Technical Report 0646

Review of Indicators for Development of Nutrient Numeric Endpoints in California Estuaries

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Executive Summary

California State Water Resources Control Board (SWRCB) is developing nutrient water quality objectives for the State's surface waters, using an approach known as the Nutrient Numeric Endpoint (NNE) framework. The NNE establishes a suite of numeric endpoints based on the ecological response of an aquatic waterbody to nutrient over-enrichment (eutrophication, e.g., algal biomass, dissolved oxygen). In addition to numeric endpoints for response indicators, the NNE framework must include models that link the response indicators to nutrient loads and other management controls. The NNE framework is intended to serve as numeric *guidanc*e to translate *narrative* water quality objectives. The NNE framework is currently under development for estuaries, with selection of appropriate ecological response indicators as the first step in developing an NNE assessment framework. The purpose of this document is to review literature supporting the use of a variety of candidate ecological response indicators, recommend a suite of indicators which met review criteria, identify data gaps and recommend next steps. Note that this review does not include data gaps relevant to the development of NNE load-response models for estuaries. Recommended NNE indicators specifically for San Francisco Bay were reviewed by McKee et al. (2011).

Recommended NNE Indicators

The NNE assessment framework is the structured set of decision rules that helps to classify the waterbody in categories from minimally to very disturbed, in order to determine if a waterbody is meeting beneficial uses, or to establish TMDL numeric targets. Development of an assessment framework begins by choosing response indicators, which were reviewed using four criteria: 1) strong linkages to beneficial uses; 2) well-vetted means of measurement; 3) ability to model the relationship between the indicator, nutrient loads and other management controls; and 4) acceptable signal to noise ratio for eutrophication assessment. Two types of indicators were designated. Primary indicators are those which met all evaluation criteria and for which regulatory endpoints should be developed. Supporting indicators fell short of meeting evaluation criteria, but may be used as supporting lines of evidence, though establishment of NNE endpoints for these indicators is not envisioned in the near term. The use of primary and supporting indicators is consistent with the freshwater streams and lakes NNE framework.

Appropriate indicators vary by estuarine class as well as habitat type. For the purposes of designating NNE indicators, California estuarine classes aggregated into two main groups according to the status of the tidal exchange with the coastal ocean: 1) "open" to surface water tidal exchange and 2) "closed" to surface water tidal exchange. Estuarine classes that fall entirely into this "open" category include enclosed bays as well as perennially tidal lagoons and river mouth estuaries. In addition, intermittently tidal lagoons and river mouths that open at least once per year may be assessed using indicators applicable to this category when the mouth of the estuary is open to surface water tidal exchange. Estuaries that are "closed" to surface water tidal exchange include intermittently and ephemerally tidal

lagoons and river mouth estuaries <u>when the mouth is closed</u>. Indicators also vary by three main estuarine habitat types: 1) unvegetated subtidal, 2) seagrass and brackish SAV, and 3) intertidal flats.

The review found four types of indicator met all evaluation criteria and are designated as primary (see summary table below): dissolved oxygen, phytoplankton biomass and productivity, and cyanobacterial abundance and toxin concentration (all subtidal habitats), macroalgal biomass and cover (fine-grained intertidal and seagrass habitats). Other indicators evaluated met three or fewer of the review criteria and designated as supporting indicators: phytoplankton assemblage, HAB cell counts and toxin concentration, urea and ammonium, light attenuation (all subtidal), light attenuation and epiphyte load (seagrass/brackish SAV), macrobenthic taxonomic composition and biomass (subtidal <18 ppt) and sediment TOC:TN:TP:TS and degree of pyritization (fined grain intertidal and shallow subtidal).

Summary of Recommended Primary and Secondary Indicators by Ocean Inlet Status and Habitat Type

Ocean Inlet Status	Habitat	Primary Indicators	Supporting Indicators
Open	All Subtidal Habitat	Phytoplankton biomass and productivity Cyanobacteria cell counts and toxin concentration[1] Dissolved oxygen	Water column nutrient concentrations and forms[2] (C, N, P, Si) Phytoplankton assemblages HAB species cell count and toxin concentrations Macrobenthic taxonomic composition, abundance & biomass Sediment C, N, P, S, particle size (and ratios therein) and degree of pyritization
	Seagrass and Brackish SAV Habitat	Phytoplankton biomass and productivity Macroalgal biomass & cover	Light attenuation, suspended sediment conc. or turbidity Seagrass areal distribution,% cover, density Epiphyte load Brackish SAV areal distribution,% cover, biomass
	Intertidal Flats	Macroalgal biomass and cover[3]	Sediment % OC, N, P, S, particle size, degree of pyritization Microphytobenthic taxonomic composition, benthic chl <u>a</u>
Closed	All Subtidal Habitat	Phytoplankton biomass and productivity Cyanobacteria cell counts and toxin concentration Dissolved oxygen Rafting or floating macroalgae biomass and % cover	Phytoplankton assemblages, including HAB species cell count and toxin concentrations Sediment C, N, P, S, particle size (and ratios therein) and degree of pyritization Microphytobenthos taxonomic composition and benthic chl <u>a</u> biomass Water column nutrient concentrations and forms[2] (C, N, P, Si)
	Brackish SAV	Phytoplankton biomass and productivity Macroalgal biomass & cover Dissolved oxygen	Light attenuation, suspended sediment conc. Epiphyte load Brackish SAV areal distribution, % cover, biomass

[1] Note that cyanobacteria cell counts and toxin concentrations are included for polyhaline and euhaline habitats in an attempt to capture effects of cyanobacteria blooms transported from freshwater and oligohaline environments.
[2] Forms referred to relative distribution of dissolved inorganic, dissolved organic, and particulate forms of nutrients, including urea and ammonium
[3] Not an ideal indicator for sandy intertidal flats. Recommend the inclusion of microphytobenthos, though factors controlling biomass not understood and little known about taxonomy as an indicator of disturbance gradient.

Data Gaps and Recommended Next Steps

Development of an NNE assessment framework for California estuaries begins by specifying how primary and supporting indicators would be used as multiple lines of evidence to diagnose adverse effects of eutrophication. This report identifies the data gaps and recommended next steps to use the identified primary and supporting indicators in development of an assessment protocol to assess eutrophication. Assessment frameworks would need to be created for habitat types identified in this review, with some differences specified by estuarine inlet status (closed or open). **Note that no attempt is made to neither prioritize nor reduce/eliminate "next steps" in any habitat types, despite acknowledged limitation in available resources. The NNE technical team assumes this prioritization and focusing of resources would be done by the SWRCB, with advice from its advisory groups.**

Dissolved Oxygen - All Subtidal Habitat in Open and Closed Estuaries

All six coastal Regional Boards have numeric dissolved oxygen objectives applicable to estuaries. However, there is generally a lack of consistency among RWQCBs in their approach. This lack of consistency resulted in the review of science supporting estuarine dissolved oxygen objectives for California estuaries (excluding San Francisco Bay) with the goal of developing a consistent approach statewide that protects specific designated uses and aquatic habitats. This study is already funded and the technical report summarizing the findings of the literature review and data synthesis will be available in June of 2011. *Data gaps and recommended next steps are identified in this document.*

Phytoplankton and Water Column Nutrient Indicators - Unvegetated Subtidal Habitat in Open Estuaries

Within the realm of phytoplankton indicators, biomass, productivity, cyanobacterial cell counts and toxin concentration are designated as primary indicators for all subtidal habitats. To establish numeric thresholds for these primary indicators, a number of data gaps and next steps must be addressed (see table below). For phytoplankton biomass and productivity, there is a large amount of experience and studies that exist globally, but a lack of data exists for most California estuaries, with the exception of San Francisco Bay (see review by McKee et al. 2011), where a water quality data set of nearly 40 years exists. It is recommended that a working group of experts be assembled to develop an assessment framework for biomass and productivity that takes into account the high spatial and temporal variability of phytoplankton, using San Francisco Bay as a "test case." For cyanobacteria cell counts and toxins concentrations, guidelines exist to establish NNE endpoints in fresh habitats, based on human and faunal exposure to toxin concentrations. The applicability of these endpoints should be examined for translation to estuarine habitats.

Summary of Data Gaps and Recommended Next Steps for Phytoplankton and Water Column Nutrient Indicators in Unvegetated Subtidal Habitat

<table>
<tr><th>Indicator</th><th>Designation</th><th>Status of Science</th><th>Recommended Next Steps</th><th>Status of Work</th></tr>
<tr><td>Phytoplankton biomass and productivity</td><td>Primary indicator</td><td>Wealth of experience and studies exists globally, but lack of data for most California estuaries and lack of specific studies to establish thresholds. Precise thresholds may vary from estuary to estuary, depending on co-factors.</td><td rowspan="3">Recommend development of a white paper and a series of expert workshops to develop NNE assessment framework for phytoplankton biomass, productivity, taxonomic composition/assemblages, abundance and/or harmful algal bloom toxin concentrations in “open” and “closed” estuaries. Include review of relevant thresholds for nutrient stoichiometry as relevant for “closed” estuaries.</td><td rowspan="3">No work under-taken</td></tr>
<tr><td>Cyanobacteria cell count and toxin conc.</td><td>Primary indicator</td><td>Data and precedent exist to establish NNE thresholds.</td></tr>
<tr><td>Nutrient stoichiometry</td><td>Supporting indicator</td><td>Lack of data in California estuaries on use of nutrient stoichiometry to predict cyanobacteria dominance in oligohaline to mesohaline habitats.</td></tr>
<tr><td>Ammonium</td><td>Supporting</td><td>Ammonium inhibition of nitrate uptake by diatoms document, although importance of this effects vis-à-vis other controls on production and species dominance not well understood</td><td>Future investigations on utility of ammonium as an indicator should be focused first on San Francisco (SF) Bay, where debate on ammonium is a priority issue. Formulate a working group of scientists to synthesize available data on factors known to control primary productivity in different regions in SF Bay, develop consensus on relative importance of ammonium inhibition of phytoplankton blooms, and evaluate potential ammonium endpoints (see McKee et al. 2011 for further details).</td><td>No work undertaken</td></tr>
<tr><td>Phytoplankton assemblages, HAB species cell count, toxin conc.</td><td>Supporting indicator</td><td>Controls on phytoplankton assemblages, euhaline and marine HAB bloom occurrence and toxin production not well understood</td><td rowspan="2">Include as indicator in monitoring program and support basic research to increase understanding of drivers.</td><td rowspan="2">Not applicable</td></tr>
<tr><td>Urea</td><td>Supporting</td><td>Lack of data on urea concentrations in estuaries</td></tr>
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Phytoplankton, Macroalgae, Epiphyte Load and Light Attenuation in Seagrass Habitats

For seagrass habitats, macroalgal biomass and cover and phytoplankton biomass are designated as primary indicators, while light attenuation and epiphyte load are designated as supporting indicators (see table below). Development of an assessment framework for seagrass based on these indicators will require addressing the following studies: 1) identify thresholds associated with adverse effects of macroalgal biomass and cover on seagrass growth, 2) collect data on light requirements of California seagrass and determine combinations of phytoplankton biomass and turbidity that result in light attenuation beyond levels of tolerance of seagrass, and 3) assemble a workshop of experts to construct assessment framework for seagrass habitat that uses macroalgae, phytoplankton, epiphyte load in a multiple lines of evidence fashion. Studies to identify thresholds associated with adverse effects of macroalgal biomass and cover are funded and will begin the summer 2011.

Data gaps and recommended next steps for development of an NNE assessment framework for seagrass habitat

Indicator	Designation	Status of Science	Recommended Next Steps	Status of Work
Macroalgal biomass and cover	Primary indicator	Data lacking on dose and response of macroalgal biomass on seagrass growth	Conduct experiments on biomass, cover and duration of macroalgae that results in reduced seagrass growth. Survey ranges of biomass, duration and cover associated with macroalgae on seagrass	Funded. Study to begin summer 2011
Phytoplankton biomass	Primary indicator	Data lacking on light requirements for California seagrass	Determine light requirements for California seagrass and survey range of epiphyte loads on seagrass beds. Develop assessment framework as a function of light attenuation, macroalgal biomass and epiphyte load	No work undertaken
Light attenuation	Supporting indicator			
Epiphyte load	Supporting indicator	Scientific foundation exists, but epiphyte load difficult to quantify		

Macroalgae, Sediment C:N:P:S Ratio, Degree of Pyritization and Microphytobenthos on Intertidal Flats

Discussion of data gaps in intertidal flat habitat in "open" estuaries distinguishes between fine-grained (mud flats) and course grained (sand-flats) habitat types. In mud flats of "open" estuaries, macroalgal biomass and percent cover are the primary NNE indicators. In these habitat types, data are lacking on the thresholds of effects of macroalgae on benthic infauna as well as documentation of the range of duration of biomass and cover associated with macroalgae on intertidal flats. To address these data gaps, recommended next steps include: 1) conducting experiments and field surveys to address these data gaps, and 2) synthesis of these data into an assessment framework. These studies are funded and underway, with an assessment framework anticipated in July 2013. In sand flats, use of macroalgae as an indicator is questionable, as it is more common to see high biomass of microphytobenthos in eutrophic conditions. Therefore, in "open" estuaries dominated by sandy intertidal flats, as is the case in river mouth estuaries, a more important indicator may be microphytobenthos biomass and taxonomic composition. Since little is known about controls on microphytobenthos, it recommended that research be supported to improve understanding of appropriate indicators of eutrophication in river mouth estuaries in the “open” condition.

Data gaps and recommended next steps for development of an NNE assessment framework for intertidal flats in “open” estuaries

Indicator	Designation	Status of Science	Recommended Next Steps	Status of Work
Macroalgal biomass and cover	Primary	Data lacking on dose and response of macroalgal biomass on benthic infauna in intertidal flats	Conduct experiments on biomass, cover and duration of macroalgae that results in reduced diversity and abundance of benthic infauna in tandem with sediment C:N:P:S and degree of pyritization. Survey ranges of biomass, duration and cover associated with macroalgae on seagrass	Funded and study in progress
Sediment C:N:P:S and degree of pyritization	Supporting indicator	Data lacking on the sensitivity of this indicator vis-à-vis primary producers		
Microphytobenthos biomass and taxonomic composition	Supporting	Data lacking effects of eutrophication on biomass and taxonomic composition across gradients of particle size and salinity	Conduct field studies that document change in biomass and taxonomic composition of microphytobenthos along disturbance gradient in sandy intertidal flats and shallow subtidal habitat of “open” estuaries.	No work undertaken

Macrobenthos Biomass, Taxonomic Composition, and Abundance, Sediment C:N:P:S and Degree of Pyritization in Subtidal Habitats >18 ppt

In subtidal habitats of “open” estuaries with salinities greater than 18 ppt, macrobenthos biomass, taxonomic composition and abundance may provide additional information on eutrophication. As macrobenthos taxonomic composition and sediment %C and %N are already being used in the assessment of sediment quality objectives, the addition of macrobenthic biomass and sediment sulfur and degree of pyritization represents an attempt to enhance information collected through the SWRCB’s Sediment Quality Objective (SQO)protocol to assess effects of eutrophication (see table below). Recommended next steps includes: 1) analysis of existing regional monitoring datasets for useful taxonomic indicators of eutrophication; and 2) conduct a pilot study in a future regional monitoring program study to test the utility of including biomass, sediment C:N:P:S ratios, and degree of pyritization as a standard part of this protocol.

Data gaps and recommended next steps for use of macrobenthos and indicators of sediment organic matter accumulation in "open" estuaries with salinities >18 ppt

Indicator	Design-ation	Status of Science	Recommended Next Steps	Status of work
Macrobenthos taxonomic composition, abundance, biomass	Supporting	Lack of data on the degree to which macrobenthos biomass, in combination with taxonomic composition and abundance, may provide specific diagnosis of eutrophication and how this would differ by salinity regime.	Analyze existing regional monitoring datasets for taxonomic indicators of eutrophication Conduct pilot study in future regional monitoring program study to test utility of including biomass in macrobenthos assessment protocol.	No work undertaken
Sediment C:N:P:S and degree of pyritization	Supporting	Lack of understanding of the sensitivity of sediment C:N:P:S ratio or degree of pyritization in diagnosing eutrophication	Analyze existing regional monitoring datasets for utility of C:N:P:S or degree of pyritization Include indicator in pilot study (polyhaline-euhaline) or field studies (oligohaline-mesohaline) to determine sensitivity and utility for NNE framework Include as indicator in experiments on effects of macroalgae on benthic infauna on intertidal flats (see below)	No work undertaken

Phytoplankton, Macroalgae and Epiphyte Load in Vegetated (Brackish SAV) and Unvegetated Subtidal Habitats of "Closed" Estuaries

In intermittently and ephemerally tidal estuaries during a "closed" tidal inlet condition, primary NNE indicators include macroalgal biomass and cover, phytoplankton biomass, cyanobacterial cell counts and toxin concentrations. The table below gives a summary of data gaps and recommended next steps for these indicators both vegetated (brackish SAV) and unvegetated subtidal habitats.

For unvegetated subtidal habitat in closed estuaries, phytoplankton grow under lentic conditions similar to that of freshwater lakes. Little data is available on the concentrations of phytoplankton biomass and speciation in California estuaries in this condition. However, it is recommended that the numeric endpoints for the California lakes NNE (phytoplankton biomass, cyanobacteria cell counts and toxin concentrations) be evaluated for applicability to unvegetated subtidal habitats.

Floating or rafting mats of macroalgae can have a significant effect on other primary producers in "closed" estuaries. No data or studies are available to document what levels of floating algae result in adverse effects. To address these data gaps, two types of studies are recommended: 1) modeling or experiments to document thresholds of effects of floating or rafting macroalgae on microphytobenthos; and 2) field studies or experiments that documents linkage between macroalgae, phytoplankton, microphytobenthos, dissolved oxygen and pelagic invertebrates as a function of nutrient loading and other co-factors.

Data gaps and recommended next steps for development of an NNE assessment framework for unvegetated and vegetated (brackish SAV habitat) in closed estuaries

Habitat Type	Indicator	Designation	Status of Science	Recommended Next Steps	Status of Work
Unvegetated Oligohaline to Mesohaline Habitat	Macroalgal biomass and cover	Primary	Lack of data on thresholds of effects of macroalgal biomass/cover associated with effects on dissolved oxygen, microphytobenthos and pelagic invertebrates	Modeling studies and/or experiments to investigate linkage between macroalgae biomass/cover and dissolved oxygen, microphytobenthos and pelagic invertebrates	No work undertaken
	Cyanobacteria cell count and toxin concentrations	Primary	Studies exist to establish thresholds for freshwater lakes.	Evaluate applicability of freshwater lakes NNE thresholds and WHO guidelines for “closed” estuaries	No work undertaken
	Phytoplankton biomass	Primary			
	Microphytobenthos biomass and taxonomic composition	Supporting	Lack of information on controls on biomass and taxonomic composition	Conduct experiments on degree to which floating macroalgae, phytoplankton and epiphyte loads adversely affect brackish SAV and microphytobenthos Conduct field studies documenting biomass, areal extent and % cover of brackish SAV relative to gradients of nutrient loading	No work undertaken
Brackish SAV	Macroalgal biomass and cover	Primary indicator	Data lacking on response of canopy-forming brackish SAV to factors that result in greater water column light attenuation: floating macroalgae, phytoplankton biomass and epiphyte load.		
	Phytoplankton biomass	Primary indicator			
	Light attenuation	Supporting indicator			
	Epiphyte load	Supporting indicator			

Full Text

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/646_ENNE_IndicatorReview.pdf