	0.27	0.06	0.19	0.34	0.22	0.24	0.15	0.21	0.28	12
GYS008	0.17	0.08	0.10	0.22	0.25	0.00	-0.09	0.30	0.25	0.37	0.27	0.12	0.20	0.46	4
WPA008	0.12	0.12	0.06	0.01	0.18	0.21	0.37	0.57	0.59	0.53	0.21	0.16	0.19	0.59	6
BUD005	0.68	0.58	0.25	-0.18	-0.99	-0.01	-0.16	0.23	0.03	0.04	0.38	0.63	0.13	1.67	11
WPA006	0.11	0.06	-0.07	-0.04	0.12	0.08	0.20	0.21	0.16	0.10	0.19	0.13	0.12	0.27	13
ELB015	0.53	0.45	0.33	0.17	-0.26	-0.30	-0.32	-0.15	-0.05	0.05	0.29	0.36	0.11	0.85	50
CMB003	0.49	0.38	0.38	0.12	-0.02	-0.39	-0.43	0.01	-0.01	0.10	0.29	0.41	0.11	0.91	50
PSB003	0.62	0.50	0.35	0.08	-0.26	-0.31	-0.52	-0.35	-0.03	0.10	0.24	0.33	0.09	1.14	29
WPA001	0.05	0.10	0.11	0.14	0.06	-0.05	-0.08	0.00	0.06	0.19	0.11	0.11	0.08	0.27	9
WPA003	0.00	-0.01	0.05	0.00	0.11	0.07	0.05	0.11	0.28	0.24	0.03	0.03	0.05	0.28	6
NSQ002	0.58	0.60	0.38	-0.22	-0.63	-0.38	-0.36	-0.05	-0.20	0.14	0.34	0.43	0.04	1.23	50
DNA001	0.74	0.64	0.31	-0.18	-0.73	-0.36	-0.35	-0.08	-0.16	0.16	0.40	0.49	0.04	1.48	35
GOR001	0.66	0.59	0.41	-0.15	-0.34	-0.25	-0.35	-0.05	-0.15	0.07	0.30	0.42	0.01	1.01	50
ADM002	0.15	0.11	0.05	-0.07	-0.17	-0.02	-0.16	-0.02	-0.10	0.04	0.04	0.13	0.01	0.32	50
GYS016	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7
WPA004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7
EAP001	0.59	0.42	0.39	-0.03	-0.26	-0.44	-0.65	-0.39	-0.32	0.03	0.18	0.35	0.00	1.24	50
PSS019	0.47	0.40	0.00	-0.04	-0.27	-0.21	-0.49	-0.32	-0.15	0.18	0.29	0.29	-0.02	0.96	50
ADM001	0.35	0.27	0.18	-0.10	-0.28	-0.28	-0.41	-0.18	-0.18	0.02	0.06	0.15	-0.04	0.76	50
GRG002	0.21	0.17	0.14	-0.15	-0.34	-0.39	-0.61	-0.34	-0.12	-0.03	0.13	0.10	-0.08	0.82	50
ADM003	0.55	0.40	0.20	-0.07	-0.38	-0.47	-0.60	-0.57	-0.38	-0.09	0.20	0.21	-0.08	1.15	50
SIN001	0.61	0.47	0.22	-0.51	-0.90	-0.40	-0.46	-0.17	-0.26	-0.03	0.36	0.46	-0.10	1.51	14
SAR003	0.50	0.43	-0.01	0.18	-0.19	-0.19	-0.55	-0.25	-0.48	-0.28	0.18	0.31	-0.10	1.05	50
BLL009	0.20	0.20	-0.19	-0.94	-0.84	-1.10	-0.90	-0.75	-0.36	-0.28	0.11	0.15	-0.32	1.30	10

Table 11. Site-specific objectives listed for each month for the ammonium enrichment variable (uM) used in the Enrichment module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
WPA001	1.74	2.86	1.59	1.79	1.64	0.54	1.61	2.75	4.26	6.09	3.26	2.35	2.07	5.56	9
SIN001	1.99	1.77	1.51	0.12	1.31	2.77	1.96	1.41	2.10	2.57	4.43	4.00	1.97	4.31	14
GYS004	1.70	1.21	1.41	1.89	1.36	1.32	1.95	3.15	4.15	3.99	2.56	1.15	1.80	3.00	12
DNA001	0.24	0.17	0.62	0.41	0.41	1.72	2.04	1.29	1.53	2.46	2.02	1.14	1.21	2.28	35
GYS008	1.63	1.23	1.03	1.10	0.85	0.37	0.63	2.07	2.36	3.83	2.41	1.10	1.16	3.46	4
OAK004	2.33	1.59	1.36	0.41	-0.44	-0.07	-0.13	-0.64	0.75	5.09	5.70	4.28	1.06	6.34	10
WPA003	0.75	1.60	0.52	0.39	1.51	0.11	-0.01	1.01	0.93	3.41	2.20	0.95	0.94	3.41	6
BUD005	1.35	0.94	0.93	0.87	0.68	2.07	0.57	0.17	0.45	2.92	3.66	2.16	0.94	3.50	11
NSQ002	0.05	0.08	0.54	0.19	0.65	1.71	2.04	1.16	1.60	2.24	1.47	0.61	0.91	2.20	50
CMB003	0.28	0.40	0.50	-0.02	0.98	1.34	0.77	0.30	1.97	0.76	0.55	0.28	0.53	1.98	50
GOR001	0.01	-0.03	0.34	-0.18	0.41	1.61	1.59	0.87	1.42	1.35	0.59	0.07	0.50	1.78	50
BLL009	0.70	0.16	0.18	0.46	0.42	-0.31	0.03	0.10	1.41	1.96	1.23	0.50	0.44	2.28	10
WPA008	1.39	0.61	-0.12	0.16	0.19	0.09	-0.05	0.16	0.70	1.57	1.30	0.49	0.34	1.70	6
ADM001	0.08	-0.03	0.32	0.17	0.36	1.20	0.86	0.53	0.24	-0.03	0.03	0.09	0.21	1.23	50
PSB003	0.09	0.02	0.32	0.04	0.21	1.58	0.92	0.12	0.20	0.54	0.05	0.13	0.16	1.55	29
ADM002	0.00	-0.02	0.11	-0.03	0.37	0.50	0.71	0.43	0.28	-0.01	0.06	0.10	0.10	0.74	50
ADM003	0.02	-0.05	0.28	-0.18	0.08	1.06	0.67	0.03	0.14	0.13	0.04	0.12	0.10	1.24	50
ELB015	0.01	0.01	0.07	-0.16	0.68	1.08	2.03	-0.01	0.51	0.09	-0.08	0.27	0.08	2.18	50
PSS019	0.04	0.07	0.66	-0.35	0.11	0.44	0.11	-0.53	-0.55	-0.29	-0.03	0.11	0.05	1.21	50
GYS016	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	7
WPA004	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.02	7
EAP001	-0.02	-0.05	0.11	-0.24	0.17	1.04	1.39	-0.34	-0.01	-0.45	0.10	0.00	-0.01	1.83	50
SAR003	0.04	-0.01	0.31	-0.47	-0.02	0.38	-0.14	-0.67	-0.44	-0.13	0.47	0.03	-0.02	1.13	50
GRG002	-0.01	-0.05	0.02	0.03	0.30	-0.37	-0.28	-0.39	-0.30	-0.39	0.38	0.06	-0.03	0.77	50
HCB004	-0.01	0.07	0.16	-0.23	0.24	-0.57	-0.09	-0.78	-0.51	-0.49	0.09	0.22	-0.05	1.02	50
WPA007	0.91	0.48	-0.35	-0.09	-0.45	-0.14	-0.01	-0.42	-0.12	0.41	1.01	-0.38	-0.10	1.46	7
WPA006	0.54	0.19	-0.36	-0.09	-0.23	-0.07	-0.59	-0.47	-0.47	0.02	0.90	-0.34	-0.16	1.49	13

Table 12. Site-specific objectives listed for each month for the ratio of dissolved inorganic nitrogen to phosphate used in the Impact module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
WPA001	209.79	151.19	123.55	196.58	67.46	24.81	14.56	12.60	13.30	21.02	58.34	121.79	**63**	**197**	**9**
GYS004	120.55	168.82	103.88	75.39	66.25	37.42	27.52	26.34	24.05	29.10	56.32	98.47	**61**	**145**	**12**
GYS008	47.56	45.60	29.52	28.83	14.66	11.58	8.53	9.35	10.12	16.86	18.30	45.42	**18**	**39**	**4**
WPA003	52.72	41.75	40.00	34.32	10.01	3.13	1.36	2.68	5.38	10.42	22.01	24.80	**16**	**51**	**6**
ADM002	11.82	11.92	12.12	12.19	11.45	11.68	11.71	11.23	10.98	11.37	11.42	11.51	**12**	**1**	**50**
GRG002	11.32	11.78	12.08	11.57	11.10	9.85	10.02	10.54	10.50	11.04	11.39	11.60	**11**	**2**	**50**
ADM001	11.52	11.81	12.18	11.75	10.89	10.79	9.96	10.05	9.81	10.36	11.02	11.03	**11**	**2**	**50**
CMB003	11.62	12.50	12.46	12.37	11.71	10.73	9.73	9.75	10.00	9.94	10.57	11.05	**11**	**3**	**50**
ADM003	11.53	11.64	12.02	11.31	11.01	10.34	9.31	8.49	9.05	9.83	10.73	11.12	**11**	**4**	**50**
ELB015	10.89	11.51	12.43	11.97	11.57	10.85	10.08	9.30	9.02	9.69	10.77	11.25	**11**	**3**	**50**
PSB003	11.12	11.51	12.27	12.08	11.21	10.46	9.38	8.61	9.39	9.92	10.34	10.60	**11**	**4**	**29**
BLL009	13.26	12.38	14.07	11.01	9.40	5.81	5.82	5.72	6.36	10.01	11.70	11.89	**11**	**8**	**10**
PSS019	11.43	11.89	12.00	11.97	10.76	9.93	7.94	8.49	8.63	10.05	9.97	11.08	**10**	**4**	**50**
EAP001	11.17	11.82	12.05	11.64	10.58	10.10	8.97	8.74	8.77	9.62	9.87	10.86	**10**	**3**	**50**
SAR003	12.13	11.36	11.62	10.96	10.84	9.81	8.22	8.23	7.48	6.35	9.61	10.89	**10**	**6**	**50**
GOR001	11.11	11.36	11.94	11.75	10.39	9.37	8.67	7.71	7.80	9.23	9.57	11.51	**10**	**4**	**50**
SIN001	11.89	12.24	12.66	10.97	7.27	4.67	4.77	5.03	5.71	8.88	10.84	11.34	**10**	**8**	**14**
NSQ002	11.47	11.34	11.80	11.22	10.18	7.51	6.97	6.43	6.34	8.37	9.15	10.80	**10**	**5**	**50**
GYS016	17.52	16.46	10.94	9.61	6.77	6.72	6.56	6.04	8.83	9.50	9.70	17.60	**10**	**12**	**7**
DNA001	11.18	11.72	11.85	11.35	8.09	6.36	6.53	5.56	5.07	7.37	9.07	10.87	**9**	**7**	**35**
WPA008	25.57	19.92	13.24	21.01	2.13	0.90	0.77	1.00	2.16	3.17	13.82	14.79	**8**	**25**	**6**
OAK004	12.42	13.07	12.05	9.82	0.94	1.76	0.36	0.25	1.77	6.51	10.94	10.89	**8**	**13**	**10**
BUD005	11.38	12.49	12.18	10.72	5.47	5.02	1.01	0.69	1.60	6.70	9.31	11.12	**8**	**12**	**11**
HCB004	9.54	9.56	9.91	9.01	7.44	6.85	4.98	5.24	5.34	6.31	8.36	8.57	**8**	**5**	**50**
WPA004	17.67	15.11	20.45	7.00	4.38	2.98	1.56	2.09	5.54	7.47	12.59	13.69	**7**	**19**	**7**
WPA006	16.70	13.54	13.52	3.04	0.40	0.58	0.27	0.81	2.28	4.64	11.52	7.80	**4**	**16**	**13**
WPA007	18.48	14.22	4.74	1.13	0.88	0.46	0.38	0.58	1.25	2.84	11.06	5.39	**2**	**18**	**7**

Table 13. Site-specific objectives listed for each month for the ratio of silicate to dissolved inorganic nitrogen used in the Impact module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
WPA007	4.35	5.63	40.46	117.68	66.71	122.89	86.22	30.60	15.73	10.80	5.17	10.73	23	119	**7**
WPA008	4.33	5.95	13.57	53.15	59.05	99.90	134.03	28.71	19.00	10.18	4.69	5.83	16	130	**6**
WPA006	4.02	5.16	9.39	78.19	190.67	127.36	238.33	29.77	12.16	9.46	3.94	7.21	11	234	**13**
WPA004	3.62	4.43	7.13	20.77	31.20	47.79	41.61	15.02	5.62	6.62	3.35	4.91	7	44	**7**
WPA003	3.56	4.51	5.55	7.08	17.40	39.93	74.52	12.83	7.06	5.39	3.62	4.07	6	71	**6**
GYS004	4.63	3.67	4.81	6.61	9.71	10.32	9.85	8.73	5.78	5.85	5.15	3.22	6	7	**12**
GYS016	4.70	4.16	6.71	9.66	17.84	6.56	8.87	5.80	4.17	4.63	3.44	5.06	5	14	**7**
GYS008	4.71	5.00	4.41	6.71	10.34	11.48	14.50	6.71	5.19	4.62	4.85	4.10	5	10	**4**
OAK004	3.38	3.55	4.14	5.70	31.46	13.08	124.94	112.38	17.35	4.26	3.16	2.54	5	122	**10**
WPA001	3.24	3.58	4.35	4.15	11.34	29.75	22.62	9.41	5.37	4.75	3.84	2.81	5	27	**9**
BUD005	2.66	2.74	2.70	3.58	11.08	4.59	190.55	196.28	69.62	4.24	2.85	2.63	4	194	**11**
HCB004	2.72	2.92	2.69	2.89	3.47	3.09	3.19	4.06	6.04	3.30	2.75	3.40	3	3	**50**
BLL009	2.08	2.09	2.34	2.55	3.15	17.06	11.20	5.50	4.23	2.95	2.13	2.02	3	15	**10**
SIN001	2.31	2.24	2.17	2.86	3.93	2.58	6.93	7.44	5.45	2.87	2.40	2.20	3	5	**14**
NSQ002	2.36	2.43	2.38	2.38	2.67	2.86	3.69	3.54	4.01	2.85	2.53	2.29	3	2	**50**
DNA001	2.40	2.51	2.45	2.51	3.31	2.28	3.33	3.94	5.09	3.17	2.59	2.43	3	3	**35**
SAR003	2.43	2.37	2.70	2.52	2.45	2.28	3.68	2.23	2.32	4.49	2.61	2.21	2	2	**50**
GOR001	2.26	2.34	2.34	2.41	2.20	2.18	2.71	3.00	2.89	2.51	2.38	2.40	2	1	**50**
PSS019	2.28	2.31	2.39	2.52	2.51	2.32	3.76	2.36	2.09	2.05	2.19	2.11	2	2	**50**
ADM003	2.17	2.21	2.25	2.31	2.30	2.23	3.09	2.29	2.35	2.29	2.16	2.06	2	1	**50**
ELB015	2.32	2.19	2.20	2.37	2.70	2.25	2.17	2.44	2.21	2.13	2.28	2.55	2	1	**50**
EAP001	2.13	2.23	2.19	2.31	2.41	2.16	2.39	2.48	2.47	2.06	2.19	2.24	2	0	**50**
PSB003	2.25	2.19	2.20	2.23	2.34	2.16	2.48	2.38	2.14	2.05	2.12	2.00	2	0	**29**
CMB003	2.35	2.43	2.31	2.22	2.12	1.97	2.02	2.16	2.26	2.14	2.31	2.16	2	0	**50**
ADM001	2.26	2.15	2.12	2.21	2.34	2.02	2.05	1.96	1.96	2.01	2.16	1.98	2	0	**50**
GRG002	2.05	2.06	2.01	1.89	1.98	2.44	2.68	2.45	2.22	2.03	1.95	2.01	2	1	**50**
ADM002	1.90	1.93	1.87	1.91	1.92	1.74	1.89	1.86	1.85	1.90	1.98	1.88	2	0	**50**

Table 14. Site-specific objectives listed for each month for the chlorophyll-a concentration variable (mg/m^2) used in the Impact module (see Table 3 for table explanation).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Median	Range	Depth (m)
HCB004	37.6	185.2	144.5	189.8	254.2	191.9	265.6	252.9	194.2	135.4	113.6	26.8	**188**	**239**	**50**
SAR003	30.2	32.3	110.5	151.3	189.7	167.0	149.1	261.8	206.0	159.6	97.4	26.7	**150**	**235**	**50**
DNA001	18.3	26.3	47.0	187.2	385.8	114.9	128.4	232.1	192.6	154.1	68.7	27.7	**122**	**367**	**35**
PSS019	23.4	37.2	170.5	121.2	224.6	111.6	164.3	259.6	177.8	69.9	27.6	23.9	**116**	**236**	**50**
BUD005	10.6	16.7	21.8	96.1	235.0	128.2	330.0	346.6	360.2	232.8	47.1	8.4	**112**	**352**	**11**
NSQ002	20.2	20.4	41.9	114.5	419.0	95.1	229.1	291.6	245.4	191.6	63.6	25.3	**105**	**399**	**50**
ADM001	18.6	27.9	49.3	74.2	237.1	158.9	282.2	195.0	163.8	109.1	23.2	23.1	**92**	**264**	**50**
GOR001	3.9	27.2	49.6	101.4	281.0	78.0	144.9	248.0	235.8	106.8	35.5	18.1	**90**	**277**	**50**
SIN001	9.8	20.6	47.4	120.5	176.0	122.8	89.8	125.7	166.9	64.9	20.5	6.5	**77**	**169**	**14**
WPA006	22.3	35.7	53.5	76.3	77.8	89.5	122.3	123.5	104.1	85.9	37.4	19.8	**77**	**104**	**13**
GRG002	24.4	23.9	69.4	83.2	128.6	105.9	109.7	129.3	123.8	60.4	18.2	13.2	**76**	**116**	**50**
ELB015	14.6	18.9	42.1	69.2	110.4	107.6	115.8	142.9	120.6	70.2	19.1	15.6	**70**	**128**	**50**
EAP001	11.2	20.7	45.5	77.0	294.2	57.4	164.7	242.6	322.4	155.3	28.6	21.7	**67**	**311**	**50**
ADM003	14.8	47.4	49.5	39.6	224.6	124.5	139.2	196.8	130.0	79.6	17.1	16.2	**65**	**210**	**50**
BLL009	7.3	15.5	48.6	117.3	83.9	85.0	73.1	97.0	91.0	22.6	14.5	3.7	**61**	**114**	**10**
CMB003	13.3	20.1	43.3	97.3	116.7	57.9	98.6	153.1	123.0	63.7	10.9	9.3	**61**	**144**	**50**
WPA004	10.3	16.5	28.2	57.0	56.3	57.1	68.2	62.2	51.8	64.5	21.4	10.3	**54**	**58**	**7**
PSB003	7.9	22.4	26.8	55.7	171.0	100.2	105.5	149.2	136.8	38.0	12.3	8.0	**47**	**163**	**29**
ADM002	17.0	14.8	36.5	38.3	97.5	45.9	159.4	131.9	95.5	55.2	24.1	18.6	**42**	**145**	**50**
OAK004	8.2	18.6	24.2	40.3	102.4	103.8	115.0	118.4	100.1	41.7	25.1	12.2	**41**	**110**	**10**
GYS016	13.5	13.1	23.9	43.9	32.1	51.2	62.0	54.8	57.9	47.2	19.5	7.4	**38**	**55**	**7**
WPA001	15.8	12.5	24.8	25.3	54.2	89.8	69.5	80.5	64.4	38.0	22.7	19.2	**32**	**77**	**9**
WPA007	13.2	16.1	25.9	31.3	31.1	35.1	41.8	44.2	46.4	38.9	18.9	11.8	**31**	**35**	**7**
WPA003	8.6	16.3	23.9	40.5	38.5	40.6	53.9	39.4	35.2	24.0	19.2	7.8	**30**	**46**	**6**
WPA008	11.7	9.5	19.2	29.7	35.2	34.8	41.6	45.9	38.6	27.8	17.2	9.0	**29**	**37**	**6**
GYS004	12.9	16.5	18.5	23.3	43.8	39.7	65.5	77.9	43.7	23.9	28.2	8.1	**26**	**70**	**12**
GYS008	5.1	7.8	10.5	14.3	22.7	22.9	38.8	29.7	19.5	17.0	14.0	5.8	**16**	**34**	**4**

Communicating the MWCI

Communication Strategy

The following section presents one approach to exploring and reporting the MWCI. Examples shown in this section illustrate the potential of the modular structure to explore causes of changing MWCI scores.

Our intention is to provide a reporting tool that makes the MWCI accessible to all users. We chose to present the index and its modules using several modes of information detail and communication to reach a wider audience. Levels include schematic and text summaries, time series, and statistical trends of individual variables. By using different modes of communication, we hope to maximize and tailor each level to a specific user base.

Our communication structure lays out the entire data aggregation process of the index (Figure 4). Information is progressively condensed and generalized to highlight significant changes, while retaining particular aspects of interest in the time-series presentation. We anticipate that transparency also leads to a higher acceptance, a challenge for indices carrying a larger number of variables.

Multiple levels of numerical detail (Figure 4) provide an option for individualized water quality tracking and allow scientists and natural resource managers to find a level that best fits their specific needs. On the highest level, we provide an overview for the public user and focus on statistically significant trends. Some detail-oriented users will want access to the source data, time series, and statistics that are available on the level showing a 10-year time series.

Non-Numerical Reporting of the MWCI

On the highest level, the MWCI uses non-numerical information in the form of maps, schematic drawings, and text. We refined a graphical approach that was previously selected for the State of the Sound (State of the Sound, 2007). In the State of the Sound, an arrow superimposed on a scale was used to illustrate the direction and severity of change. We decided to continue and refine this visual reporting tool while providing a more quantitative approach to the length, direction, and scale of the arrow.

Given the differences in geographical settings, the concept of shifting baselines (trends) can be non-intuitive. Therefore, we placed the MWCI into a qualitative context of existing chronic water quality conditions. We use a color gradient that we place behind the arrow (Figure 5). The additional information is for contextual information only and remains static. We do this by graphically merging our index trends with information on water quality. To see how we calculated the color gradient, see the section in this report entitled, *Areas of Chronic Water Quality Issues as Complementary Information to the MWCI.*

The intention of the color gradient is to place observed changes into the context of chronic water quality gradients. The approach is used exclusively as a communication tool and is not intended to replace a water quality assessment based on water quality standards.

While we calculate these two aspects independently and present them separately on maps (Figure 4a), we have graphically merged them on the regional reporting level (Figure 4b and Figure 5).

A combination of arrow and color gradient allows us to communicate different yet complementary pieces of information. A color gradient and precisely scaled arrow can report the MWCI (changing baseline conditions) side-by-side with pre-existing chronic water quality (1999-2008). The combined approach communicates if changes are in areas that are generally of a higher concern.

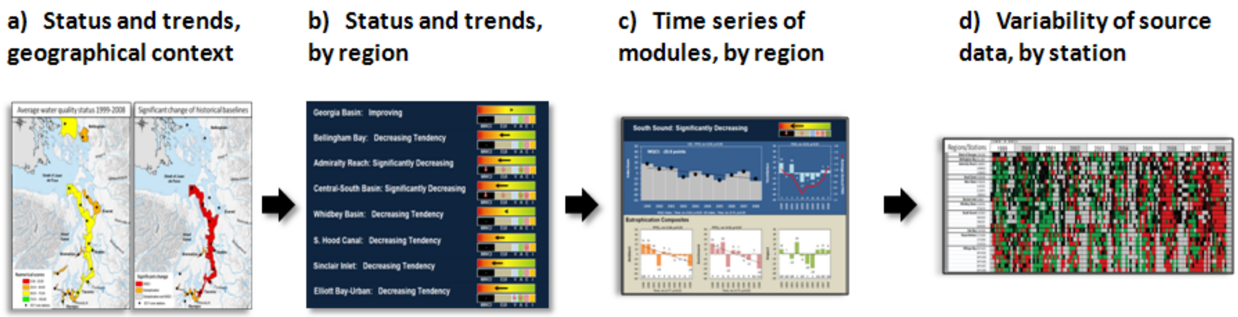

Figure 4. Visual presentation of different layers within the MWCI.

Reporting scheme of the MWCI using multiple layers of visual presentation. Each layer provides information in different spatial or temporal context. We explain each layer in Figures 5, 6, 9, 11-13.

Four different layers allow users to select which aspect of the data structure to explore:

a) Maps present the geographical context of the existing and developing water quality issues.

b) Regional summaries provide a schematic assessment of significantly shifting baselines in context of pre-existing regional conditions.

c) A time series of individual modules and indices provide temporal context.

d) Variability of source data features large-scale fluctuations in water quality variables throughout the station network.

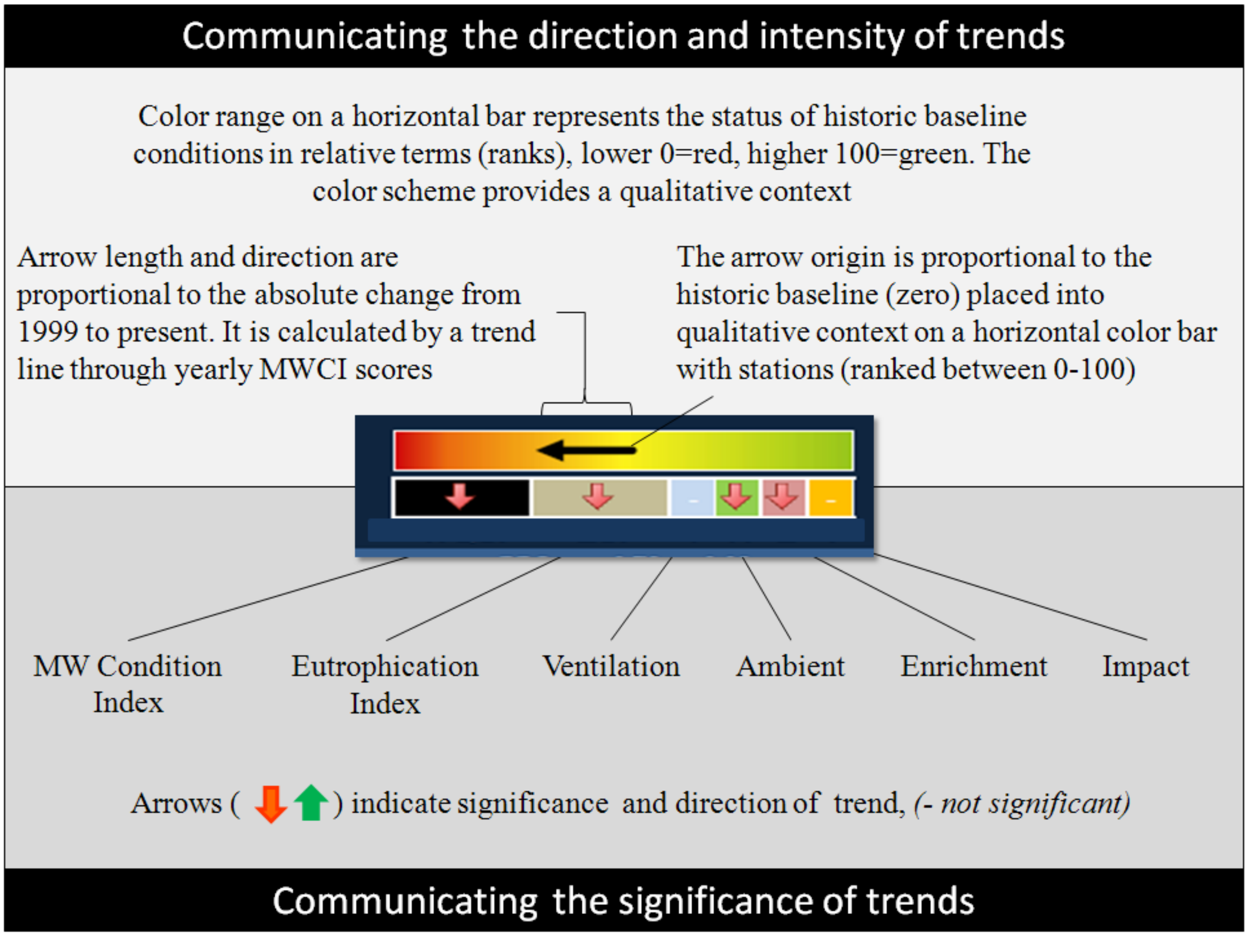

Figure 5. Communicating the status and trends for water quality by region.

For a regional perspective, we present information in the form of a calibrated arrow. Its length and direction summarizes the relative change in conditions of the MWCI since the establishment of baseline conditions in 1999 to 2008. Specifically, we scaled the length to the change from 1999 to present. To reduce inter-annual variability, we use the slope of a trend line to calculate the absolute change since 1999 (not shown). Additionally, we communicate the status of pre-existing water quality condition (1999 to 2008) using a color gradient to denote the range of conditions found among regions during the establishment of the baseline period. We superimpose the arrow graphically on the static color gradient. The origin of the arrow reflects the pre-existing conditions at a given station relative to other stations' baseline conditions. For example, a baseline in Oakland Bay (low quality) is more in the red than in the Main Basin (better quality).

Color-coded squares below the horizontal color bar summarize the module trends of the index. Up or down arrows report significant trends (Spearman Rank correlations with time, $p<0.05$) in the indices (MWCI, Eutrophication Index) and each of the four modules (Ventilation, Ambient, Enrichment and Impact). A dash indicates the absence of a significant trend. An upward pointing arrow (green) indicates a significant positive change in the environment; a downward arrow (red) indicates a significant negative change.

This combined schematic presentation allows users to study the improvement or decline in water quality in the context of pre-existing conditions (1999-2008). The length and origin of the arrow illustrates the severity by which regional conditions have progressed from baseline. The color gradient shows the relative context if this occurred in a region with pre-existing low water quality conditions. Below the arrow, a tabular reporting system communicates if modules of the index show significant temporal trends over a 10-year period. The regional reporting level also includes numerical information that was used for the schematic simplification (Figure 6).

Numerical Reporting of the MWCI

If a significant trend is determined in any of the modules (using Spearman Rank correlation of score vs. time), an upward or downward pointing arrow appears in a tab. Tabs are left otherwise empty. The direction of the arrows in the tabs communicates a negative or positive significant 10-year trend, the color of the arrow emphasizes the quality of the change (good = up and green, or bad = down and red).

A detailed data layer shows individual module and index scores (Figure 4c, Figure 6) as well as trends over time. We designed this level to give the user more tools to explore and evaluate the interplay and change of module scores. We chose a running 10-year time window to provide sufficient temporal context to evaluate the effect of the Pacific Decadal Oscillation (PDO).

The temporal context addresses the needs of natural resource managers and scientists to explore changes in water conditions over time scales that match large-scale ocean fluctuations. The upper ribbon of the panel summarizes the entire panel and modules graphically repeating the reporting approach on the regional level and illustrating how both reporting approaches are connected.

Statistical tools are provided also over the 10-year timeframe to emphasize significant tends (Figure 6) and guide the communication of scientists and managers. To provide a context of influences beyond the reaches of Washington State, we included climatic and oceanographic information in the form of existing oceanic indices: PDO Index and Upwelling Index. The correlation of each module and index with NOAA's climatic and oceanographic indices communicates the large-scale ocean climate context. See the section in this report entitled, *MWCI in the Context of Climatic and Oceanographic Variability*.

At the foundation of the reporting matrix (Figure 4c), we present de-seasonalized source data for each of the 12 variables also over a 10-year timeframe. This level provides detailed insight into the monthly fluctuation and anomalies of all variables for each station. The level of presentation specifically targets scientists and marine industries.

A summary of our communication pyramid showing our information reduction for the MWCI on higher levels can be seen in Figure 7.

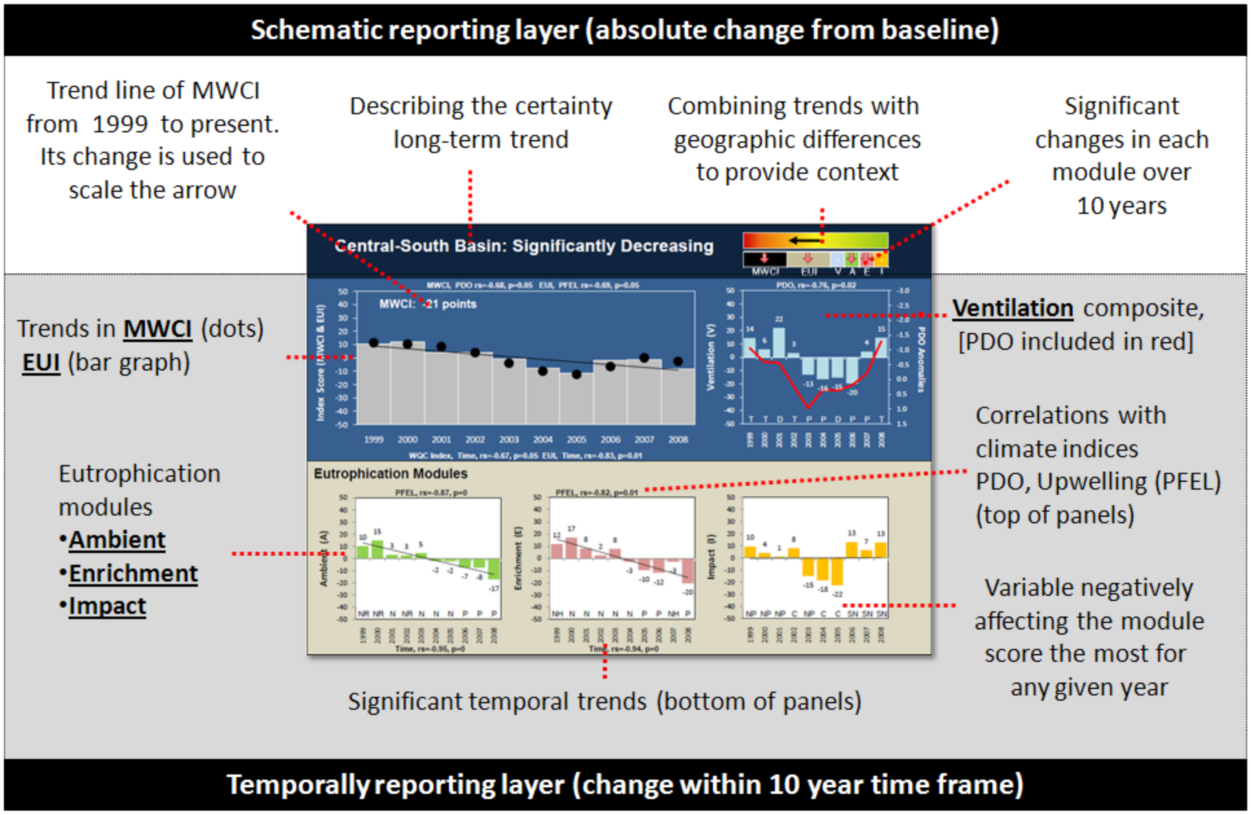

Figure 6. Communicating the temporal trend for regional water quality.

We present a temporal context for each module for the more interested index user. Ten-year trends provide the basis for significance testing and change in the schematic presentations on the top row (the upper banner is a summary interpretation of the tables below). Directly below, we present the annual MWCI and Eutrophication Index (EUI) scores and trend over a 10-year period in the larger graphic panel. The lower three panels show the time series of eutrophication modules: Ambient, Enrichment, and Impact. Lines communicate trends in the modules scores. The Ventilation module describes the physical influence on eutrophication and is due to its significance raised to the middle level to the right of the index panel.

We communicate statistically significant trends (Spearman Rank correlation against time) below each panel. To provide context within climate and oceanographic conditions, we superimpose anomalies of the Pacific Decadal Oscillation (PDO) Index on the Ventilation module (red line). We show statistical test results (Spearman Rank correlation) conducted for each module with two ocean indices, the PDO or NOAA's Upwelling Index (PFEL) above each panel. To point to drivers of the index, we display the lowest scoring variable within each module at the bottom of the panel.

AMBIENT: N = Nitrate, P = Phosphate, NR = Ratio of nitrate to dissolved inorganic nitrogen (DIN).
ENRICHMENT: N = Nitrate, P = Phosphate, A = Ammonium.
IMPACT: NP = Ratio of DIN to phosphate, SN = Ratio of silicate to DIN, C = Chlorophyll a.
VENTILATION: T = Thermal energy content, P = Potential energy, D = Dissolved oxygen.

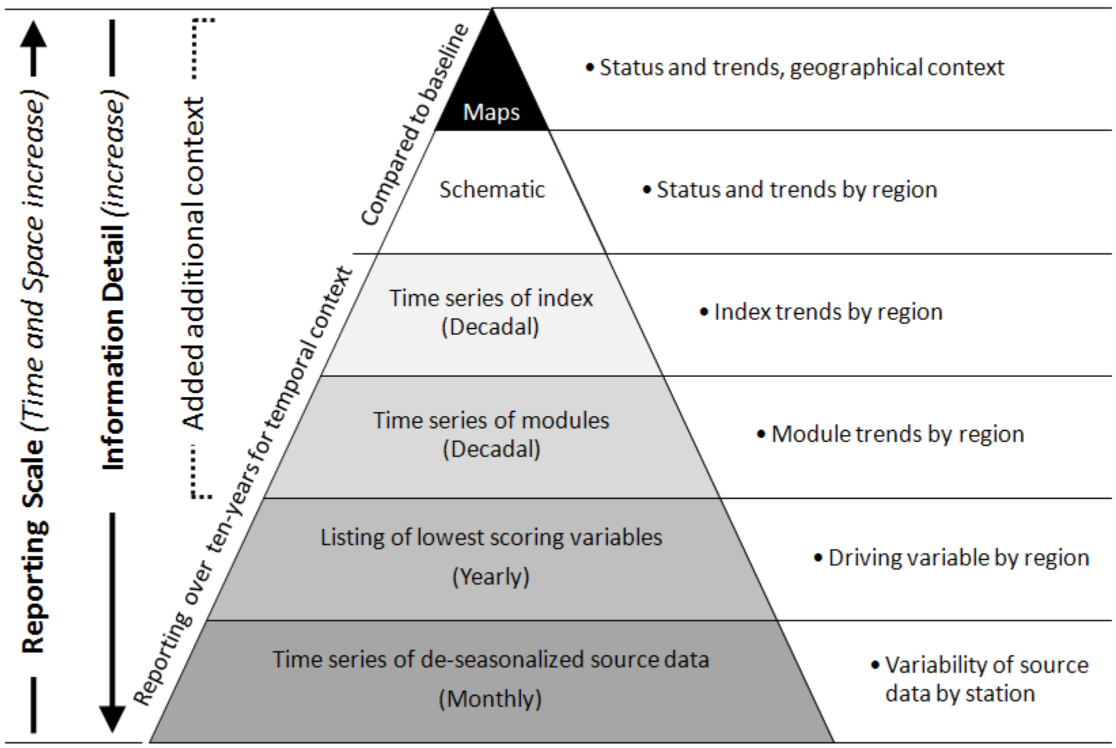

Figure 7. Hierarchy of scale and information for reported layers.

Our strategy to report the modular MWCI is to show different levels of detail and context that resonates with a broad range of users. Our presentation strategy spans the range from de-seasonalized source data to schematic presentations that focus only on significant changes in the environment. We present each step of the data aggregation so that the index can be used as an exploration and communication tool at the same time.

In the following sections we will present specific aspects of our communication strategy.

Reporting the MWCI by Region

We chose to condense the volume of information and reduce the large number of stations by forming statistically pre-determined reporting regions. This step is optional for large datasets and is explored in this report.

We pre-determined MWCI reporting regions statistically to reduce the number of stations (initially n=27) (Figure 8). With the help of reporting regions, we use individual station scores to generate an average regional score. This results in a reduced amount of information and complexity within Ecology's large monitoring network. The similarity between stations was statistically determined using the software program PRIMER (Clarke and Gorley, 2006). We used the full suite of variables available to the program for all core stations (n=16 variables, Table 15). One-hundred ninety-two (12 months x 16 variables=192) variables were clustered assuming average Euclidean distances resulting in 14 statistically distinct (significant) reporting regions. Average Euclidean distances is a common distance measure for multi-dimensional scaling. We expanded the reporting regions to 17 geographically coherent clusters (Figure 8).

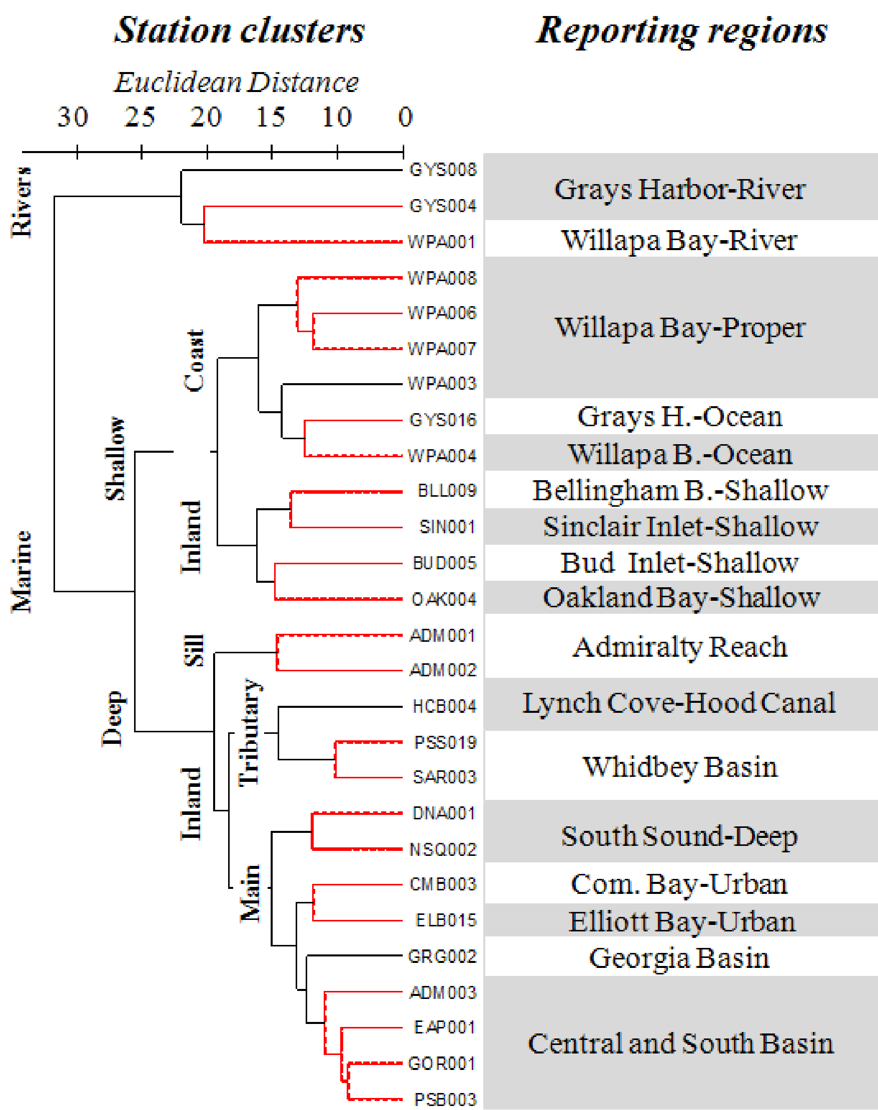

Figure 8. Grouping stations into 17 reporting regions based on similar characteristics.

Red lines indicate stations that are not significantly distinguishable using multi-dimensional scaling and have therefore been combined.

Com. Bay: Commencement Bay, Tacoma.
Central and South Basin: Central and South Basins of Puget Sound.

To provide a quantitative approach to selecting reporting regions, we grouped stations into statistically pre-determined reporting regions. We based station groups on multi-dimensional scaling criteria of 16 variables (Table 15). We used the full suite of available variables in the program to best differentiate the stations. The approach employed cluster analysis (PRIMER) using 10-year monthly averages of each variable. The analysis resulted in 192 individual variables (12 10-year monthly averages and 16 variables) accounting for seasonality. Some shallow stations grouped closely. We therefore separated shallow stations to achieve geographically coherent reporting regions.

Table 15. Variables used to define index-reporting regions by means of statistics.

We used all variables available from Ecology's core routine monitoring stations to allow the best differentiation for reporting regions.

Continuous measurements	Discrete samples	
	Concentrations	Ratios
Thermal energy content. Energy required for vertical mixing (-ΔPE). Dissolved oxygen content. Water clarity. Chlorophyll-a concentration. Similarity of station water density to nearby marine reference stations.	Ortho phosphate. Nitrate. Nitrite. Ammonia. Silicate. Fecal coliform bacteria. Enrichment of nitrate, phosphate, and ammonium.	Nitrate:DIN. Silicate:DIN.

DIN: Dissolved inorganic nitrogen

Areas of Chronic Water Quality Issues as Complementary Information to the MWCI

The MWCI reports on shifting baseline conditions. To place observations into the context of existing environmental conditions (e.g., some stations have lower water quality, others have higher water quality), we used a ranking scheme which compares stations relative to one another, using 16 water quality variables. This concept was introduced in the section entitled, *Non-Numerical Reporting of the MWCI*, and we expand on it here. We present this additional information on the higher schematic reporting levels to provide qualitative context for the public. It is not an integral part of the index calculation and we therefore explain it only briefly. We restrict the qualitative information on the water quality status to maps (Figure 4a) and color gradients on the regional layer of the reporting matrix (Figure 4c, Figure 6). The information should be used only for communication purposes.

We ranked stations (Figure 9) using a similar suite of water quality variables that we used in the MWCI. However, we limited our ranking scheme to yearly medians of each station's baseline conditions. We calculated station rank sums by adding ranks from individual variables and scaling rank sums between 0 and 100 for each station. Minima and maxima were determined using the theoretical achievable extremes at either end of the spectrum (e.g., a station would have consistently lowest or highest scores for all variables). We then selected the range in scales for station ranking (0-100). Resulting station ranks ranged from a low of 35 (Oakland Bay) to a high of 62 (north Admiralty Inlet). This approach allows sufficient space for the arrow to develop in either direction within the schematic reporting layer (Figure 5). We averaged station ranks using our statistically pre-determined reporting regions. We now could overlay the color gradient from 0 to 100 with the MWCI scale (-50 to +50) suited for the arrow. In this way, we graphically combined the arrow and schematic color gradient (Figure 6) to report change in the context of existing qualitative conditions.

The baseline is the only commonality both approaches share, which we show by the location of the base of the arrow on the color gradient.

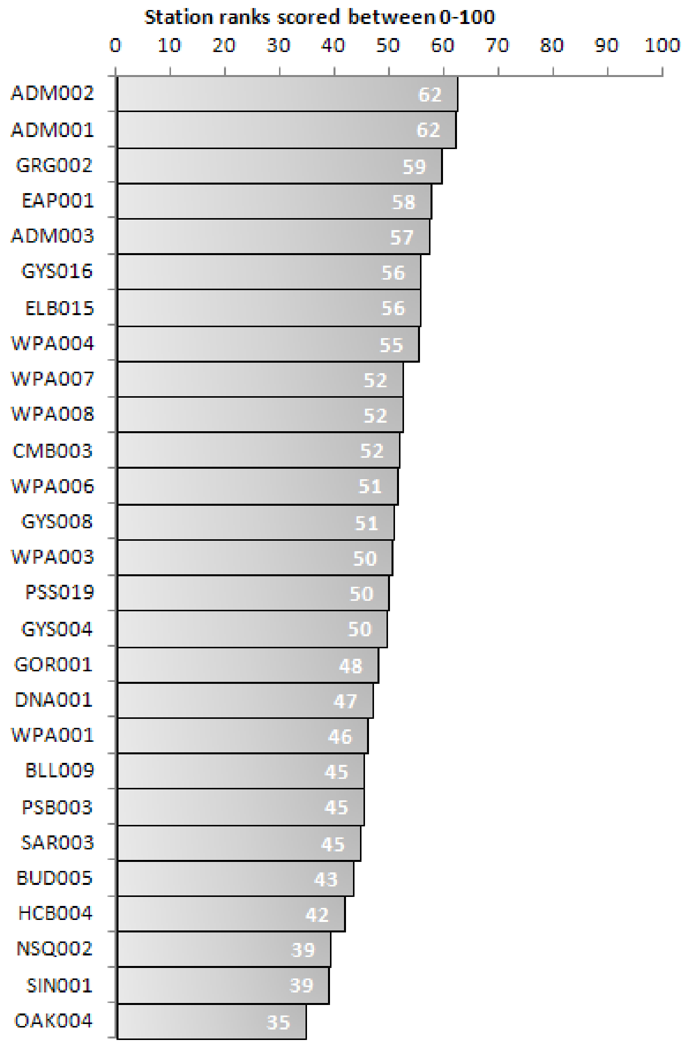

Figure 9. Reporting relative water quality within the 27-station network.

To provide the context of pre-existing conditions for higher reporting levels, we present relative water quality within our station network. This analysis is numerically independent from the MWCI and only for communication purposes. Ranks are based on the comparison of 16 water quality variables. We calculated station rank sums by adding ranks from individual variables and scaling rank sums between 0 and 100 for each station. See text for details.

We made one adjustment in the selection of variables. High river silicate concentrations strongly skewed the ranking towards river stations. Data collected closest to rivers reflect freshwater influences from meltwater during early summer and are fundamentally different from marine data used to develop the index. We replaced the variable with water transparency. The criteria for ranking stations are shown in Table 16.

Table 16. Criteria inherent to scoring stations.
This approach is for communication purposes only.

Improving with higher values	Improving with lower values
Physical variables	
Optical transparency of water.	Thermal energy content. Energy required for vertical mixing. Similarity in water masses based on density.
Chemical variables	
Silicate:DIN. DIN:phosphate. Dissolved oxygen content. Nitrate:DIN.	Nitrate and phosphate concentrations. Enrichment of nitrate, phosphate, and ammonium in relation to reference station (JEMS 30-80 meters).
Biological variable	
	Chlorophyll-a concentration

DIN: Dissolved inorganic nitrogen

MWCI in the Context of Climatic and Oceanographic Variability

We recognize that trends and variability in estuarine water quality cannot be understood in isolation of large-scale oceanographic patterns (Paerl et al., 2006). To provide the large-scale climatic context, we place the modules and index scores into the context of regional, large-scale, climatic, and oceanographic patterns. Information on existing indices reporting on physical ocean conditions is not part of the mathematical calculation of the MWCI. Instead, we show their values (PDO) in the panel of the Ventilation module or in the form of a statistical correlation above each module (Figure 6). We do this by correlating modules of the MWCI with known oceanic indices, PDO and Upwelling.

We restricted the information on ocean indices to the time series (Figure 4c and Figure 6). We omitted the statistical correlation with ocean indices on communication levels targeted for the public (Figure 4a-b), assuming that these indices are not well known.

Pacific Decadal Oscillation (PDO) Index

PDO is a pattern of Pacific climate variability that shifts phases on an inter-decadal time scale and affects Washington’s marine waters (Mantua et al., 1997). The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20° N. During a *warm*, or *positive*, phase, the west Pacific becomes cool and part of the eastern ocean warms; during a *cool* or *negative* phase, the opposite pattern occurs. We obtain data at the web site of the Joint Institute for the Study of the Atmosphere and Ocean at the University of Washington.

The PDO is defined as the leading principal component of north Pacific monthly sea-surface-temperature variability. Numeric values used for our calculation of the PDO Index are available from http://jisao.washington.edu/pdo/PDO.latest. The PDO Index is updated every two or three months.

Although there are several patterns of behavior in the decadal oscillation, the most significant one seems to be in regime shifts between *warm* and *cool* patterns, which last about 10 years (Francis et al., 1998; Mantua et al., 1997). This motivated us to entertain a moving 10-year time window to illustrate significant changes, Figure 6.

Coastal Upwelling Indices

The Upwelling Indices are generated by NOAA's Pacific Fisheries Environmental Laboratory (PFEL) for locations along the west coast of North America. Upwelling is the upward movement of deeper ocean water that occurs when persistent winds move surface water offshore. Upwelled waters are typically cooler, saltier, enriched in nutrients, and lower in dissolved oxygen compared to surface waters. Upwelling can affect water quality in Washington's marine water bodies.

The following is from the PFEL upwelling website, www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/upwell_menu_NA.html :

> "On a monthly basis, the Pacific Fisheries Environmental Laboratory generates indices of the intensity of large-scale, wind-induced coastal upwelling at 15 locations along the west coast of North America. The indices are based on estimates of offshore Ekman transport driven by geostrophic wind stress. Geostrophic winds are derived from six-hourly synoptic and monthly mean surface atmospheric pressure fields. The pressure fields are provided by the U.S. Navy Fleet Numerical Meteorological and Oceanographic Center (FNMOC), Monterey, CA.
>
> The idea behind the upwelling indices is to develop simple time series that represent variations in coastal upwelling. Daily and monthly index time series are provided regularly to scientists and managers concerned with marine ecosystems, and have been used in scores of studies and scientific publications."

Data on the upwelling anomalies for 48 N and 125 W (closest Upwelling Index location to northwest Washington) can be downloaded from the NOAA ftp site at ftp://orpheus.pfeg.noaa.gov/outgoing/upwell/monthly/upanoms.mon.

Statistical Evaluation of Trends and Their Relation to Ocean Conditions

Statistical evaluation of trends guides the interpretation of shifting baseline conditions over a 10-year moving timeframe. The goal is to provide scientists with additional tools to communicate conditions to management with greater confidence. The trend analysis is therefore restricted to the levels aimed at scientists. Non-parametric correlation statistics (Spearman Rank) provide the information. We report significant trends below each module (Figure 4c, Figure 7). We report significant trends on higher reporting levels only schematically to include the importance of trends to the public.

Updating the MWCI Reporting Structure

We release new MWCI scores yearly and add them to the pre-existing 10-year index-reporting period. Since the reporting scheme of the MWCI combines temporally fixed information and annually updated information, we try to summarize the updating scheme in Figure 10. The pillars of the index are the baseline conditions that remain fixed in time. Reporting regions and information on relative water quality are also fixed in time. Both additional pieces of information support the communication strategy, provide context, and will not be updated routinely. This ensures backward compatibility of index scores to allow for a trend analysis of MWCI scores.

We provide yearly updated information for all module and MWCI scores as well as the 10-year trend and correlation analysis.

Presentation	**Combined reporting matrix**	
Fixed decadal reporting frame (-10 years to present)	Determining significant change over a decade	Correlating index and module scores with PDO and Upwelling indices
Expanding reporting frame (1999 to present)	Determining absolute change over time by regression (change is proportional to length of arrow)	
Annual reporting frame	Module and index scores based on 12 months of data	
Fixed reporting frame 1999-2008	Site-specific objectives (baseline)	Ranking stations by pre-existing conditions
	Temporal context	**Spatial context**

Figure 10. Framework for reporting the MWCI.

We update the MWCI yearly. The index relies on several frameworks: a temporally fixed (black shading), an annual reporting approach (gray), an expanding timeframe (lighter gray), and a decadal moving report framework (white). Baseline conditions of water quality are fixed in time. Reporting regions remain fixed in time to allow a backward compatibility. Contrary to that, we update statistical trends over a 10-year advancing timeframe matching roughly the footprint of variation of the PDO. Overall shifting baselines are reported over an ever-increasing timeframe.

Differences between the MWCI and Ecology's Previous Indices

Ecology's previous *Water Quality of Concern* and *Sensitivity to Eutrophication* indices used up to five water quality variables. Both indices included a four-step water quality-scoring scheme. However, final index scores were often adjusted to reflect heuristically defined natural environmental conditions, and both indices lacked statistical capabilities. The use of a "one size fits all" water quality objective in the highly seasonal and spatially variable estuarine environment did not detect environmental change within the context of natural seasonal variability. Both indices were sensitive to outliers (no statistics) and environmental gradients, which required expert judgments to resolve. The MWCI supplants previous indices and adopts a strictly quantitative, seasonally, and geographically based reference approach.

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Results

Index and Module Scores from Individual Stations

We calculated the yearly index and module scores for 27 stations, 1999 to 2008:

- MWCI and Eutrophication Index, Tables 17 and 18.
- Ventilation and Ambient modules, Tables 19 and 20.
- Enrichment and Impact modules, Tables 21 and 22.

Calculations of the MWCI for more recent years can be found on Ecology's marine waters website: www.ecy.wa.gov/programs/eap/mar_wat/mwm_intr.html.

The volume of information that we generate is apparent and explains our effort to propose spatially summarized information products. See *Reporting the Index by Regions* section in this report.

The years 2003 to 2006 mark a period (red colors) of lower index scores affecting both indices (MWCI and Eutrophication Index) and all four modules (Ventilation, Ambient, Enrichment, Impact). The pattern extended across the entire station network of the Puget Sound region, the San Juan Islands, southern Georgia Basin, and the coastal bays (Grays Harbor and Willapa Bay). The scale suggests the importance of large-scale ocean and climate variability for marine monitoring programs.

We observed that lower scores for the Eutrophication Index and two of its modules, Ambient and Enrichment, persisted for longer into 2008. The decrease was confined to Salish Sea stations. Enrichment scores are already corrected for ocean influences using salt as a passive tracer, yet scores continued to decrease. The lower scores in both modules suggest that ocean influences and other factors jointly caused nutrient increases.

The Ventilation module recovered towards the end of the decade at all stations, suggesting a smaller impact on the oxygen availability (colder temperatures and more oxygen).

The large-scale fluctuations of index and module scores span across our entire station network. This suggests that oceanic and climate variations must be considered to understand water quality conditions in Washington State.

Table 17. Yearly station scores listed for the MWCI, 1999-2008.

Color gradients superimposed onto the table show conditions with scores below (red) or above (green) baseline conditions (white).

	Station	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Marine Water Condition Index	ADM001	19.4	13.3	11.1	-0.3	-4.6	-7.0	-4.7	-11.9	3.3	5.5
	ADM002	20.4	13.2	5.6	9.0	4.5	-3.9	-1.0	-0.9	3.2	-4.2
	ADM003	15.8	17.1	6.5	2.5	-6.5	-1.7	-10.7	3.3	3.0	1.9
	BLL009	10.1	12.5	23.2	-2.7	0.7	5.6	-13.0	-9.8	6.8	2.4
	BUD005	8.4	13.6	16.7	1.5	-11.5	-8.8	-6.6	-0.9	7.6	4.2
	CMB003	16.6	8.3	13.0	-2.7	-6.3	-0.8	-4.2	-0.7	6.4	-4.2
	DNA001	15.0	10.4	13.0	-13.8	2.8	-0.7	-1.0	0.0	2.0	0.8
	EAP001	5.4	19.4	16.4	9.7	-3.4	-5.8	-6.1	-4.9	2.8	-1.9
	ELB015	28.1	18.8	5.4	-3.6	-9.2	3.2	-16.1	-9.3	3.5	3.4
	GOR001	23.1	14.4	17.3	20.2	11.6	-4.0	-16.9	-2.1	-3.4	-2.8
	GRG002	-2.2	13.9	12.5	-2.4	-1.8	9.8	-2.4	-6.6	1.6	9.0
	GYS004	9.4	8.8	11.1	-1.2	-6.1	-2.0	1.2	-13.1	8.9	11.1
	GYS008	15.8	11.0	18.2	-6.7	-3.1	-1.2	-17.6	-12.0	9.4	16.0
	GYS016	7.9	2.3	-0.3	1.3	-1.7	4.0	2.4	3.1	4.7	6.5
	HCB004	16.3	6.7	9.2	1.7	-4.1	-7.6	-0.8	-12.0	5.6	10.0
	NSQ002	23.3	17.5	14.6	1.3	5.0	0.2	-9.3	-4.2	3.7	-1.3
	OAK004	16.2	13.3	11.6	-4.0	-1.0	-10.9	-2.6	3.9	-1.2	-10.8
	PSB003	22.7	13.0	12.5	-6.3	-3.8	-1.4	-5.2	-8.9	8.1	0.4
	PSS019	15.6	5.1	8.2	-2.3	-3.1	-13.9	-1.6	-7.9	11.9	6.7
	SAR003	5.7	10.4	8.4	-9.0	-0.2	-6.8	-0.8	9.8	3.7	7.2
	SIN001	7.6	16.1	13.0	-0.4	-1.5	-5.4	-5.9	-10.2	3.5	1.2
	WPA001	8.1	6.2	14.4	5.4	2.7	-2.3	-14.7	-2.8	9.7	7.5
	WPA003	9.2	15.7	11.3	0.7	-4.2	5.2	-1.9	-11.0	3.7	9.8
	WPA004	8.6	6.1	14.1	-3.3	-5.8	9.5	-0.9	-5.6	7.4	6.6
	WPA006	13.9	4.5	14.6	5.5	-0.4	-1.4	-4.5	-2.1	-0.3	10.3
	WPA007	15.4	4.1	18.2	4.5	-5.9	-0.3	-9.9	-6.9	-7.4	17.8
	WPA008	15.9	11.1	19.3	7.1	0.1	-12.5	-14.0	-4.8	-8.3	9.0

Table 18. Yearly station scores listed for the Eutrophication Index, 1999-2008.

Color gradients superimposed onto the table show conditions with scores below (red) or above (green) baseline conditions (white).

	Station	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Eutrophication Index	ADM001	18.3	12.2	4.3	2.7	-8.6	1.1	-0.7	-7.1	2.9	1.4
	ADM002	23.8	10.0	1.9	9.6	6.8	-1.8	1.4	3.1	-1.3	-13.0
	ADM003	11.1	16.3	1.9	2.8	-1.5	5.6	-10.3	10.0	3.5	-0.6
	BLL009	9.2	14.8	21.1	-4.2	-0.9	6.8	-15.4	-8.6	9.7	0.8
	BUD005	8.7	11.5	14.4	4.2	-9.8	-8.6	-6.0	1.9	8.6	-1.1
	CMB003	16.6	5.6	8.0	-3.0	-4.1	-2.4	-4.7	6.5	4.2	-5.6
	DNA001	14.4	5.6	11.7	-18.4	13.0	1.9	0.2	3.7	4.2	-7.8
	EAP001	4.1	22.2	12.6	11.1	1.1	-5.6	-6.3	0.9	-0.6	-10.5
	ELB015	28.6	16.7	0.6	-3.3	-9.2	3.7	-14.9	-4.3	8.3	-1.0
	GOR001	26.3	16.7	14.2	23.3	14.4	-4.2	-15.1	0.9	-5.1	-9.3
	GRG002	-10.4	11.7	11.1	2.4	3.2	7.5	-0.8	-4.9	-1.9	10.2
	GYS004	10.3	9.5	7.4	-5.5	-6.7	2.9	0.8	-15.1	12.9	10.1
	GYS008	9.9	11.4	13.5	-9.0	-2.6	10.3	-15.4	-11.7	8.2	14.2
	GYS016	2.8	2.5	-2.4	-0.1	-1.2	9.3	7.5	2.8	0.7	4.3
	HCB004	24.0	7.1	0.0	2.8	-2.4	-0.5	2.5	-10.5	4.6	2.2
	NSQ002	22.2	15.1	11.7	-8.3	12.2	0.3	-5.8	0.9	7.1	-8.6
	OAK004	13.2	13.3	9.9	-2.1	0.0	-6.2	-3.4	8.3	-2.7	-12.2
	PSB003	22.5	11.8	10.0	-7.6	-0.8	-0.7	-3.3	0.6	5.6	-1.4
	PSS019	15.3	7.8	2.6	-4.9	-2.3	-11.8	1.0	-5.0	11.8	2.2
	SAR003	-0.1	13.3	4.5	-7.7	3.7	-2.3	3.2	13.6	-0.3	2.8
	SIN001	4.6	18.7	11.7	1.9	-2.0	-7.9	-5.6	-6.8	6.5	-6.5
	WPA001	8.9	7.8	7.0	6.1	2.8	9.2	-15.6	-9.3	11.8	5.7
	WPA003	9.1	19.4	6.3	4.3	-2.5	12.5	-4.3	-12.0	0.6	7.6
	WPA004	7.0	8.6	8.1	-4.4	0.6	11.9	-0.6	0.0	10.5	-1.7
	WPA006	14.1	8.6	11.8	8.1	3.6	3.7	-6.6	-3.9	-1.0	2.6
	WPA007	13.9	10.0	13.2	7.9	-0.2	0.4	-16.6	-5.6	-6.8	15.4
	WPA008	16.9	13.3	18.6	13.5	1.2	-5.6	-15.6	-9.7	-12.5	2.3

Table 19. Yearly station scores listed for the Ventilation module, 1999-2008.

Color gradients superimposed onto the table show conditions with scores below (red) or above (green) baseline conditions (white).

	Station	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Ventilation Module	**ADM001**	22.7	16.7	31.5	-9.3	7.1	-31.5	-16.7	-26.2	4.5	17.9
	ADM002	10.0	22.7	16.7	7.1	-2.4	-10.0	-8.3	-13.0	16.7	22.2
	ADM003	30.0	19.4	20.4	1.9	-21.4	-23.3	-11.9	-16.7	1.5	9.3
	BLL009	13.0	5.6	29.3	1.9	5.6	1.9	-5.6	-13.6	-1.7	7.1
	BUD005	7.6	20.0	23.3	-6.7	-16.7	-9.3	-8.3	-9.3	4.5	20.0
	CMB003	16.7	16.7	27.8	-1.5	-13.0	4.2	-2.8	-22.2	13.0	0.0
	DNA001	16.7	25.0	16.7	0.0	-27.8	-8.3	-4.5	-11.1	-4.5	26.7
	EAP001	9.3	11.1	27.8	5.6	-16.7	-6.7	-5.6	-22.2	13.0	24.1
	ELB015	26.7	25.0	19.7	-4.5	-9.3	1.9	-19.7	-24.1	-11.1	16.7
	GOR001	13.3	7.6	26.7	11.1	3.3	-3.3	-22.2	-11.1	1.9	16.7
	GRG002	22.2	20.4	16.7	-16.7	-16.7	16.7	-7.1	-11.9	12.1	5.6
	GYS004	6.7	6.7	22.2	11.9	-4.5	-16.7	2.4	-7.1	-3.3	14.0
	GYS008	33.3	10.0	32.4	0.0	-4.5	-35.7	-24.1	-13.0	13.0	21.4
	GYS016	23.3	1.5	6.0	5.6	-3.3	-11.9	-13.0	4.2	16.7	13.0
	HCB004	-6.7	5.6	36.7	-1.9	-9.3	-29.2	-10.6	-16.7	8.3	33.3
	NSQ002	26.7	25.0	23.3	30.0	-16.7	0.0	-19.7	-19.4	-6.7	20.4
	OAK004	25.0	13.3	16.7	-10.0	-4.2	-25.0	0.0	-9.3	3.3	-6.7
	PSB003	23.3	16.7	20.0	-2.4	-13.0	-3.3	-10.6	-37.5	15.6	5.6
	PSS019	16.7	-2.8	25.0	5.6	-5.6	-20.4	-9.3	-16.7	12.1	20.0
	SAR003	23.3	1.5	20.0	-13.0	-11.9	-20.4	-13.0	-1.5	15.5	20.4
	SIN001	16.7	8.3	16.7	-7.1	0.0	1.9	-6.7	-20.4	-5.6	24.1
	WPA001	5.6	1.5	36.7	3.3	2.4	-36.7	-11.9	16.7	3.3	13.0
	WPA003	9.3	4.5	26.2	-10.0	-9.3	-16.7	5.6	-7.9	13.0	16.7
	WPA004	13.3	-1.5	31.8	0.0	-25.0	2.4	-1.9	-22.2	-1.9	31.5
	WPA006	13.3	-7.6	23.1	-2.4	-12.5	-16.7	1.9	3.3	1.9	33.3
	WPA007	20.0	-13.6	33.3	-5.6	-23.3	-2.4	10.0	-11.1	-9.3	25.0
	WPA008	13.0	4.5	21.4	-11.9	-3.3	-33.3	-9.3	10.0	4.2	29.2

Table 20. Yearly station scores listed for the Ambient module, 1999-2008.

Color gradients superimposed onto the table show conditions with scores below (red) or above (green) baseline conditions (white).

	Station	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Ambient Module	ADM001	20.8	13.6	9.3	-1.9	-3.3	5.6	16.7	-26.2	1.9	-9.3
	ADM002	35.7	6.7	-11.1	2.4	10.0	6.7	20.8	-9.3	2.4	-22.2
	ADM003	20.8	22.7	1.9	-4.2	3.3	20.4	-7.1	-3.3	1.5	-9.3
	BLL009	4.2	13.9	35.2	-12.5	9.3	1.9	-16.7	-4.5	-3.3	2.4
	BUD005	0.0	13.3	30.0	0.0	-12.5	0.0	1.5	1.9	10.6	-13.3
	CMB003	20.4	4.5	13.0	-1.5	-13.0	2.4	10.0	0.0	12.5	-13.3
	DNA001	22.2	9.3	31.5	-41.7	16.7	16.7	-1.9	-5.6	9.3	-20.0
	EAP001	-11.1	30.0	16.7	4.2	5.6	1.9	1.9	-5.6	7.1	-20.4
	ELB015	20.8	13.6	3.3	-23.3	-2.4	16.7	-9.3	-13.0	16.7	1.9
	GOR001	22.2	20.4	20.4	33.3	27.8	10.0	-16.7	-11.1	-8.3	-20.4
	GRG002	-23.3	13.0	8.3	-7.1	2.4	20.8	16.7	-11.1	-5.6	12.5
	GYS004	3.3	20.0	25.0	-16.7	0.0	-5.6	-11.9	-21.4	16.7	1.9
	GYS008	-1.9	25.0	30.0	-22.2	5.6	-2.4	-20.4	-13.0	9.3	11.9
	GYS016	-5.6	-1.5	-16.7	16.7	-1.9	-5.6	16.7	12.5	-4.2	9.3
	HCB004	31.5	13.6	1.9	1.9	-5.6	11.9	1.5	-20.4	0.0	-3.3
	NSQ002	16.7	10.0	24.1	-33.3	16.7	16.7	9.3	-7.6	11.9	-31.5
	OAK004	16.7	20.4	30.0	0.0	-4.2	2.4	7.6	-13.0	-13.0	-33.3
	PSB003	16.7	10.0	10.0	-21.4	7.1	10.0	10.0	-4.2	1.5	-13.0
	PSS019	33.3	13.3	11.9	-5.6	12.5	-25.0	1.9	-9.3	6.7	-13.3
	SAR003	-4.2	30.0	7.1	-8.3	11.1	-7.1	20.8	-1.5	-9.3	1.9
	SIN001	-3.3	22.7	16.7	-7.1	0.0	-12.5	3.3	-16.7	13.9	-8.3
	WPA001	12.5	13.3	1.9	3.3	-2.4	16.7	-11.9	-16.7	13.3	9.3
	WPA003	8.3	23.3	7.1	8.3	0.0	0.0	1.9	-16.7	5.6	12.5
	WPA004	-9.3	10.6	13.6	-5.6	-2.4	16.7	4.2	0.0	16.7	-1.9
	WPA006	12.5	10.6	20.8	11.9	2.4	-16.7	-4.2	-3.3	1.9	5.6
	WPA007	16.7	6.7	23.3	0.0	1.9	-11.1	-20.8	-5.6	-1.9	16.7
	WPA008	20.8	13.3	20.0	7.1	5.6	-16.7	-16.7	-3.3	-20.8	12.5

Table 21. Yearly station scores listed for the Enrichment module, 1999-2008.

Color gradients superimposed onto the table show conditions with scores below (red) or above (green) baseline conditions (white).

	Station	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Enrichment Module	**ADM001**	20.8	13.6	5.6	-6.7	-2.4	5.6	4.2	-7.1	-1.9	0.0
	ADM002	35.7	20.0	0.0	-2.4	16.7	3.3	8.3	-1.9	-4.2	-27.8
	ADM003	12.5	16.7	1.9	0.0	7.1	9.3	2.4	10.0	1.5	-9.3
	BLL009	8.3	11.1	23.3	-4.2	-1.9	1.9	-16.7	-7.6	13.3	-7.1
	BUD005	4.5	17.9	23.3	4.5	-9.3	-16.7	-4.8	-1.9	10.6	-6.7
	CMB003	23.3	13.6	9.3	-7.6	-9.3	1.9	6.7	8.3	1.9	-30.0
	DNA001	11.1	9.3	9.3	-25.0	16.7	4.2	20.4	5.6	-1.9	-20.0
	EAP001	0.0	30.0	11.9	12.5	5.6	1.9	-1.9	-2.8	-2.4	-24.1
	ELB015	29.2	22.7	0.0	0.0	-2.4	-1.9	-13.0	-13.0	2.8	-10.0
	GOR001	33.3	24.1	16.7	25.0	27.8	6.7	-8.3	-5.6	-25.0	-20.4
	GRG002	-3.3	13.0	8.3	7.1	7.1	8.3	11.9	-16.7	-1.9	0.0
	GYS004	20.0	13.3	0.0	-1.9	-13.3	2.4	16.7	-21.4	10.0	9.3
	GYS008	20.0	13.6	7.1	-13.0	-6.7	31.0	-5.6	-27.8	3.3	12.5
	GYS016	20.4	4.5	1.9	-13.3	-3.3	7.1	-1.9	0.0	4.2	5.6
	HCB004	16.7	7.6	-1.9	6.7	-3.3	-9.1	4.5	-9.3	8.3	3.3
	NSQ002	16.7	30.0	13.0	-16.7	10.0	6.7	3.3	-4.5	-7.1	-16.7
	OAK004	25.0	14.0	-3.6	-4.5	2.2	0.0	4.8	10.0	-6.0	-16.7
	PSB003	20.8	10.0	10.0	-5.6	7.1	0.0	3.3	-5.6	1.5	-6.7
	PSS019	12.5	6.7	0.0	-9.3	-4.2	-8.3	16.7	-13.0	13.3	3.3
	SAR003	-4.2	10.0	12.5	-12.5	2.4	2.4	-1.9	16.7	6.7	-3.3
	SIN001	13.6	28.8	13.0	-7.1	-12.5	-13.0	-7.6	1.9	5.6	-13.0
	WPA001	16.7	6.7	9.3	7.1	4.2	-8.3	-13.0	-11.1	13.3	1.9
	WPA003	16.7	25.0	11.9	7.1	-9.3	12.5	-5.6	-16.7	-5.6	4.2
	WPA004	16.7	13.6	4.5	-5.6	0.0	7.1	0.0	0.0	-1.9	6.0
	WPA006	27.3	10.6	12.5	-5.6	-4.2	16.7	-5.6	-5.6	-14.0	2.4
	WPA007	20.0	16.7	17.9	15.2	-10.0	-6.3	-19.6	-5.6	-9.3	18.0
	WPA008	22.7	23.3	21.4	15.2	-7.1	-16.7	-20.0	-11.1	-8.3	-1.9

Table 22. Yearly station scores listed for the Impact module, 1999-2008.

Color gradients superimposed onto the table show conditions with scores below (red) or above (green) baseline conditions (white).

	Station	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Impact Module	**ADM001**	13.2	9.4	-1.9	16.7	-20.0	-7.7	-23.1	11.9	8.6	13.3
	ADM002	0.0	3.3	16.7	28.9	-6.3	-15.5	-25.0	20.4	-2.2	11.1
	ADM003	0.0	9.4	1.9	12.5	-15.0	-13.0	-26.2	23.3	7.6	16.7
	BLL009	15.0	19.4	4.8	4.2	-10.0	16.7	-13.0	-13.6	19.0	7.1
	BUD005	21.4	3.3	-10.0	8.1	-7.7	-9.3	-14.7	5.6	4.5	16.7
	CMB003	6.0	-1.5	1.9	0.0	10.0	-11.5	-30.6	11.1	-1.9	26.7
	DNA001	10.0	-1.9	-5.6	11.5	5.6	-15.2	-17.9	11.1	5.2	16.7
	EAP001	23.3	6.7	9.1	16.7	-7.9	-20.4	-19.0	11.1	-6.5	13.0
	ELB015	35.7	13.6	-1.6	13.3	-22.7	-3.8	-22.4	13.0	5.6	5.2
	GOR001	23.3	5.6	5.6	11.5	-12.5	-29.3	-20.4	19.4	18.0	13.0
	GRG002	-4.5	9.3	16.7	7.1	0.0	-6.5	-31.0	13.2	1.9	18.0
	GYS004	7.7	-4.8	-2.9	2.0	-6.7	11.9	-2.4	-2.4	12.1	19.2
	GYS008	11.5	-4.5	3.3	8.3	-6.7	2.4	-20.4	5.6	12.1	18.2
	GYS016	-6.5	4.5	7.7	-3.6	1.7	26.2	7.7	-4.2	2.0	-1.9
	HCB004	23.9	0.0	0.0	0.0	1.7	-4.2	1.5	-1.9	5.6	6.7
	NSQ002	33.3	5.2	-1.9	25.0	10.0	-22.4	-30.0	14.7	16.7	22.4
	OAK004	-2.0	5.6	3.3	-1.6	2.0	-20.8	-22.7	27.8	10.7	13.3
	PSB003	30.0	15.5	10.0	4.2	-16.7	-12.1	-23.3	11.5	13.6	15.5
	PSS019	0.0	3.3	-4.2	0.0	-15.2	-2.0	-15.5	7.1	15.5	16.7
	SAR003	7.9	0.0	-6.0	-2.2	-2.4	-2.2	-9.3	25.8	1.7	10.0
	SIN001	3.6	4.5	5.6	20.0	6.5	1.9	-12.5	-5.6	0.0	1.9
	WPA001	-2.4	3.3	10.0	7.9	6.5	19.2	-22.0	0.0	8.6	6.0
	WPA003	2.4	10.0	0.0	-2.6	1.9	25.0	-9.3	-2.6	1.9	6.0
	WPA004	13.6	1.5	6.3	-2.0	4.2	11.9	-6.0	0.0	16.7	-9.3
	WPA006	2.4	4.5	2.0	18.0	12.5	11.1	-10.0	-2.9	9.3	0.0
	WPA007	5.0	6.7	-1.7	8.3	7.7	18.4	-9.3	-5.6	-9.3	11.5
	WPA008	7.1	3.3	14.5	18.0	5.2	16.7	-10.0	-14.7	-8.3	-3.8

We reduce the volume of information by using regional reporting, and we restrict information to higher order indices (MWCI and the Eutrophication Index). This reduces noise in the annual index scores and reduces the number of reporting units. By calculating trends from 1999 to 2008[5], we additionally reduce inter-annual variability to focus attention on trends with a high degree of certainty (trends are included in Table 23, 24). As a result, we arrive at a clearer picture: the largest overall changes in the MWCI and Eutrophication Index are predominantly occurring in the reporting region of Admiralty Reach, Central Basin and South Sound.

[5] Table 20 includes the overall change using linear trend analysis.

Table 23. Annual scores of the MWCI aggregated into 17 reporting regions, 1999-2008.

A reduced volume of information simplifies the communication of environmental conditions. Using trend analysis allows us to report developing conditions parallel to statistically significant index observations.

MWCI	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Trend
Admiralty Reach	19.9	13.3	8.3	4.4	-0.1	-5.4	-2.9	-6.4	3.2	0.7	-20.8
Georgia Basin	-2.2	13.9	12.5	-2.4	-1.8	9.8	-2.4	-6.6	1.6	9	-4.2
Grays Harbor-Ocean	7.9	2.3	-0.3	1.3	-1.7	4	2.4	3.1	4.7	6.5	1.8
Grays Harbor-River	12.6	9.9	14.6	-3.9	-4.6	-1.6	-8.2	-13	9.1	13.5	-8.6
S. Hood Canal	16.3	6.7	9.2	1.7	-4.1	-7.6	-0.8	-12	5.6	10	-11
Central-South Basin	15	14	12.1	7.5	-0.3	-6.4	-8.8	-2.9	3.6	1	-19.9
Bellingham Bay	10.1	12.5	23.2	-2.7	0.7	5.6	-13	-9.8	6.8	2.4	-18.2
Sinclair Inlet	7.6	16.1	13	-0.4	-1.5	-5.4	-5.9	-10	3.5	1.2	-17.1
Oakland Bay	16.2	13.5	14.1	-1.3	-6.3	-9.8	-4.6	1.5	3.2	-3.3	-19.7
South Sound	19.2	14	13.8	-6.3	3.9	-0.2	-5.1	-2.1	2.8	-0.3	-20.2
Elliott Bay-Urban	28.1	18.8	5.4	-3.6	-9.2	3.2	-16	-9.3	3.5	3.4	-25.9
Commencement Bay	16.6	8.3	13	-2.7	-6.3	-0.8	-4.2	-0.7	6.4	-4.2	-16.2
Whidbey Basin	10.7	7.8	8.3	-5.7	-1.7	-10	-1.2	1	7.8	6.9	-4
Willapa Bay-Ocean	8.6	6.1	14.1	-3.3	-5.8	9.5	-0.9	-5.6	7.4	6.6	-5.1
Willapa Bay-Proper	13.6	8.9	15.9	4.5	-2.6	-2.3	-7.6	-6.2	-3.1	11.7	-14.9
Willapa Bay-River	8.1	6.2	14.4	5.4	2.7	-2.3	-15	-2.8	9.7	7.5	-8
Budd Inlet-Shallow	8.4	13.6	16.7	1.5	-12	-8.8	-6.6	-0.9	7.6	4.2	-11.5

Table 24. Annual scores of the Eutrophication Index aggregated into 17 reporting regions, 1999-2008.

A reduced volume of information simplifies the communication of environmental conditions. Using trend analysis allows us to report developing conditions parallel to statistically significant index observations.

Eutrophication Index	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Trend
Admiralty Reach	21	11.1	3.1	6.2	-0.9	-0.3	0.3	-2	0.8	-5.8	-21.6
Georgia Basin	-10	11.7	11.1	2.4	3.2	7.5	-0.8	-4.9	-1.9	10.2	0.3
Grays Harbor-Ocean	2.8	2.5	-2.4	-0.1	-1.2	9.3	7.5	2.8	0.7	4.3	3.6
Grays Harbor-River	10.1	10.4	10.4	-7.2	-4.6	6.6	-7.3	-13	10.6	12.2	-5.4
S. Hood Canal	24	7.1	0	2.8	-2.4	-0.5	2.5	-11	4.6	2.2	-16
Central-South Basin	14.2	15.7	7.8	8.1	2.9	-4	-7.7	1.7	2.4	-4.5	-21
Bellingham Bay	9.2	14.8	21.1	-4.2	-0.9	6.8	-15	-8.6	9.7	0.8	-17.3
Sinclair Inlet	4.6	18.7	11.7	1.9	-2	-7.9	-5.6	-6.8	6.5	-6.5	-18.6
Oakland Bay	13.2	12.4	12.2	1.1	-4.9	-7.4	-4.7	5.1	2.9	-6.7	-18.2
South Sound	18.3	10.3	11.7	-13	12.6	1.1	-2.8	2.3	5.7	-8.2	-18.1
Elliott Bay-Urban	28.6	16.7	0.6	-3.3	-9.2	3.7	-15	-4.3	8.3	-1	-22.5
Commencement Bay	16.6	5.6	8	-3	-4.1	-2.4	-4.7	6.5	4.2	-5.6	-13.3
Whidbey Basin	7.6	10.6	3.6	-6.3	0.7	-7	2.1	4.3	5.8	2.5	-3.5
Willapa Bay-Ocean	7	8.6	8.1	-4.4	0.6	11.9	-0.6	0	10.5	-1.7	-5
Willapa Bay-Proper	13.5	12.8	12.5	8.4	0.5	2.8	-11	-7.8	-4.9	7	-20.6
Willapa Bay-River	8.9	7.8	7	6.1	2.8	9.2	-16	-9.3	11.8	5.7	-8.6
Budd Inlet-Shallow	8.7	11.5	14.4	4.2	-9.8	-8.6	-6	1.9	8.6	-1.1	-12.2

Ocean Climate (PDO) Conditions and Upwelling Intensity Relevant to Water Quality

The MWCI aggregates data over a one-year period. We therefore have averaged oceanic indices (PDO, Upwelling) also over a year to match the temporal resolution of the MWCI (Tables 25 and 26).

Table 25. Anomalies of the oceanographic Pacific Decadal Oscillation (PDO) Index, 1999-2008.

Month:	1	2	3	4	5	6	7	8	9	10	11	12	Yearly Average
1999	-0.32	-0.66	-0.33	-0.41	-0.68	-1.3	-0.66	-0.96	-1.53	-2.23	-2.05	-1.63	-1.06
2000	-2	-0.83	0.29	0.35	-0.05	-0.44	-0.66	-1.19	-1.24	-1.3	-0.53	0.52	-0.59
2001	0.6	0.29	0.45	-0.31	-0.3	-0.47	-1.31	-0.77	-1.37	-1.37	-1.26	-0.93	-0.56
2002	0.27	-0.64	-0.43	-0.32	-0.63	-0.35	-0.31	0.6	0.43	0.42	1.51	2.1	0.22
2003	2.09	1.75	1.51	1.18	0.89	0.68	0.96	0.88	0.01	0.83	0.52	0.33	0.97
2004	0.43	0.48	0.61	0.57	0.88	0.04	0.44	0.85	0.75	-0.11	-0.63	-0.17	0.35
2005	0.44	0.81	1.36	1.03	1.86	1.17	0.66	0.25	-0.46	-1.32	-1.5	0.2	0.38
2006	1.03	0.66	0.05	0.4	0.48	1.04	0.35	-0.65	-0.94	-0.05	-0.22	0.14	0.19
2007	0.01	0.04	-0.36	0.16	-0.1	0.09	0.78	0.5	-0.36	-1.45	-1.08	-0.58	-0.20
2008	-1	-0.77	-0.71	-1.52	-1.37	-1.34	-1.67	-1.7	-1.55	-1.76	-1.25	-0.87	-1.29

Table 26. Anomalies of an oceanographic index reporting on annual anomalies of the Upwelling Index, 1999-2008, at 48° N 125° W.

Month:	1	2	3	4	5	6	7	8	9	10	11	12	Yearly Average
1999	-55	-232	-75	7	0	-14	10	-2	18	26	-30	43	-25
2000	28	-55	-10	-5	-14	-2	-9	11	-3	20	28	-7	-2
2001	-36	5	11	-2	-1	0	35	-20	0	30	-58	-30	-6
2002	21	1	15	9	-7	-8	15	18	0	39	-50	-119	-6
2003	-144	44	-46	-14	-10	11	-4	7	-1	4	65	-128	-18
2004	-32	-63	4	0	-3	-7	-4	-13	0	37	74	79	6
2005	16	47	13	-13	-21	-9	-4	18	20	-11	63	24	12
2006	-21	45	-26	0	-1	8	21	55	14	57	12	18	15
2007	73	5	1	-7	15	-18	-22	-4	9	16	72	58	17
2008	61	34	9	6	-1	4	-5	-14	3	34	40	88	22

Annual index values for the PDO Index show a warmer period in the middle of the last decade (approx. between 2003 and 2006). This can be seen in the pattern of the thermal energy across all sampling stations (Figure 11a).

Annual anomalies of the Upwelling Index show a significant increase in upwelling from 1999 to 2008, suggesting that surface nutrient concentrations along the coast could affect Washington's marine waters. Overall, nutrient concentrations increased over the 10-year period (Figure 11b).

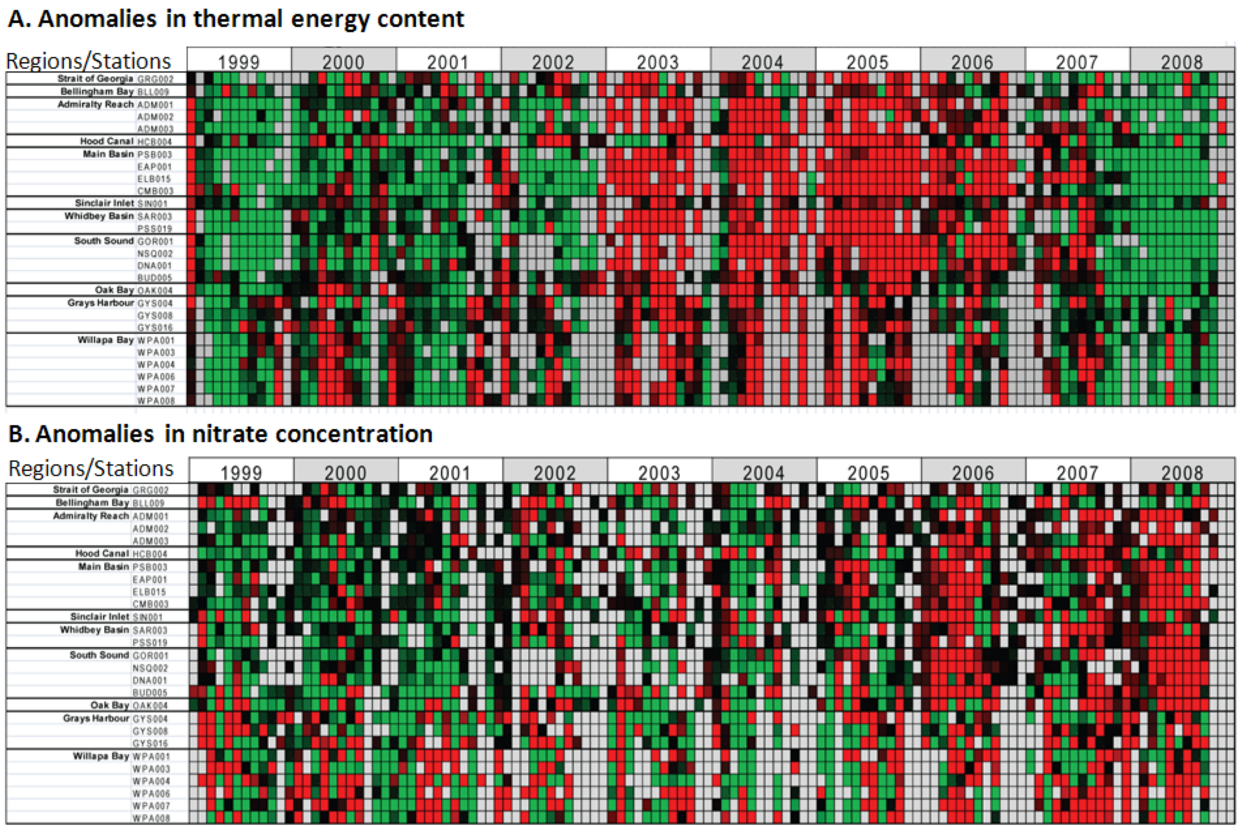


Figure 11. Using heat maps to visualize the variability of data at stations over time.

Seasonal variability in source data is very high. The MWCI is based on de-seasonalized data that focus on the variability of water quality variables over longer periods. To graphically summarize large datasets we use heat maps to show, for example, the variability of (A) temperature [expressed as thermal energy content (GJ/m^2)] and (B) nitrate (uM) around site-specific historic baselines. Heat maps provide an effective tool to communicate patterns spanning large portions of the monitoring network.

Each color pixel represents a month; we show the changes from baseline (50%, black) in color. We calculate heat maps by subtracting seasonal and site-specific baseline conditions from the dataset. The color range represents the percentiles of the dataset: 25^{th} percentile (green), 50^{th} percentile (black), 75^{th} percentile (red).

In this example, thermal energy content (A) shows a warmer period in the middle of the reference period, 1999-2008. Nitrate concentrations (B) show a 10-year increase illustrated by the shift from green to red from left to right, especially in the Puget Sound stations.

Heat maps for all 12 variables are found in Appendix A, Tables A-1 to A-12.

Correlation of water quality variables with climate (PDO) and upwelling indices

The PDO Index is significantly correlated with the Ventilation module in 77% of the reporting regions (Table 27). This suggests that the Ventilation module captures the large-scale oceanographic "climate variability" in the dataset. In contrast, the impact of upwelling correlated with only 18% of the reporting regions (Admiralty Reach, Central Basin), suggesting a restricted influence of upwelling for Admiralty Reach and Central Basin.

Our results suggest that the PDO is the dominant climate influence on Washington's estuarine and inland marine water bodies.

Table 27. Significant correlations (Spearman Rank correlations $p<0.05$) between Ocean Climate Indices (PDO and Upwelling) and components of the modular MWCI sorted by reporting region.

Region	Modules				Indices	
	Ambient	Enrichment	Impact	Ventilation	MWCI	Eutrophication Index
Admiralty Reach	-		-	PDO	-	-
Central-South Basin	Upwelling	Upwelling	-	PDO	PDO	Upwelling
Sinclair Inlet	-	-	Upwelling	PDO	PDO	-
S. Hood Canal	-	-	-	PDO	PDO	
Elliott Bay-Urban	-	-	PDO	PDO	PDO	PDO
Whidbey Basin	-	-	PDO	PDO	PDO	PDO
Budd Inlet-Shallow	-	-	-	PDO	PDO	PDO
Grays Harbor-Ocean	PDO	PDO	-		-	-
Grays Harbor-River	-	-	-	PDO	PDO	PDO
Oakland Bay	-	-	-	PDO	PDO	-
South Sound	-	-	-	PDO	-	-
Willapa Bay-Ocean	-	-	-	PDO	-	-
Willapa Bay-Proper	-	-	-	PDO	PDO	-
Willapa Bay-River	-	-	-	-		PDO
Georgia Basin	-	-	-	-	-	-
Bellingham Bay	-	-	-	-	-	-
Commencement Bay	-	-	-	-	-	-

PDO: Pacific Decadal Oscillation Index
Upwelling: Upwelling Index

Table 28. Significant temporal trends (Spearman Rank correlations $p<0.05$, years vs. score) of components of the modular MWCI over a 10-year period.

Listed is the strength of the significance using the correlation coefficient.

Region	Modules				Indices	
	Ambient	Enrichment	Impact	Ventilation	MWCI	Eutrophication Index
Central-South Basin	-0.95	-0.94	-	-	-0.67	-0.83
Admiralty Reach	-0.68	-0.90	-	-	-0.70	-0.82
Willapa Bay-Proper	-0.76	-	-	-		-0.76
Oakland Bay	-0.65	-0.75	-	-	-	-
South Sound	-0.65	-	-	-	-	-
Elliott Bay-Urban	-0.65	-	-	-0.67	-	-
Commencement Bay	-0.64	-	-	-		-
S. Hood Canal	-	-0.75	-	-	-	-
Sinclair Inlet	-	-	-	-	-	-
Georgia Basin	-	-	-	-	-	-
Grays Harbor-Ocean	-	-	-	-	-	-
Grays Harbor-River	-	-	-	-	-	-
Bellingham Bay	-	-	-	-	-	-
Whidbey Basin	-	-	-	-	-	-
Willapa Bay-Ocean	-	-	-	-	-	-
Willapa Bay-River	-	-	-	-	-	-
Budd Inlet-Shallow	-	-	-	-	-	-

Regional Water Conditions Communicated using both Status and Trends

To convey spatial gradients and persistent differences in water quality (status), we included information that allows a qualitative comparison between reporting regions (Figures 12a and 13a). These differences were established based on station ranks in 16 variables and are intended for communication purposes to accompany the MWCI (previously explained in the section entitled, *Areas of Chronic Water Quality Issues as Complementary Information to the MWCI*).

The status map complements the findings of the MWCI by placing significant changes that are reported by the MWCI (Figures 12b and 13b) into the context of pre-existing spatial gradients in water quality.

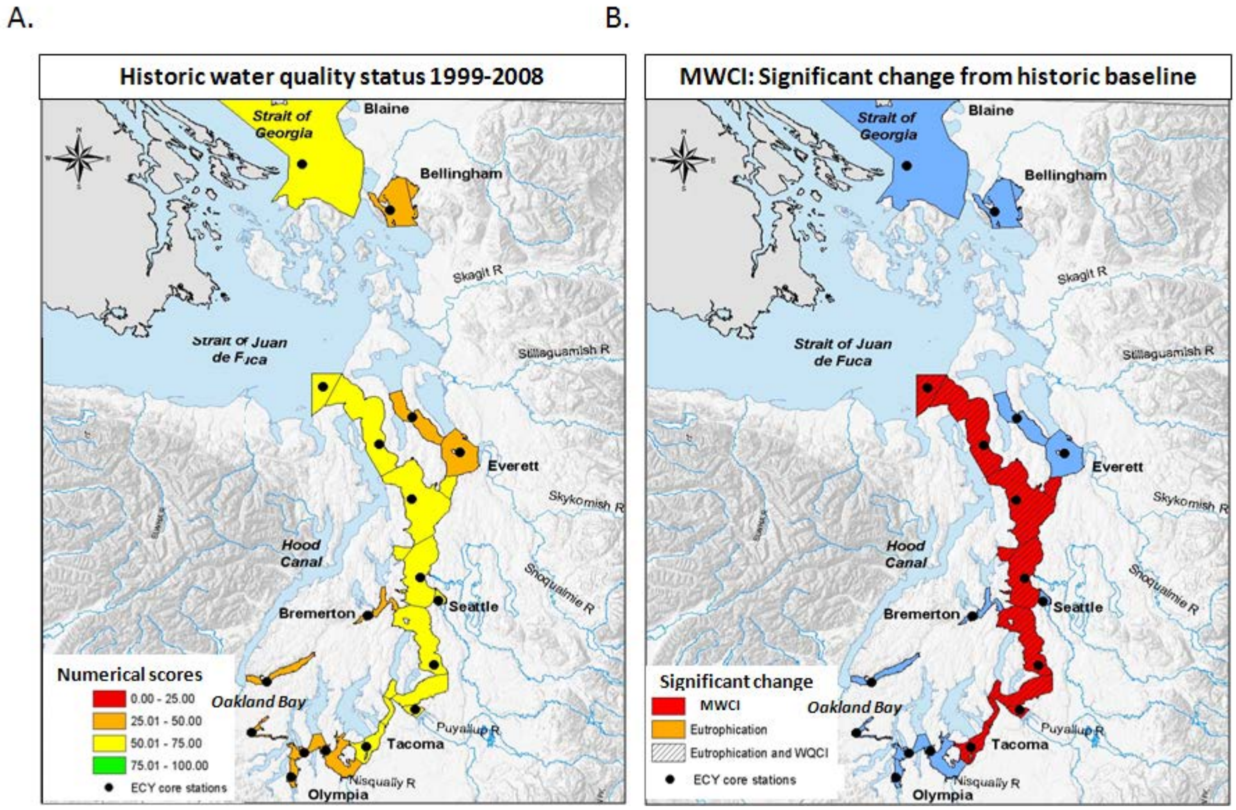


Figure 12. Presentation of status and trends in water quality in Puget Sound.

Maps show persistent water quality issues (A) determined by ranking stations. Significant trends in water conditions in the larger Puget Sound region from 1999 to 2008 are shown in B. Regional boundaries include stations grouped into reporting regions. The boundary to shore and between basins has been arbitrarily set for visual purposes. Regional ranks were scaled between 0 and 100. Ranks of individual stations can be found in Figure 9.

While chronic low water quality exists in shallow distant bays of Puget Sound (A), we observed significant downward trends in the MWCI and the Eutrophication Index along the main urban corridor of Puget Sound (B). Dark blue shaded areas show areas with no significant temporal trend.

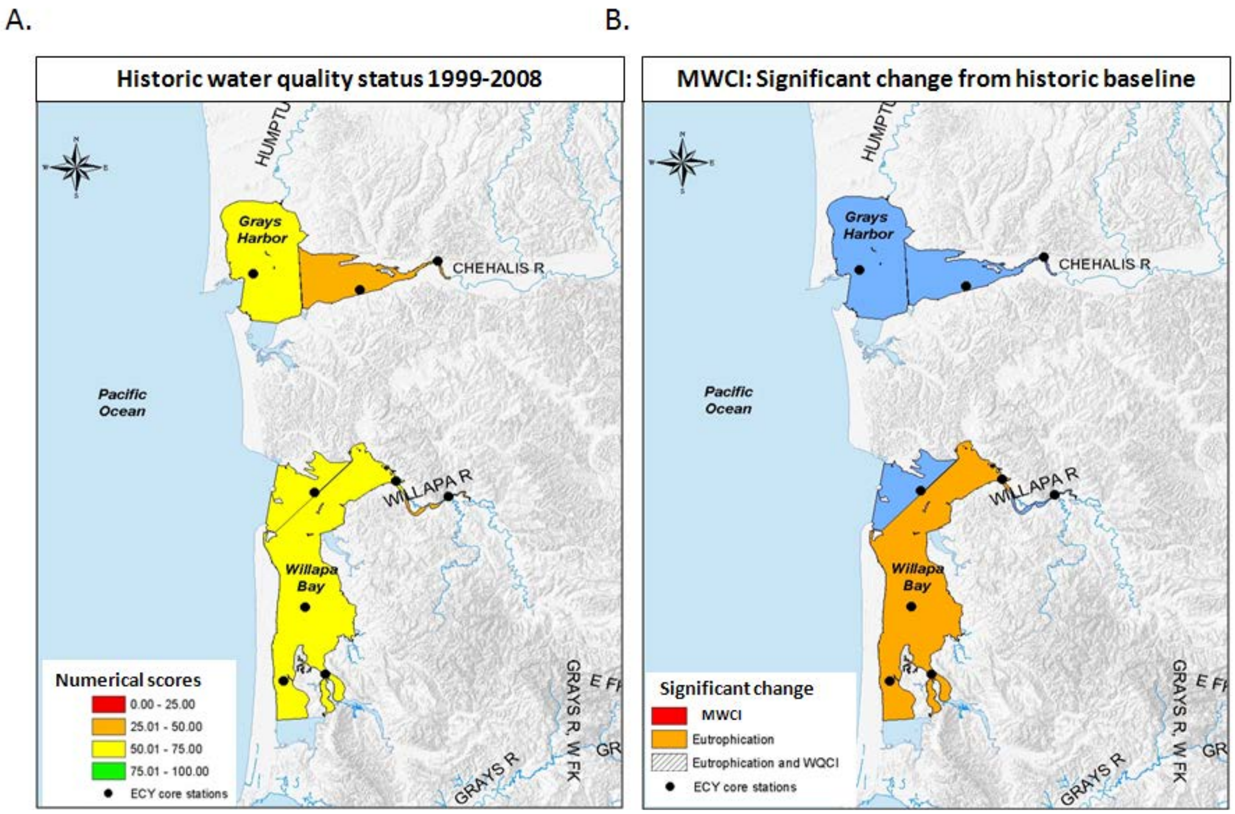


Figure 13. Presentation of status and trends in water quality in the coastal estuaries: Grays Harbor and Willapa Bay.

Maps showing pre-existing persistent water quality issues (A) and current trends (B) in water conditions in the coastal bays (Grays Harbor and Willapa Bay) from 1999 to 2008. Regional boundaries include stations grouped into reporting regions. The boundary to shore has been arbitrarily set for visual purposes only.

While lower water quality existed predominantly in Grays Harbor (A) near river stations (see also Figure 9), significant 10-year downward trends were observed in the Eutrophication Index in the main portion of Willapa Bay. Darker blue shaded areas show regions with no significant temporal trend.

Regional water conditions in the context of relative water quality

As expected, low station ranks are geographically located in terminal ending inlets (Figures 12a, 13b).

Example: Oakland Bay

Oakland Bay is removed from ocean water sources and receives an influx of fresh-water from Shelton, Washington. Oakland Bay ranked lowest with an overall score of 35 points (Figure 9) followed by stations with known chronic water quality issues (Georgia Basin - Puget Sound Ecosystem Indicators Report, 2002). These stations include Sinclair Inlet (39), Nisqually (42), South Hood Canal (42), Budd Inlet (43), Saratoga Passage (45), Bellingham Bay (45), and West Point (45). In contrast, Ecology's Admiralty Reach stations ranked highest: North Admiralty Inlet and Admiralty Sill, both with 62, followed by Georgia Basin (59), East Passage (58), and South Admiralty Inlet (57).

At the coast, the Willapa Bay river station ranked lowest (46), and the Grays Harbor ocean station ranked highest (56). Yet, the lowest scores from the coast fell in the middle of the range of Puget Sound station scores. This illustrates that Oakland Bay has the largest chronic water quality issues.

MWCI scores and statistical trends by geographic region

Example: Oakland Bay

Oakland Bay chronically has the lowest water quality (score 35). We indicate this schematically by the origin of the horizontal arrow on the color gradient backdrop (red to orange) in Table 29 and in Appendix A, Figure A-9. Baseline conditions are declining indicated by the negative MWCI score and the length and direction of the horizontal arrow on the color gradient backdrop. These are not significant (Table 28), but quite large. Over 10 years the MWCI dropped 19.7 points (Table 23 and Figure A-9). Decreasing trends should be closely monitored.

The Eutrophication Index closely follows the MWCI (see red downward pointing arrow in box EUI in Figure A-9).

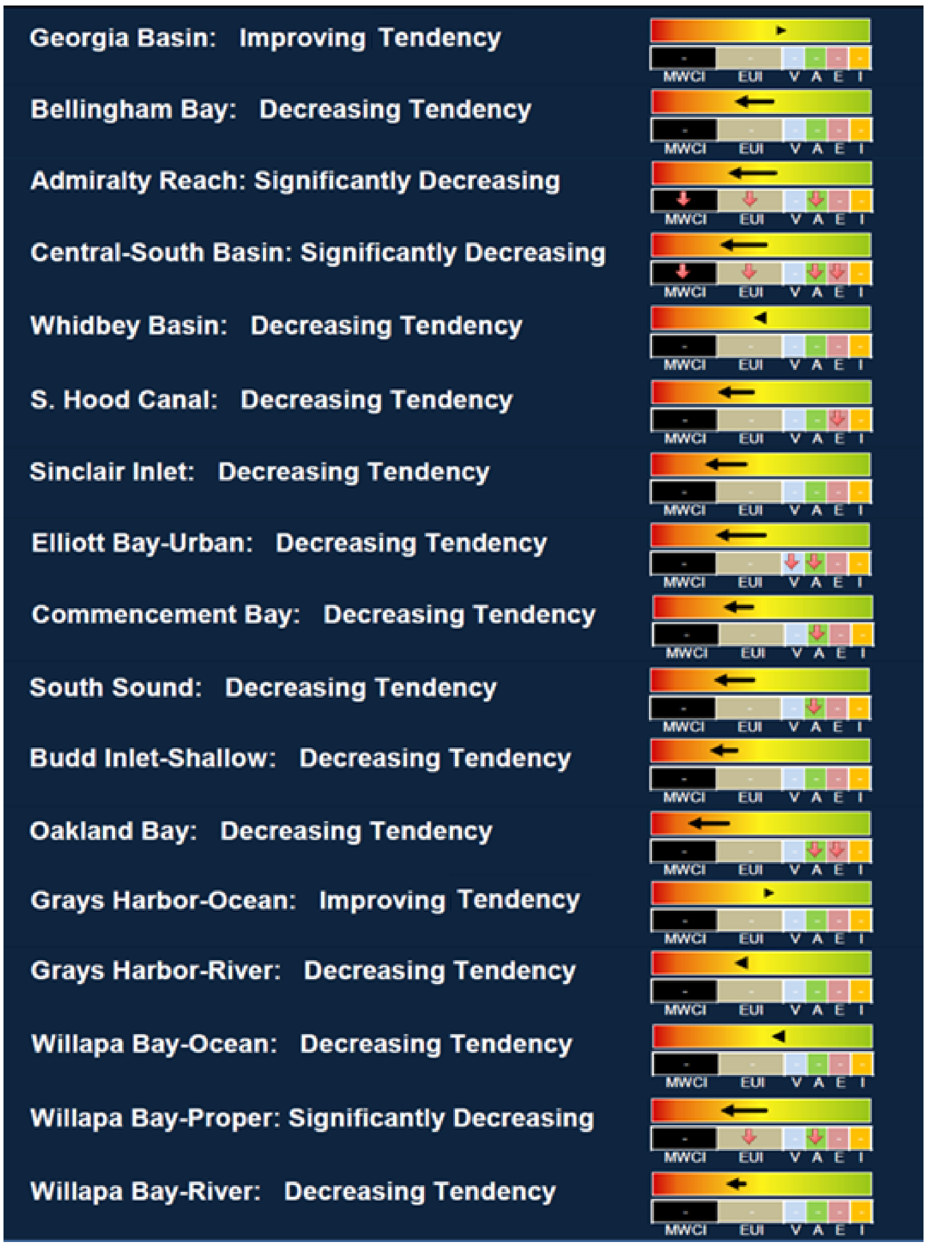
Within the eutrophication modules (Ambient, Enrichment, Impact), the Ambient and Enrichment modules are reporting a significant negative trend (indicated by the text reporting the correlation coefficient and significant level "p" below the module figure panels; see Figure 6 for explanation). Ambient nutrient conditions are also significantly declining. A parallel negative significant trend in the Enrichment module suggests that ocean influences are not likely a cause. The nutrient balance between silicate, nitrogen, and phosphate and algal biomass has not significantly degraded. On the contrary, the Impact module shows an improving tendency, which suggests that nutrient ratios and the nutrient balance are stable.

The Ventilation module summarizes changes in the physical condition of the oxygen budget. Because of its distance from the ocean, Oakland Bay behaved independently of larger scale ocean climate conditions (no correlation with the Ventilation module).

In summary, the MWCI score for Oakland Bay showed a decreasing tendency and remains a place of chronic low water quality.

Table 29. Regional changes in MWCI scores for all 17 reporting regions.

Schematically summarized are regional changes in MWCI scores (direction and length of arrow) for all reporting regions (listed from north to south). We included tabs below the color bar to communicate the statistical significance of the observed change using a 10-year time window. Tabs listed from left to right are MWCI, Eutrophication Index (EUI), and modules Ventilation (V), Ambient (A), Enrichment (E), and Impact (I). A text description “Significant” and “Tendency” communicates the certainty of our observations in the indices (MWCI and EUI) over a 10-year window. We are very certain about negative changes in Admiralty Reach, Central Basin, and Willapa Bay-Proper. Oakland Bay also continues to decline at a fast pace (long arrow), but we are less certain about the trend.



All regions

During 1999-2008, the largest significant changes in water quality (MWCI scores) within Ecology's station network were observed for Admiralty Reach (MWCI score -21.6) and Puget Sound's Central Basin sites (MWCI score -21.0) (Figure 12b). We detected significant changes in eutrophication (Eutrophication Index) in the same regions in addition to Willapa Bay-Proper (MWCI score -20.6).

We saw decreases in the MWCI scores at most other stations, although with less statistical certainty: Elliott Bay (-22.5), Bellingham Bay (-17.3), Southern Hood Canal (-16.0), Budd Inlet (-12.2), Willapa Bay (-8.6, River) (-5.0, Ocean) (Figures 12b, 13b). These regions showed decreasing scores due to a significant change in the nutrient concentrations and nutrient enrichment that permeated the entire station network (Figure 11b). MWCI scores were relatively consistent (not significant) in Grays Harbor (+3.6, Ocean) (-5.4 River), Georgia Basin (+0.3), and Whidbey Basin (-3.5), illustrating relatively stable conditions for these regions.

Discussion

This MWCI report focuses on results within the baseline period of MWCI, giving only brief examples of trends from 1999 to 2008. The implementation of the MWCI for Ecology's long-term marine monitoring dataset was successful. The index successfully demonstrated the strength of a modular approach and the use of environmentally informed baseline conditions to address the complexity of the interaction between eutrophication and ocean influences in Washington's marine waters. The modular structure of the MWCI allows scientists to explore the dataset without having to conduct independent data analysis. Given the importance of protecting Washington's marine water bodies, easy, timely, and transparent access to environmental data is a high priority.

The MWCI

The MWCI reports changes in water variables relative to known baseline conditions and emphasizes significant changes with the help of statistical filters. The MWCI's application to Ecology's 10-year dataset illustrates its sensitivity in detecting significant environmental changes that are, in many cases, significantly lower than natural seasonal variations. The capability of the MWCI formulation to discern and differentiate such long-term signals from large environmental variability justifies our approach for using the MWCI.

For the public, the MWCI communicates two independent pieces of information side by side. This allows to place shifting baseline conditions into a context of pre-existing spatial pattern of water quality. We therefore included pre-existing geographic differences in water quality in both forms: maps and color gradients. By providing these two contrasting approaches, we could draw a more comprehensive picture for Washington's marine water conditions and emphasize areas that need heightened attention.

While low water quality in areas of limited water exchange tend to persist, significant changes have occurred more rapidly along the mainstem of Puget Sound, paralleling the urban corridor from the city of Olympia to Admiralty Reach. The major drivers of lower MWCI scores in Puget Sound from 1999 to 2008 were macronutrients. The MWCI communicates these negative changes in the Ambient module for Admiralty Reach, Central and South Puget Sound, Elliott, Commencement and Oakland Bays, and for Willapa Bay-Proper at the coast. These changes suggest increasing nutrient conditions that could be of oceanic or regional origin.

The significant MWCI trends for Puget Sound's Central Basin and Admiralty Reach indicate that Puget Sound continues to increase in nutrients on a large temporal and spatial scale. River loads of nitrogen on the other hand have declined (Hallock 2009). One possible explanation for the increase in nutrient conditions above ocean conditions is the increase in population density over the last 10 years, consistent with other U.S. estuaries (Paerl et al., 2006). This localized increase in population affects nutrient discharges for many sewage treatment plants limited to two mechanical and biological treatment stages and could increase non-point inputs (e.g., storm-water, failing septic tanks). Nutrient inputs from sewage treatment plants are sizable (Roberts et al., 2008).

Signs of these non oceanic nutrient increases appear in distinct regions. This is indicated by significant negative 10-year trends in the Enrichment modules for Central Basin, Admiralty Reach, Oakland Bay, and Southern Hood Canal.

The Enrichment module is an important component to account for ocean influences in the MWCI as it reports on non-oceanic nutrient changes. It is beyond the scope of the index to provide scientific causality for the nutrient increases. Instead we explore and highlight the importance of several potential causes of this eutrophication to facilitate communication among scientists, natural resources managers, and stakeholders.

Baseline Conditions

It is critical that an index be able to sensitively detect environmental change against an appropriate baseline. The strength of naturally informed baseline conditions is that natural spatial and temporal variability are appropriately addressed. Formulating a set of eco-regions for the index is thereby omitted. This is in particularly important in highly dynamic and strongly variable estuarine environments.

Baseline conditions selected for the MWCI are not intended to reflect pristine marine water conditions of Washington State. Instead, they provide a comprehensive snapshot in time to track eutrophication and marine conditions with great sensitivity and high statistical separation power.

We have chosen to maintain a temporally fixed baseline period to provide a backward compatibility of the MWCI for trend analysis. Although this limits the number of repeated samples per month to establish the baseline, it was sufficient to estimated median values. The selection of a ten-year time period (1999 to 2008) limited the number of replicate samples per month to a maximum of 10 data points. Taking missed sampling events into account, each variable achieved on average at least 6.8 sampling events ($N>6.8$) to formulate a baseline. Winter months provided the largest uncertainties (Appendix A, Table A-13 to A-16), however conditions were more uniform in winter due to stronger mixing, dilution by rainwater and low biological activity.

The Four MWCI Modules

Eutrophication modules: Ambient, Enrichment, and Impact

The separation of the MWCI into modules to communicate the likelihood of eutrophication illustrates the strength of a modular structure. We therefore strongly encourage a transparent data structure that allows users to explore the underlying cause of eutrophication and the natural influences of ocean processes.

Eutrophication is indicated if all three eutrophication modules – Ambient, Enrichment, and Impact (Figure 1) – are decreasing in score. From 1999 to 2008, we saw an increase in eutrophication in the Central Basin, Admiralty Reach, and Willapa Bay-Proper (Table 29).

The MWCI has the capacity to report on the significance of oceanic nutrient conditions and partially account for ocean influences. We demonstrate in this report that ocean influences can drive large-scale nutrient conditions in Puget Sound and the two coastal estuaries and add significantly to processes of eutrophication. From 1999 to 2008, upwelling anomalies have significantly increased, and the Upwelling Index significantly correlated with several eutrophication modules in Puget Sound's Central Basin. This coincides with a significant downward trend in the Ambient module. Regions affected are the Central Basin, Admiralty Reach, Willapa Bay-Proper, Oakland Bay, South Sound, Elliott Bay, and Commencement Bay (Table 29).

The Enrichment module takes ocean influences into account. It reported significant declines for Southern Hood Canal, Central Basin, and Oakland Bay from 1999 to 2008 (Table 29).

The significant downward trends and complementary Ambient and Enrichment module scores confirm that nutrient enrichment above ocean source water has been occurring in the Central Puget Sound Basin and Oakland Bay.

The Impact module can provide information about ecological consequences of increasing nutrient concentrations and an increase in the imbalance in macronutrients. While overall nutrients have significantly changed in both Ambient and Enrichment modules, nutrient ratios of the Impact module remained relatively steady in mid-basin and mid-channel water bodies. This observation is encouraging for the present nutrient condition of Puget Sound and the coast. The Impact module correlated significantly with the PDO Index in Elliott Bay and Whidbey Basin and with the PFEL Index in Sinclair Inlet. The cause is unclear.

In conclusion, the side-by-side presentation of all three eutrophication modules provides additional and valuable information to the MWCI and is a tool to explore and communicate environmental changes in the context of large-scale oceanic conditions. The modular approach allows us to differentiate parallel processes that on first sight might be falsely interpreted.

Ventilation module

The Ventilation module is separated from the Eutrophication modules. We demonstrate that the Ventilation module tracks large-scale oceanographic signals (PDO Index). The responsiveness to large-scale physical factors was very strong. The Ventilation module was sensitive enough to detect larger-scale climatic patterns that extend beyond regional water quality conditions. The module responded to ocean variability in the main basins of Puget Sound including Admiralty Reach, Puget Sound's Central Basin, Sinclair Inlet, S. Hood Canal, Elliott Bay, Whidbey Basin, Budd Inlet, Oakland Bay, and South Sound. However, significant temporal trends were observed only for Elliott Bay

As expected, the coast was also strongly influenced by the ocean, showing a correlation of the PDO with the Ventilation module for Willapa Bay-Ocean, Willapa Bay-Proper, and two river stations, Willapa Bay-River and Grays Harbor River. The Ventilation module therefore provides additional information on large-scale ocean processes that can be folded into the communication strategy.

Conclusions and Recommendations

Conclusions

The Marine Water Condition Index (MWCI) constitutes an improvement over Ecology's previous water quality indices. We designed the MWCI to reduce the large component of environmental variability in order to detect subtle changes over time. The MWCI proved to be a sensitive and effective tool for detecting small environmental changes in baseline conditions of the marine environment. Its statistical approach allows us to highlight environmentally important trends. The selection of site-specific baseline conditions allows us to detect changes at each station with high precision.

A drawback is that the MWCI is not designed to detect change in extremes in environmental conditions when median conditions remain unchanged. Other monitoring approaches to address this issue are needed. These approaches include using continuously deployed sensors and reporting tools focusing on the amplitude, frequency, and duration of events.

Despite considerable variability in the long-term marine monitoring dataset, we found significantly increasing nutrient concentrations and placed them into the context of environmental factors. The modularity of the MWCI proves to be effective in differentiating the interaction between natural conditions, large-scale forcing factors, and the interaction of human influences on Washington's marine water conditions. The MWCI therefore is a tool to evaluate water quality trends and remediation efforts in the context of multiple interacting influences.

While changes in MWCI scores do not necessarily convey water conditions in absolute terms, the scores have informational value in providing focus and objectivity in water quality discussions.

Recommendations

Our finding highlights significant negative changes in water conditions along the urbanized corridor of Puget Sound; this area should be monitored.

While the absolute increase in ambient nutrient concentrations appears small, ecological processes could mask true nutrient increases. It is beyond of the scope of the MWCI to evaluate the large-scale implications of the observed changes but particular attention should be given to nutrient ratio shifts indicative of eutrophication.

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Appendices

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Appendix A. Regional Trends of the MWCI Modules

This appendix presents detailed information on individual MWCI trends and source data. For additional explanation on the 10-year trend figures (A-1 through A-17), see Figure 6 in the report.

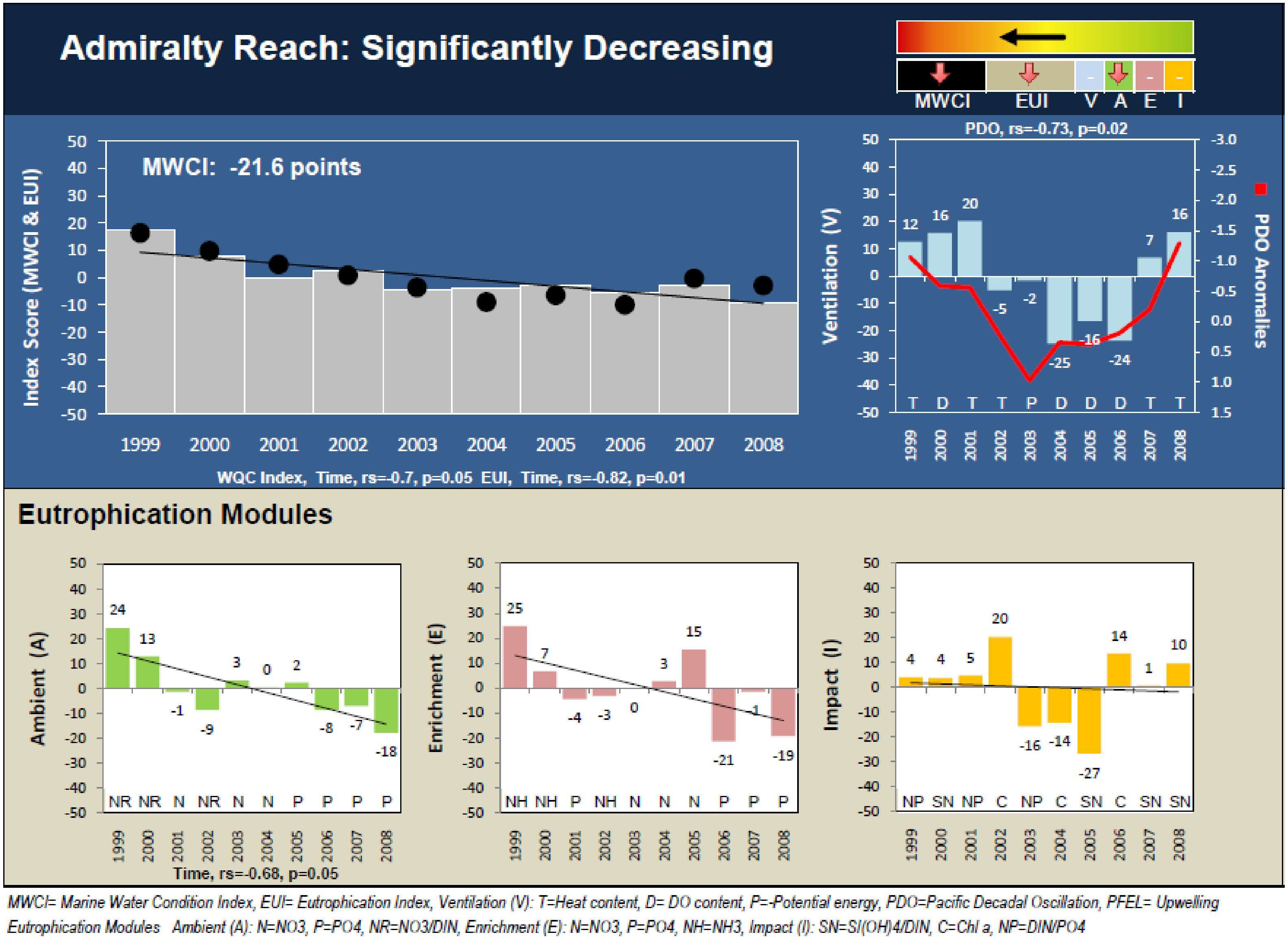
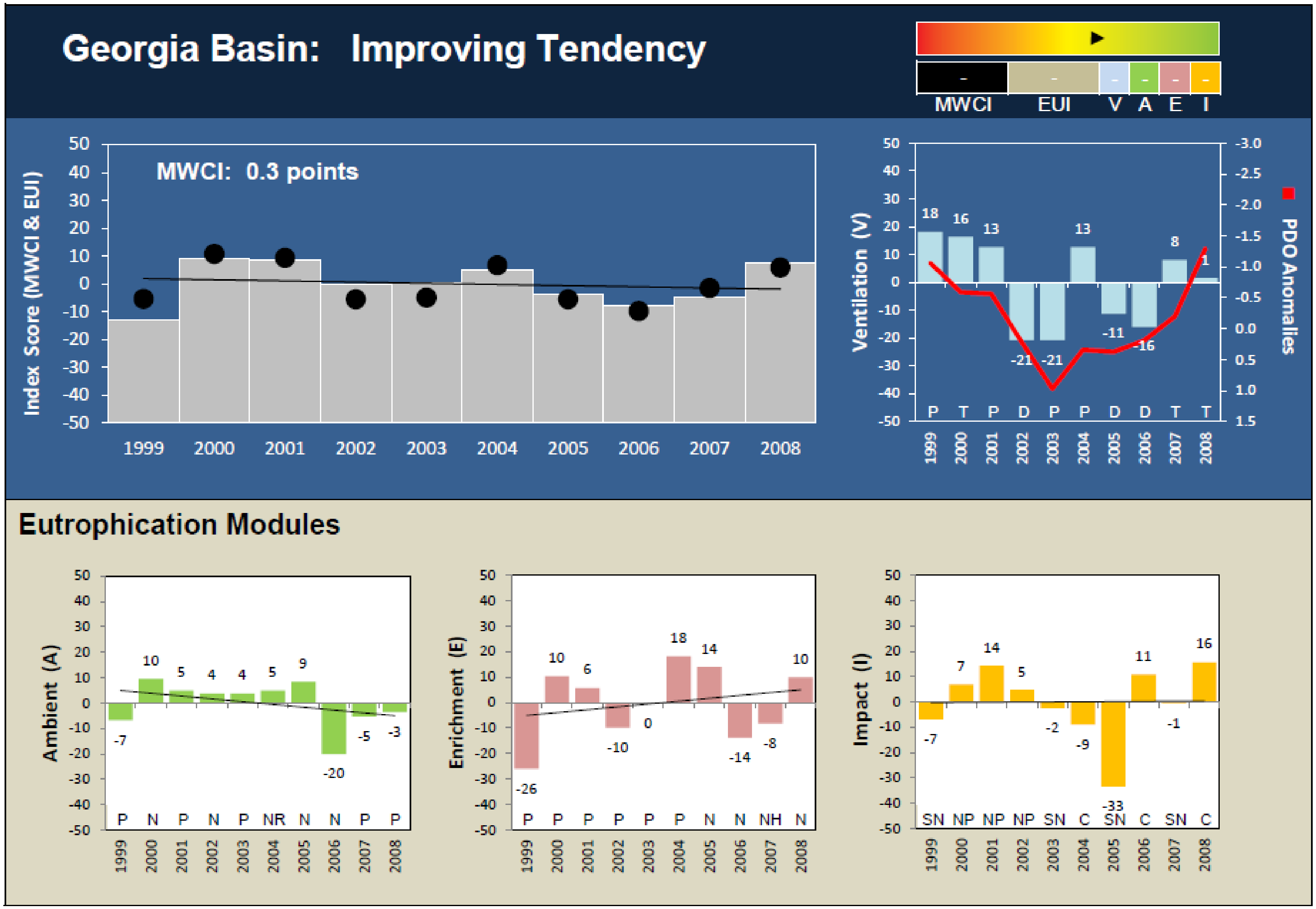


Figure A-1. Ten-year trends for the MWCI reporting region Admiralty Reach.



MWCI= Marine Water Condition Index, EUI= Eutrophication Index, Ventilation (V): T=Heat content, D= DO content, P=-Potential energy, PDO=Pacific Decadal Oscillation, PFEL= Upwelling

Eutrophication Modules Ambient (A): N=NO3, P=PO4, NR=NO3/DIN, Enrichment (E): N=NO3, P=PO4, NH=NH3, Impact (I): SN=Si(OH)4/DIN, C=Chl a, NP=DIN/PO4

Figure A-2. Ten-year trends for the MWCI reporting region Georgia Basin.

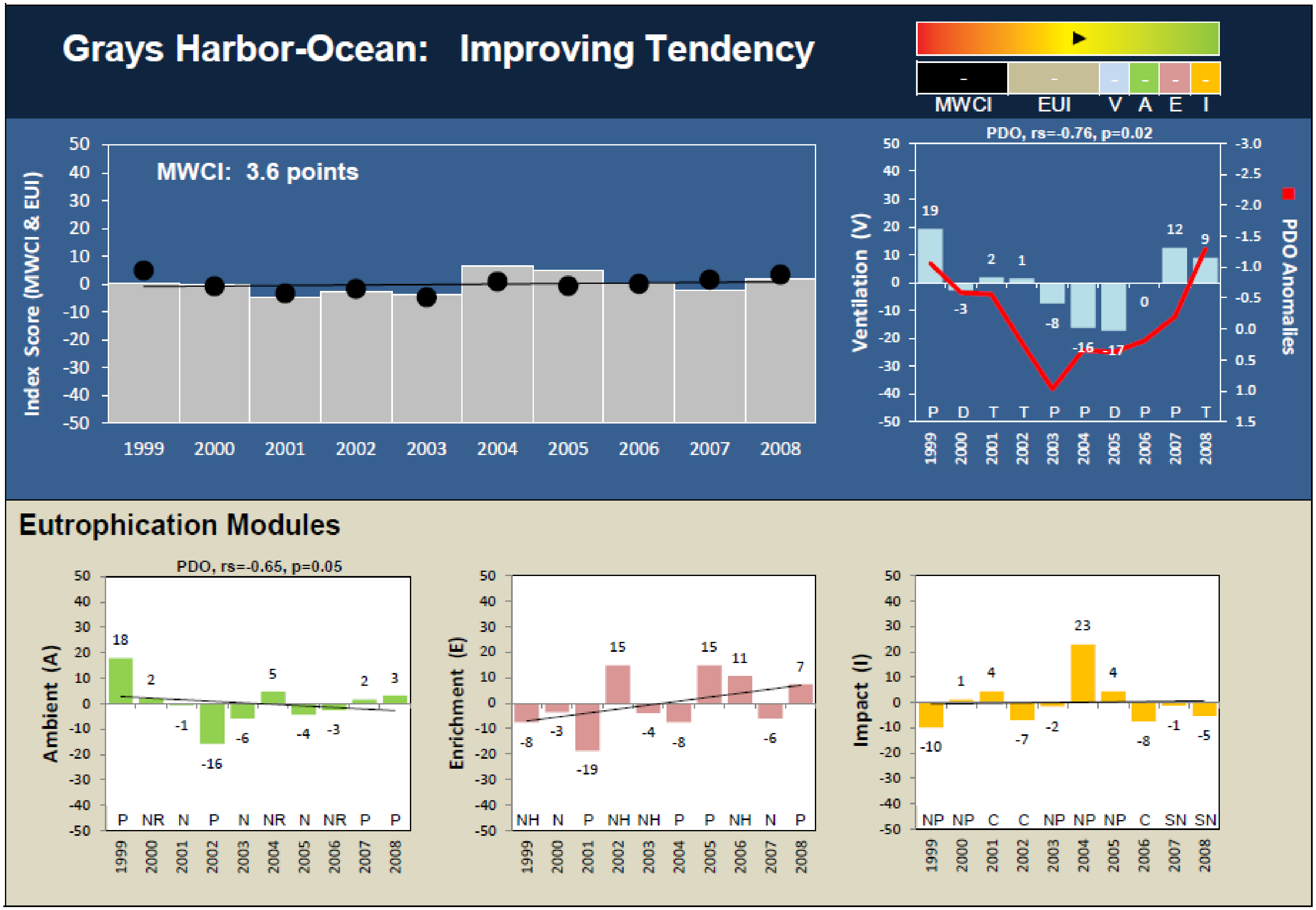


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Figure A-3. Ten-year trends for the MWCI reporting region Grays Harbor-Ocean.

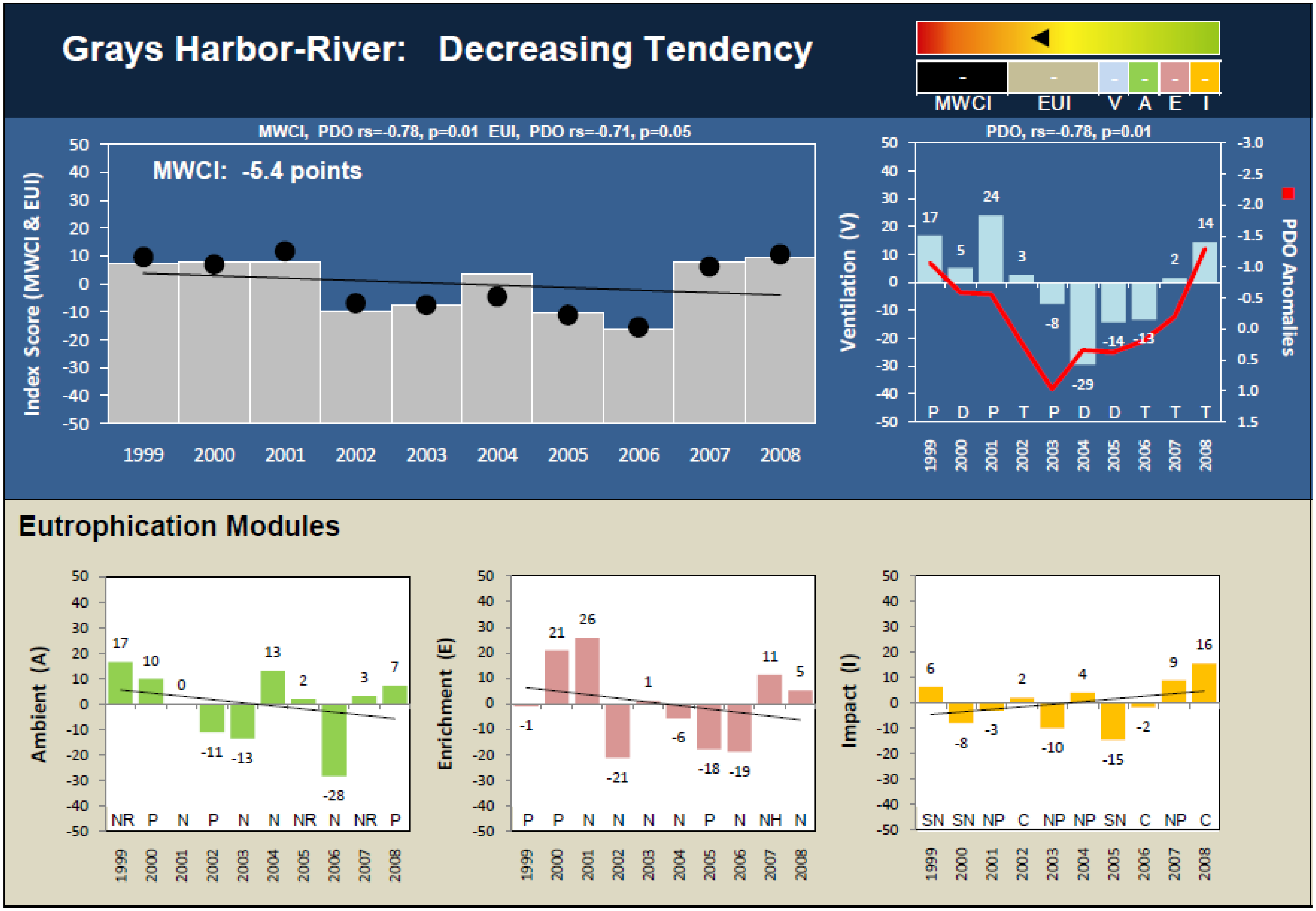

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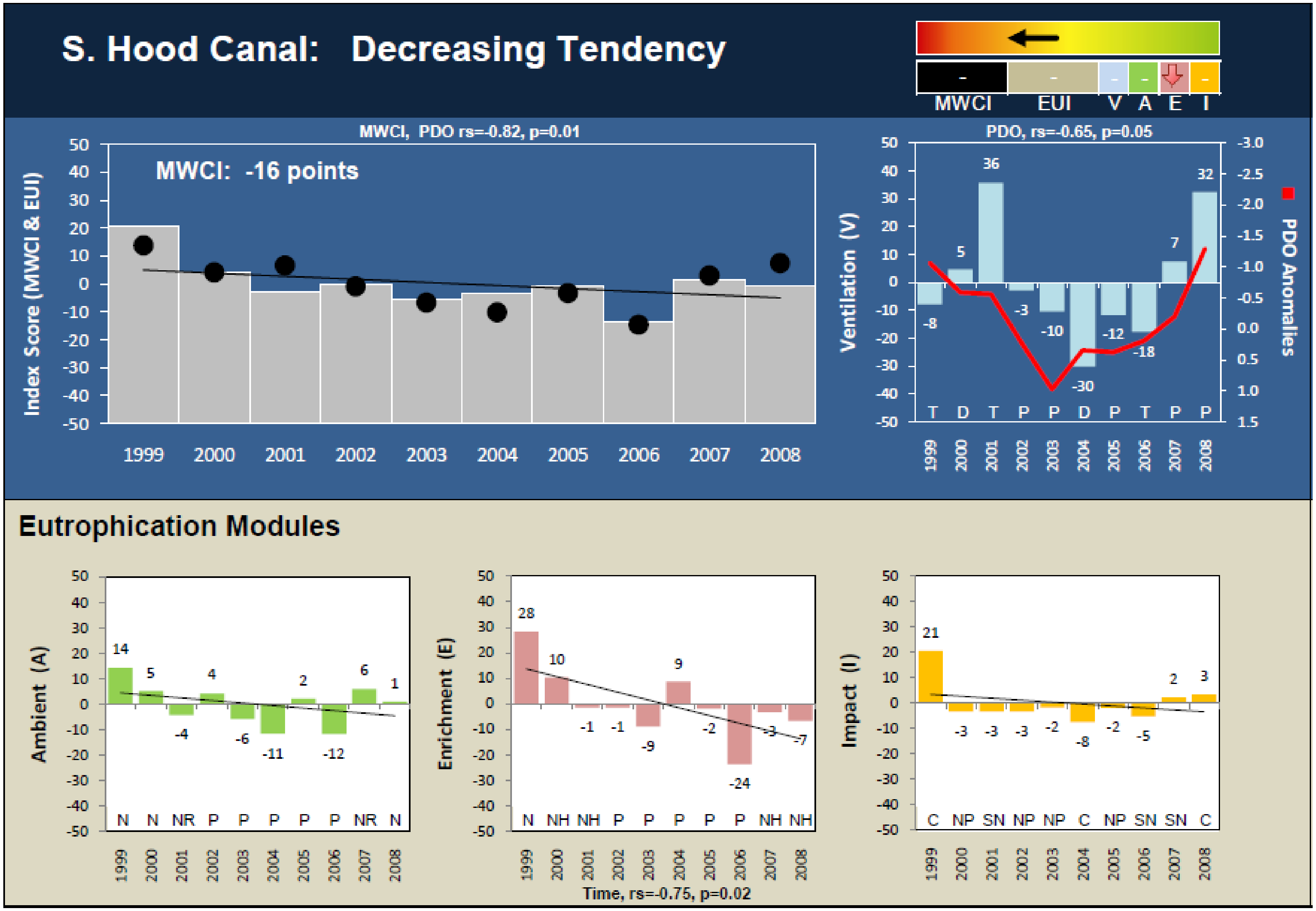
Figure A-4. Ten-year trends for the MWCI reporting region Grays Harbor-River.



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Eutrophication Modules Ambient (A): N=NO3, P=PO4, NR=NO3/DIN, Enrichment (E): N=NO3, P=PO4, NH=NH3, Impact (I): SN=SI(OH)4/DIN, C=Chl a, NP=DIN/PO4

Figure A-5. Ten-year trends for the MWCI reporting region S. Hood Canal.

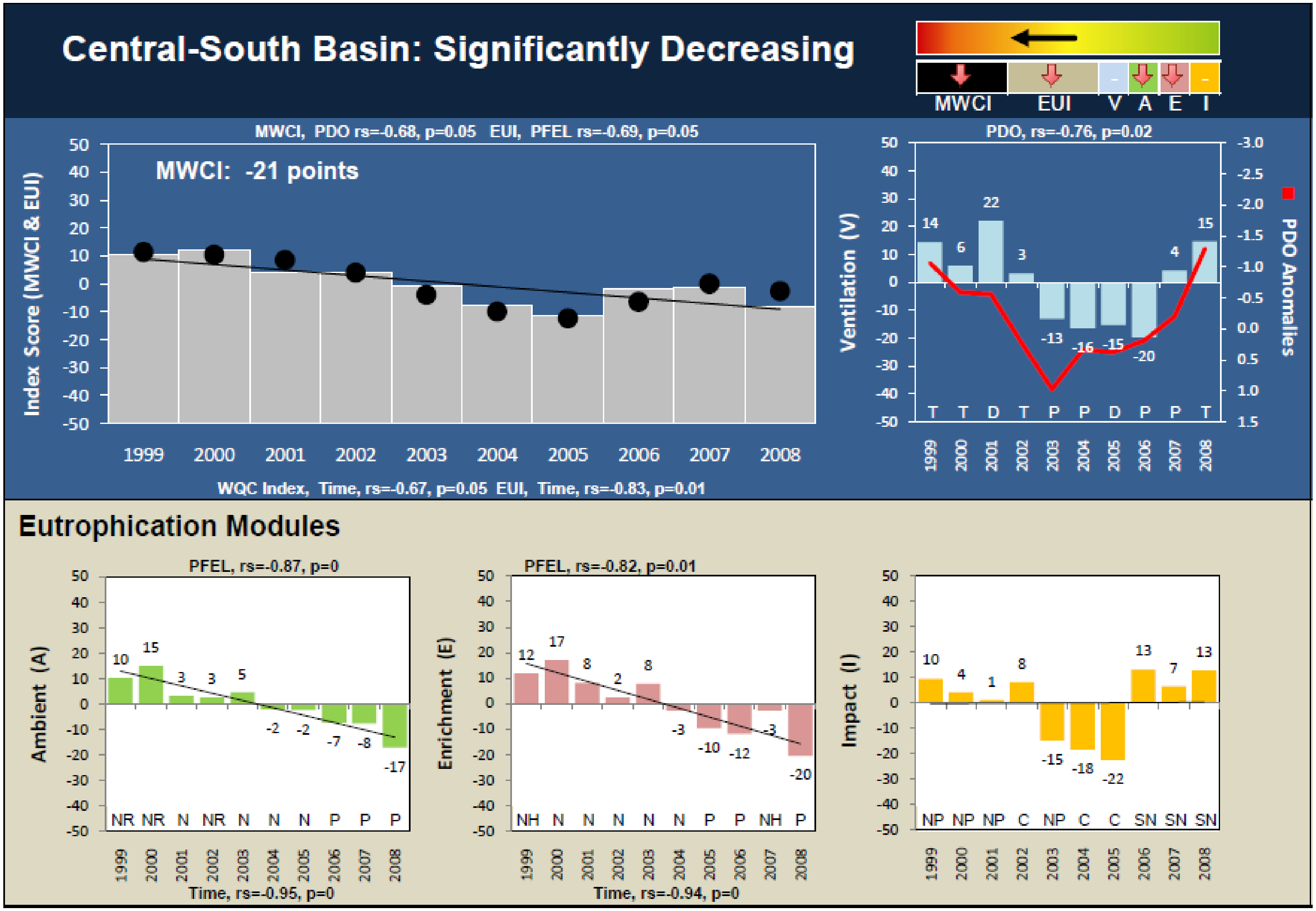

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Figure A-6. Ten-year trends for the MWCI reporting region Central-South Basin.

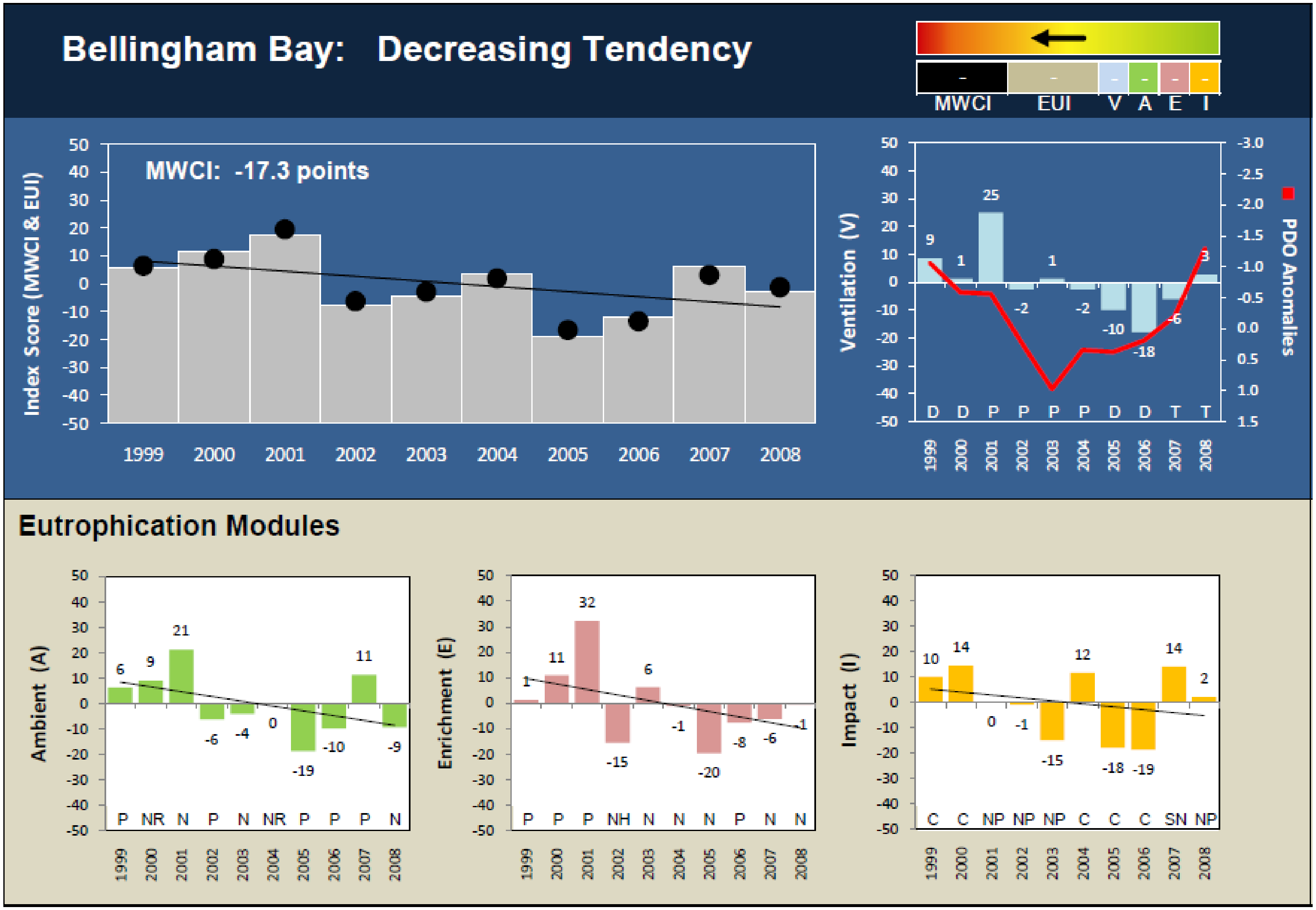

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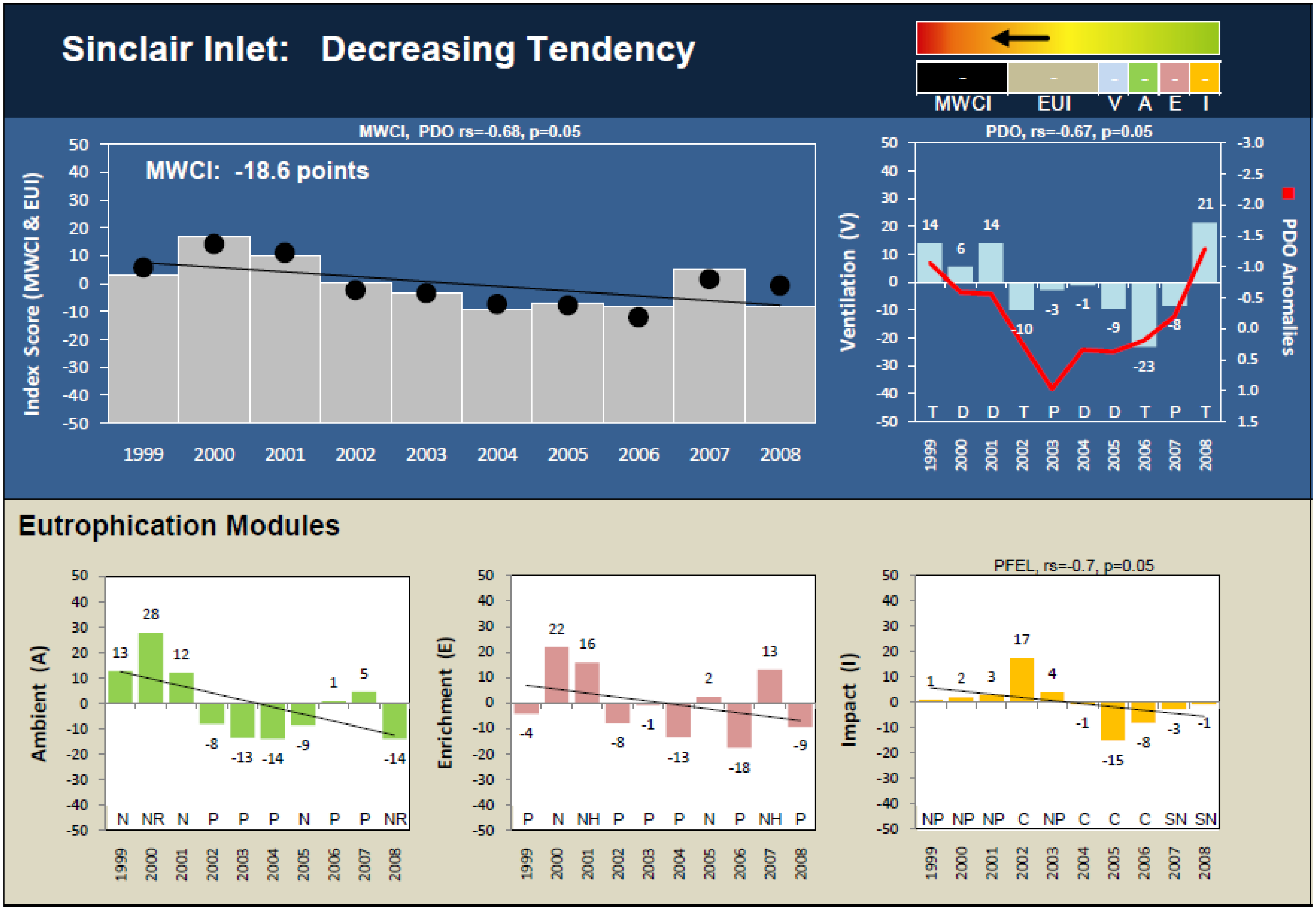
Figure A-7. Ten-year trends for the MWCI reporting region Bellingham Bay.



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Eutrophication Modules Ambient (A): N=NO3, P=PO4, NR=NO3/DIN, Enrichment (E): N=NO3, P=PO4, NH=NH3, Impact (I): SN=SI(OH)4/DIN, C=Chl a, NP=DIN/PO4

Figure A-8. Ten-year trends for the MWCI reporting region Sinclair Inlet.

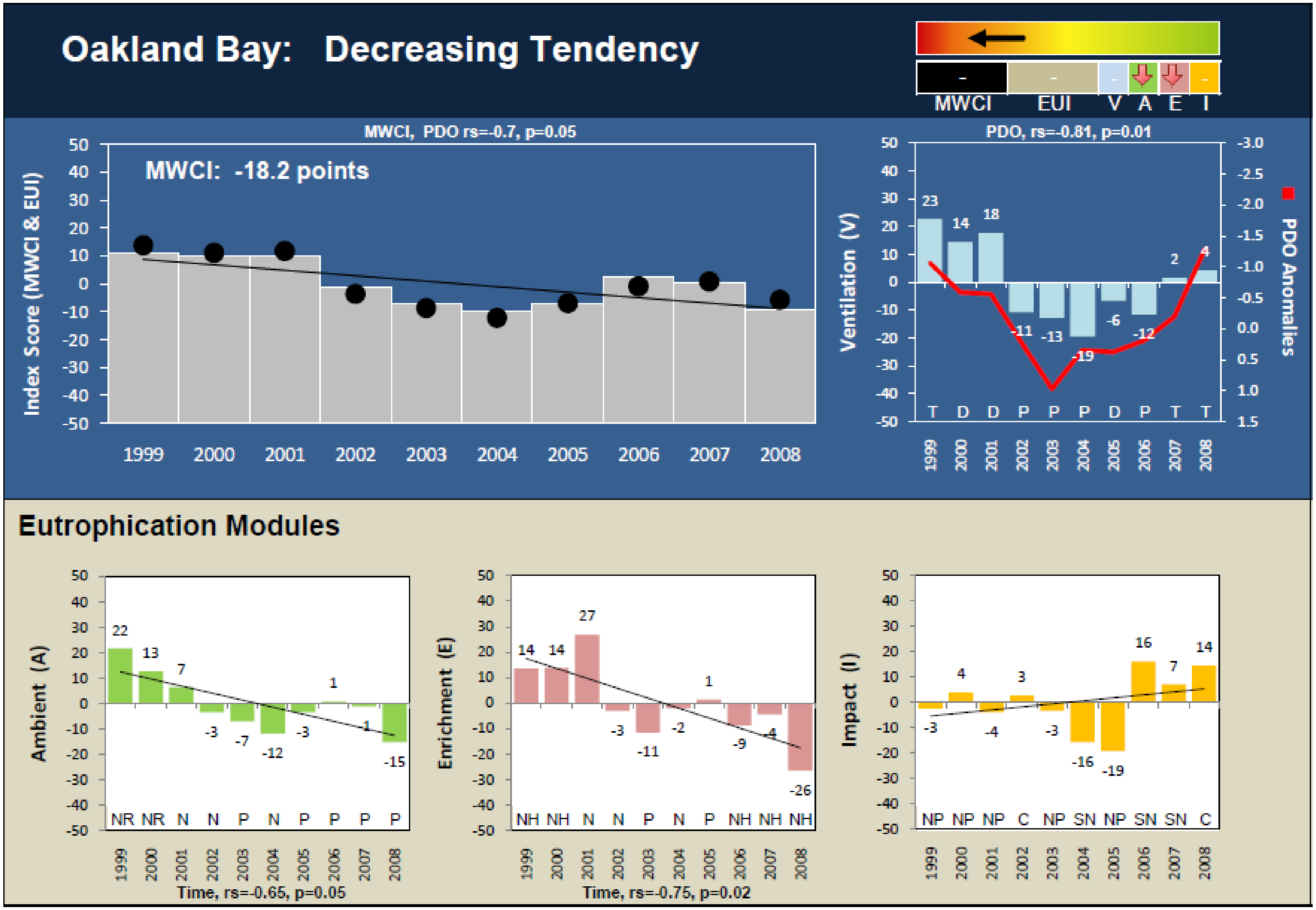

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Figure A-9. Ten-year trends for the MWCI reporting region Oakland Bay.

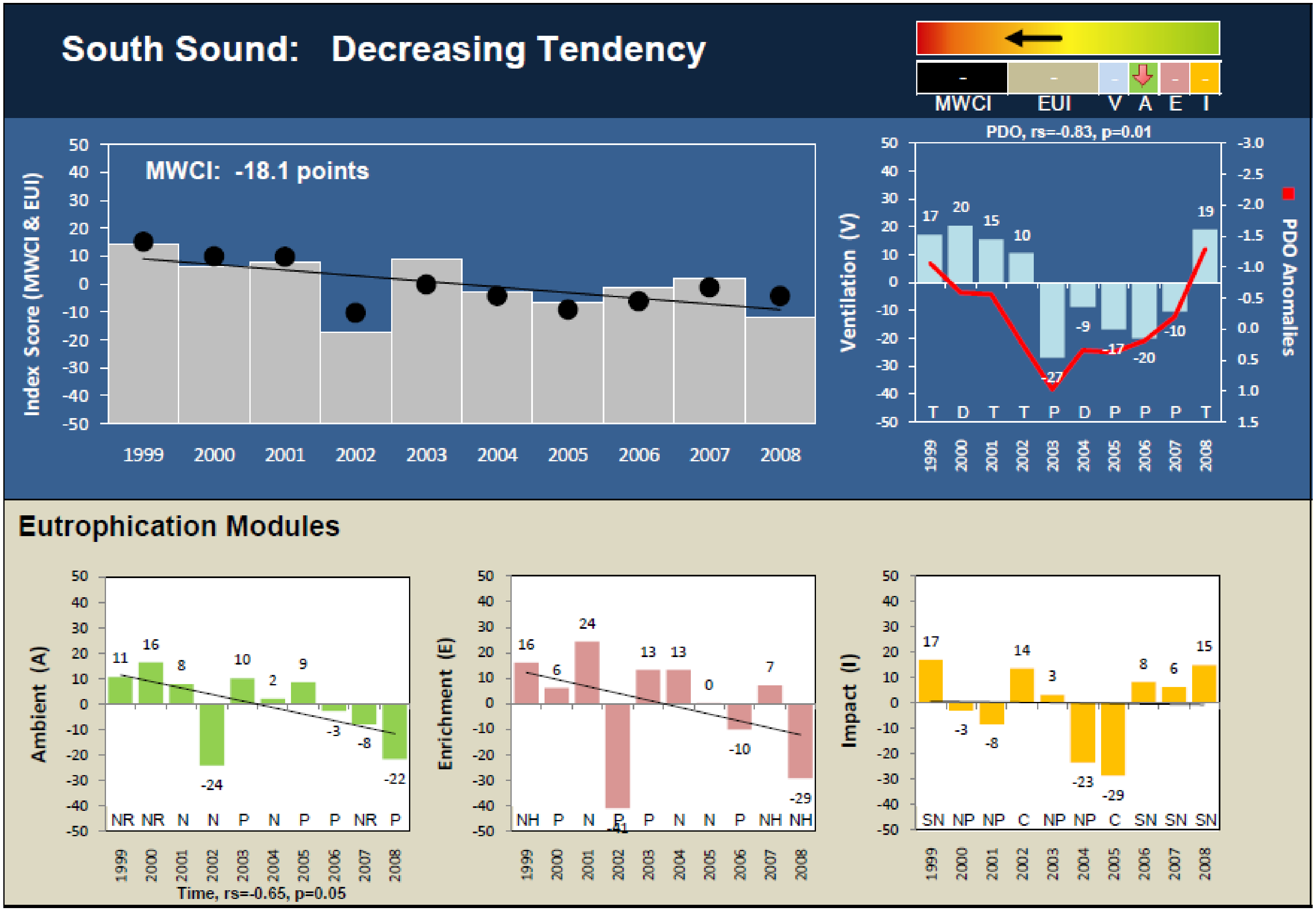

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Figure A-10. Ten-year trends for the MWCI reporting region South Sound.

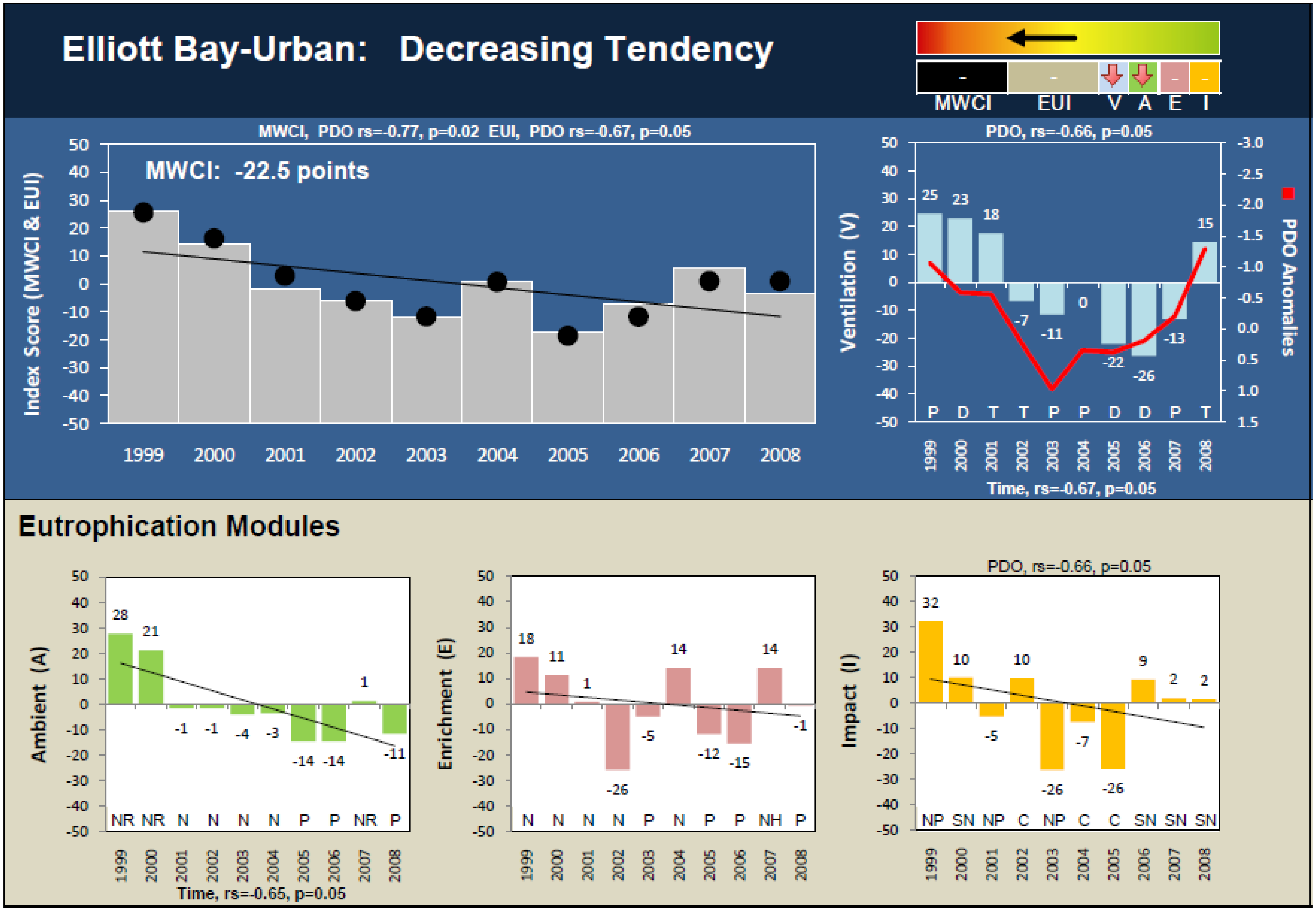

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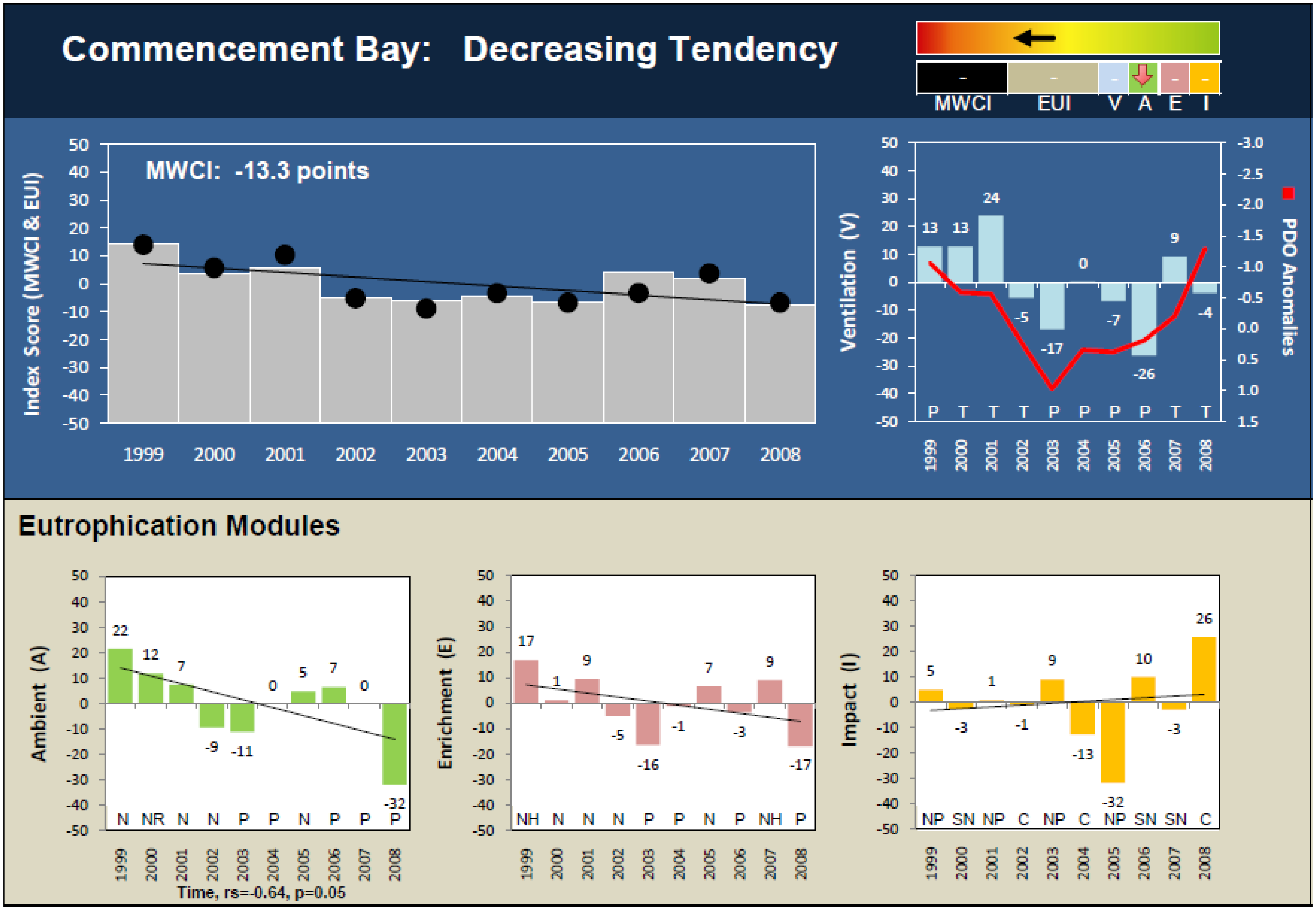
Figure A-11. Ten-year trends for the MWCI reporting region Elliott Bay-Urban.



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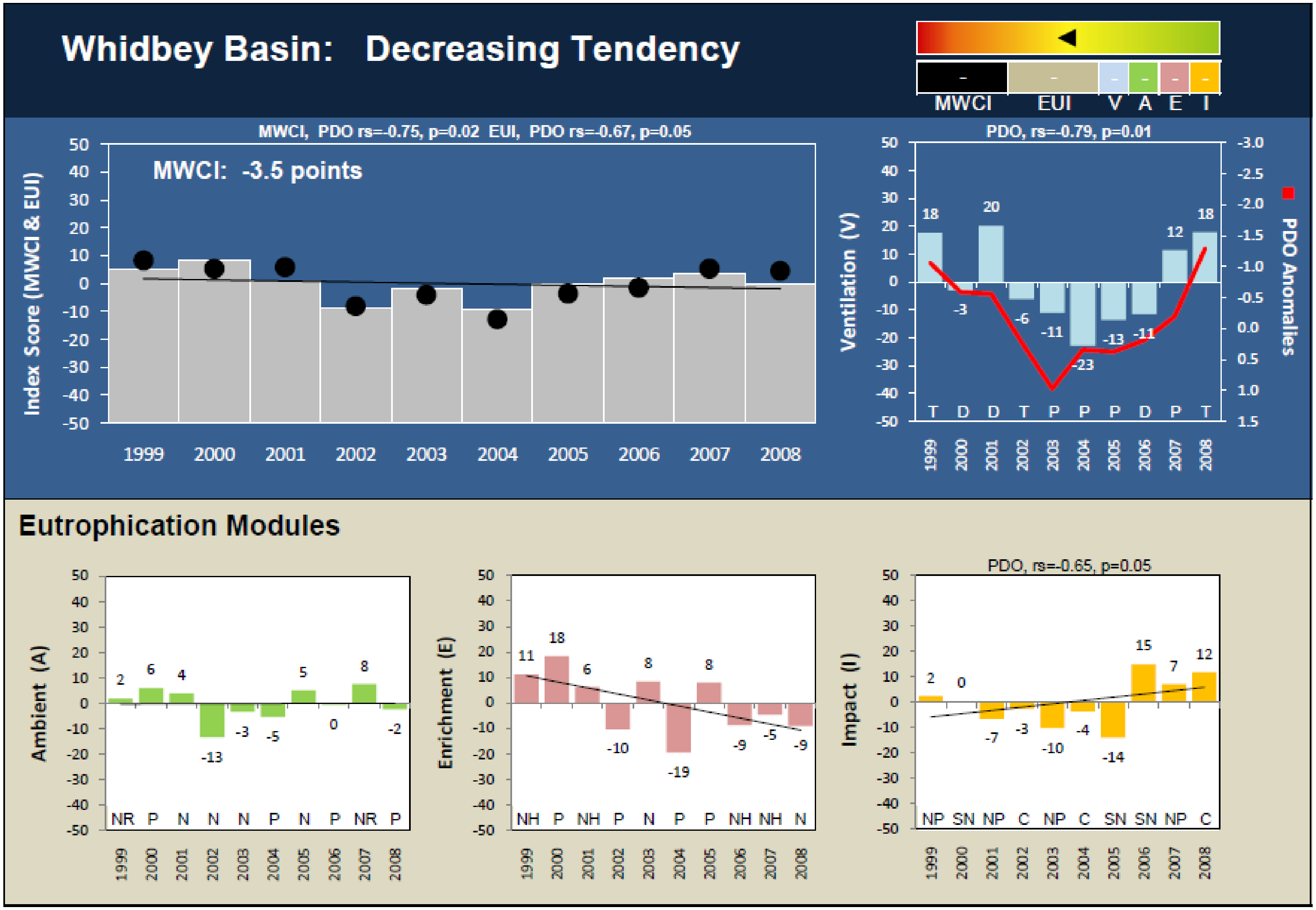
Eutrophication Modules Ambient (A): N=NO3, P=PO4, NR=NO3/DIN, Enrichment (E): N=NO3, P=PO4, NH=NH3, Impact (I): SN=SI(OH)4/DIN, C=Chl a, NP=DIN/PO4

Figure A-12. Ten-year trends for the MWCI reporting region Commencement Bay.



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Eutrophication Modules Ambient (A): N=NO3, P=PO4, NR=NO3/DIN, Enrichment (E): N=NO3, P=PO4, NH=NH3, Impact (I): SN=SI(OH)4/DIN, C=Chl a, NP=DIN/PO4

Figure A-13. Ten-year trends for the MWCI reporting region Whidbey Basin.

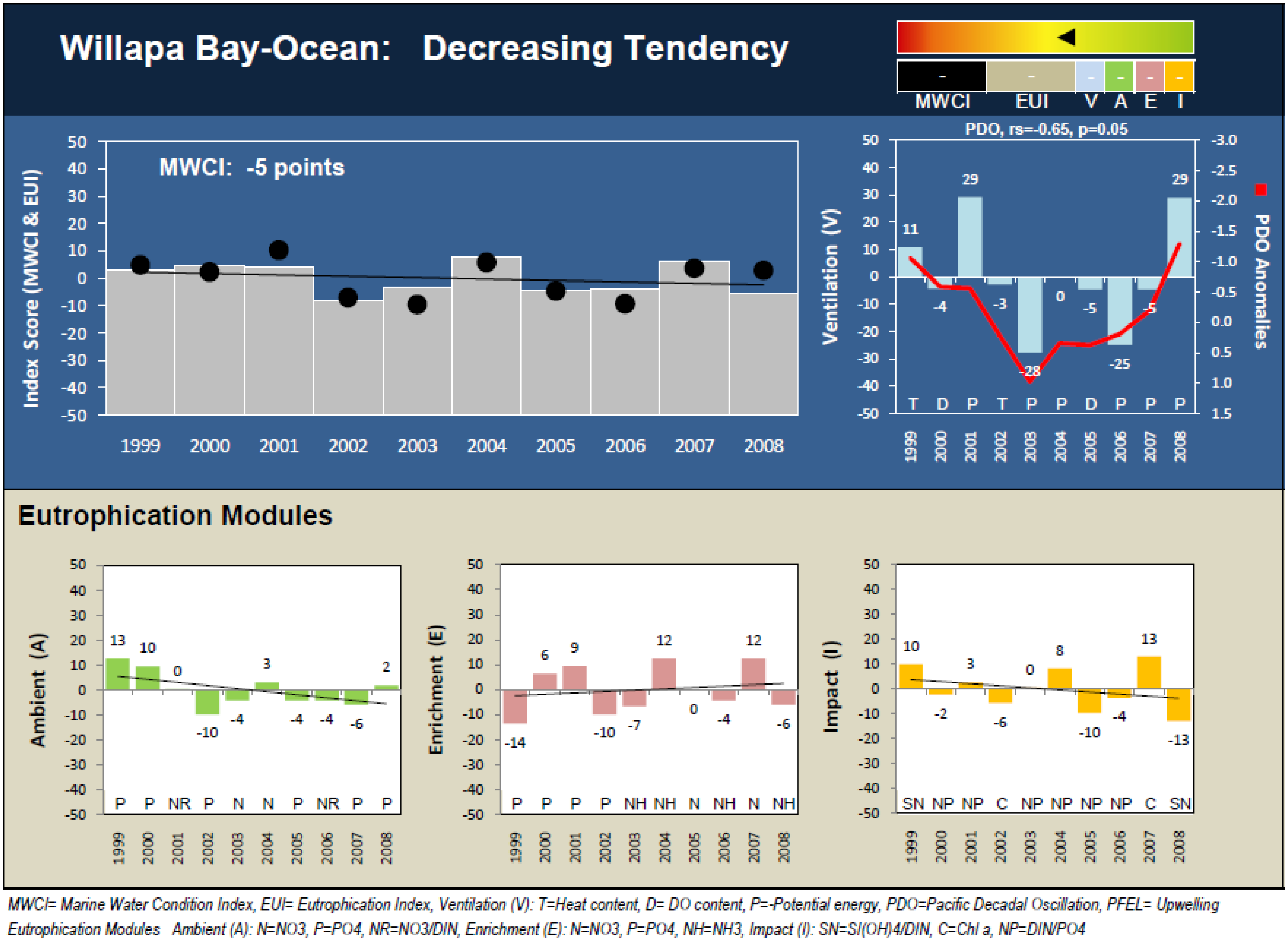
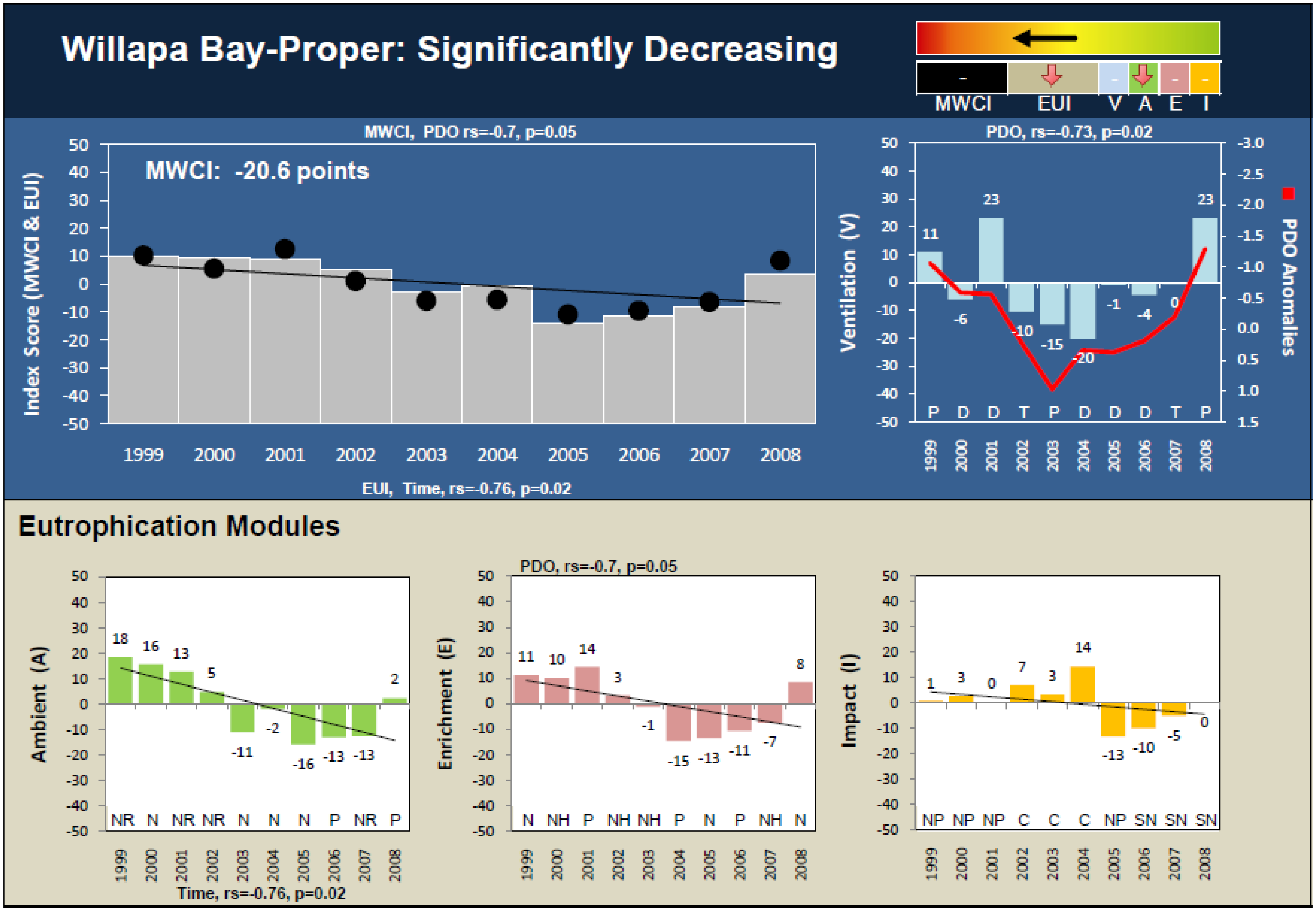


Figure A-14. Ten-year trends for the MWCI reporting region Willapa Bay-Ocean.



MWCI= Marine Water Condition Index, EUI= Eutrophication Index, Ventilation (V): T=Heat content, D= DO content, P=-Potential energy, PDO=Pacific Decadal Oscillation, PFEL= Upwelling
Eutrophication Modules Ambient (A): N=NO3, P=PO4, NR=NO3/DIN, Enrichment (E): N=NO3, P=PO4, NH=NH3, Impact (I): SN=SI(OH)4/DIN, C=Chl a, NP=DIN/PO4

Figure A-15. Ten-year trends for the MWCI reporting region Willapa Bay-Proper.

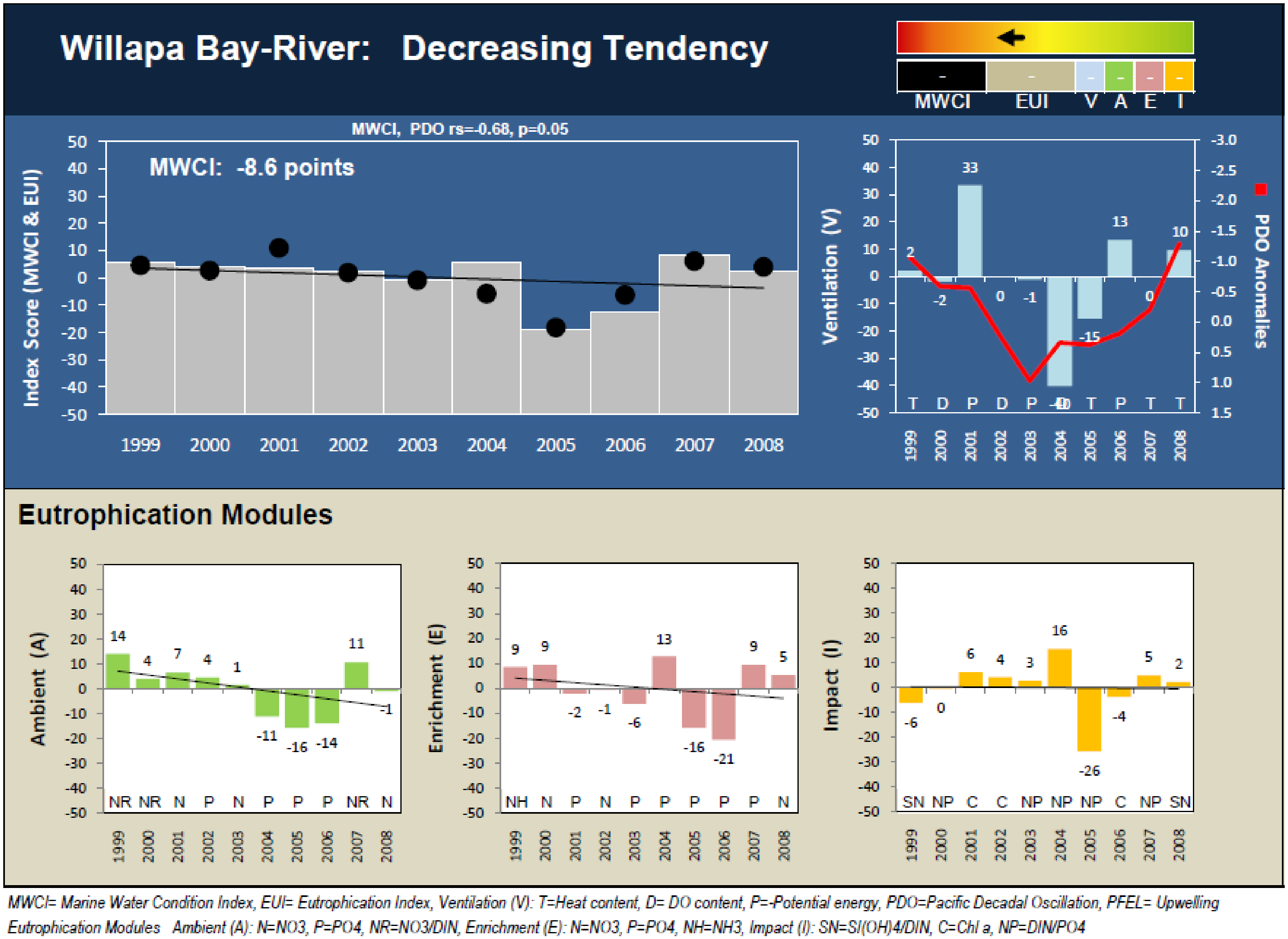
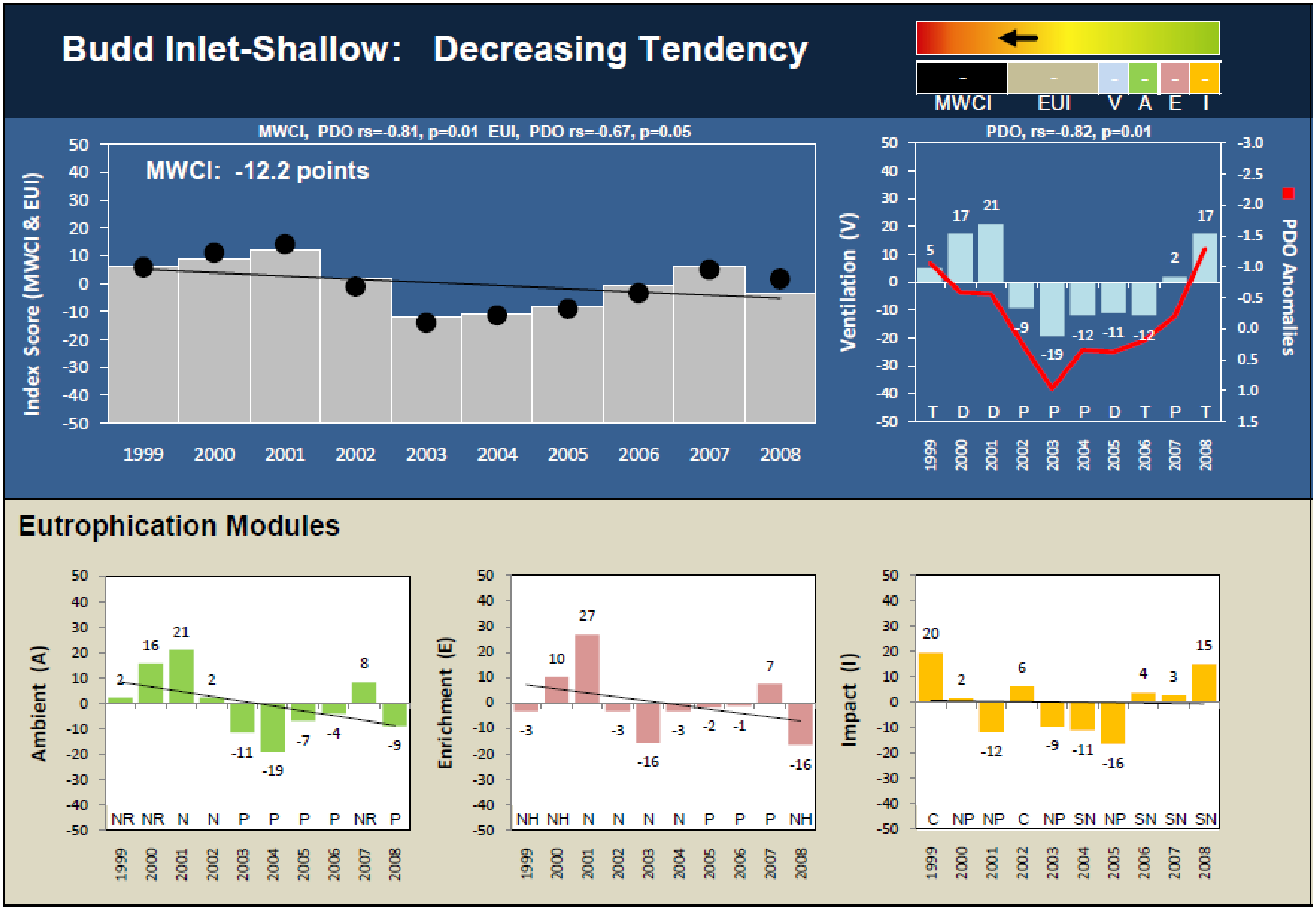


Figure A-16. Ten-year trends for the MWCI reporting region Willapa Bay-River.



MWCI= Marine Water Condition Index, EUI= Eutrophication Index, Ventilation (V): T=Heat content, D= DO content, P=-Potential energy, PDO=Pacific Decadal Oscillation, PFEL= Upwelling
Eutrophication Modules Ambient (A): N=NO3, P=PO4, NR=NO3/DIN, Enrichment (E): N=NO3, P=PO4, NH=NH3, Impact (I): SN=SI(OH)4/DIN, C=Chl a, NP=DIN/PO4

Figure A-17. Ten-year trends for the MWCI reporting region Budd Inlet-Shallow.

Table A-1. Ten-year anomalies for the MWCI variable nitrate (uM).

Black indicates no anomaly, **red** indicates a positive anomaly, **green** indicates a negative anomaly, and **gray** indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

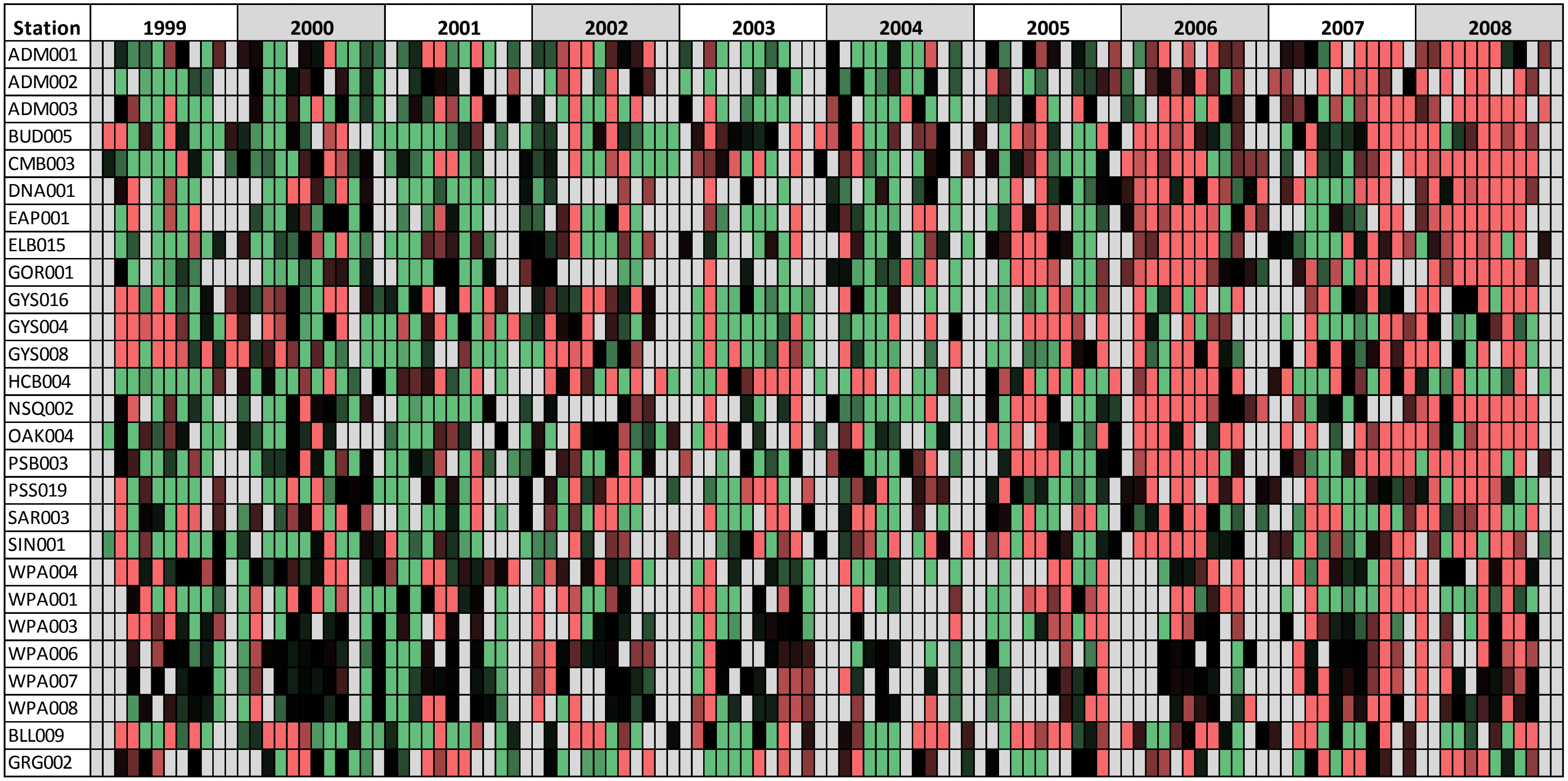


Table A-2. Ten-year anomalies for MWCI variable phosphate (uM).

Black indicates no anomaly, red indicates a positive anomaly, green indicates a negative anomaly, and gray indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (green), 50th percentile (**black**), and 75th percentile (red).

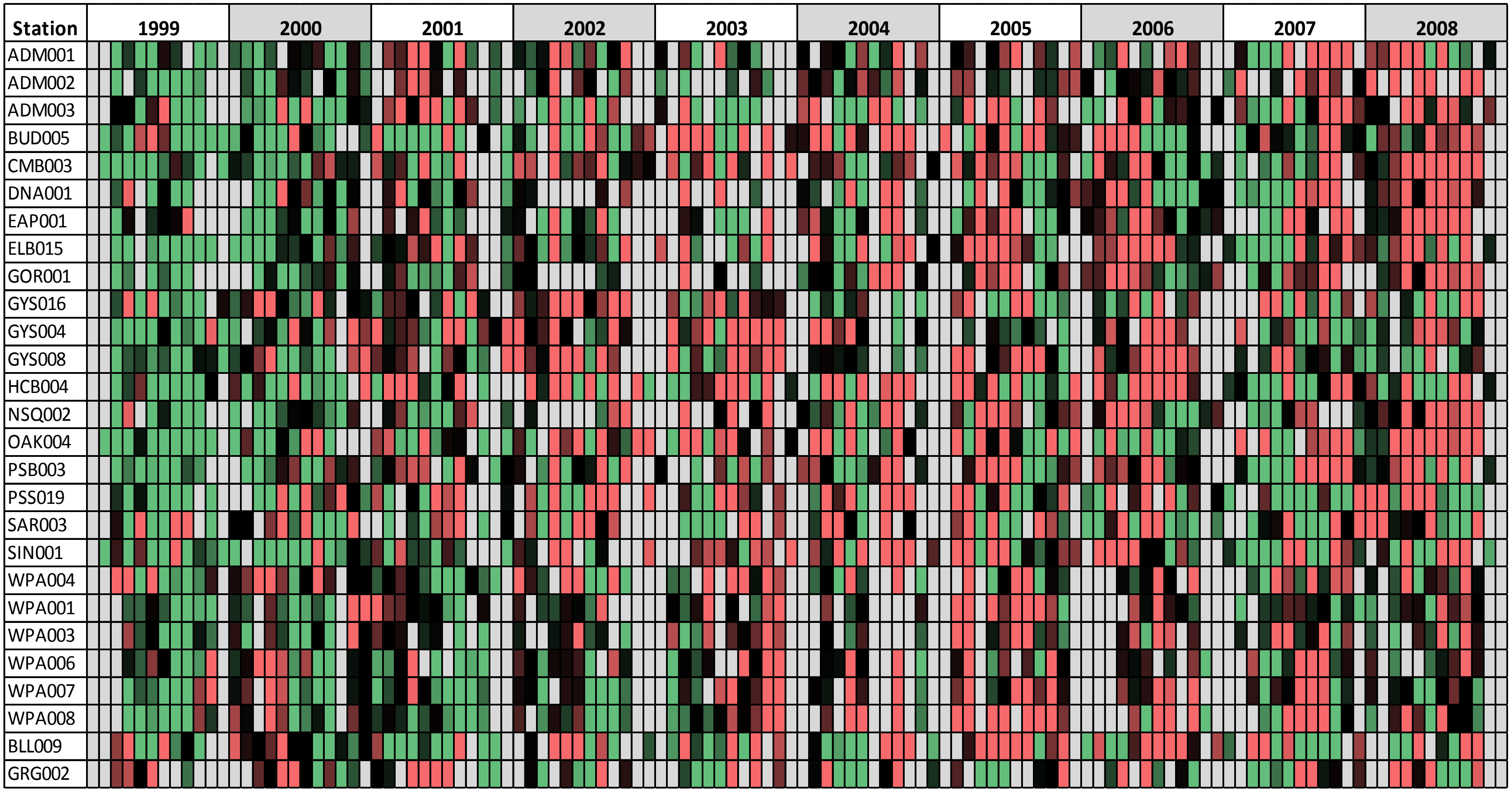


Table A-3. Ten-year anomalies for the MWCI variable nitrate:DIN ratio.

Black indicates no anomaly, **red** indicates a positive anomaly, **green** indicates a negative anomaly, and **gray** indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

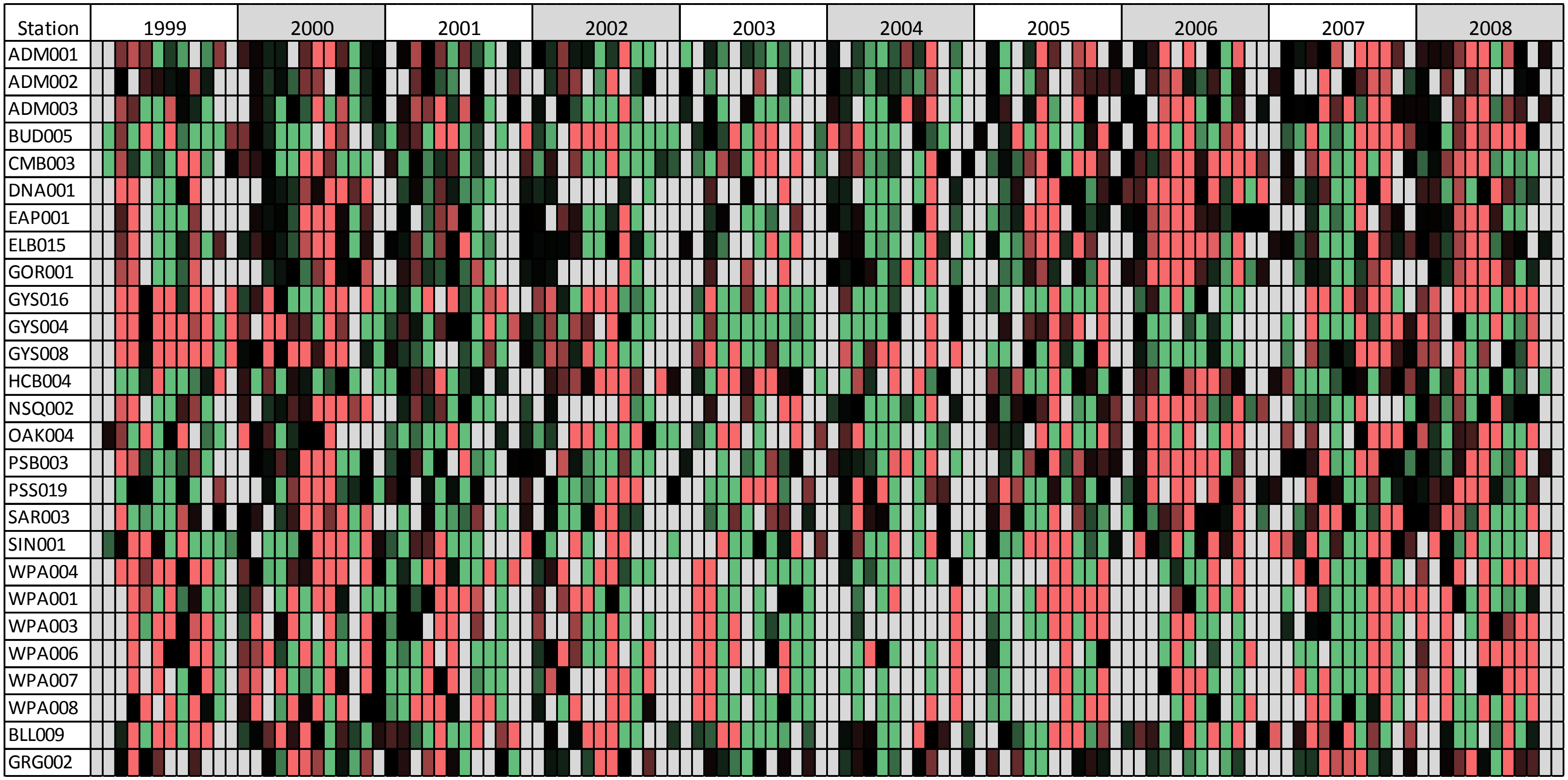


Table A-4. Ten-year anomalies for the MWCI variable nitrate enrichment (uM).

Black indicates no anomaly, red indicates a positive anomaly, green indicates a negative anomaly, and gray indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (green), 50th percentile (**black**), and 75th percentile (red).

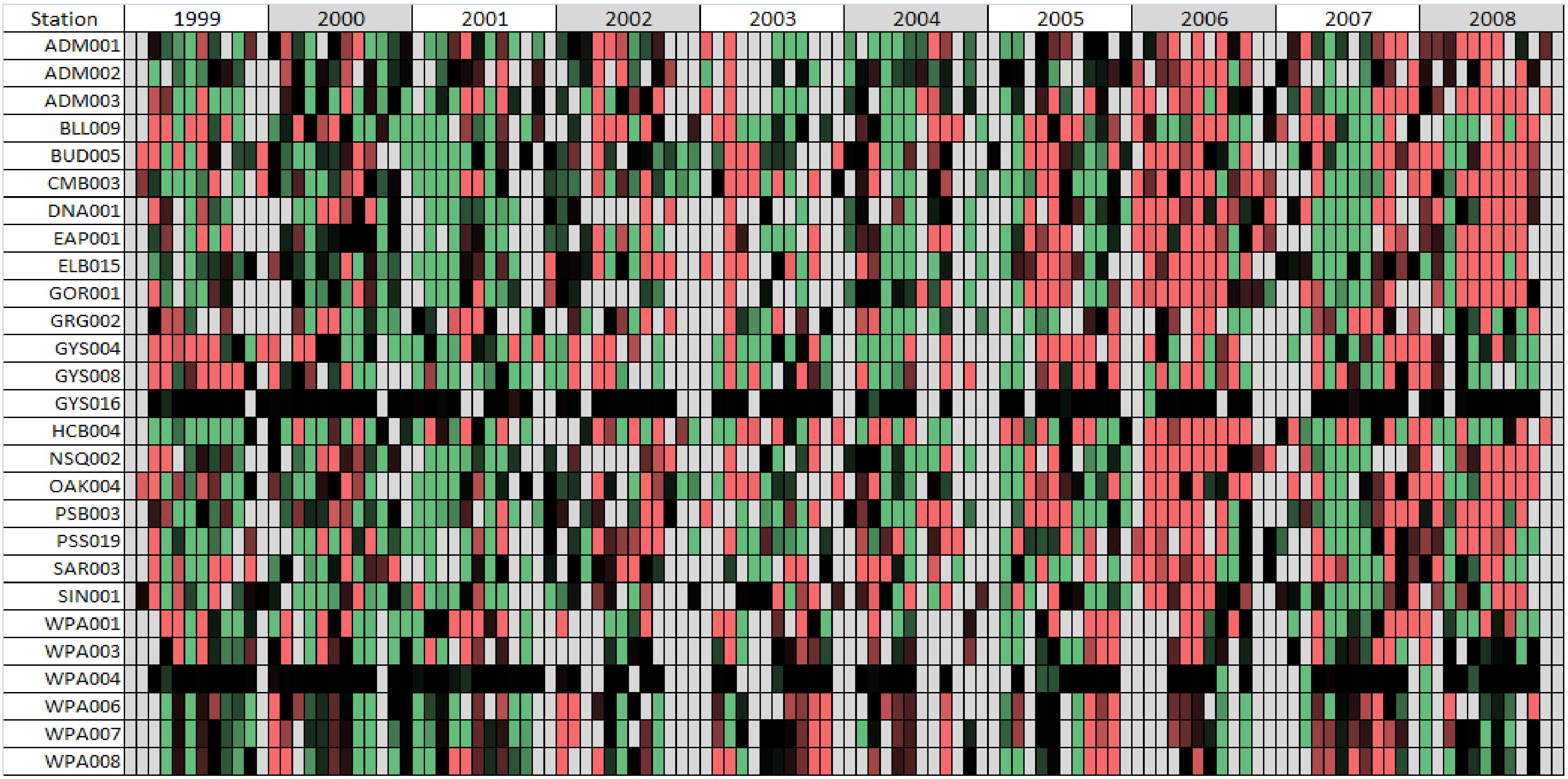


Table A-5. Ten-year anomalies for the MWCI variable phosphate enrichment (uM).

Black indicates no anomaly, **red** indicates a positive anomaly, **green** indicates a negative anomaly, and **gray** indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

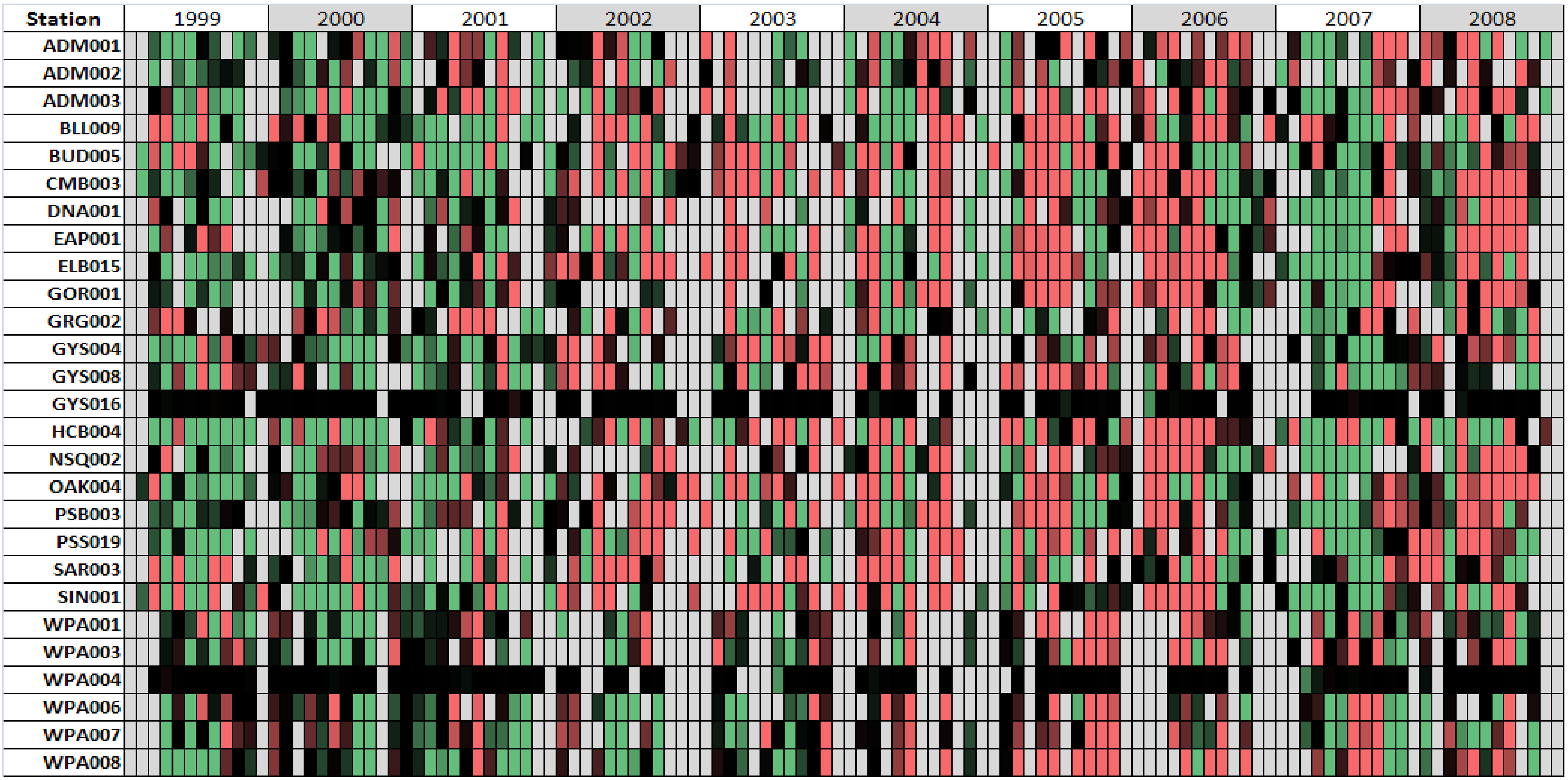


Table A-6. Ten-year anomalies for the MWCI variable ammonium enrichment (uM).

Black indicates no anomaly, red indicates a positive anomaly, green indicates a negative anomaly, and gray indicates missing data. Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month. The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

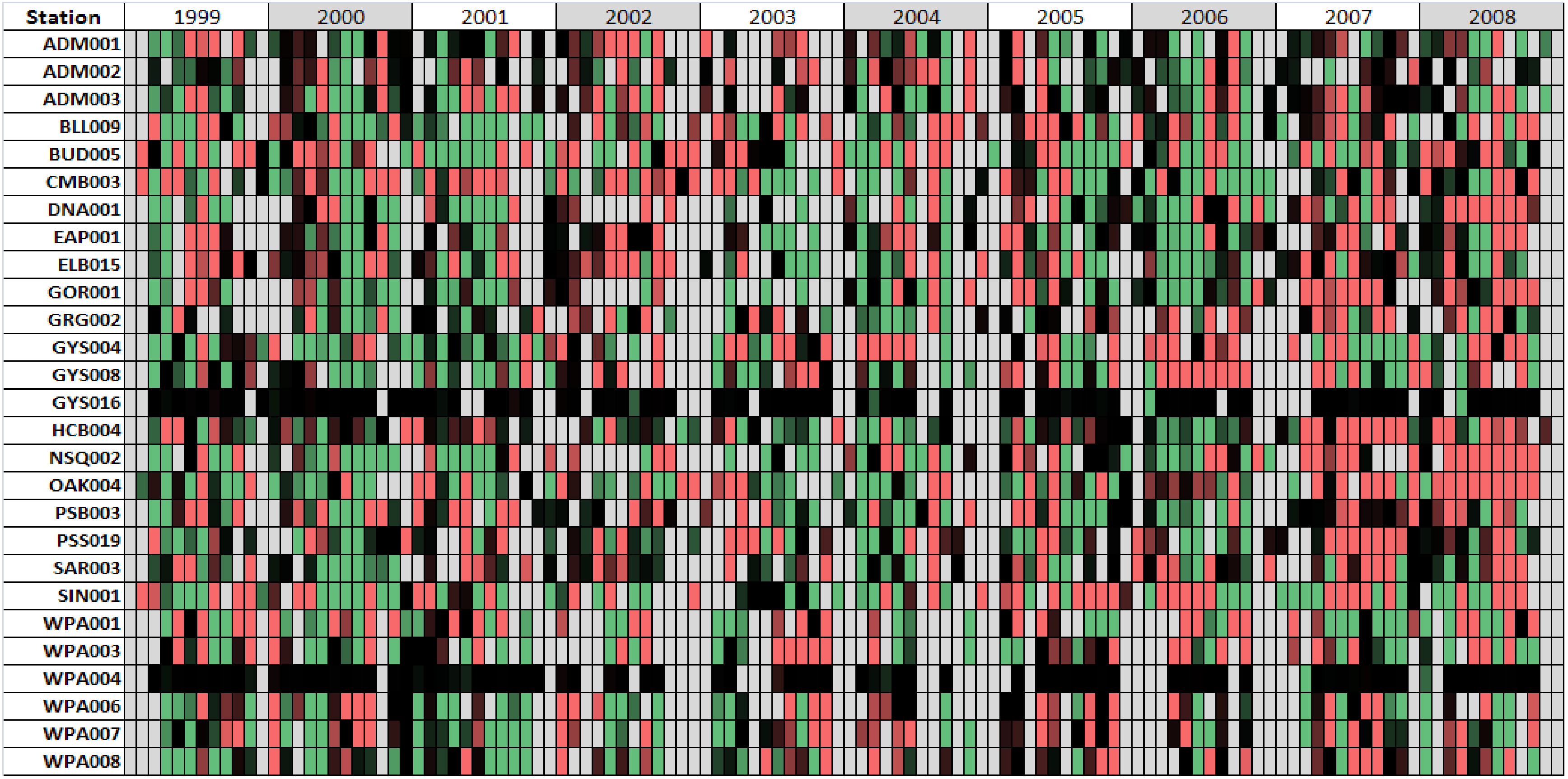


Table A-7. Ten-year anomalies for the MWCI variable DIN:phosphate ratio.

Black indicates no anomaly, **red** indicates a positive anomaly, **green** indicates a negative anomaly, and **gray** indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

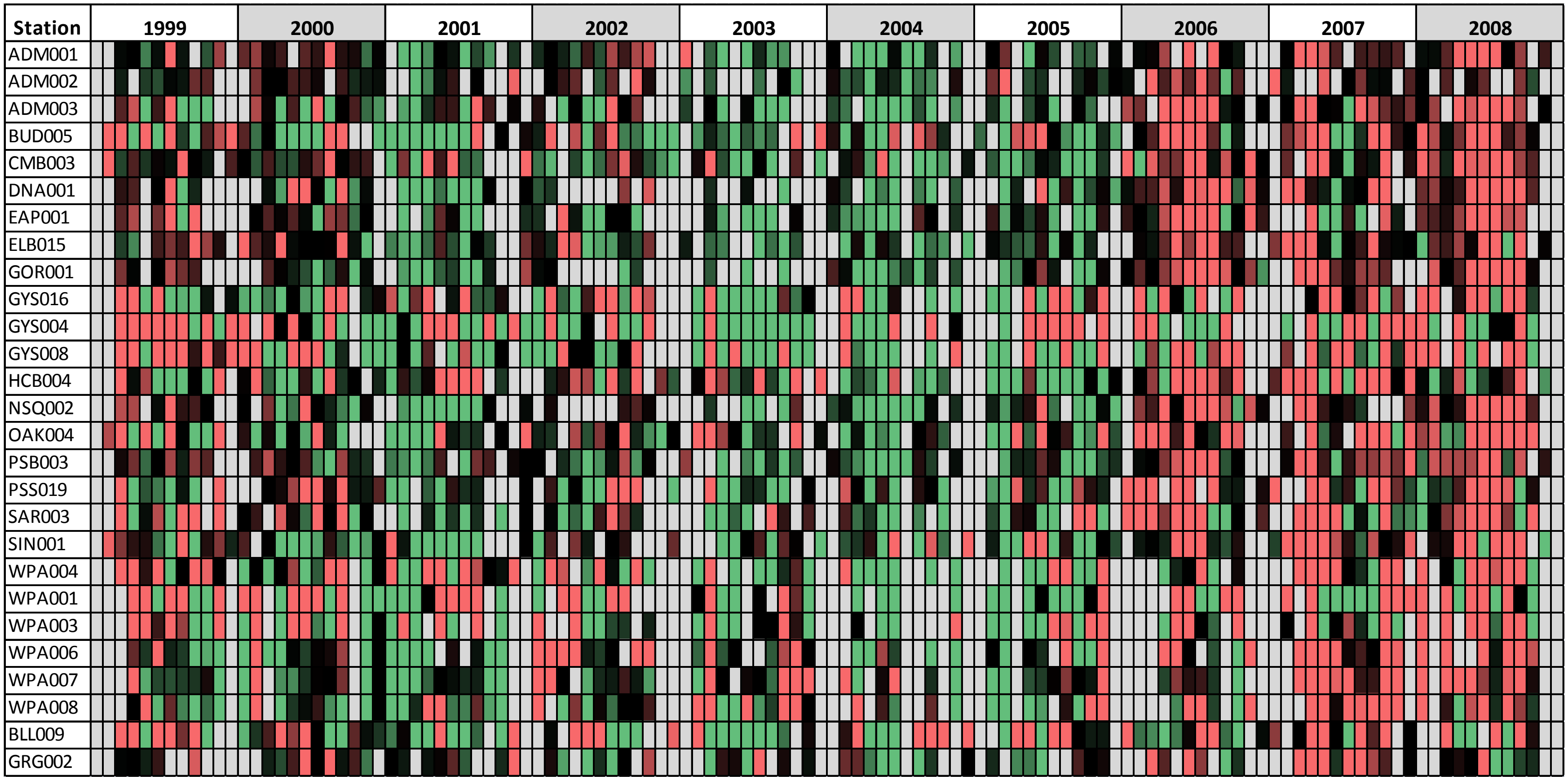


Table A-8. Ten-year anomalies for the MWCI variable silicate:DIN ratio.

Black indicates no anomaly, red indicates a positive anomaly, green indicates a negative anomaly, and gray indicates missing data. Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month. The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

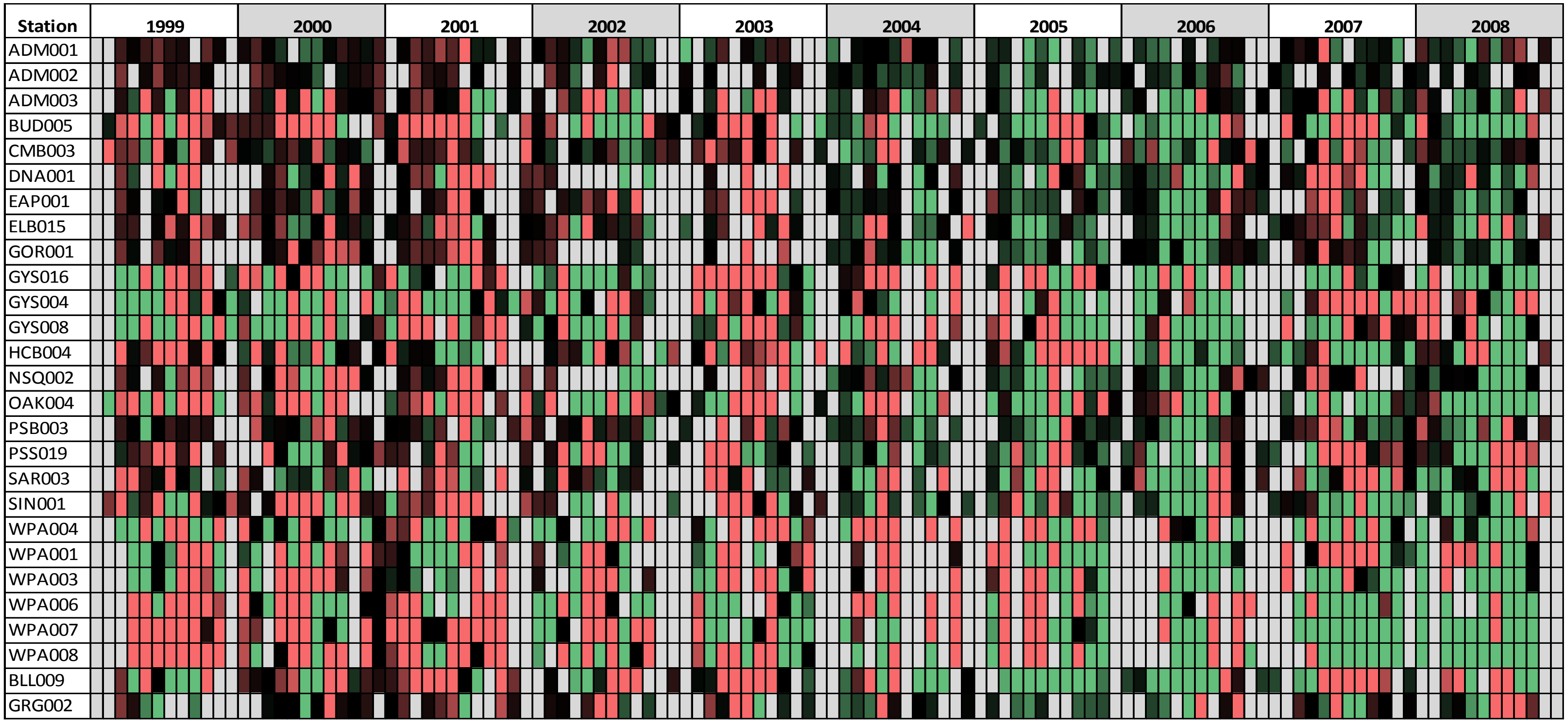


Table A-9. Ten-year anomalies for the MWCI variable chlorophyll-a (mg/m^2).

Black indicates no anomaly, **red** indicates a positive anomaly, **green** indicates a negative anomaly, and **gray** indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

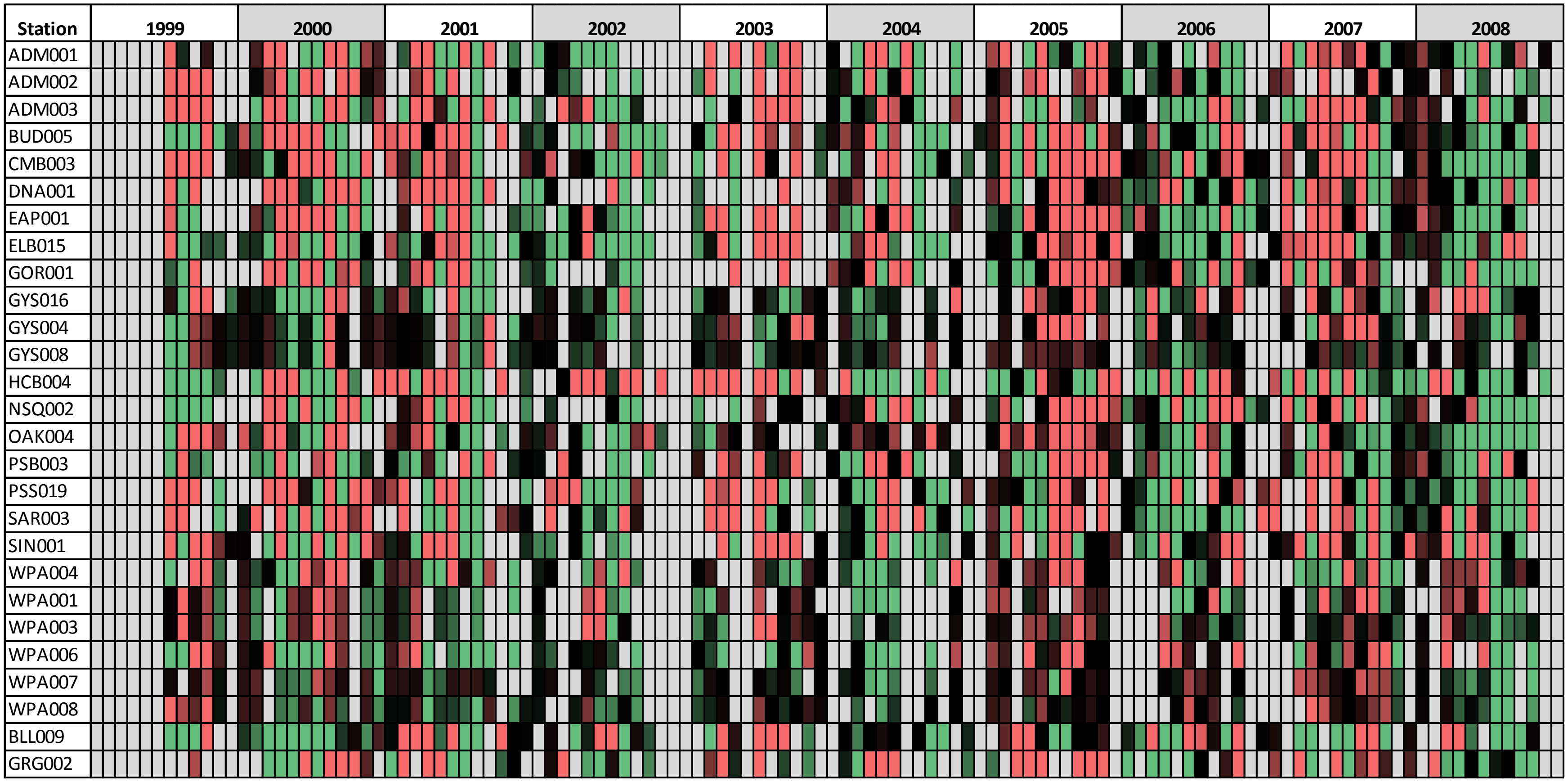


Table A-10. Ten-year anomalies for the MWCI variable thermal energy (GJ/m^2).

Black indicates no anomaly, **red** indicates a positive anomaly, **green** indicates a negative anomaly, and **gray** indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

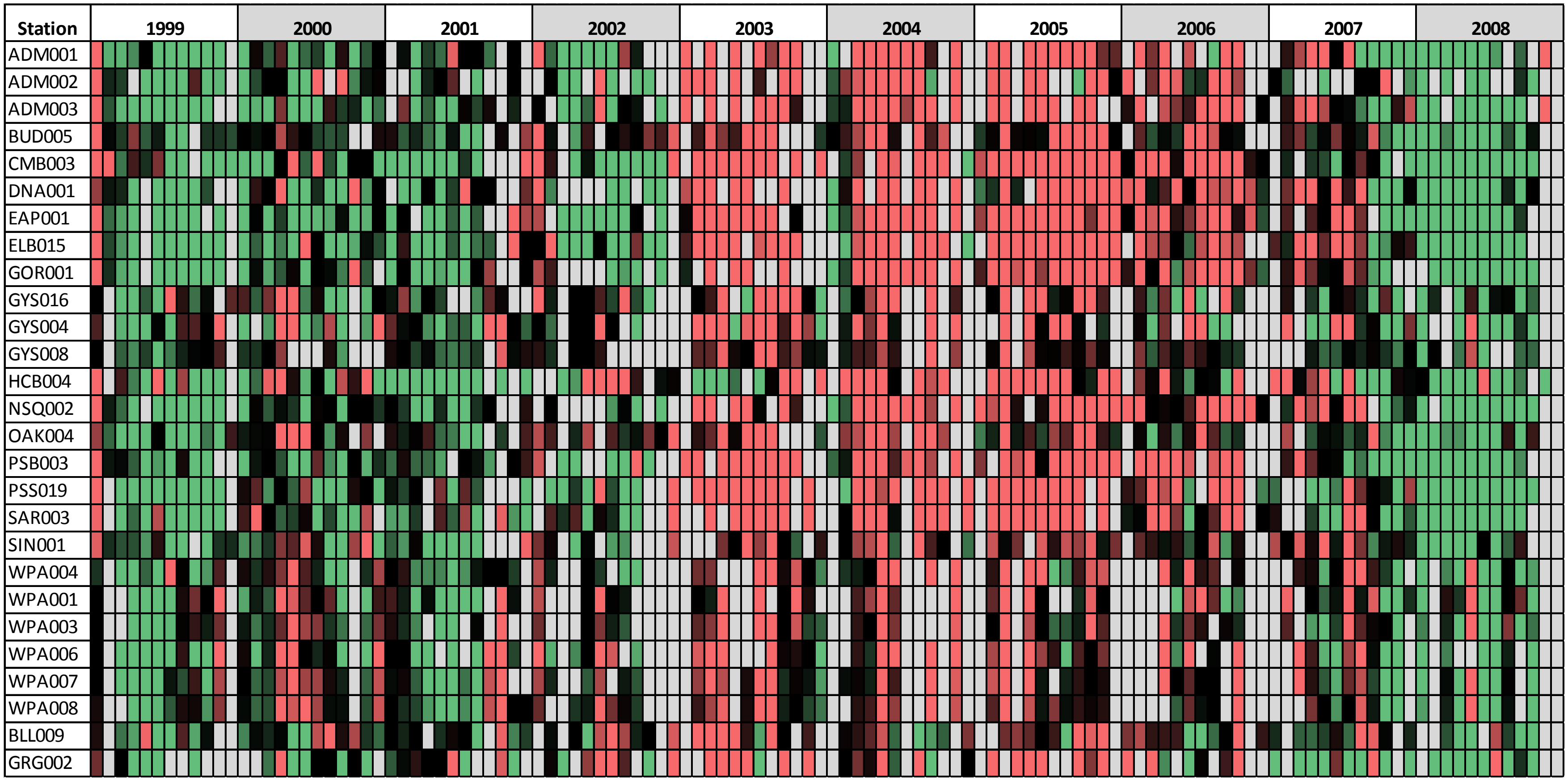


Table A-11. Ten-year anomalies for the MWCI variable potential energy (kJ/m^2).

Black indicates no anomaly, **red** indicates a positive anomaly, **green** indicates a negative anomaly, and **gray** indicates missing data.
Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month.
The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

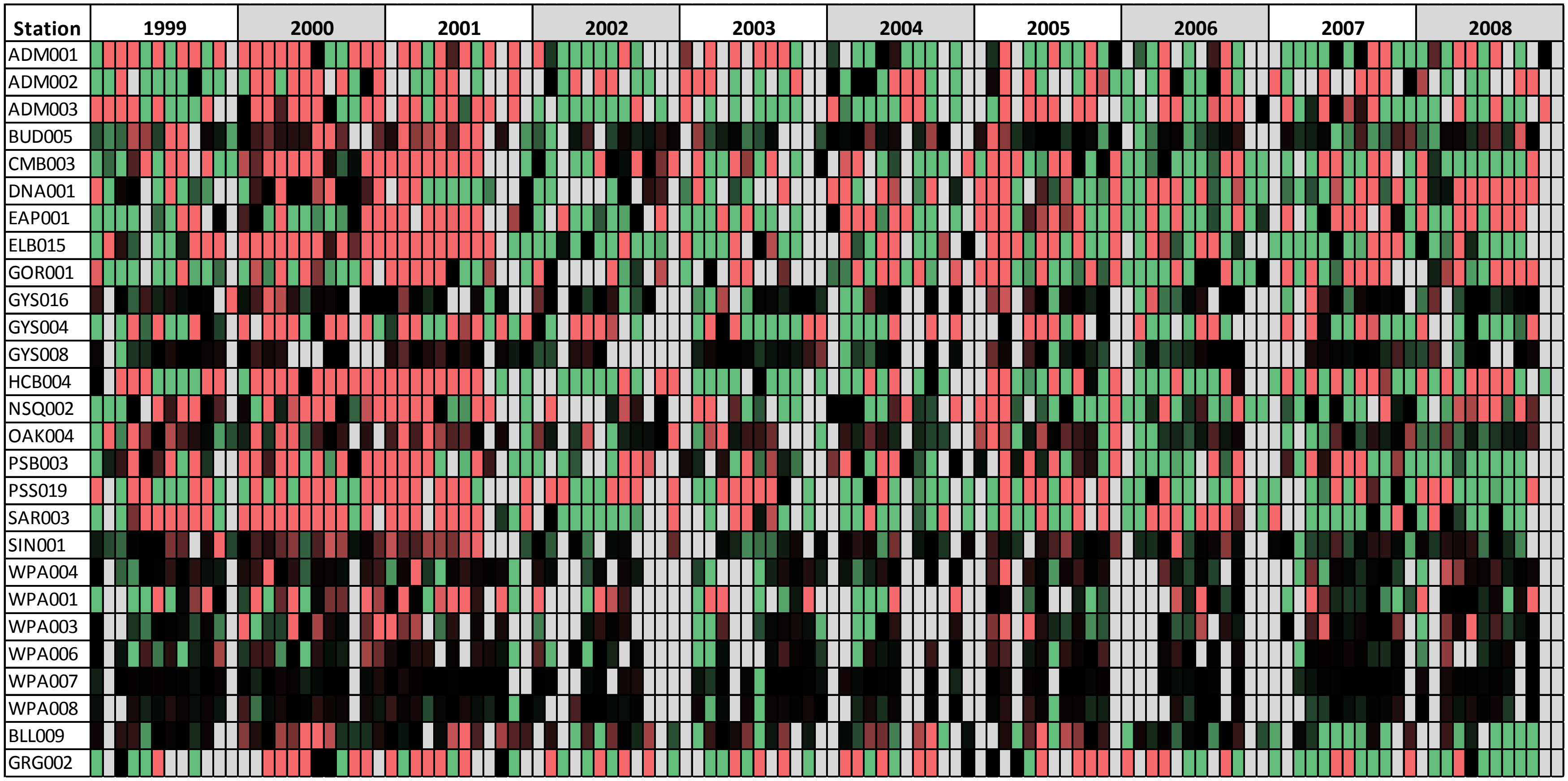


Table A-12. Ten-year anomalies for the MWCI variable dissolved oxygen (kg/m^2).

Black indicates no anomaly, red indicates a positive anomaly, green indicates a negative anomaly, and gray indicates missing data. Heat maps were calculated by subtracting seasonal and site-specific baseline conditions from the dataset. Each color pixel represents a month. The color range represents the percentiles of the dataset: 25th percentile (**green**), 50th percentile (**black**), and 75th percentile (**red**).

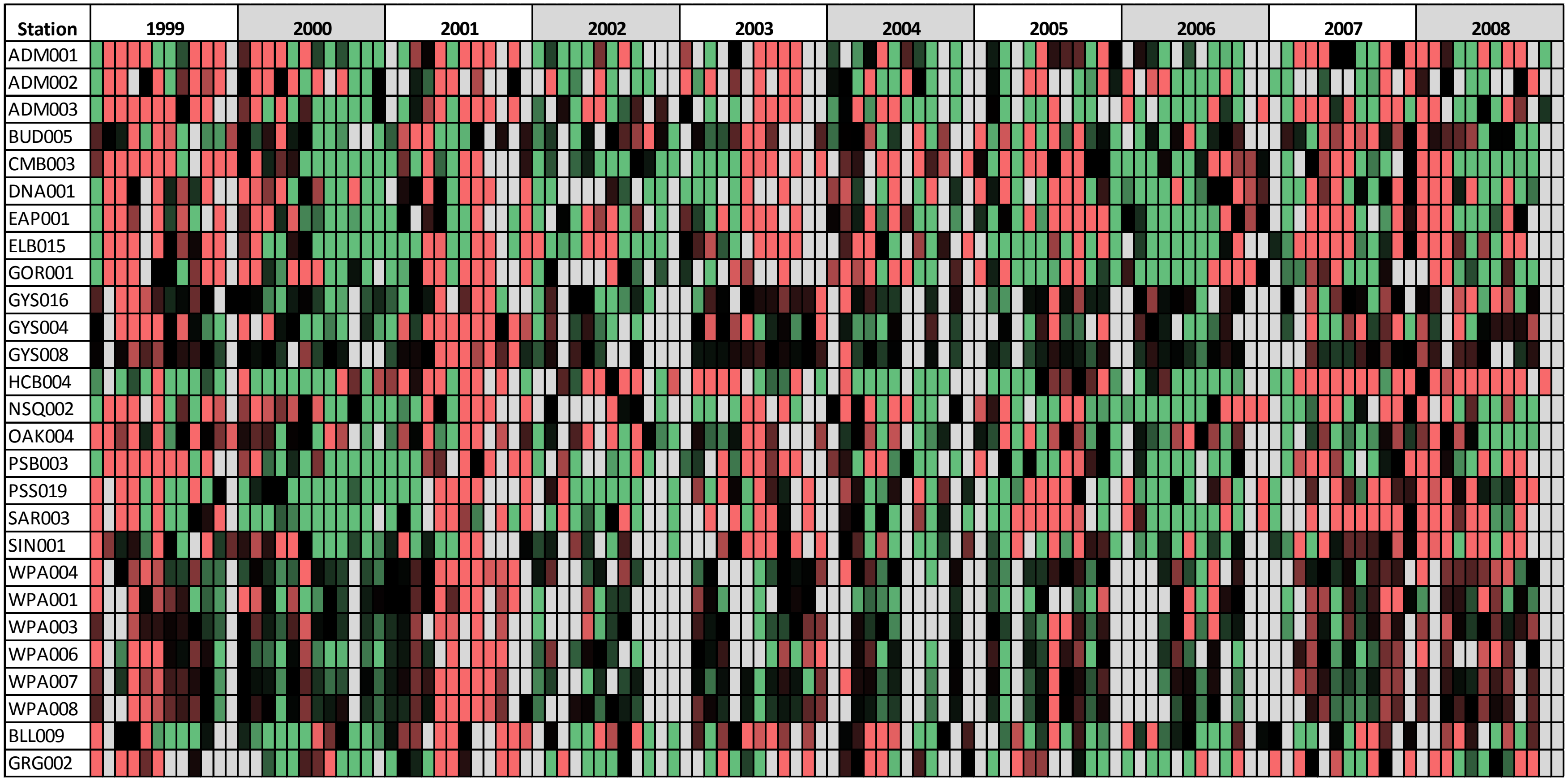


Table A-13. Number of replicates that we used to develop our baseline for nitrate, phosphate, and nitrate:DIN ratio.

	Nitrate (µM L-1)													Phosphate (µM L-1)													NO3 : DIN												
Station/Month	1	2	3	4	5	6	7	8	9	10	11	12	**Avg.**	1	2	3	4	5	6	7	8	9	10	11	12	**Avg.**	1	2	3	4	5	6	7	8	9	10	11	12	**Avg.**
ADM001	5	7	10	9	7	10	8	9	9	6	6	2	**7.3**	5	7	10	9	7	10	8	9	9	6	6	2	**7.3**	5	7	10	9	7	10	8	9	9	6	6	2	**7.3**
ADM002	5	5	9	5	8	8	7	5	9	8	4	3	**6.3**	5	5	9	5	8	8	7	5	9	8	4	3	**6.3**	5	5	9	5	8	8	7	5	9	8	4	3	**6.3**
ADM003	5	7	7	9	9	10	10	9	10	5	5	3	**7.4**	5	7	7	9	9	10	10	9	10	5	5	3	**7.4**	5	7	7	9	9	10	10	9	10	5	5	3	**7.4**
BLL009	4	6	9	10	10	9	9	10	9	8	4	5	**7.8**	4	6	9	10	10	9	9	10	9	8	4	5	**7.8**	4	6	9	10	10	9	9	10	9	8	4	5	**7.8**
BUD005	6	9	9	10	10	10	8	9	8	9	4	7	**8.3**	6	9	9	10	10	10	9	10	8	9	4	7	**8.4**	6	9	9	10	10	10	8	9	8	9	4	7	**8.3**
CMB003	5	10	8	10	10	10	9	10	8	9	4	7	**8.3**	5	10	8	10	10	10	9	10	8	9	4	7	**8.3**	5	10	8	10	10	10	9	10	8	9	4	7	**8.3**
DNA001	4	6	8	8	6	9	7	9	9	6	4	3	**6.6**	4	6	8	8	6	9	7	9	9	6	4	3	**6.6**	4	6	8	8	6	9	7	9	9	6	4	3	**6.6**
EAP001	4	6	8	10	8	10	9	9	7	5	5	2	**6.9**	4	6	8	10	8	10	9	9	7	5	5	2	**6.9**	4	6	8	10	8	10	9	9	7	5	5	2	**6.9**
ELB015	6	8	10	10	8	9	9	10	10	8	4	3	**7.9**	6	8	10	10	8	9	9	10	10	8	4	3	**7.9**	6	8	10	10	8	9	9	10	10	8	4	3	**7.9**
GOR001	3	5	9	8	7	9	8	8	10	5	4	2	**6.5**	3	5	9	8	7	9	8	8	10	5	4	2	**6.5**	3	5	9	8	7	9	8	8	10	5	4	2	**6.5**
GRG002	1	4	8	9	9	10	7	5	8	7	4	2	**6.2**	1	4	8	9	9	10	7	5	8	7	4	2	**6.2**	1	4	8	9	9	10	7	5	8	7	4	2	**6.2**
GYS004	4	7	8	9	9	9	9	9	10	6	7	4	**7.6**	4	7	8	9	9	9	9	9	10	6	7	4	**7.6**	4	7	8	9	9	9	9	9	10	6	7	4	**7.6**
GYS008	4	9	8	9	9	9	8	9	10	7	6	4	**7.7**	4	9	8	9	9	10	8	9	10	7	6	4	**7.8**	4	9	8	9	9	9	8	9	10	7	6	4	**7.7**
GYS016	4	8	8	9	9	10	9	8	10	8	5	2	**7.5**	4	8	8	9	9	10	9	8	10	8	5	2	**7.5**	4	8	8	9	9	10	9	8	10	8	5	2	**7.5**
HCB004	4	9	10	10	9	10	9	10	9	8	5	5	**8.2**	4	9	10	10	10	10	9	10	9	8	5	5	**8.3**	4	9	10	10	9	10	9	10	9	8	5	5	**8.2**
NSQ002	3	6	9	8	7	9	9	8	9	7	4	4	**6.9**	3	6	9	8	7	9	9	8	9	7	4	4	**6.9**	3	6	9	8	7	9	9	8	9	7	4	4	**6.9**
OAK004	4	10	8	10	8	9	7	7	6	9	4	5	**7.3**	4	10	8	10	10	10	8	10	8	9	4	5	**8.0**	4	10	8	10	8	9	7	7	6	9	4	5	**7.3**
PSB003	5	6	9	10	9	9	10	10	10	7	6	3	**7.8**	5	6	9	10	9	9	10	10	10	7	6	3	**7.8**	5	6	9	10	9	9	10	10	10	7	6	3	**7.8**
PSS019	4	6	8	9	10	10	8	10	9	6	5	5	**7.5**	4	6	8	9	10	10	8	10	9	6	5	5	**7.5**	4	6	8	9	10	10	8	10	9	6	5	5	**7.5**
SAR003	3	7	8	10	10	10	8	9	8	7	5	3	**7.3**	3	7	8	10	10	10	8	9	8	7	5	3	**7.3**	3	7	8	10	10	10	8	9	8	7	5	3	**7.3**
SIN001	4	8	8	10	10	9	9	10	8	7	5	8	**8.0**	4	8	8	10	10	9	9	10	8	7	5	8	**8.0**	4	8	8	10	10	9	9	10	8	7	5	8	**8.0**
WPA001	4	5	6	7	10	9	9	8	7	7	6	2	**6.7**	4	5	6	7	10	9	9	8	7	7	6	2	**6.7**	4	5	6	7	10	9	9	8	7	7	6	2	**6.7**
WPA003	4	5	5	6	9	8	7	9	6	8	6	1	**6.2**	4	5	5	6	10	9	8	9	6	8	6	1	**6.4**	4	5	5	6	9	8	7	9	6	8	6	1	**6.2**
WPA004	4	5	9	7	8	8	8	9	9	8	7	1	**6.9**	4	5	9	7	10	9	9	9	9	8	7	1	**7.3**	4	5	9	7	8	8	8	9	9	8	7	1	**6.9**
WPA006	4	5	8	8	5	8	5	8	8	8	7	1	**6.3**	4	5	8	8	8	9	5	8	9	8	7	1	**6.7**	4	5	8	8	5	8	5	8	8	8	7	1	**6.3**
WPA007	4	6	7	7	5	7	7	8	9	8	6	1	**6.3**	4	6	7	7	9	10	9	9	9	8	6	1	**7.1**	4	6	7	7	5	7	7	8	9	8	6	1	**6.3**
WPA008	4	4	6	7	8	6	7	9	9	8	7	1	**6.3**	4	4	6	7	10	10	8	9	9	8	7	1	**6.9**	4	4	6	7	8	6	7	9	9	8	7	1	**6.3**
Avg.	**4**	**7**	**8**	**9**	**8**	**9**	**8**	**9**	**9**	**7**	**5**	**3**	**7.2**	**4**	**7**	**8**	**9**	**9**	**9**	**8**	**9**	**9**	**7**	**5**	**3**	**7.3**	**4**	**7**	**8**	**9**	**8**	**9**	**8**	**9**	**9**	**7**	**5**	**3**	**7.2**

Table A-14. Number of replicates that we used to develop our baseline for the enrichment of nitrate, phosphate, and ammonium.

Station/Month	NO3 Enrichment 1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	5	7	10	8	7	9	8	8	9	5	6	2	**7.0**
ADM002	5	5	9	5	8	8	6	5	9	8	4	3	**6.3**
ADM003	5	7	7	8	9	9	10	9	10	5	5	3	**7.3**
BLL009	4	6	9	9	10	9	9	10	9	8	4	5	**7.7**
BUD005	6	9	9	10	10	9	9	10	7	7	4	7	**8.1**
CMB003	5	9	8	9	10	10	9	10	7	8	4	7	**8.0**
DNA001	4	6	8	7	6	9	7	9	9	6	4	3	**6.5**
EAP001	4	6	8	10	8	10	9	9	7	5	5	2	**6.9**
ELB015	6	8	10	10	8	9	9	10	10	7	3	3	**7.8**
GOR001	3	5	9	8	7	9	8	8	10	5	4	2	**6.5**
GRG002	1	4	8	9	9	10	7	5	8	7	4	2	**6.2**
GYS004	4	7	7	9	9	9	9	8	10	5	6	4	**7.3**
GYS008	4	8	7	9	8	10	6	7	10	7	5	2	**6.9**
GYS016	4	8	7	9	8	9	9	8	10	8	4	2	**7.2**
HCB004	4	8	10	10	10	9	9	10	9	7	5	5	**8.0**
NSQ002	3	5	9	8	6	9	9	8	9	7	4	4	**6.8**
OAK004	4	10	8	10	10	9	8	10	8	7	4	5	**7.8**
PSB003	5	6	9	10	8	8	9	10	10	7	5	3	**7.5**
PSS019	4	6	8	8	10	10	8	10	9	5	5	5	**7.3**
SAR003	3	7	7	8	10	10	8	9	8	5	5	3	**6.9**
SIN001	4	8	8	10	9	9	9	10	7	6	4	8	**7.7**
WPA001	4	5	5	6	9	9	8	7	7	7	6	2	**6.3**
WPA003	3	5	5	5	9	9	8	9	6	7	6	1	**6.1**
WPA004	4	5	8	7	9	9	8	9	9	7	6	1	**6.8**
WPA006	4	5	7	8	7	9	5	8	8	7	5	1	**6.2**
WPA007	4	6	6	7	9	10	7	9	8	7	6	1	**6.7**
WPA008	4	4	5	7	9	10	8	9	8	7	6	1	**6.5**
Avg.	**4**	**6**	**8**	**8**	**9**	**9**	**8**	**9**	**9**	**7**	**5**	**3**	**7.0**

Station/Month	PO4 Enrichment 1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	5	7	10	8	7	9	8	8	9	5	6	2	**7.0**
ADM002	5	5	9	5	8	8	6	5	9	8	4	3	**6.3**
ADM003	5	7	7	8	9	9	10	9	10	5	5	3	**7.3**
BLL009	4	6	9	9	10	9	9	10	9	8	4	5	**7.7**
BUD005	6	9	9	10	10	9	9	10	7	7	4	7	**8.1**
CMB003	5	9	8	9	10	10	9	10	7	8	4	7	**8.0**
DNA001	4	6	8	7	6	9	7	9	9	6	4	3	**6.5**
EAP001	4	6	8	10	8	10	9	9	7	5	5	2	**6.9**
ELB015	6	8	10	10	8	9	9	10	10	7	3	3	**7.8**
GOR001	3	5	9	8	7	9	8	8	10	5	4	2	**6.5**
GRG002	1	4	8	9	9	10	7	5	8	7	4	2	**6.2**
GYS004	4	7	7	9	9	9	9	8	10	5	6	4	**7.3**
GYS008	4	8	7	9	8	10	6	7	10	7	5	2	**6.9**
GYS016	4	8	7	9	8	9	9	8	10	8	4	2	**7.2**
HCB004	4	8	10	10	10	9	9	10	9	7	5	5	**8.0**
NSQ002	3	5	9	8	6	9	9	8	9	7	4	4	**6.8**
OAK004	4	10	8	10	10	9	8	10	8	7	4	5	**7.8**
PSB003	5	6	9	10	8	8	9	10	10	7	5	3	**7.5**
PSS019	4	6	8	8	10	10	8	10	9	5	5	5	**7.3**
SAR003	3	7	7	8	10	10	8	9	8	5	5	3	**6.9**
SIN001	4	8	8	10	9	9	9	10	7	6	4	8	**7.7**
WPA001	4	5	5	6	9	9	8	7	7	7	6	2	**6.3**
WPA003	3	5	5	5	9	9	8	9	6	7	6	1	**6.1**
WPA004	4	5	8	7	9	9	8	9	9	7	6	1	**6.8**
WPA006	4	5	7	8	7	9	5	8	8	7	5	1	**6.2**
WPA007	4	6	6	7	9	10	7	9	8	7	6	1	**6.7**
WPA008	4	4	5	7	9	10	8	9	8	7	6	1	**6.5**
Avg.	**4**	**6**	**8**	**8**	**9**	**9**	**8**	**9**	**9**	**7**	**5**	**3**	**7.0**

Station/Month	NH4 Enrichment 1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	5	7	10	8	7	9	8	8	9	5	6	2	**7.0**
ADM002	5	5	9	5	8	8	6	5	9	8	4	3	**6.3**
ADM003	5	7	7	8	9	9	10	9	10	5	5	3	**7.3**
BLL009	4	6	9	9	10	9	9	10	9	8	4	5	**7.7**
BUD005	6	9	9	10	10	9	9	10	7	7	4	7	**8.1**
CMB003	5	9	8	9	10	10	9	10	7	8	4	7	**8.0**
DNA001	4	6	8	7	6	9	7	9	9	6	4	3	**6.5**
EAP001	4	6	8	10	8	10	9	9	7	5	5	2	**6.9**
ELB015	6	8	10	10	8	9	9	10	10	7	3	3	**7.8**
GOR001	3	5	9	8	7	9	8	8	10	5	4	2	**6.5**
GRG002	1	4	8	9	9	10	7	5	8	7	4	2	**6.2**
GYS004	4	7	7	9	9	9	9	8	10	5	6	4	**7.3**
GYS008	4	8	7	9	8	10	6	7	10	7	5	2	**6.9**
GYS016	4	8	7	9	8	9	9	8	10	8	4	2	**7.2**
HCB004	4	8	10	10	10	9	9	10	9	7	5	5	**8.0**
NSQ002	3	5	9	8	6	9	9	8	9	7	4	4	**6.8**
OAK004	4	10	8	10	10	9	8	10	8	7	4	5	**7.8**
PSB003	5	6	9	10	8	8	9	10	10	7	5	3	**7.5**
PSS019	4	6	8	8	10	10	8	10	9	5	5	5	**7.3**
SAR003	3	7	7	8	10	10	8	9	8	5	5	3	**6.9**
SIN001	4	8	8	10	9	9	9	10	7	6	4	8	**7.7**
WPA001	4	5	5	6	9	9	8	7	7	7	6	2	**6.3**
WPA003	3	5	5	5	9	9	8	9	6	7	6	1	**6.1**
WPA004	4	5	8	7	9	9	8	9	9	7	6	1	**6.8**
WPA006	4	5	7	8	7	9	5	8	8	7	5	1	**6.2**
WPA007	4	6	6	7	9	10	7	9	8	7	6	1	**6.7**
WPA008	4	4	5	7	9	10	8	9	8	7	6	1	**6.5**
Avg.	**4**	**6**	**8**	**8**	**9**	**9**	**8**	**9**	**9**	**7**	**5**	**3**	**7.0**

Table A-15. Number of replicates that we used to develop our baseline for chlorophyll-a and ratios of DIN:phosphate and silicate:DIN.

	DIN: PO4												
Station/Month	1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	5	7	10	9	7	10	8	9	9	6	6	2	**7.3**
ADM002	5	5	9	5	8	8	7	5	9	8	4	3	**6.3**
ADM003	5	7	7	9	9	10	10	9	10	5	5	3	**7.4**
BLL009	4	6	9	10	10	9	9	10	9	8	4	5	**7.8**
BUD005	6	9	9	10	10	10	9	10	8	9	4	7	**8.4**
CMB003	5	10	8	10	10	10	9	10	8	9	4	7	**8.3**
DNA001	4	6	8	8	6	9	7	9	9	6	4	3	**6.6**
EAP001	4	6	8	10	8	10	9	9	7	5	5	2	**6.9**
ELB015	6	8	10	10	8	9	9	10	10	8	4	3	**7.9**
GOR001	3	5	9	8	7	9	8	8	10	5	4	2	**6.5**
GRG002	1	4	8	9	9	10	7	5	8	7	4	2	**6.2**
GYS004	4	7	8	9	9	9	9	9	10	6	7	4	**7.6**
GYS008	4	9	8	9	9	10	8	9	10	7	6	4	**7.8**
GYS016	4	8	8	9	9	10	9	8	10	8	5	2	**7.5**
HCB004	4	9	10	10	10	10	9	10	9	8	5	5	**8.3**
NSQ002	3	6	9	8	7	9	9	8	9	7	4	4	**6.9**
OAK004	4	10	8	10	10	10	8	10	8	9	4	5	**8.0**
PSB003	5	6	9	10	9	9	10	10	10	7	6	3	**7.8**
PSS019	4	6	8	9	10	10	8	10	9	6	5	5	**7.5**
SAR003	3	7	8	10	10	10	8	9	8	7	5	3	**7.3**
SIN001	4	8	8	10	10	9	9	10	8	7	5	8	**8.0**
WPA001	4	5	6	7	10	9	9	8	7	7	6	2	**6.7**
WPA003	4	5	5	6	10	9	8	9	6	8	6	1	**6.4**
WPA004	4	5	9	7	10	9	9	9	9	8	7	1	**7.3**
WPA006	4	5	8	8	8	9	5	8	9	8	7	1	**6.7**
WPA007	4	6	7	7	9	10	9	9	9	8	6	1	**7.1**
WPA008	4	4	6	7	10	10	8	9	9	8	7	1	**6.9**
Avg.	**4**	7	**8**	9	**9**	9	**8**	9	**9**	7	**5**	3	**7.3**

	SI(OH)4: DIN												
Station/Month	1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	5	7	10	9	7	10	8	9	9	6	6	2	**7.3**
ADM002	5	5	9	5	8	8	7	5	9	8	4	3	**6.3**
ADM003	5	7	7	9	9	10	10	9	10	5	5	3	**7.4**
BLL009	4	6	9	10	10	9	9	10	9	8	4	5	**7.8**
BUD005	6	9	9	10	10	10	9	10	8	9	4	7	**8.4**
CMB003	5	10	8	10	10	10	9	10	8	9	4	7	**8.3**
DNA001	4	6	8	8	6	9	7	9	9	6	4	3	**6.6**
EAP001	4	6	8	10	8	10	9	9	7	5	5	2	**6.9**
ELB015	6	8	10	10	8	9	9	10	10	8	4	3	**7.9**
GOR001	3	5	9	8	7	9	8	8	10	5	4	2	**6.5**
GRG002	1	4	8	9	9	10	7	5	8	7	4	2	**6.2**
GYS004	4	7	8	9	9	9	9	9	10	6	7	4	**7.6**
GYS008	4	9	8	9	9	10	8	9	10	7	6	4	**7.8**
GYS016	4	8	8	9	9	10	9	8	10	8	5	2	**7.5**
HCB004	4	9	10	10	10	10	9	10	9	8	5	5	**8.3**
NSQ002	3	6	9	8	7	9	9	8	9	7	4	4	**6.9**
OAK004	4	10	8	10	10	10	8	10	8	9	4	5	**8.0**
PSB003	5	6	9	10	9	9	10	10	10	7	6	3	**7.8**
PSS019	4	6	8	9	10	10	8	10	9	6	5	5	**7.5**
SAR003	3	7	8	10	10	10	8	9	8	7	5	3	**7.3**
SIN001	4	8	8	10	10	9	9	10	8	7	5	8	**8.0**
WPA001	4	5	6	7	10	9	9	8	7	7	6	2	**6.7**
WPA003	4	5	5	6	10	9	8	9	6	8	6	1	**6.4**
WPA004	4	5	9	7	10	9	9	9	9	8	7	1	**7.3**
WPA006	4	5	8	8	8	9	5	8	9	8	7	1	**6.7**
WPA007	4	6	7	7	9	10	9	9	9	8	6	1	**7.1**
WPA008	4	4	6	7	10	10	8	9	9	8	7	1	**6.9**
Avg.	**4**	7	**8**	9	**9**	9	**8**	9	**9**	7	**5**	3	**7.3**

	Chl a (mg m-2)												
Station/Month	1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	3	7	9	7	7	8	9	9	7	6	6	3	**6.8**
ADM002	4	6	8	5	8	6	6	5	8	7	4	3	**5.8**
ADM003	4	7	7	7	9	7	10	9	9	6	5	3	**6.9**
BLL009	4	5	8	9	8	7	9	10	9	9	4	5	**7.3**
BUD005	6	9	8	9	9	7	9	10	8	9	4	6	**7.8**
CMB003	5	9	6	8	9	8	9	10	8	9	4	7	**7.7**
DNA001	4	8	7	6	7	7	8	9	8	6	5	4	**6.6**
EAP001	4	8	7	9	9	8	10	10	6	5	6	4	**7.2**
ELB015	5	9	9	9	9	8	9	10	10	8	5	3	**7.8**
GOR001	3	7	7	7	8	7	9	9	9	5	4	3	**6.5**
GRG002	3	5	7	8	7	8	7	4	8	7	4	2	**5.8**
GYS004	4	7	6	8	7	8	9	8	10	4	7	4	**6.8**
GYS008	3	8	6	8	8	8	7	7	10	6	7	5	**6.9**
GYS016	4	8	6	8	7	8	9	8	10	6	5	3	**6.8**
HCB004	3	8	9	9	9	8	9	10	9	8	5	5	**7.7**
NSQ002	3	7	7	7	7	7	10	9	8	7	5	4	**6.8**
OAK004	4	9	7	9	9	7	9	10	8	8	4	4	**7.3**
PSB003	4	7	8	9	8	5	9	10	8	7	5	3	**6.9**
PSS019	4	6	7	9	8	8	8	10	9	5	5	5	**7.0**
SAR003	4	7	5	9	8	8	9	10	8	6	6	4	**7.0**
SIN001	5	7	7	9	8	7	9	10	8	7	4	7	**7.3**
WPA001	3	5	5	5	8	8	7	7	7	5	7	1	**5.7**
WPA003	4	5	5	5	8	8	8	9	7	6	6	2	**6.1**
WPA004	4	6	7	6	8	8	9	8	9	6	7	2	**6.7**
WPA006	4	5	7	7	6	8	7	8	8	6	7	2	**6.3**
WPA007	4	6	6	7	8	8	8	8	8	6	5	2	**6.3**
WPA008	4	4	5	6	8	8	9	9	8	6	7	3	**6.4**
Avg.	**4**	7	**7**	8	**8**	8	**9**	9	**8**	7	**5**	4	**6.8**

Table A-16. Number of replicates that we used to develop our baseline for thermal energy, potential energy, and dissolved oxygen.

Station/Month	Thermal Energy (GJ m-2) 1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	6	8	10	8	9	9	9	9	10	6	7	3	**7.8**
ADM002	7	7	9	5	9	8	6	5	9	8	5	3	**6.8**
ADM003	7	8	8	8	10	9	10	9	10	6	6	3	**7.8**
BLL009	5	6	9	9	10	9	9	10	9	9	4	6	**7.9**
BUD005	7	10	9	10	10	9	9	10	7	8	4	7	**8.3**
CMB003	7	10	8	9	10	10	9	10	7	9	5	9	**8.6**
DNA001	8	10	9	7	7	9	8	9	9	7	6	5	**7.8**
EAP001	9	9	8	10	9	10	10	10	7	5	8	5	**8.3**
ELB015	7	10	10	10	9	9	9	10	10	8	6	5	**8.6**
GOR001	8	9	9	8	8	9	9	9	10	6	6	3	**7.8**
GRG002	4	5	9	9	9	10	7	5	8	7	4	3	**6.7**
GYS004	5	6	7	9	9	10	9	8	10	5	7	4	**7.4**
GYS008	5	8	7	9	9	9	6	7	8	7	6	3	**7.0**
GYS016	5	9	7	9	9	9	8	8	10	8	5	3	**7.5**
HCB004	5	8	10	10	10	9	9	10	9	8	6	6	**8.3**
NSQ002	7	9	9	8	7	9	10	9	9	7	7	5	**8.0**
OAK004	6	10	8	10	10	9	9	10	8	8	5	6	**8.3**
PSB003	8	8	9	10	9	8	9	10	10	7	5	4	**8.1**
PSS019	6	8	9	9	10	10	8	10	9	6	5	6	**8.0**
SAR003	6	7	9	8	10	10	9	10	9	6	6	5	**7.9**
SIN001	6	9	8	10	9	9	9	10	7	7	4	8	**8.0**
WPA001	5	5	6	7	9	9	8	7	7	7	7	2	**6.6**
WPA003	5	5	6	7	9	9	8	8	7	7	6	2	**6.6**
WPA004	5	6	8	7	9	9	8	9	9	7	7	2	**7.2**
WPA006	5	5	8	8	7	9	6	8	8	7	7	2	**6.7**
WPA007	5	6	8	8	9	10	7	9	8	7	6	2	**7.1**
WPA008	5	4	6	8	9	10	9	9	8	7	7	3	**7.1**
Avg.	**6**	**8**	**8**	**9**	**9**	**9**	**8**	**9**	**9**	**7**	**6**	**4**	**7.6**

Station/Month	-Potential Energy (KJ m-2) 1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	6	8	10	8	9	9	9	9	10	6	7	3	**7.8**
ADM002	7	7	9	5	9	8	6	5	9	8	5	3	**6.8**
ADM003	7	8	8	8	10	9	10	9	10	6	6	3	**7.8**
BLL009	5	6	9	9	10	9	9	10	9	9	4	6	**7.9**
BUD005	7	10	9	10	10	9	9	10	7	8	4	7	**8.3**
CMB003	7	10	8	9	10	10	9	10	7	9	5	9	**8.6**
DNA001	8	10	9	7	7	9	8	9	9	7	6	5	**7.8**
EAP001	9	9	8	10	9	10	10	10	7	5	8	5	**8.3**
ELB015	7	10	10	10	9	9	9	10	10	8	6	5	**8.6**
GOR001	8	9	9	8	8	9	9	9	10	6	6	3	**7.8**
GRG002	4	5	9	9	9	10	7	5	8	7	4	3	**6.7**
GYS004	5	6	7	9	9	10	9	8	10	5	7	4	**7.4**
GYS008	5	8	7	9	9	9	6	7	8	7	6	3	**7.0**
GYS016	5	9	7	9	9	9	8	8	10	8	5	3	**7.5**
HCB004	5	8	10	10	10	9	9	10	9	8	6	6	**8.3**
NSQ002	7	9	9	8	7	9	10	9	9	7	7	5	**8.0**
OAK004	6	10	8	10	10	9	9	10	8	8	5	6	**8.3**
PSB003	8	8	9	10	9	8	9	10	10	7	5	4	**8.1**
PSS019	6	8	9	9	10	10	8	10	9	6	5	6	**8.0**
SAR003	6	7	9	8	10	10	9	10	9	6	6	5	**7.9**
SIN001	6	9	8	10	9	9	9	10	7	7	4	8	**8.0**
WPA001	5	5	6	7	9	9	8	7	7	7	7	2	**6.6**
WPA003	5	5	6	7	9	9	8	8	7	7	6	2	**6.6**
WPA004	5	6	8	7	9	9	8	9	9	7	7	2	**7.2**
WPA006	5	5	8	8	7	9	6	8	8	7	7	2	**6.7**
WPA007	5	6	8	8	9	10	7	9	8	7	6	2	**7.1**
WPA008	5	4	6	8	9	10	9	9	8	7	7	3	**7.1**
Avg.	**6**	**8**	**8**	**9**	**9**	**9**	**8**	**9**	**9**	**7**	**6**	**4**	**7.6**

Station/Month	Dissolved Oxygen (Kg m-2) 1	2	3	4	5	6	7	8	9	10	11	12	Avg.
ADM001	6	8	10	8	9	9	9	10	10	6	7	3	**7.9**
ADM002	7	7	9	5	9	8	6	5	9	8	5	3	**6.8**
ADM003	7	8	8	8	10	9	10	9	10	6	6	3	**7.8**
BLL009	5	6	9	9	9	9	9	9	9	9	4	6	**7.8**
BUD005	7	10	9	10	10	9	9	10	7	8	4	7	**8.3**
CMB003	7	10	8	9	10	10	9	10	7	9	5	9	**8.6**
DNA001	8	10	9	7	7	9	8	9	9	7	6	5	**7.8**
EAP001	9	9	8	10	9	10	10	10	7	5	8	5	**8.3**
ELB015	7	10	10	10	9	9	9	10	10	8	6	5	**8.6**
GOR001	8	9	9	8	8	9	9	9	10	6	6	3	**7.8**
GRG002	4	5	9	9	8	10	7	5	8	7	4	3	**6.6**
GYS004	5	7	7	9	9	10	9	8	10	5	7	4	**7.5**
GYS008	5	8	7	9	9	10	7	7	10	7	6	3	**7.3**
GYS016	5	9	7	9	9	9	9	8	10	8	5	3	**7.6**
HCB004	5	8	10	10	10	9	9	10	9	8	6	6	**8.3**
NSQ002	7	9	9	8	7	9	10	9	9	7	7	5	**8.0**
OAK004	6	10	8	10	10	9	9	10	8	8	5	6	**8.3**
PSB003	8	8	9	10	9	8	9	9	10	7	5	4	**8.0**
PSS019	6	8	9	9	9	10	8	10	9	6	5	6	**7.9**
SAR003	6	7	9	8	9	10	9	10	9	6	6	5	**7.8**
SIN001	6	9	8	10	9	9	9	10	7	7	4	8	**8.0**
WPA001	5	5	6	7	9	9	8	7	7	7	7	2	**6.6**
WPA003	5	5	6	7	9	9	8	9	7	7	6	2	**6.7**
WPA004	5	6	8	7	9	9	8	9	9	7	7	2	**7.2**
WPA006	5	5	8	8	7	9	6	8	8	7	6	2	**6.6**
WPA007	5	6	8	8	9	10	8	9	8	7	6	2	**7.2**
WPA008	5	4	6	8	9	10	9	9	8	7	6	3	**7.0**
Avg.	**6**	**8**	**8**	**9**	**9**	**9**	**9**	**9**	**9**	**7**	**6**	**4**	**7.6**

Appendix B. Example Calculations

Table B-1. Yearly calculation of de-seasonalized variable, module, and MWCI scores for each station.

This table shows a step-by-step example of how we (1) evaluate monthly measured parameters against site-specific baseline conditions and (2) determine the frequency of measurements that exceed prior established baseline conditions for each month. This table follows how we compare baseline conditions (hypothetical) with measured variables to arrive at a yearly Module score.

Step 1. We determine monthly variability around our baselines to determine the number of failed tests for an entire year.
We then apply the index equation to calculate (Vi).
To adjust the data to fit our schematic graphic, we shift the scale from 0-100 to -50 to +50 (by subtracting 50).

Variable 1					**Variable 2**					**Variable 3**				
Month	**Baseline**	**New data**	**Difference**	**Test**	**Month**	**Baseline**	**New data**	**Difference**	**Test**	**Month**	**Baseline**	**New data**	**Difference**	**Test**
1	5.67	5.98	0.30	yes	**1**	0.2	-0.2	-0.4	no	**1**	5.0	5.7	0.7	yes
2	4.58	-	-	-	**2**	0.5	0.8	0.3	yes	**2**	5.3	5.9	0.7	yes
3	4.01	3.81	-0.20	no	**3**	0.7	1.2	0.4	yes	**3**	5.5	5.3	-0.2	no
4	4.35	4.45	0.10	yes	**4**	1.0	1.2	0.2	yes	**4**	5.8	-	-	-
5	5.28	5.06	-0.22	no	**5**	1.1	1.3	0.2	yes	**5**	5.9	5.8	-0.1	no
6	5.96	6.48	0.52	yes	**6**	1.2	1.5	0.3	yes	**6**	6.0	6.2	0.2	yes
7	5.75	5.64	-0.12	no	**7**	1.2	0.7	-0.5	no	**7**	6.0	6.9	0.9	yes
8	4.85	5.34	0.49	yes	**8**	1.1	0.9	-0.2	no	**8**	5.9	6.0	0.1	yes
9	4.09	3.49	-0.60	no	**9**	1.0	1.7	0.8	yes	**9**	5.7	-	-	-
10	4.16	3.77	-0.39	no	**10**	0.7	1.3	0.6	yes	**10**	5.5	5.8	0.3	yes
11	5.00	-	-	-	**11**	0.5	1.0	0.6	yes	**11**	5.3	5.2	-0.1	no
12	5.84	5.30	-0.54	no	**12**	0.2	0.5	0.3	yes	**12**	5.0	5.1	0.1	yes
	Negative score			**4**		**Negative score**			**9**		**Negative score**			**8**
	Positive score			**6**		**Positive score**			**3**		**Positive score**			**3**
	Total counts			**10**		**Total counts**			**12**		**Total counts**			**11**
	Failed tests		**4:10 x 100=40**			**Failed tests**		**9:12 x 100=75**			**Failed tests**		**8:11 x 100=72.73**	
	Scale shift		**40-50= -10**			**Scale shift**		**75-50= 25**			**Scale shift**		**72.73-50= 22.73**	

Step 2. We calculate yearly module score (e.g., Ambient) based on three variable test scores for the new data for each station.

Arithmetic mean of Variable 1 + Variable 2 +Variable 3	
Variable 1	= (-10+ 25 + 22.73) :3 = 12.58
Variable 2	…
Variable 3	…

Step 3. We calculate the Eutrophication Index score based on module scores 1-3 using the new data for each station.

Arithmetic mean of Variable 1 + Variable 2 +Variable 3	
Ambient	12.58
Enrichment	…
Impact	…
Score	**(12.58+…+…): 3= 14.19**

Step 4. We calculate the MWCI score based on modules scores 1-4 using the new data for each station.

Arithmetic mean of Module 1 + Module 2 + Module 3	
Ambient	12.58
Enrichment	…
Impact	…
Ventilation	…
Score	**(12.58+…+…): 4= 5**

Step 5. We convert and report module and index scores on a regional level.
To reduce the volume of reporting stations, we average stations falling into pre-determined reporting regions (these were statistically determined using cluster analysis).

A. Pooling module scores from each station through reporting regions.					
Reporting Region	Station	Ambient	Enrichment	Impact	Ventilation
A (n=4)	ADM001	12.58	…	…	…
	ADM002	…	…	…	…
	…	...	...	...	...
	…	...	...	...	...
Regional mean:		**(12.58+…+…+…):4 = 12.58**	**(…+…+…+…):4=…**	**(…+…+…+…):4=…**	**(…+…+…+…):4=…**
B (n=2)	CMB003	...	…	…	…
	EAP001	…	…	…	…
Regional mean:		**(…+…):2=…**	**(…+…):2=…**	**(…+…):2=…**	**(…+…):2=…**
And so on for all 27 stations and 17 reporting regions…					

Step 5 (continued)

B. Reporting yearly Eutrophication Index scores from each station pooled by reporting regions

Reporting Region	Station	Eutrophication Index (Ambient+Enrichment+Impact)
A (n=4)	ADM001	(12.58+…+…): 3= 14.19
	ADM002	…
	ADM003	...
	…	...
Regional mean:		**(…+…+…+14.19):4=14.19**
B (n=2)	CMB003	…
	EAP001	…
Regional mean:		**(…+…):2=…**
And so on for all 27 stations and 17 reporting regions…		

C. Reporting yearly MWCI scores from each station pooled by reporting regions

Reporting Region	Station	MWCI (Ambient+Enrichment+Impact+Ventilation)
A (n=4)	ADM001	(12.58+…+…+…): 4= 5
	ADM002	…
	ADM003	…
	…	…
Regional mean:		**(…+…+…+5):4=5**
B (n=2)	CMB003	…
	EAP001	…
Regional mean:		**(…+…+…):n=…**
And so on for all 27 stations and 17 reporting regions…		

Step 6. We report the MWCI score in temporal context from 1999 to present.

We use a linear interpolation of the yearly MWCI scores to reduce inter-annual index variability at the higher reporting levels.

The interpolation allows us to calculate the overall change from 1999 to present which we used to scale the arrow in the schematic reporting layer (arrow length and direction).

Year	Yearly MWCI score	Linearly interpolated between 1999 to current	
1999	**0**	**-0.36**	**Increasing timeframe of interpolation**
2000	1	0.07	
2001	0	0.50	
2002	1	0.94	
2003	2	1.37	
2004	2	1.80	
2005	2	2.24	
2006	3	2.67	
2007	3	3.10	
2008	3	3.54	
2009	4	3.97	
2010	5	4.41	
2011	**5**	**4.84**	
Slope 1999-2011		**0.434**	
Offset 1999-2011		**-867**	
Interpolated score is used to scale the arrow length in the schematic presentation: 2011-1999= 4.84 - -0.36= 5.2			

Appendix C. Glossary, Acronyms, and Abbreviations

Glossary

Ambient: Surrounding environmental condition (e.g., surrounding air temperature).

Ambient module: One of four modules in the MWCI, and one of three modules in the Eutrophication Index.

Anthropogenic: Human-caused.

Baseline: Environmental reference conditions established for each month and each location in the period 1999-2008. A baseline is statistically representing median values of each variable after depth integration.

Central-South Basin: The central and transition into south basins of Puget Sound.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Delta potential energy: Is typically a negative number used in physical oceanography to approximate the energy needed to break up an existing density stratification of the water column by vertical mixing. The number is generated using a vertically well mixed reference.

Dissolved oxygen: A measure of the amount of oxygen dissolved in water.

Ekman: Ekman transport is the term given for the 90 degree net transport of the surface water layer due to wind forcing.

Enrichment: A term used to conservatively estimate the change in nutrient to salt balance of ocean water as, for example, it interacts with coastal processes such as dilution with freshwater, biological, and geological processes and pollution.

Enrichment module: One of four modules in the MWCI, and one of three modules in the Eutrophication Index.

Eutrophication: Eutrophication is the addition of artificial or non-artificial substances, such as nitrates and phosphates, through fertilizers or sewage, to a fresh or marine water system. The condition enhances the primary productivity and phytoplankton biomass of the waterbody. Negative environmental effects include loss of oxygen in the water with severe reductions in fish and other animal populations. Other species may experience an increase in population that negatively affects other species in the local ecosystem. Estuaries tend to be naturally eutrophic because land-derived nutrients are concentrated where run-off enters a confined channel. Upwelling in coastal systems also promotes increased productivity by conveying deep, nutrient-rich waters to the surface, where the nutrients can be assimilated by algae.

Eutrophication Index: A sub index of the MWCI that uses the modules Ambient, Enrichment, and Impact to communicate changes in eutrophication relative to established baseline conditions in Puget Sound and coastal Bays, Willapa Bay, and Grays Harbor.

Geostrophic: A geostrophic current is an oceanic flow in which the pressure gradient force is balanced by the Coriolis force.

Hypoxia: Low oxygen.

Impact module: One of four modules in the MWCI, and one of three modules in the Eutrophication Index.

Index: A communication tool used for reporting complex information in an accessible numerical format (e.g., a set of conditions expressed on a 0-100 scale).

Marine water: Salt water.

Marine Water Condition Index (MWCI): An index that uses four modules, Ambient, Enrichment, Impact, and Ventilation, to communicate changes in water quality relative to established baseline conditions in Puget Sound and coastal Bays, Willapa Bay, and Grays Harbor.

Noise: Variability in the data that reduces the ability to see a signal in the data.

Pacific Decadal Oscillation (PDO): A pattern of Pacific climate variability that shifts phases on an inter-decadal time scale and affects Washington's marine waters. The PDO is detected as warm or cool surface waters in the Pacific Ocean, north of 20° N.

Parameter: Water quality constituent being inferred from measurements (analyte). Typically a physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Proxy: A measurement allowing an estimate of a condition or process using measurements that do not fully describe the condition or process in its entity.

Upwelling: A process by which deeper, colder, and nutrient-rich ocean water is brought to the surface.

Upwelling Index (UI): An index developed by NOAA's PFEL relating coastal parallel wind stress to upwelling along the Pacific northwest coast.

Ventilation module: One of four modules in the MWCI.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

Acronyms and Abbreviations

-ΔPE	Potential energy required for vertical mixing
CTD	Conductivity/Temperature/Depth profiler
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
Ecology	Washington State Department of Ecology
EUI	Eutrophication Index
JEMS	Joint Effort to Monitor the Strait
MWCI	(See Glossary above)
NOAA	National Oceanic and Atmospheric Administration
PDO	(See Glossary above)
PFEL	Pacific Fisheries Environmental Laboratory

Chemicals

Chl-a	chlorophyll-a
NH_4	ammonium
NO_3	nitrate
PO_4	phosphate
$Si(OH)_4$	silicate

Units of Measurement

°C	degrees centigrade
g	gram, a unit of mass
g/m	grams per meter
GJ/m^2	gigajoule (10^9 Joules) per square meter of depth integrated thermal energy
J	Joule, a unit of energy
kg	kilograms, a unit of mass equal to 1,000 grams.
kg/m^2	kilograms per square meter of ocean surface integrated over depth
kJ	kilojoule, a unit of energy equal to 1,000 Joules
l	liter
m	meter
mg	milligrams
mg/l	milligrams per liter
mg/m^2	milligrams per square meter of ocean surface integrated over depth
psu	practical salinity units
ug	micrograms
uM	micromolar (a chemistry unit)