Exploring Development of Numeric Nitrogen Targets in Portland Area, Casco Bay, Maine under the Nutrient Scientific Technical Exchange Partnership and Support (N-STEPS)

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1 INTRODUCTION

In response to recent recommendations from the Casco Bay Nutrient Council, Maine Department of Environmental Protection (MDEP) is working to develop numeric nutrient criteria for nitrogen for the Portland vicinity of Casco Bay within the area designated as an SC waterbody classification (Figure 1). Though these waters are not currently subject to numeric nutrient criteria, TN thresholds do apply to the ambient waters in the vicinity of outfalls for the purposes of Reasonable Potential (RP) analyses for wastewater discharge licensing. To date, RP assessments have utilized two total nitrogen (TN) threshold values to address aquatic life use of Maine's marine and estuarine waters:

1) 0.32 mg/L for protection of eelgrass, when historically mapped as present within close proximity to the discharge in question; and

2) 0.45 mg/L for protection of dissolved oxygen, when eelgrass has not been historically mapped within close proximity to the discharge in question.

Maine DEP's definition of "close proximity" has been eelgrass located approximately 0.5 km from the wastewater outfall, or as informed by Best Professional Judgement (BPJ) based on known eelgrass resources.

The TN threshold value currently used in Maine's marine and estuarine wastewater permits for protection of eelgrass is a concentration used regionally by United States Environmental Protection Agency (USEPA) licensing staff (David Webster, personal communication). The MDEP decision to use 0.32 mg/L was due to its numerical midpoint between 0.34 mg/L, a concentration deemed protective of eelgrass by the Massachusetts Estuary Project, and 0.30 mg/L, an average concentration from the lower Piscataqua River where Maine DEP observed epiphytic growth on eelgrass that resulted in a 2012 impaired waters listing due to eelgrass loss. The TN threshold value used for dissolved oxygen originates from a New Hampshire Department of Environmental Services (NH DES) guidance document for the Great Bay estuary (NH DES 2009) and was utilized in an EPA-issued wastewater discharge license in the Taunton River estuary in Massachusetts (USEPA 2015).

From 2016-2020, MDEP monitored a range of water quality parameters across sites in western Casco Bay[1]. Additional monitoring efforts carried out by MDEP include aerial surveys of the Portland vicinity to enable eelgrass delineation and establishment and monitoring of eelgrass health metrics at three beds at varying distances from the East End wastewater treatment facility outfall. Additional ambient data are available through historic and ongoing water quality monitoring by Friends of Casco Bay (FOCB), a University of Maine buoy with comprehensive sensor suite adjacent to the discharge (August-October 2019), and high-resolution nitrate and ammonium analyzer data managed by the Casco Bay Estuary Partnership (CBEP) (summer 2019).

This N-STEPS effort leveraged the information gained through the above-mentioned monitoring efforts to 1) identify a spatial frame for analysis, 2) develop conceptual models relating nutrient enrichment effects to biological responses, 3) compile data, 4) explore classification options for this area, and 5) conduct distributional, predictive reference and stressor-response analyses to support development of nitrogen targets which may ultimately be incorporated into numeric nutrient criteria for the Portland vicinity of Casco Bay by MDEP.

[1] Ambient monitoring efforts include discrete measurement of temperature, salinity, dissolved oxygen, pH, chlorophyll, turbidity, transparency, and photosynthetically active radiation (PAR), and surface characterization of nitrogen and phosphorus species, chlorophyll a and total suspended solids (TSS) on ebb and flood tides approximately every three weeks from May-October. Unattended sonde deployments measuring temperature, salinity, dissolved oxygen, and pH occur at select locations. Acquisition of aerial photography and eelgrass ground truthing for areal extent and percent cover assist with identification of sensitive aquatic life in proximity to nitrogen sources.

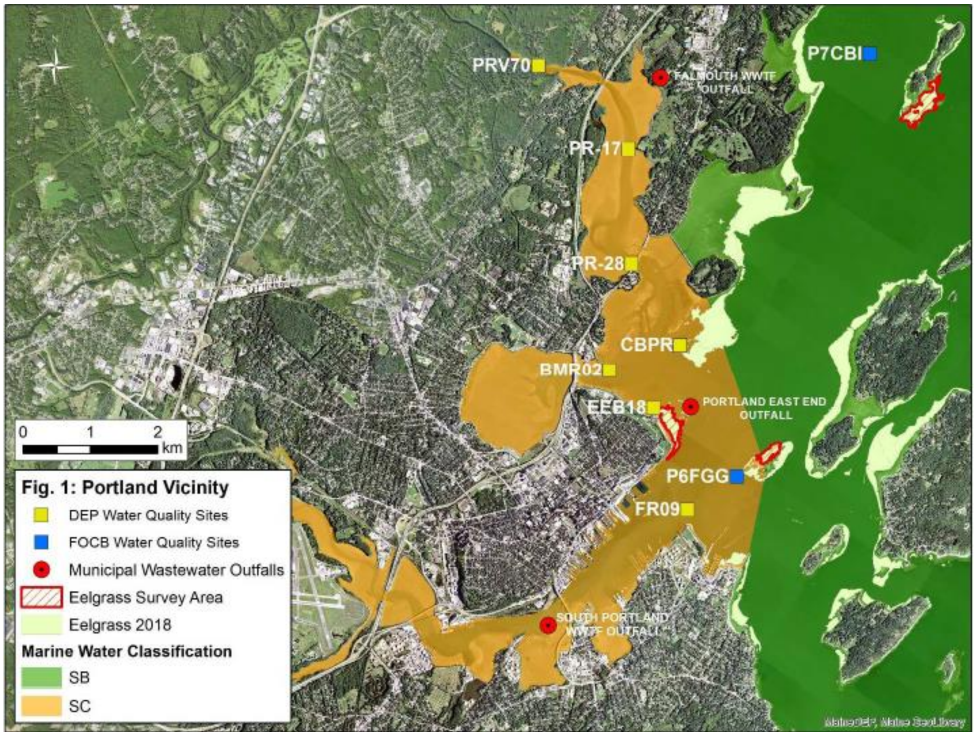

Figure 1. Map of Portland East End outfall and eelgrass survey areas

2 SPATIAL FRAME

The spatial frame determines the spatial area that is the focus of target development and from which data will be extracted for the analyses. Directly, the area that is the focus of nitrogen target development includes the Fore River and Presumpscot River estuaries and intervening marine waters of the Portland, Maine, region classified as SC waters (Figure 1). The class SB waters outside of the class SC region are not a focus of these targets. The Portland area includes areas known to support eelgrass, outfalls from 3 municipal wastewater treatment facilities, and runoff from the surrounding landscape which includes a mosaic of land uses, most evidently urban Portland.

In addition to the Portland SC waters, the spatial frame from which data were to be extracted for use was expanded to include other estuaries along the Maine coast for which MDEP has relevant data. The reason for this was the decision by the MDEP and the stakeholder group, Portland Area Nitrogen Group (PANG), to pursue the application of distributions of nitrogen concentrations from less developed estuaries as well as estuaries known to support eelgrass as a line of evidence. This expanded the spatial frame to include several estuaries (herein referred to as reference estuaries) for which the state also had collected water quality data (Figure 2), including the Machias, Penobscot Bay (including Belfast and Rockport areas), Penobscot River, Harraseeket, Royal and Cousins, Saco, Mousam, and York estuaries. Note that the use of the term “reference” here should not be construed as undeveloped or pristine. It merely connotes less development than the Portland area and that these are a reference from which distributions can be extracted as a benchmark for the Portland area. From this reference population, we later discuss also using distributions from those with the least anthropogenic nitrogen load and those known to support eelgrass as additional relevant populations.

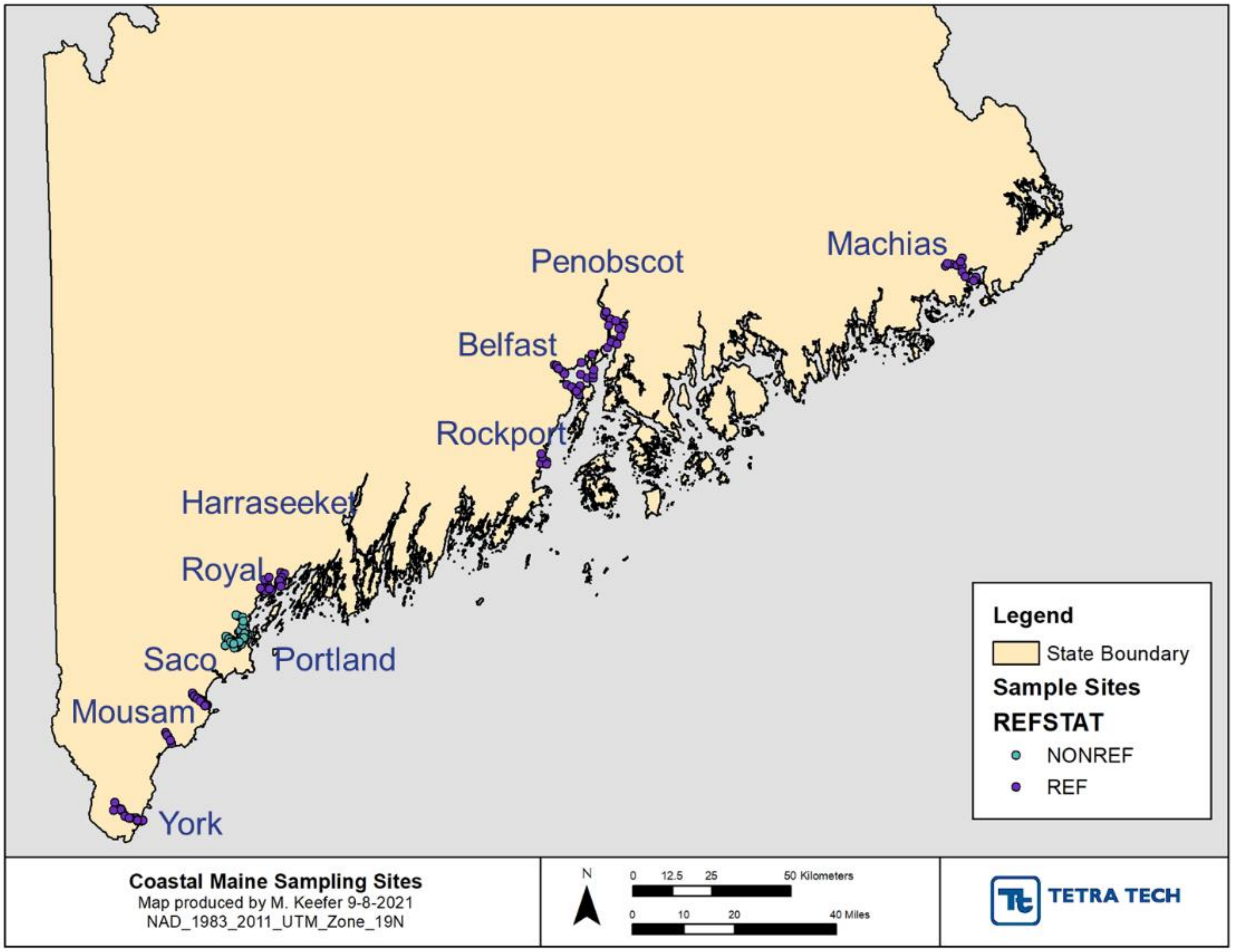

Figure 2. Map of estuaries considered for inclusion as part of the reference distribution line of evidence.

3 DATA

A comprehensive dataset of water quality parameters was provided by MDEP to N-STEPS. These included a set of discrete water quality observations from the Portland area and from other estuaries across the spatial frame (Figure 2). These data included 85,000+ observations in the Portland area and 79,000+ from other estuaries for nutrients, dissolved oxygen, chlorophyll (corrected for pheophytin), Secchi depth, and turbidity. Additional data on tide, wind, weather, and ancillary measures were provided but not used. These observations came from 169 sites in the Portland area and 271 sites from across the other estuaries. In the Portland area, more than 70% of the observations were collected by Friends of Casco Bay, 28% by MDEP, and the balance by miscellaneous entities. For the other estuaries, most of the data were collected by MDEP (53%) and the balance by a range of academic, consulting, and non-governmental organizations.

In addition to the discrete monitoring data, MDEP also provided continuous monitoring data collected at 10 fixed stations within the Portland region and 13 stations outside the Portland area (Royal-Cousins, Harraseeket, Machias, Mousam, and York). These included 355,000+ measurements in the Portland region across depth, dissolved oxygen, pH, salinity, conductance, temperature, and turbidity and 364,000+ from the other estuaries for the same variables plus chlorophyll. MDEP also provided a set of 283 directly measured light attenuation (k_d) estimates using vertical irradiance profiles for 19 sites in the Portland area, including measurements in Casco Bay, the Fore River, and the Presumpscot River.

The raw data were processed to prepare data. This preparation included removing sites with only single synoptic runoff samples where there was concern of bias in water quality conditions, removal of erroneous synoptic and sonde values that had not been corrected in MDEP's original QA process, calculation of additive total nitrogen from 18 observations, and a few other small corrections. We also removed samples from outside the algal growing season period, which was May to October. This resulted in, for example, nearly 1800 total nitrogen samples from 165 sites and 771 chlorophyll *a* corrected for pheophytin samples from 99 sites. The data were also converted to growing site-year average data using only data from May-October and most of the analyses were done using growing season site-year averages since this is a scale at which most sites will be assessed. This resulted in, for example, 328 site-year average total nitrogen values (126 from the Portland Area and 202 from reference waterbodies) from 165 sites (47 from the Portland area and 119 from reference waterbodies). The as-analyzed dataset is available for those interested in evaluating the data. The sites used in the final analysis are listed in Appendix 1. Please note that the only chlorophyll *a* data presented in this report is synoptic pheophytin-corrected chlorophyll *a*.

Lastly, MDEP provided nitrogen loading data for 12 estuaries that included annual load of total nitrogen (TN, kg) and total load expressed per unit of contributing watershed area (kg/km^2) generated using Model My Watershed.

Model My Watershed is a watershed modeling web application that enables citizens, conservation practitioners, municipal decision-makers, educators, and students to:

- Analyze real land use and soil data in their neighborhoods and watersheds
- Model stormwater runoff and water-quality impacts using professional-grade models
- Compare how different conservation or development scenarios could modify runoff and water quality

Model My Watershed is based on the Generalized Watershed Loading Function-Enhanced (GWLF-E) model, which has been utilized by USEPA. Data sources are all conventional national datasets, including weather, soils, and landcover.

Loads were split into natural TN (from Wooded Areas, Wetlands, Open Land, Barren Areas, Stream Bank Erosion, and Subsurface Flow) and anthropogenic TN (from Hay/Pasture, Cropland, Low-Density Mixed, Medium-Density Mixed, High-Density Mixed, Low-Density Open Space, Farm Animals, Point Sources, and Septic Systems). For each of the 12 estuaries, MDEP also identified which were known to support eelgrass currently (Table 1, A. Brewer, personal communication).

Table 1. Total Nitrogen load to various estuaries in Maine expressed as annual load and areal load (per contributing watershed area), expressed as total and split into natural and anthropogenic sources. Estuaries are ordered by increasing anthropogenic TN load. Also shown for the same waters are whether they are known to currently support eelgrass anywhere in the receiving estuary.

		Annual TN Load (kg/y)			Annual Areal TN Load (kg/km^2/y)				Eelgrass
Resource	**Area (km^2)**	**Total**	**Natural**	**Anthropogenic**	**Total**	**Natural**	**Anthropogenic**	**Natural/ Anthropogenic**	**Support**
Machias River Estuary	2,084	379,907	357,180	22,726	182	171	11	15.7	Yes
York River Estuary	87	13,839	11,344	2,496	159	130	29	4.5	Yes
Saco River Estuary	4,389	1,959,821	1,823,496	136,325	446	415	31	13.4	Yes
Penobscot River Estuary	3,228	1,075,431	947,434	127,997	333	294	40	7.4	No
Rockport	29	5,482	4,260	1,222	191	149	43	3.5	Yes
Upper Penobscot Bay	4,071	1,445,473	1,242,421	203,051	355	305	50	6.1	Yes
Presumpscot River Estuary	1,677	501,186	390,523	110,663	299	233	66	3.5	No
Mousam River Estuary	324	94,144	66,484	27,660	291	205	85	2.4	No
Royal/Cousins Estuary	424	106,877	66,857	40,020	252	158	94	1.7	No
Harraseeket River Estuary	48	14,718	6,866	7,852	304	142	162	0.9	Yes
West Casco Bay	1,839	1,090,642	492,057	598,586	593	268	325	0.8	Yes
Fore River Estuary	135	166,073	26,979	139,093	1,231	200	1,031	0.2	Yes

4 CONCEPTUAL MODEL

As part of the analysis process, a conceptual model linking nutrient sources to management goals (designated uses) was developed (Figure 3). The importance of the conceptual model is to capture known relationships supported by scientific literature and embodied knowledge as to the pathways through which nitrogen affects designated uses. These pathways include important assessment endpoints that link to management goals and for which values can be developed or have been developed to protect the management goals they represent. An example of this is dissolved oxygen, for which regulatory numeric criteria exist to protect aquatic life.

A detailed conceptual model was developed linking nutrient sources to management goals in Casco Bay (Appendix 2). A simplified version illustrates that nutrient sources come from the landscape, both naturally and from anthropogenic sources, as well as from Atlantic upwelling along the Gulf of Maine boundary. These nutrient sources affect dissolved and particulate nutrient concentrations. Increases in nutrients affect primary productivity (and the loading of organic matter into the system) and the composition of phototrophs (both planktonic and benthic). Increased primary productivity leads to increased organic matter in the water column that attenuates light, impacting submerged aquatic vegetation (SAV) which require substantial light at depth for germination and sustained growth. Increased organic matter also creates greater demand for oxygen as heterotrophic decomposers (e.g., bacteria, fungi) and their food web consume organic matter and respire. Shifts in assemblage structure occur because phototrophs differ in their competitive ability for nutrient uptake and light. Some taxa, often those with higher nutrient requirements or uptake efficiencies, can produce blooms that reduce water clarity, produce unsightly growth and generate toxins when nutrients are elevated. This can have adverse effects on recreation, human health, and other taxa.

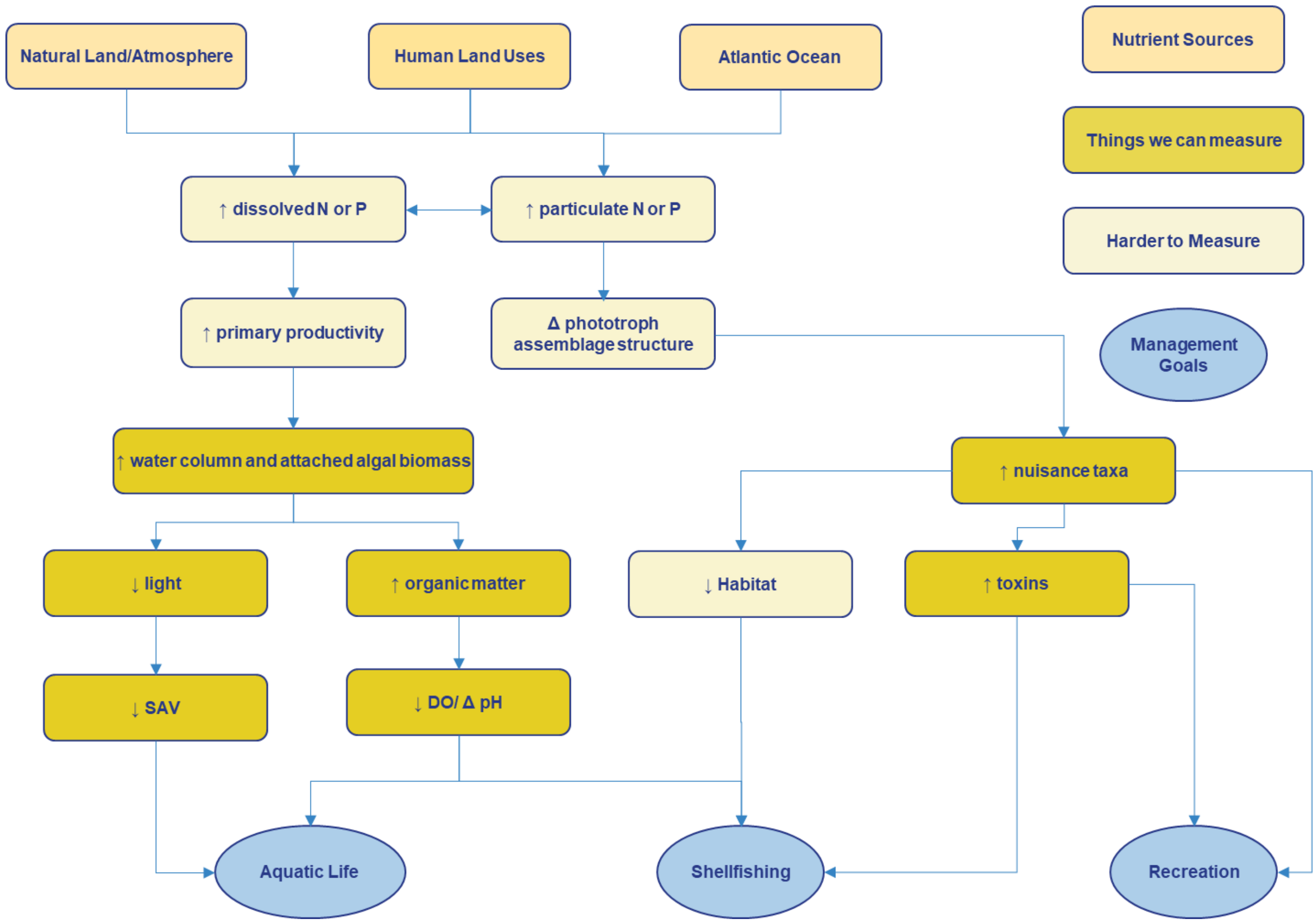

Figure 3. Simplified conceptual model of nutrient impacts to the Portland Area of Casco Bay

5 CLASSIFICATION

Classification refers to the organization of ecological units into those within which variability in nutrient behavior and nutrient-response dynamics is expected to be less than that across these units. This allows us to separate the signal of real differences in unique nutrient behavior and response to anthropogenic effects from the noise of natural variability. For example, it is known that nutrient concentrations tend to be higher near freshwater, riverine areas than in more marine areas closer to the open ocean boundary. These two areas may differ, therefore, in the natural nutrient dynamics. Freshwater areas may also be higher in turbidity from landward sources and associated with the mixing of fresh and marine waters. This difference in turbidity affects light, which means the response of phototrophs to nutrients in such environments may be different as well.

We first explored organizing the Portland Area into 5 units (Figure 4). The presumption was that these units reflected different influences of riverine or land based and open marine water sources.

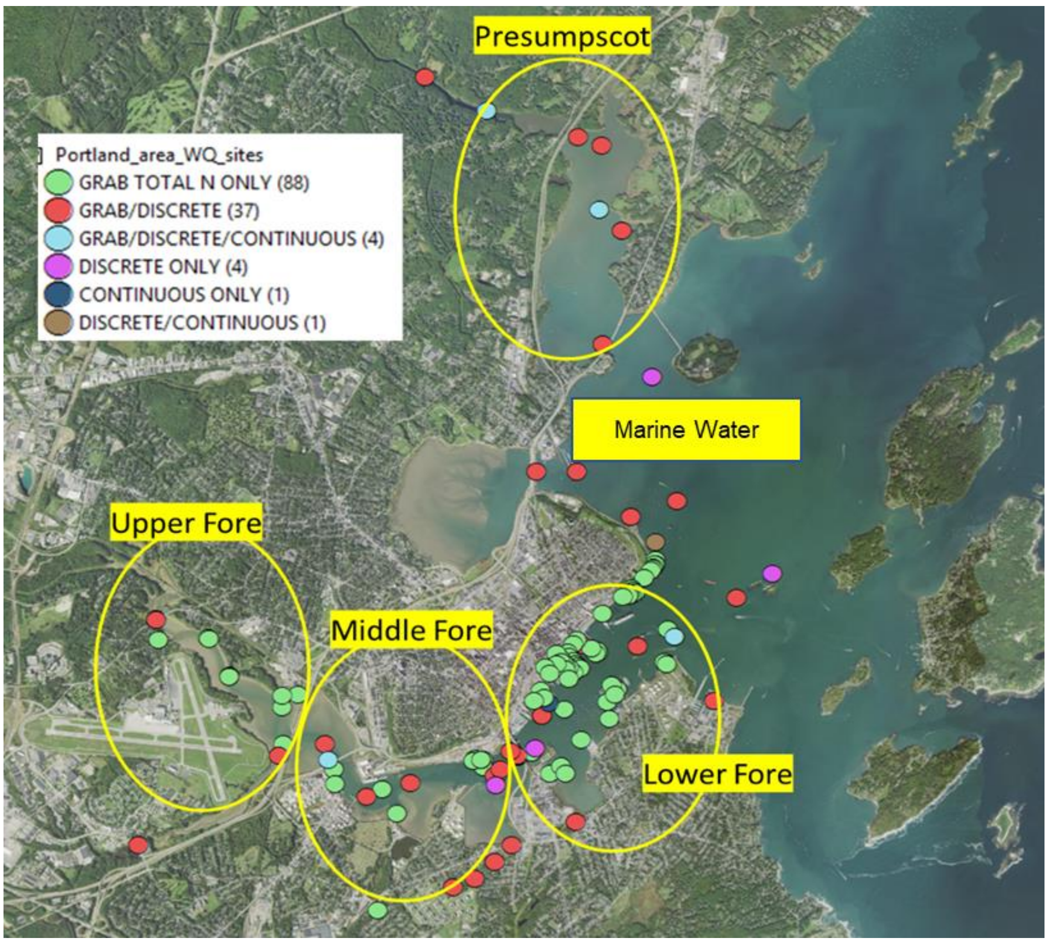

Figure 4. Draft classification of Portland area estuaries with sites labeled by availability of data types.

We realized after the first exploratory data analysis and feedback from technical experts from PANG that the classification was somewhat unique to Portland and did not transfer to other estuaries in Maine and was missing sufficient consideration of elements such as depth, salinity, residence time, temperature, and mixing differences among these sites. Therefore, we pursued a second topology to better organize the Portland area as well as other estuaries into a common classification that could be used for better comparability among estuarine systems as well.

For the second classification, we first started with the natural morphology of these estuaries, identifying primarily upper estuarine portions (influenced more by freshwater) and then the estuarine portions influenced by open ocean water. We called the intervening areas, Lower Estuarine. We then explored depth integrated, long-term average salinity dynamics among sites within these preliminary classes. Sites required a minimum of 5 salinity observations. We adjusted site definitions based on the following rules:

Upper Estuarine:	Mean salinity <24 and physically located near upper estuary
Lower Estuarine:	Intermediate, but mean salinity >=24 and not exposed (that is, generally confined within an embayment or channel form)
Marine Waters:	Mean salinity >27 and standard deviation <2.5 and generally exposed locations

We tried to follow these rules as strictly as we could, but a strict definition would require equivalent salinity sampling across sites, so we did the best we could with the available data and schedule. In some cases, a visual adjustment to a site class was made despite its salinity information; for example, when a proximate site with substantial data showed quite different salinity behavior and it was clear the sites shared a similar class. Individual sites were then assigned to classes. Final classes for different estuaries are shown in Table 2 (based on averages of grab sample data from the whole year), noting that some estuaries have more than one class. A map of classes in the Portland Area is shown in Figure 5 for context. Other estuaries were broken into comparable classes.

Table 2. Salinity statistics for different estuaries by classification.

		Salinity				
Estuary	Classification	Count	Average	Standard Deviation	Max	Min
Upper Fore	Upper Estuarine	296	21.2	9.1	33.3	0.0
Presumpscot	Upper Estuarine	588	12.6	12.3	31.2	0.0
Mousam	Upper Estuarine	49	14.6	11.4	30.9	0.1
Penobscot River	Upper Estuarine	2198	20.7	6.4	30.0	0.0
Royal-Cousins	Upper Estuarine	481	15.7	8.5	31.3	0.0
Saco	Upper Estuarine	148	7.7	9.0	28.6	0.0
York	Upper Estuarine	47	11.5	8.3	23.3	0.0
Middle Fore	Lower Estuarine	655	30.1	1.9	33.3	18.3
Lower Fore	Lower Estuarine	1093	29.8	2.5	33.7	4.0
Presumpscot	Lower Estuarine	270	25.2	6.5	31.9	6.3
Harraseeket	Lower Estuarine	991	30.1	3.7	33.9	1.5
Machias	Lower Estuarine	243	28.8	3.8	34.0	2.4
Mousam	Lower Estuarine	39	26.1	7.4	31.0	7.3
Penobscot Bay	Lower Estuarine	230	27.6	2.4	31.5	16.7
Penobscot River	Lower Estuarine	412	24.2	4.9	31.0	5.2
Royal-Cousins	Lower Estuarine	442	27.2	5.4	34.9	1.6
York	Lower Estuarine	305	28.5	4.1	31.8	0.2

Marine Waters Portland	Marine Waters	6168	29.1	3.0	33.9	2.1
Harraseeket	Marine Waters	114	32.0	0.3	32.6	31.6
Machias	Marine Waters	167	32.2	1.1	34.4	28.6
Penobscot Bay	Marine Waters	232	29.4	1.8	33.8	23.7
Rockport	Marine Waters	1917	30.1	1.7	32.4	15.2
Royal-Cousins	Marine Waters	27	30.8	0.8	31.9	29.4
York	Marine Waters	34	30.8	0.6	31.3	29.8

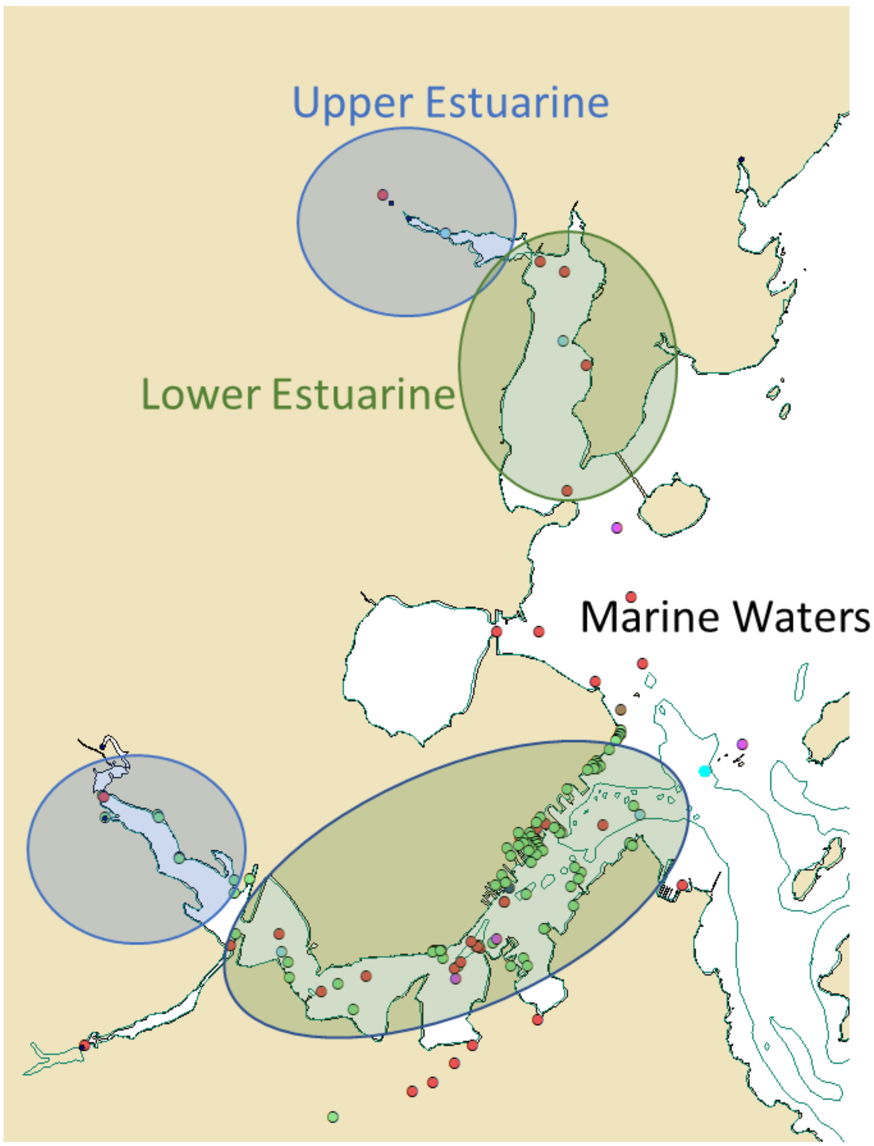

Figure 5. Map of final classes in the Portland Area

6 ANALYSES

We pursued two primary analytical lines of evidence for this work: 1) reference-based analyses using distributions from a reference population and a predicted reference model using multiple regression and 2) stressor-response analyses attempting to link chlorophyll and TN to target response conditions protective of DO and eelgrass as well as models of TN and chlorophyll to identify TN concentrations associated with potential chlorophyll targets. The results of these lines could be combined with other information (e.g., scientific literature, mechanistic models) in crafting decisions regarding protective criteria. Both approaches are scientifically defensible and both have pros and cons to be weighed as they are considered.

Reference Line of Evidence

The reference line derives nutrient targets from populations of similar waters either presumed or known to be supporting uses or valued assessment endpoint conditions. It tends to use the most data because it does not require paired stressor-response combinations. This line of evidence is also supported by USEPA nutrient criteria guidance, including the estuarine and coastal criteria guidance, and was used for deriving the current rivers and streams recommended national 304a criteria (USEPA 2001). On the other hand, the reference line has been criticized as generating thresholds not specifically linked to demonstrable impacts, with the degree of protection (or lack thereof) somewhat unknown. Of course, where reference populations are not expressing adverse conditions, protection can likely be presumed. Moreover, the percentiles chosen can be used to adjust for uncertainty in the population condition, but it is a concern that has been expressed. Another concern is the degree to which reference populations represent the target water. For small, forested watershed streams, with an abundance of samples from which to choose and sample, this is less an issue. For large estuaries, the site specificity in hydraulics, residence time, geography, topography, climate, etc. may make finding appropriate reference waters more difficult.

Stressor-Response Line of Evidence

The stressor-response line of evidence attempts to quantify relationships from the conceptual model linking nutrients to assessment endpoint targets reflecting protection (or harm) to the management goals (designated uses). It attempts to identify those nutrient values that are associated with impacts and can include estimates of uncertainty (e.g., error). This line is also supported by USEPA estuarine nutrient criteria guidance, USEPA stressor-response guidance, and is the basis of the recently finalized USEPA national 304a lake criteria (USEPA 2001, USEPA 2010; USEPA 2021). On the other hand, field-based stressor-response relationships can be highly variable and the error around values can be large (unlike those from, say, randomized controlled laboratory toxicity studies). Moreover, models of distant paired relationships that omit intermediate causal pathway steps (e.g., nutrients and dissolved oxygen) can be subject to influence from confounding co-occurring stressors or modifying variables. These concerns require careful consideration when evaluating this evidence.

6.1 Reference Distributional Analysis

The first analyses we conducted were distributional analyses. The basis for this approach is that the distribution of nutrients and response variables from waters that either approximate natural conditions or are known to support the management goals one is attempting to protect or restore should be an appropriate guide for protective conditions in the target water. Such waters, often called reference waters, can be defined using contributing land use conditions or observed conditions in the receiving water. In this case, we used modeled anthropogenic nitrogen loading rates and known eelgrass support as characteristics to define reference. We refer to all the non-Portland area estuaries as reference, we refer to the 4 estuaries with the lowest anthropogenic loading rates as the Lowest 4 (Machias, Penobscot River, Saco, and York) and then those that support eelgrass as supporting. All data were based on log-transformed total nitrogen and summary values were back-transformed for graphing. Please note that two of the Lowest 4 reference estuaries share the same use designation (SC) as the Portland Area, and two are SB.

We first describe nutrient distributions in the Portland Area organized by the original classification. TN concentrations are highest in the Upper Fore and lowest in the Marine Waters (Figure 6, Table 3). Medians in the Upper Fore exceed the RP thresholds for DO and eelgrass, and in the Middle Fore and Presumpscot, for eelgrass protection.

In general, TN concentrations in most reference estuaries are lower than in the Portland Region (Figure 7, Table 3), with some indicating substantially lower TN concentrations.

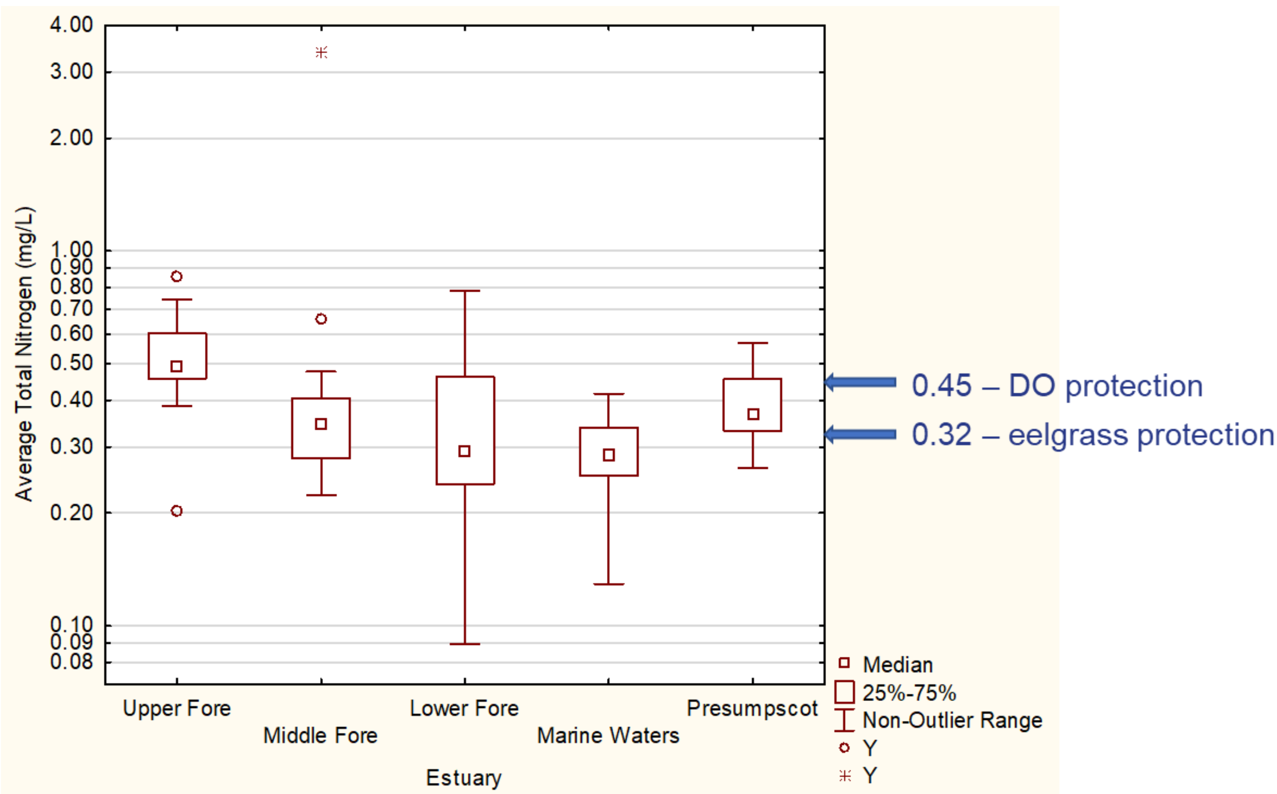

Figure 6. Distribution of average annual growing season (May-October) total nitrogen by Portland area waterbody. For reference, the current reasonable potential TN thresholds used by MDEP to protect DO and eelgrass are shown. Boxes indicate the quartile range and inner boxes the medians. Whiskers are the non-outlier range and the circles are considered outliers.

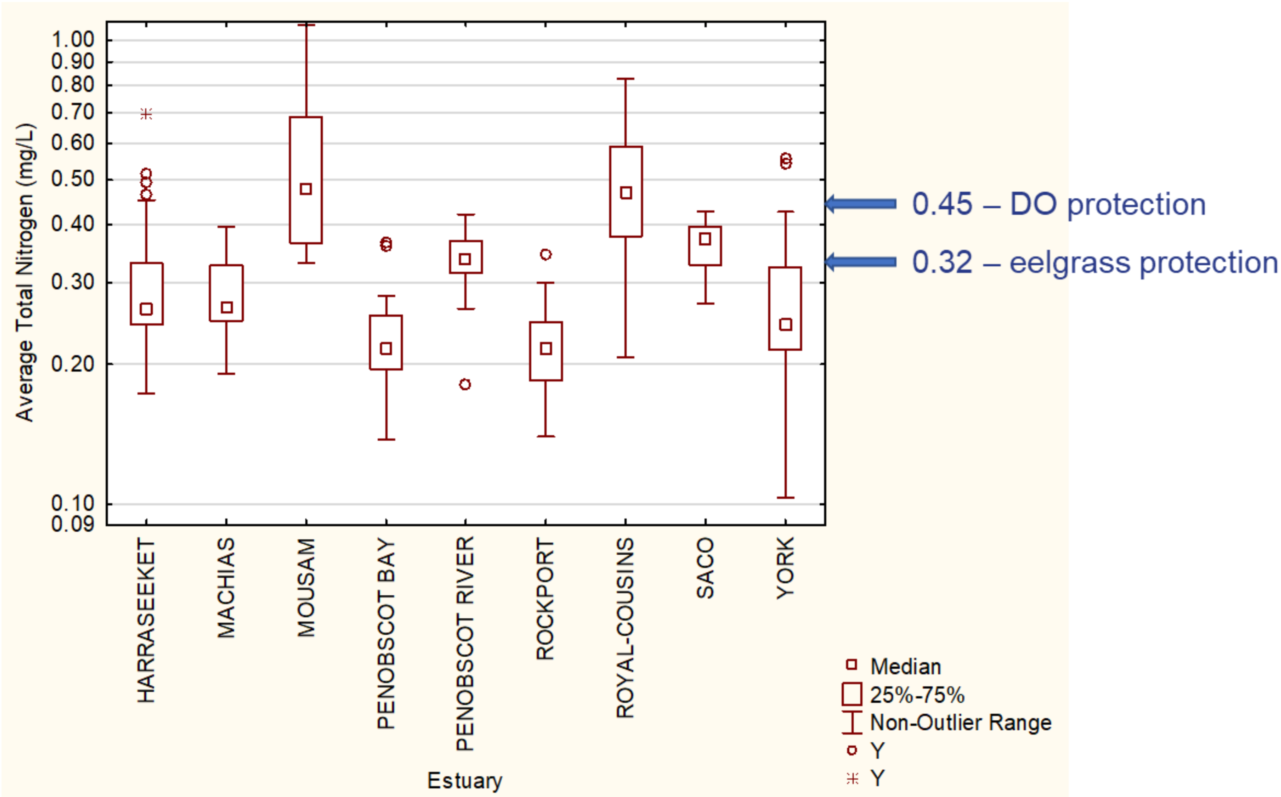

Figure 7. Distribution of average annual growing season (May-October) total nitrogen by reference estuaries. Other information as in Figure 6.

Table 3. Distributional statistics of average annual growing season (May-October) TN in Portland Area sites and reference estuaries. The Portland Area data are shown for the original classification (first 5) and the revised classes. Reference estuary data are shown for all sites first and then by class for sites that could be assigned a site (based on available salinity data) across estuaries and within estuaries. The Lowest 4 reference estuaries (with the lowest anthropogenic areal TN loading rates) are underlined.

Portland Sites							
	N	Mean	Median	10th	25th	75th	90th
Upper Fore	13	0.498	0.49	0.386	0.457	0.602	0.741
Middle Fore	25	0.366	0.344	0.238	0.28	0.405	0.477
Lower Fore	21	0.324	0.292	0.219	0.239	0.461	0.622
Marine Waters	45	0.288	0.286	0.24	0.252	0.338	0.361
Presumpscot	20	0.387	0.366	0.299	0.331	0.456	0.552
Fore River							
Upper Estuarine	14	0.490	0.489	0.386	0.417	0.602	0.741
Lower Estuarine	45	0.345	0.322	0.223	0.244	0.44	0.622
Marine Waters	45	0.288	0.286	0.24	0.252	0.338	0.361
Presumpscot							
Upper Estuarine	15	0.412	0.401	0.331	0.345	0.509	0.559
Lower Estuarine	5	0.321	0.33	0.265	0.319	0.331	0.368

Reference Estuaries							
	N	Mean	Median	10th	25th	75th	90^{th}
All Sites Combined							
Machias	9	0.277	0.265	0.191	0.248	0.327	0.396
Penobscot River	43	0.337	0.338	0.295	0.315	0.370	0.397
Saco	19	0.359	0.373	0.285	0.328	0.397	0.420
York	22	0.259	0.244	0.156	0.215	0.324	0.427
Penobscot Bay	24	0.219	0.217	0.168	0.195	0.255	0.282
Rockport	33	0.216	0.216	0.171	0.184	0.247	0.277
Harraseeket	25	0.295	0.262	0.221	0.243	0.331	0.496
Royal	36	0.457	0.471	0.288	0.378	0.591	0.660
Mousam	9	0.450	0.386	0.331	0.364	0.671	0.685
Upper Estuarine	72	0.407	0.381	0.312	0.337	0.474	0.607
Penobscot River	34	0.349	0.344	0.404	0.331	0.370	0.404
Saco	11	0.361	0.380	0.310	0.328	0.397	0.397
York	3	0.352	0.324	0.241	0.241	0.559	0.559
Royal	18	0.544	0.561	0.396	0.470	0.607	0.706
Mousam	6	0.540	0.575	0.364	0.386	0.685	0.804
Lower Estuarine	64	0.303	0.286	0.221	0.242	0.356	0.472
Machias	4	0.276	0.276	0.217	0.233	0.327	0.351
Penobscot River	6	0.309	0.311	0.277	0.30	0.322	0.335
York	12	0.268	0.244	0.194	0.235	0.289	0.427
Penobscot Bay	6	0.240	0.223	0.199	0.210	0.255	0.361
Harraseeket	22	0.301	0.266	0.224	0.243	0.364	0.496
Royal	13	0.385	0.376	0.288	0.311	0.450	0.550
Mousam	1	0.331	0.331	0.331	0.331	0.331	0.331

Reference Estuaries							
	N	Mean	Median	10th	25th	75th	90th
Marine Waters	48	0.217	0.218	0.169	0.188	0.252	0.276
Machias	2	0.218	0.218	0.191	0.191	0.248	0.248
York	2	0.174	0.174	0.142	0.142	0.215	0.215
Penobscot Bay	8	0.217	0.234	0.138	0.203	0.249	0.256
Rockport	32	0.214	0.214	0.171	0.182	0.243	0.276
Harraseeket	2	0.228	0.228	0.200	0.200	0.259	0.259
Royal	2	0.320	0.320	0.270	0.270	0.379	0.379

We next organized data by the proposed classes. For the Portland Area, median average annual growing season TN concentrations in the Fore and Presumpscot declined in a downstream direction from Upper Estuarine and Lower Estuarine to Marine Waters locations (Figure 8, Table 3). The Upper Estuarine median was above the eelgrass and DO thresholds, the median for the Lower Estuarine at the eelgrass threshold, and the median for Marine Waters was just below the current eelgrass protection threshold.

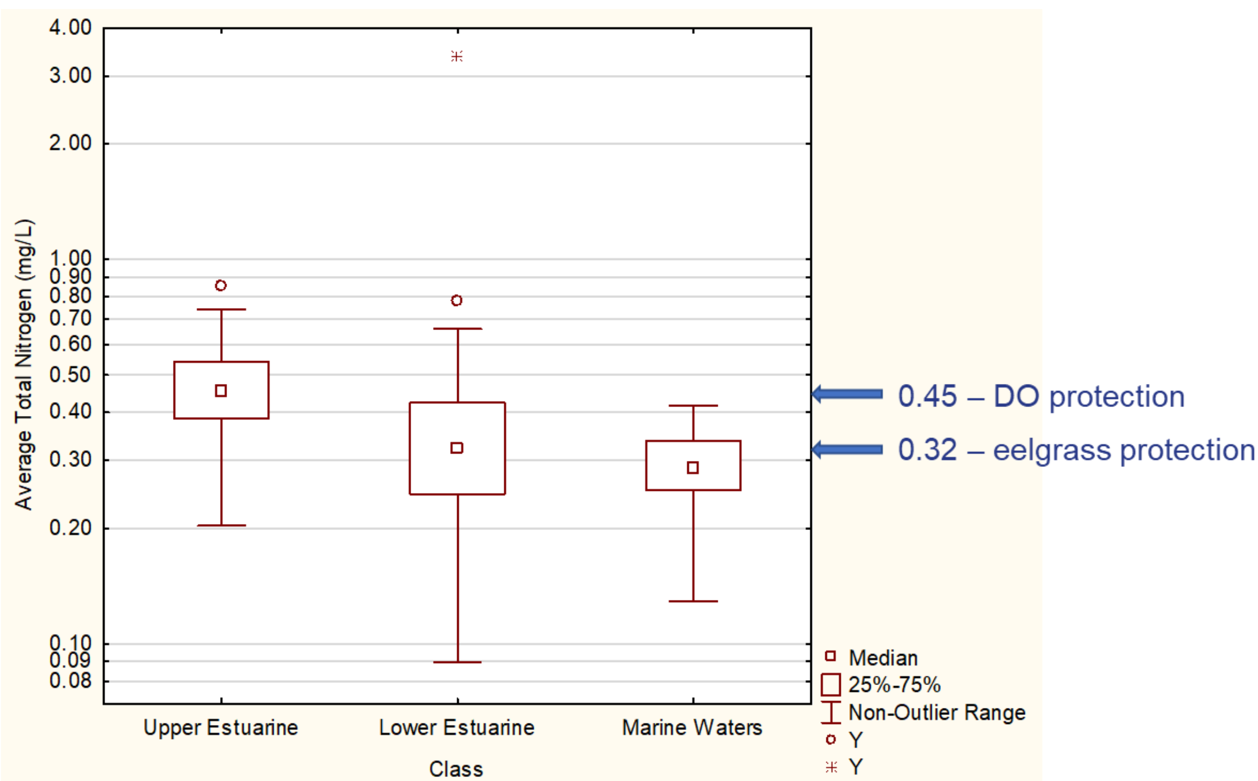

Figure 8. Distribution of average annual growing season (May-October) total nitrogen by Portland Area site classes. Other information as in Figure 6.

We examined the same distributions for reference estuaries outside the Portland region, and the distribution of values by site class were lower for all three classes. For the Marine Waters classes, most of annual average growing season TN values were below the DO threshold eelgrass thresholds (Figure 9, Table 4). For the Lower Estuarine class, most were below the DO threshold and between 50 and 75% of values were below the eelgrass threshold. For the Upper Estuarine class, between 50 and 75% of observed annual growing season averages were below the DO threshold, but most were above the eelgrass threshold.

We looked at the same distributions for the Lowest 4 reference estuaries (lowest anthropogenic TN loading rates): the Machias, Penobscot River, Saco, and York. Median values in the Lowest 4 reference estuaries were even lower than those for all the reference estuaries (Figure 10, Table 4).

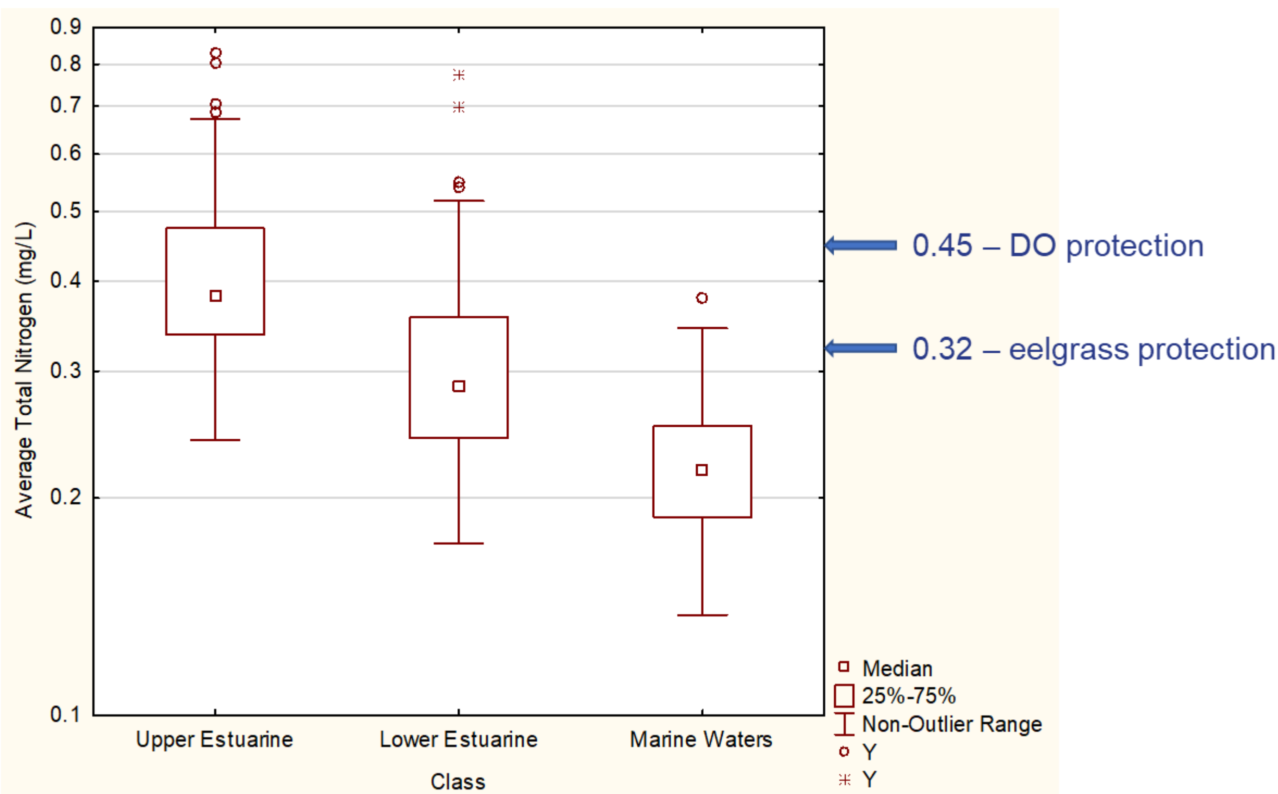

Figure 9. Distribution of average annual growing season (May-October) total nitrogen in reference estuaries by site class. Other information as in Figure 6.

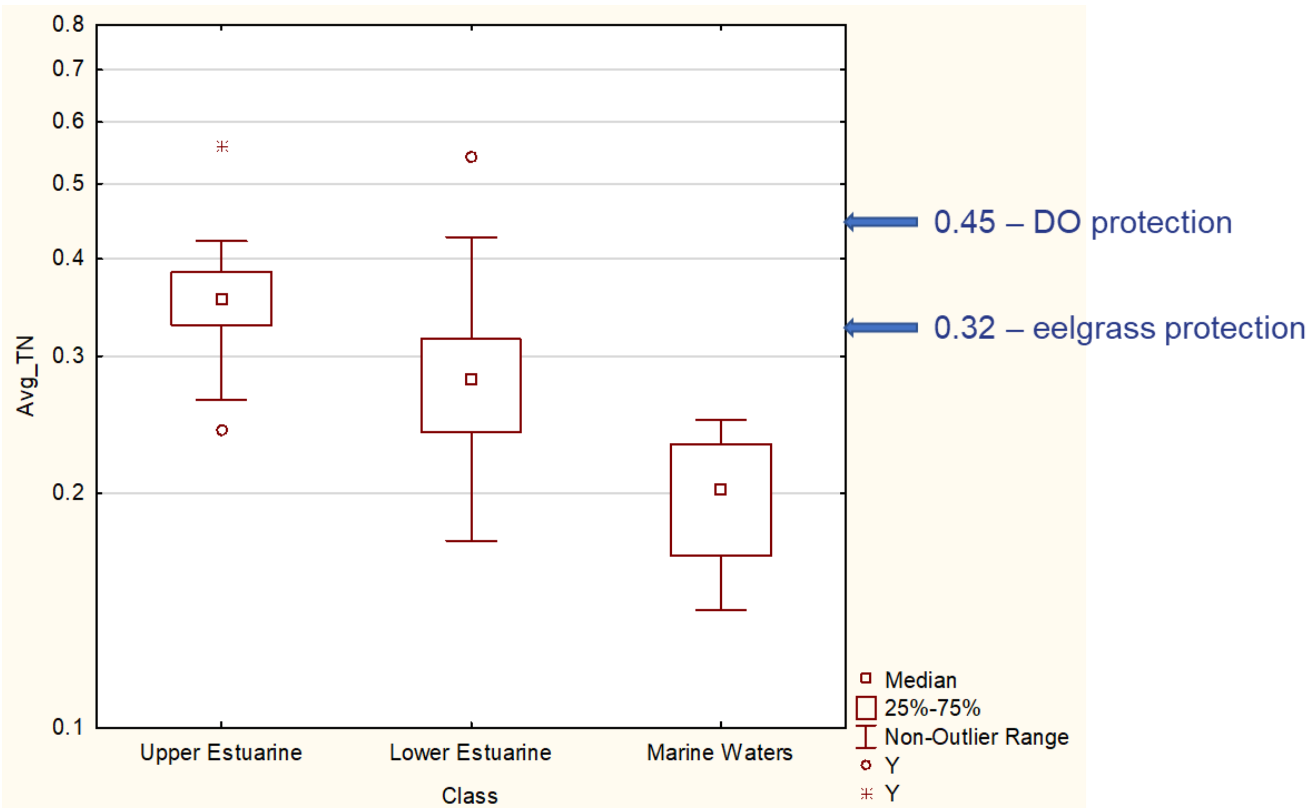

Figure 10. Distribution of average annual growing season (May-October) total nitrogen in Lowest 4 reference estuaries by site class. Other information as in Figure 6.

Table 4. Distributional statistics of average annual growing season (May-October) TN in reference estuaries and various reference estuary subgroups by class.

All Reference Estuaries							
Class	N	Mean	Median	10th	25th	75th	90th
Upper Estuarine	72	0.407	0.381	0.312	0.337	0.474	0.607
Lower Estuarine	64	0.303	0.286	0.221	0.242	0.356	0.472
Marine Waters	48	0.217	0.218	0.169	0.188	0.252	0.276
Lowest 4 Reference Estuaries							
Class	N	Mean	Median	10th	25th	75th	90th
Upper Estuarine	48	0.352	0.355	0.299	0.329	0.385	0.404
Lower Estuarine	22	0.280	0.281	0.217	0.239	0.316	0.351
Marine Waters	4	0.195	0.202	0.142	0.164	0.231	0.248
Seagrass Supporting							
Class	N	Mean	Median	10th	25th	75th	90th
Upper Estuarine	14	0.359	0.380	0.271	0.324	0.397	0.399
Lower Estuarine	44	0.281	0.256	0.210	0.235	0.318	0.465
Marine Waters	46	0.213	0.215	0.169	0.186	0.247	0.267

Next, we examined TN distributions in those reference estuaries currently supporting eelgrass growth based on known surveys. TN concentrations in Lower Estuarine and Marine Waters classes were well below the eelgrass protection threshold (Figure 11, Table 4). The lower quartile of Upper Estuarine classes also approximates the eelgrass threshold.

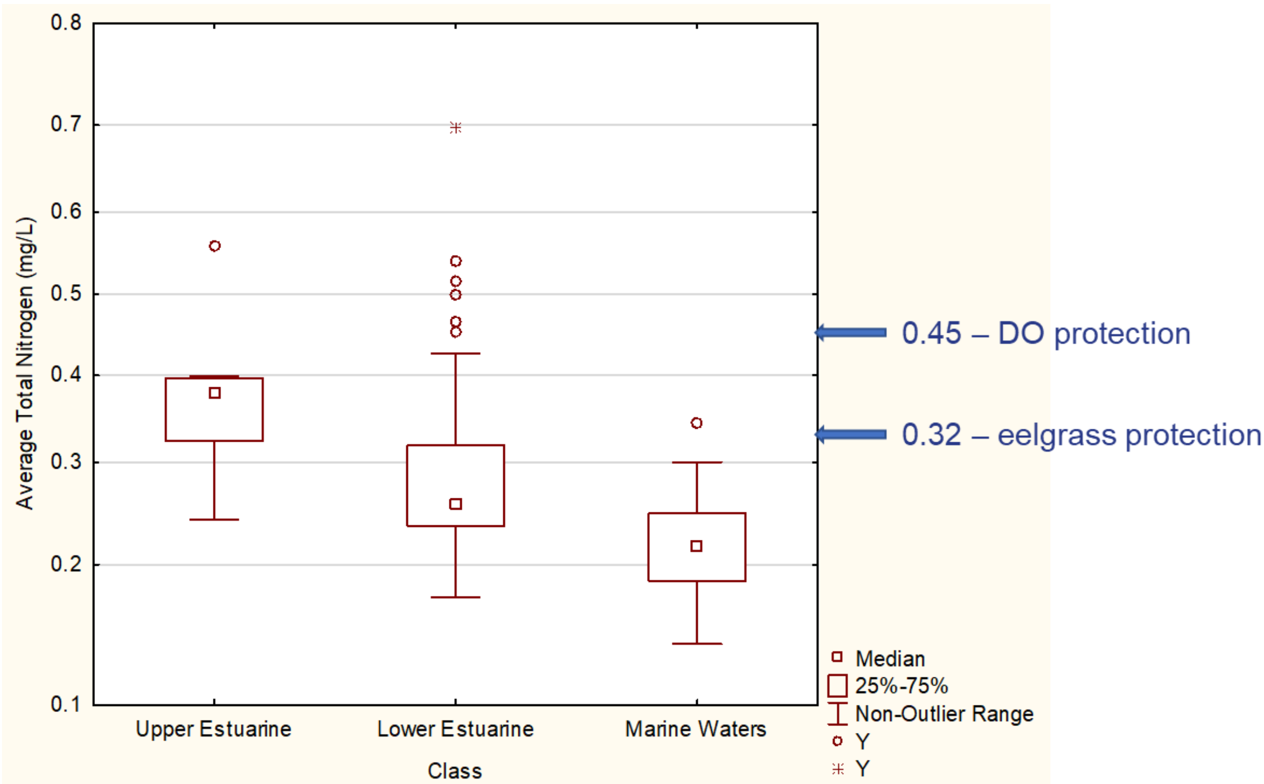

Figure 11. Distribution of average annual growing season (May-October) total nitrogen in the reference estuaries supporting eelgrass by site class. Other information as in Figure 6.

6.2 Predictive Reference

In addition to characterizing distributional statistics of reference locations, we also attempted to model the reference site condition. We constructed a multiple regression model of average annual growing season TN using some of the major drivers of TN variability across marine and estuarine waters: salinity and temperature. We also constructed the model using both Portland area and reference estuary data and included a binomial variable for reference sites (1) and Portland Area sites (0). In this way, we could use all the data but also model the predicted response for Portland area locations based on their salinity and temperature if they were in the reference population.

The multiple regression model generated was significant and explained 39% of the variability in TN concentrations across the state (Table 5). The equation was:

Annual Average Growing Season $Log_{10}TN$ = -0.694068 – 0.078990(Reference Status) – 0.007285(Average Salinity) + 0.025491(Average Temperature),

where salinity is average annual depth integrated growing season (May-October) salinity in ppt and temperature is average annual depth integrated growing season (May-October) temperature in degrees centigrade. We tested for a significant effect of latitude and none was identified, so it was excluded from the model. Average annual growing season salinity and temperature are negatively correlated (r=-0.41), so these two predictors are not independent, although the correlation is low.

Table 5. Multiple linear regression model coefficients (b) and model statistics

N=324	R= .61, R^2= .37, Adjusted R^2= .37, F(3,320)=63.179, p<0.0000			
	Coefficient	Standard Error	t	p-value
Intercept	-0.64329	0.07265	-8.85442	0.0000
Reference Status	-0.07366	0.015563	-4.73295	0.0000
Average Salinity	-0.007678	0.001057	-7.26732	0.0000
Average Temperature	0.022998	0.003367	6.82954	0.0000

From this model, we made predictions for TN in the Portland Area waterbody classes using their average annual growing season salinity and temperature values (Table 6). The upper value of the 50th prediction interval around the regression prediction was used to approximate the 75th percentile reference distribution value.

Table 6. Predicted Reference Condition for Portland Area Classes. Temp – temperature, PI – prediction interval

		Reference	Salinity (ppt)	Temp (degree C)	TN (mg/L)	Upper 50th PI TN (mg/L)
Presumpscot	Upper Estuarine	1	5.9	19	0.473	0.673
	Lower Estuarine	1	23	16	0.298	0.423
Fore	Upper Estuarine	1	22	18	0.337	0.479
	Lower Estuarine	1	29	16	0.268	0.381
Portland Area	Marine Waters	1	28	16	0.273	0.387

6.3 Stressor-Response

The second line of analyses pursued had to do with evaluating stressor-response relationships. We first sought to identify a pheophytin-corrected chlorophyll *a* (herein, chlorophyll) target consistent with the protection of dissolved oxygen (DO) conditions and sufficient light for eelgrass as described by the conceptual model. We then constructed models to evaluate TN concentrations associated with any emergent chlorophyll targets. Note again, as above, that synoptic pheophytin corrected chlorophyll *a* was the only chlorophyll data used in these analysis and this report.

6.3.1 Chlorophyll and Continuous DO

We looked at relationships between chlorophyll and continuous DO measurements. We examined relationships between daily minima, maxima, averages, and field ranges, averaged by month and matched to available discrete water quality data from the same month at the continuous sensor locations. We did not find any significant relationships that could inform a chlorophyll target.

We did, however, find significant increases in maximum DO and average DO range with discrete monthly average TN concentration. These relationships were highly variable and could not be used to derive a TN target consistent with desired DO conditions.

6.3.2 Chlorophyll, TN and Synoptic DO

We found significant relationships between synoptic (non-continuous, field measured) DO and chlorophyll. We used binomial logit models where the response is whether a DO value was below (1) or above (0) the 85% saturation DO criterion for class SB waters in Maine (MRS Title 38 §465-B). This model was significant and indicated that the probability of failing the SB standard was higher than 10% between 3 and 5 ug/L chlorophyll (Figure 12). The likelihood of failing the SB DO standard was also higher than 10% around a TN concentration of 0.45 (Figure 13). No observed values were less than 70%, the DO criterion for SC waters.

Note that the sample size was small for these analyses (especially for low DO observances).

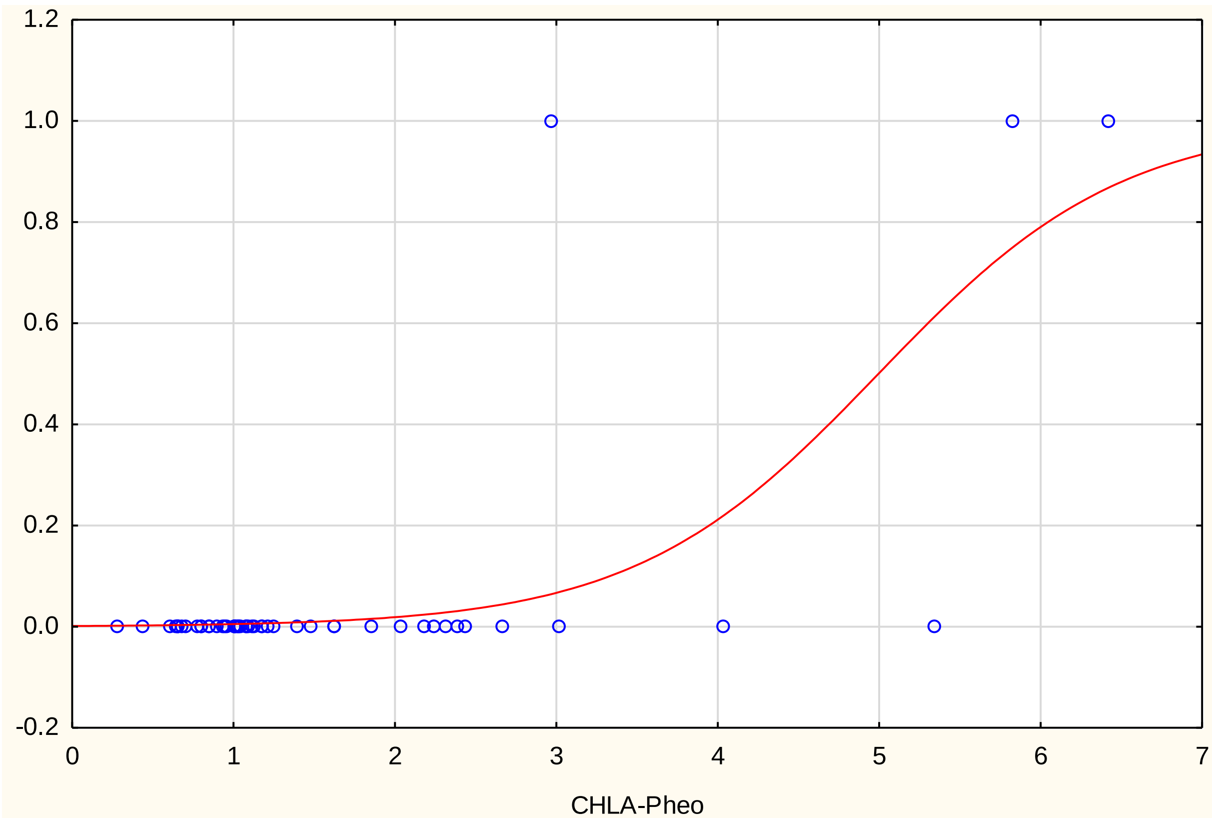

Figure 12. Logit model of probability of DO being below 85% saturation (y-axis) as a function of chlorophyll concentration (CHLA-Pheo, ug/L)

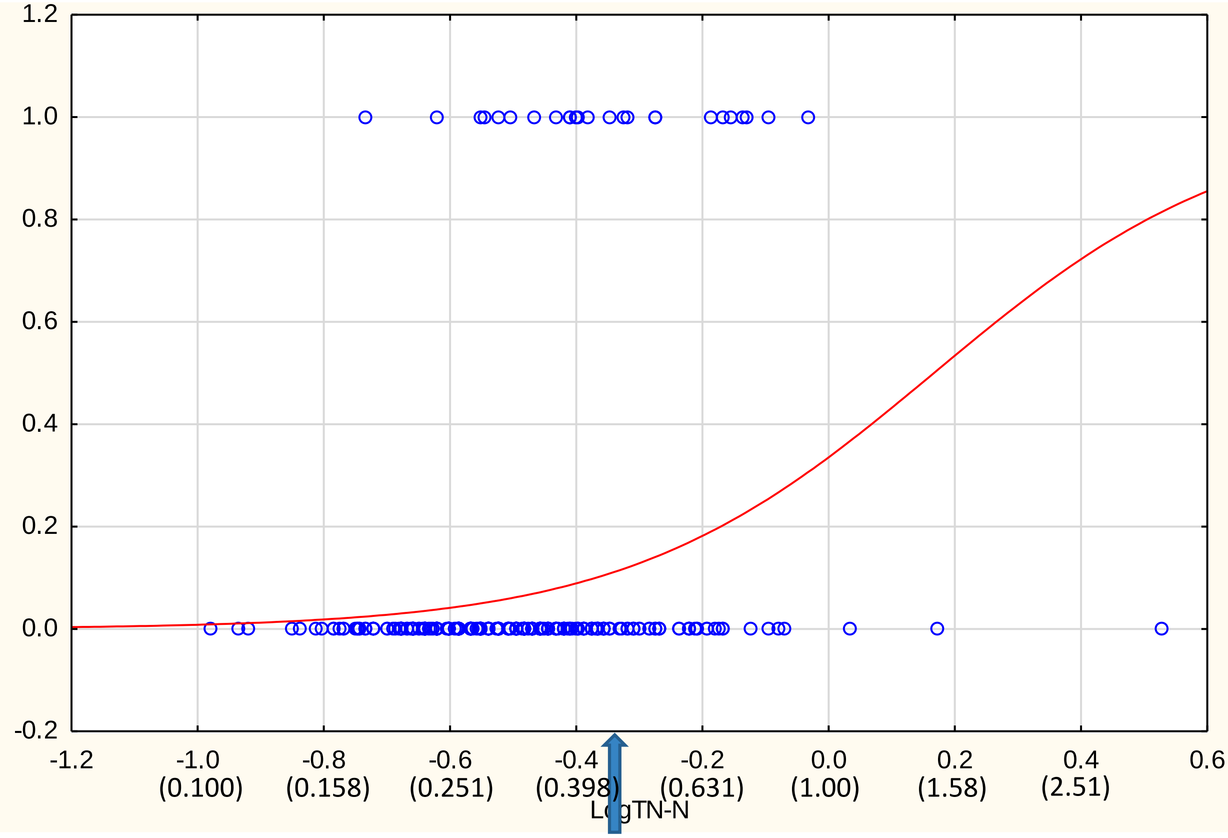

Figure 13. Logit model of probability of DO being below 85% saturation (y-axis) as a function of TN concentration (LogTN-N, mg/L). The DO RP threshold is shown for context. Values in parentheses are untransformed TN (mg/L).

6.3.3 Chlorophyll, TN and Light Attenuation (K_d)

There were relatively few measurements of light attenuation paired to synoptic chlorophyll (N=68) and most came from the Portland region instead of across the state coastal waters. Relationships between light attenuation (K_d) and chlorophyll were opposite of predictions – light attenuation decreased as chlorophyll concentration increased rather than increased. Therefore, models to associate chlorophyll with K_d targets needed for eelgrass growth could not be confidently made.

K_d increased (i.e., light attenuation increased) with TN, which is as expected if TN increases chlorophyll concentrations (see below). We used a K_d target of 0.6, which would provide 22% of ambient surface light at 2.5m restoration depth. This percent surface light target has been shown to be required for maintaining eelgrass growth in the Northeast (Latimer et al. 2014) and was used for the Great Bay estuary (NH DES 2009). A recent report on nitrogen targets for Long Island Sound (LIS) reported the following with regards to eelgrass light needs:

> "*The amount of surface light required at maximum colonization depth for eelgrass (Zostera marina), the dominant seagrass in LIS, across the Northern Hemisphere ranges from 4 to 44*

percent (Latimer et al. 2014), and along the East Coast of the United States, minimum requirements for eelgrass populations range between 15 and 35 percent (Latimer et al. 2014). Latimer et al. (2014) used a mean of 22 percent, which was also cited as a growing season average value in Vaudrey (2008a,b). More recent long-term (more than 100 days) experimental mesocosm research in New Hampshire and Maine found that Zostera marina requires more light for seedling development and growth (Ochieng et al. 2010). In that study, seedlings grown at 34 and 58 percent surface irradiance had greater photosynthetic capacity than those grown at 11 percent. Similarly, morphological growth measures (shoots, rhizome growth, and shoot production) critical for long-term survival were significantly higher at 34 and 58 percent than at 11 percent; however, growth at 34 percent was still less than optimal to maintain long-term meadows. The authors concluded that "seedlings exposed to light levels less than 34 percent surface irradiance during the growing season are unlikely to survive winter light and temperature stress," suggesting that light levels above 34 percent might be necessary for sufficient growth to sustain successful development of seedlings (Ochieng et al. 2010). While seedling growth was less than optimal at 34 percent, however, growth was supported; therefore, a value between 11 percent and 34 percent could still support seedling growth. Another study in Narragansett Bay, RI, also found that Zostera marina seedlings grew better at higher light (72 percent of ambient) than at medium light (23 percent) (Bintz and Nixon 2001). Even with some reduction in seedling shoot and root measures, however, seedling growth rates were comparable, and survivorship was 94 percent at 23 percent ambient light, suggesting that an average of 22 percent would support seedling growth in LIS."

The Lambert-Beer law quantifies the relationship between light attenuation, depth (z) and percent surface light (i_z/i_o):

$$Z = \frac{\ln\left(\frac{i_z}{i_o}\right)}{-K_d}$$

Rearranging, one gets a K_d value of 0.6 for 22% light at 2.5m restoration depth.

The relationship between TN and K_d was expressed as a binomial (value of 1 if K_d >0.6). There were more paired data with K_d and TN (N=132) and the logit model resulted in a 56% probability of not providing 22% light at 2.5m (i.e., K_d>0.6) at a TN value of 0.32 mg/L, the seagrass target (Figure 14). The probability falls below 50% at a TN concentration of approximately 0.25 mg/L.

It is important to note that this model is not a direct response model. TN does not, itself, attenuate light. It presumably leads to the growth of chlorophyll in the water column, which is known to attenuate light. In this data set, however, chlorophyll was not related to K_d directly and increased TN may be associated with higher contribution of freshwater, which can carry higher concentrations of colored dissolved organic matter (cDOM) and suspended solids (TSS). Both cDOM and TSS also attenuate light. Without controlling for their effects, these K_d based stressor-response results should not be considered conclusive.

In addition, there was insufficient data to produce models for each class, so this model is a combined class model, as noted above.

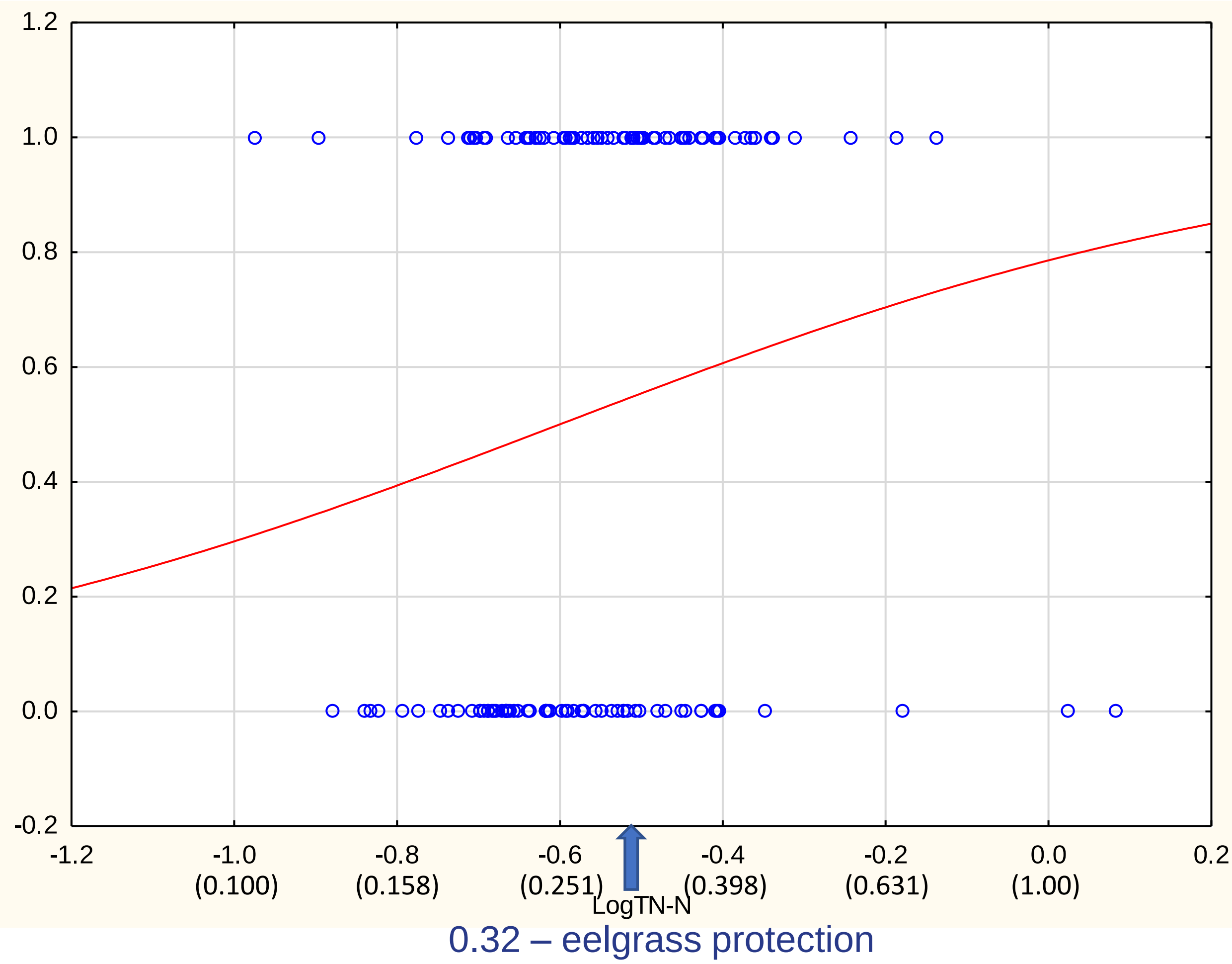

Figure 14. Logit model of probability of K_d >0.6 (y-axis) as a function of TN concentration (LogTN-N, mg/L). The eelgrass RP threshold is shown for context. Values in parentheses are untransformed TN concentration (mg/L).

6.3.4 Chlorophyll and TN

We found a significant relationship between paired annual average growing season chlorophyll and TN concentration. Unlike the other stressor-response analyses where we used grab data to preserve sufficient data, here we use annual average growing season values to match the scale at which assessment, and thus criteria, are likely to be made. Fortunately, we had sufficient data to produce robust models. We used values of 4 and 5 ug/L as a target chlorophyll threshold for this analysis. Long Island Sound uses 5.5 ug/L as an estuarine target for protecting uses which include aquatic life and eelgrass (Vaudrey et al. 2008a,b) and the Massachusetts Bays project considered bays with chlorophyll between 3 and 5 ug/L in Excellent to Fair Health in terms of use protection, including for DO and eelgrass (Howes et al. 2003). Consistent with these observations, the 75th percentile of reference estuaries in Maine is 3.9 ug/L chlorophyll. We modeled both 4 and 5 ug/L chlorophyll using logit models and both increased significantly with TN (Figure 15).

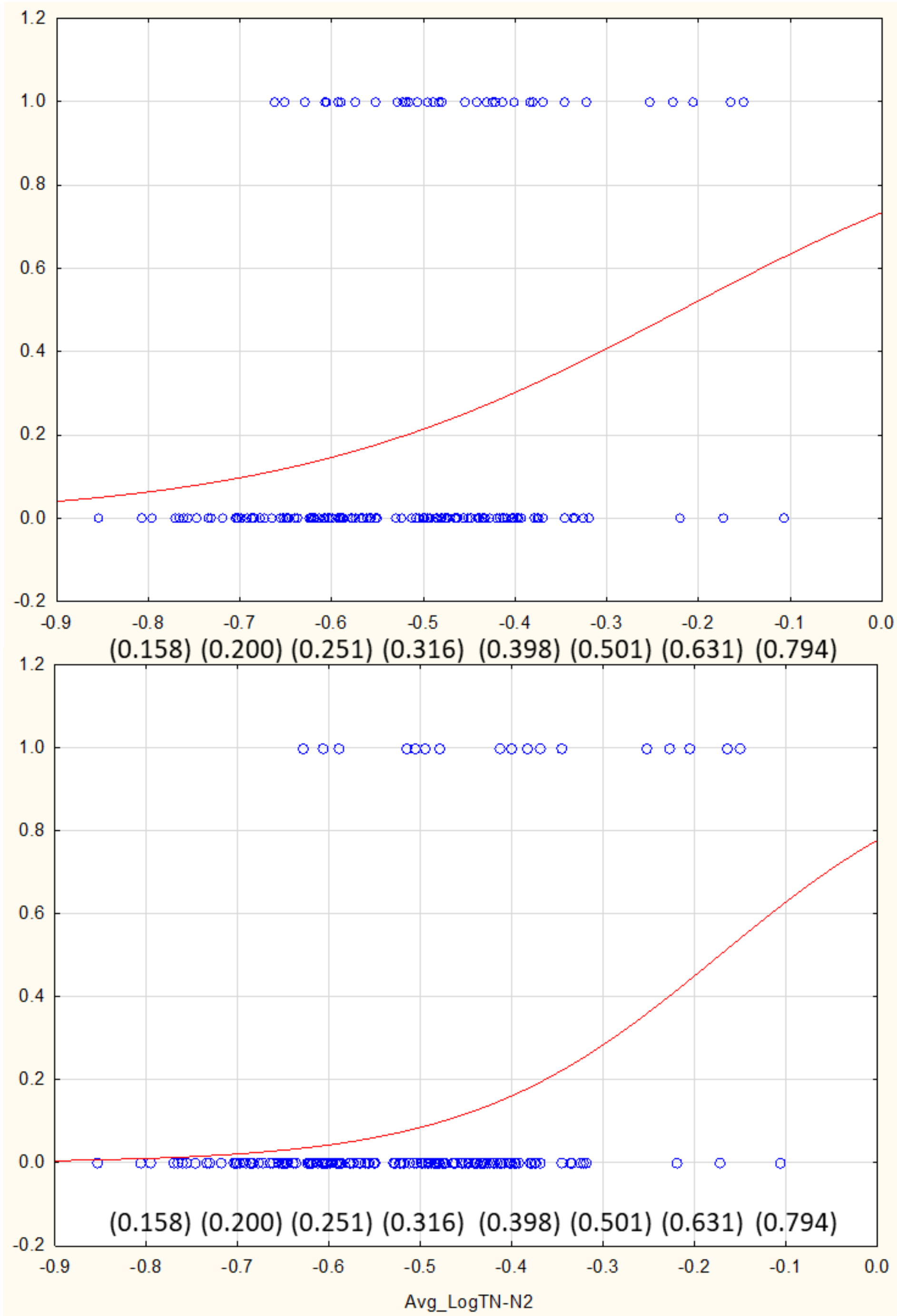

Figure 15. Logit model of probability of annual average chlorophyll > 4 ug/L (y-axis, top) or > 5 ug/L (y-axis, bottom) as a function of annual average TN concentration (Avg_LogTN, mg/L). Values in parentheses are untransformed TN concentration (mg/L).

These models were solved for probabilities greater than 10% and the associated TN values are shown in Table 7.

Table 7. Logit model solutions. Average annual growing season TN concentration (mg/L) associated with the probability of exceeding annual average chlorophyll concentrations of 5 and 4 ug/L.

>5 ug/L		>4 ug/L	
TN	Probability	TN	Probability
0.126	1%	0.126	4%
0.158	1%	0.158	6%
0.200	2%	**0.204**	**10%**
0.251	4%	0.251	15%
0.333	**10%**	0.316	21%
0.398	16%	0.355	26%
0.472	25%	0.501	41%
0.631	45%	0.631	52%
0.794	63%	0.794	63%

7 SYNTHESIS

We pursued two primary analytical lines of evidence for this work: 1) reference-based analyses using distributions from a reference population and a predicted reference model using multiple regression and 2) stressor-response analyses attempting to link chlorophyll and TN to target response conditions protective of DO and eelgrass as well as models of TN and chlorophyll to identify TN concentrations associated with potential chlorophyll targets. The results of these lines could be combined with other information (e.g., scientific literature, mechanistic models) in crafting decisions regarding protective criteria. Both approaches are scientifically defensible and both have pros and cons to be weighed as they are considered.

For the reference line of evidence in this exercise, we calculated deciles and quartiles and extracted the upper quartile for reference site reference values in each class. The 75th percentile was that used in EPA guidance for reference waters (USEPA 2001), but other percentiles could be used as described in the section describing this method above. For stressor-response analyses, with logit regressions we used a 10% probability for most analyses as the 10% exceedance threshold is commonly used as an assessment allowance. For the light attenuation endpoint, the 10th percentile was beyond the experience of the model, so we used a value where there was less than 50% likelihood of meeting the attenuation target. These values too, could be adjusted based on state policy. Please note that data were combined from all the classes to conduct the stressor-response analyses because paired data were limited and producing class specific models would have produced models with too little data to resolve. Therefore, the synthesis values for this line are the same across classes.

The synthesis of the various lines of evidence are provided for comparison in a figure for each Portland Area waterbody class (Upper Estuarine, Lower Estuarine and Marine Waters). For each figure, current TN concentration in that class of waters is indicated at the top in light blue, the reference lines of evidence are shown next in black, the stressor-response lines in red, and the current RP thresholds values at the bottom in darker blue (Figure 16).

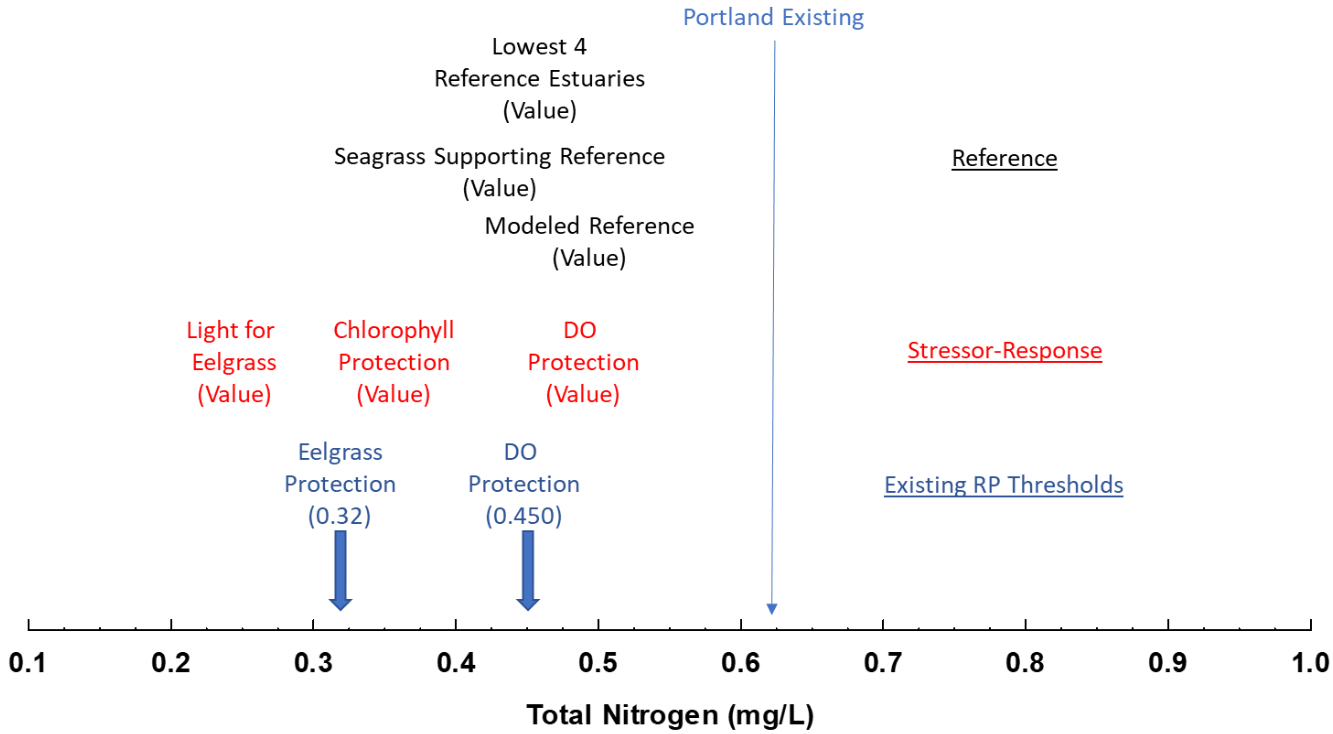

Figure 16. Template for synthesizing TN thresholds by lines of evidence for each waterbody class.

7.1 Upper Estuarine

Existing annual average growing season TN concentrations in the Presumpscot (0.412 mg/L) Upper Estuarine class were lower than those in the Fore (0.490 mg/L, Figure 17). The latter were higher than the 75th percentile of the 4 reference estuaries with the lowest anthropogenic nitrogen loading rates (0.385 mg/L) and the 75th percentile of reference estuaries supporting seagrass (0.397 mg/L), but similar to the modeled annual average growing season reference concentration upper 50th prediction intervals for the Fore (0.479 mg/L) and less than that for the Presumpscot (0.673 mg/L) Upper Estuarine classes. The Presumpscot locations are lower salinity, and thus predict higher TN concentrations, closer to riverine values. Stressor-response lines produced TN values of 0.250 mg/L for the K_d endpoint (>50% likely to provide sufficient light) and 0.437 mg/L for the DO endpoint. It is worth stressing that both the K_d analysis was likely confounded by the effects of cDOM and TSS which could not be accounted for and that the DO analysis was based on relatively few low DO observations. TN concentrations associated with meeting average annual growing season chlorophyll concentrations of 4 and 5 ug/L ranged from 0.204 to 0.333 mg/L respectively. These chlorophyll targets were based on other northeast estuarine values and not on Maine based analyses. Stressor-response models to link chlorophyll to DO and K_d were insignificant or too uncertain using the Maine dataset to generate chlorophyll *a* targets.

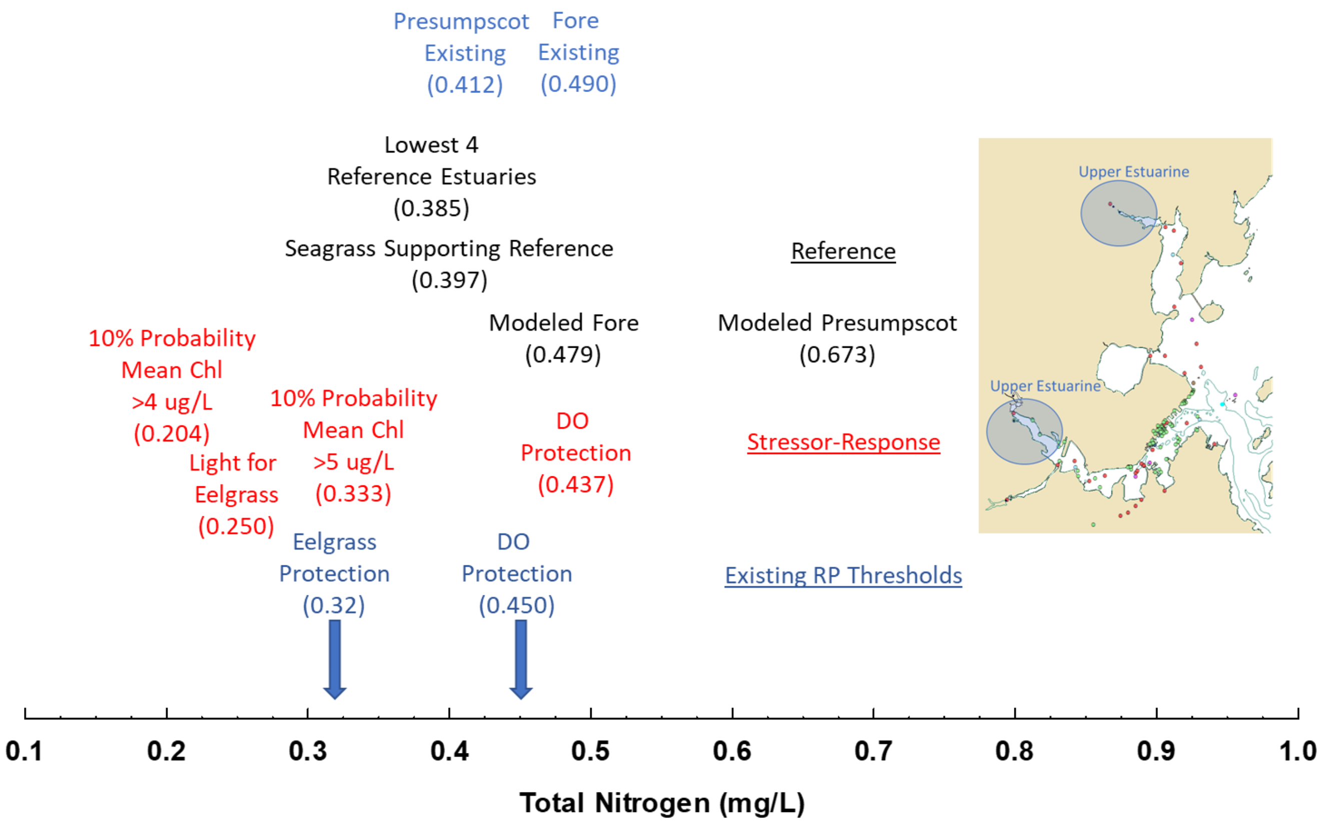

Figure 17. Synthesis of analysis endpoints for the Upper Estuarine class of waters in the Portland Area.

7.2 Lower Estuarine

For the Lower Estuarine class, values for existing conditions and reference were lower than for the Upper Estuarine class (Figure 18). Existing Lower Estuarine average annual growing season TN concentrations in the Presumpscot (0.321 mg/L) were lower than those in the Fore (0.345 mg/L). Both of these were higher than the 75th percentile of the Lowest 4 reference estuaries (0.316 mg/L) and the 75th percentile of reference estuaries supporting seagrass (0.318 mg/L), but lower than the modeled annual average growing season reference concentration upper 50th prediction interval in the Fore (0.381 mg/L) and Presumpscot (0.423 mg/L) Lower Estuarine class. Stressor-response lines produced the same values reported above for the Upper Estuarine class.

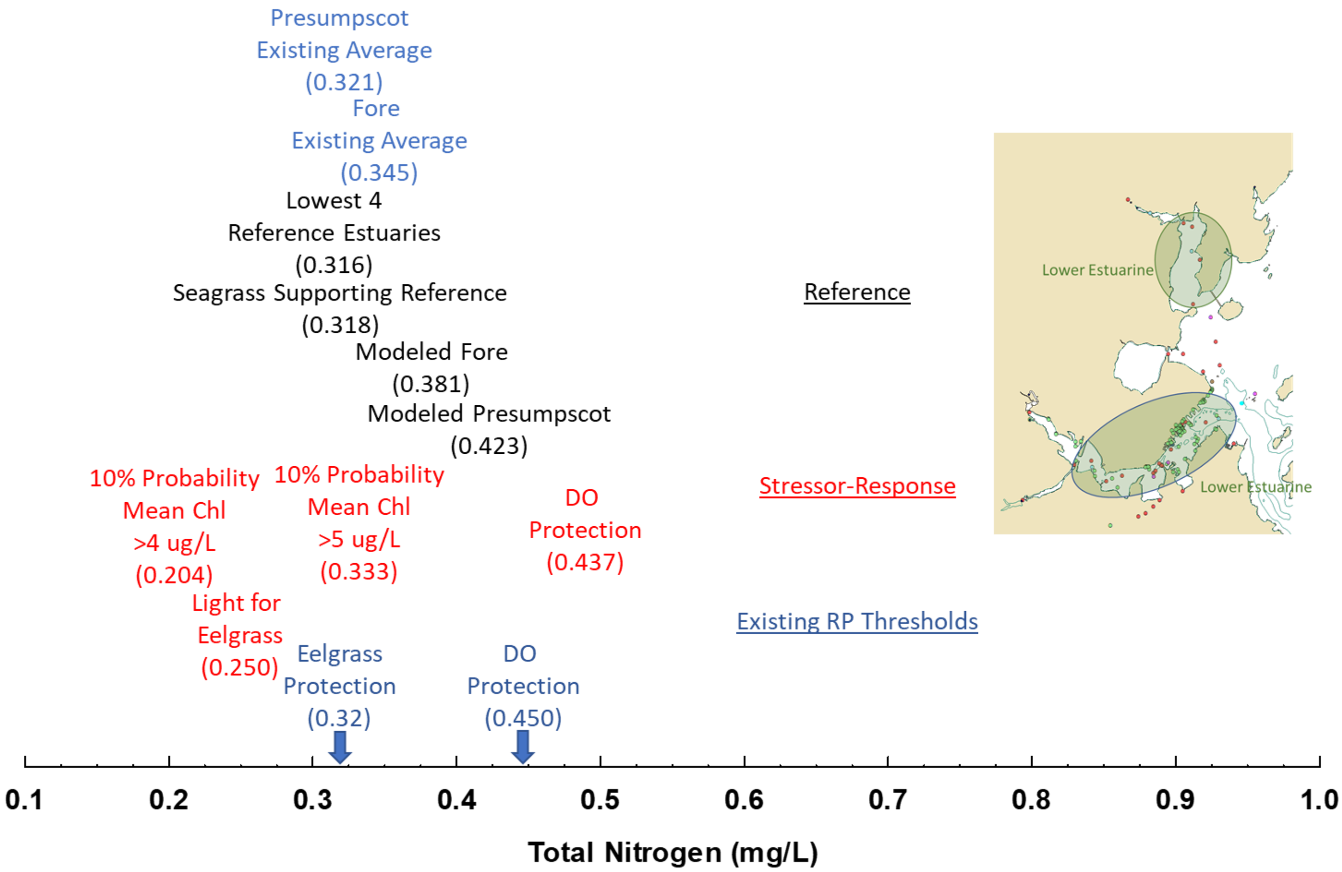

Figure 18. Synthesis of analysis endpoints for the Lower Estuarine class of waters in the Portland Area.

7.3 Marine Waters

For the Marine Waters class, existing mean average annual growing season TN concentrations in the Marine Waters of the Portland Area (0.288 mg/L) were the lowest of all three classes and below the eelgrass RP threshold (0.320 mg/L). This existing condition was, however, still higher than the 75th percentile of the Lowest 4 reference estuaries (0.231 mg/L) and the 75th percentile of reference estuaries supporting seagrass (0.247), but lower than the modeled annual average growing season reference concentration upper 50th prediction interval for Marine Waters of the Portland Area (0.387 mg/L). Stressor-response lines produced the same values reported above for the Upper Estuarine class.

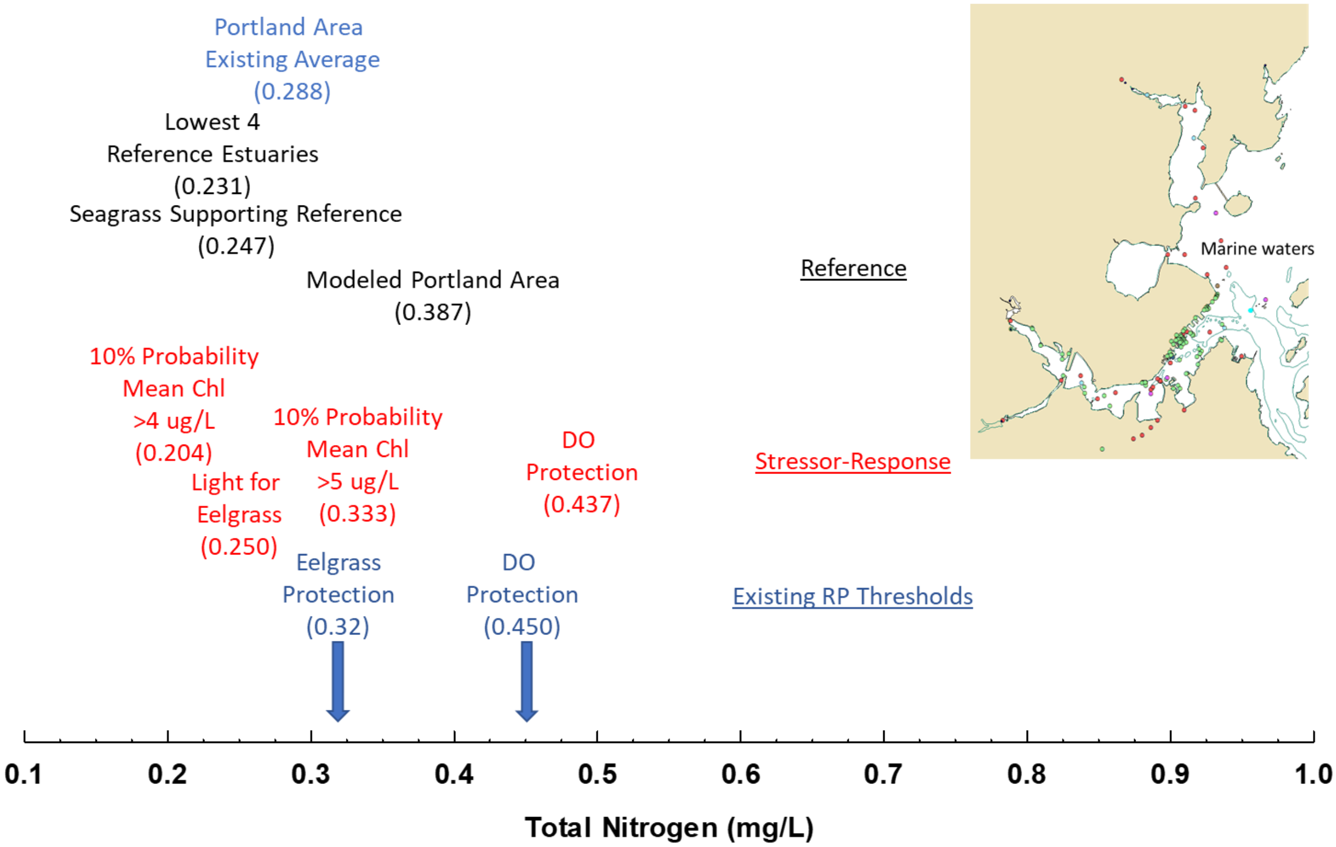

Figure 19. Synthesis of analysis endpoints for the Marine Waters class of waters in the Portland Area.

8 DATA GAPS

A full assessment of data needs is somewhat beyond the scope of this analysis summary, but some observations are worth pointing out. First, it was recognized that macroalgae are an assessment endpoint of concern for both recreation/aesthetics and aquatic life. There were no data on macroalgal densities for us to link to nutrient levels. More information on this important endpoint would help.

Light attenuation (K_d) is an important variable for the protection of seagrasses, but the amount of paired chlorophyll and K_d data was somewhat limiting. A concerted effort to collect this paired information, along with cDOM and TSS across the Maine coastal systems would be invaluable and some effort to design an appropriate study with input from regional professionals to develop a K_d~chlorophyll model would likely produce useful information.

The continuous DO data, while valuable, was limited in space and time. These data are difficult and expensive to collect, and in dynamic estuarine systems can be difficult to link to the organic sources driving their behavior. More attention to the design of a program that might better link algal productivity to DO dynamics in this system is potentially warranted if of interest.

The hydrodynamics of the Maine coast are complex. To improve the reference distribution analyses, more intensive characterization of the hydrodynamic, stratification, residence time and salinity characteristics at sampling sites would help refine the classifications. This could improve the relevance of various reference location data to site specific target development – by knowing which class is the best reference. Classification is, indeed, and artificial and ongoing project.

Lastly, continued collection of eelgrass data statewide would help with classification and with population data on this endpoint. Paired with water quality data, over time, this would also improve potential stressor-response models.

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APPENDIX 1 – SAMPLE SITE LOCATIONS USED IN ANALYSIS

Sites listed as Class NA were outside Portland and had fewer than 5 salinity samples with which to estimate salinity and assign confidently to a class. Sites in Bold are in the Portland area (including the Presumpscot); reference sites are not bolded. Within those two groups, sites are organized by longitude (West to East).

SITESEQ	CLASS	CURRENT_SITE_NAME	LATITUDE	LONGITUDE	Source
128308	**NA**	**LONG CREEK - LC01**	**43.6332600**	**-70.3130500**	**MDEP BLWQ MARINE**
128284	**Upper Estuarine**	**FORE RIVER - FR01**	**43.6588900**	**-70.3111100**	**MDEP BLWQ MARINE**
90660	**Upper Estuarine**	**STROUDWATER BRIDGE - STR54**	**43.6587340**	**-70.3109000**	**FRIENDS OF CASCO BAY**
128286	**Upper Estuarine**	**FORE RIVER - FR02**	**43.6526000**	**-70.3002100**	**MDEP BLWQ MARINE**
128310	**Upper Estuarine**	**LONG CREEK - LC02**	**43.6436580**	**-70.2927620**	**MDEP BLWQ MARINE**
127588	**NA**	**FORE RIVER - BT119**	**43.6449370**	**-70.2921620**	**FRIENDS OF CASCO BAY**
91464	**NA**	**CASCO BAY - FORE RIVER - CBFR01 - NCCA**	**43.6450000**	**-70.2860000**	**EPA**
128288	**Lower Estuarine**	**FORE RIVER - FR03**	**43.6431700**	**-70.2855800**	**MDEP BLWQ MARINE**
127587	**NA**	**FORE RIVER - BT116**	**43.6421500**	**-70.2847030**	**FRIENDS OF CASCO BAY**
136096	**Lower Estuarine**	**PORTLAND HARBOR - PH3**	**43.6391190**	**-70.2798310**	**MDEP BLWQ MARINE**
127585	**NA**	**FORE RIVER - BT110**	**43.6399980**	**-70.2775240**	**FRIENDS OF CASCO BAY**
128290	**Lower Estuarine**	**FORE RIVER - FR04**	**43.6407400**	**-70.2735700**	**MDEP BLWQ MARINE**
142536	**NA**	**PRESUMPSCOT RIVER - PR01**	**43.7206300**	**-70.2730250**	**DEA ENGINEERING UNIT**
124454	**NA**	**ANTHOINE CREEK - AC01**	**43.6290000**	**-70.2670000**	**MDEP BLWQ MARINE**
124456	**NA**	**ANTHOINE CREEK - AC02**	**43.6300000**	**-70.2640000**	**MDEP BLWQ MARINE**
90644	**Upper Estuarine**	**WALTON PARK - PRV70**	**43.7169110**	**-70.2639990**	**FRIENDS OF CASCO BAY**
127583	**NA**	**FORE RIVER - BT099**	**43.6427010**	**-70.2628940**	**FRIENDS OF CASCO BAY**
128293	**Lower Estuarine**	**FORE RIVER - FR05A**	**43.6416610**	**-70.2611800**	**MDEP BLWQ MARINE**
97797	**NA**	**PORTLAND HARBOR - 5**	**43.6407000**	**-70.2610600**	**MER**
124458	**NA**	**ANTHOINE CREEK - AC04**	**43.6320000**	**-70.2610000**	**MDEP BLWQ MARINE**
127584	**NA**	**FORE RIVER - BT100**	**43.6419930**	**-70.2607880**	**FRIENDS OF CASCO BAY**
128296	**Lower Estuarine**	**FORE RIVER - FR05B**	**43.6423940**	**-70.2603500**	**MDEP BLWQ MARINE**
136093	**Lower Estuarine**	**PORTLAND HARBOR - PH2**	**43.6444700**	**-70.2589110**	**MDEP BLWQ MARINE**
124460	**NA**	**ANTHOINE CREEK - AC05**	**43.6338600**	**-70.2586100**	**MDEP BLWQ MARINE**

SITESEQ	CLASS	CURRENT_SITE_NAME	LATITUDE	LONGITUDE	Source
90606	Lower Estuarine	KNIGHTVILLE LANDING - KVL84	43.6440000	-70.2580000	FRIENDS OF CASCO BAY
128298	Lower Estuarine	FORE RIVER - FR06	43.6438900	-70.2577800	MDEP BLWQ MARINE
128987	NA	BACK COVE - CBBC	43.6761850	-70.2559320	FRIENDS OF CASCO BAY
97791	NA	PORTLAND HARBOR - 4	43.6448200	-70.2553600	MER
91465	NA	CASCO BAY - FORE RIVER - CBFR02 - NCCA	43.6486000	-70.2544000	EPA
128300	Lower Estuarine	FORE RIVER - FR07	43.6486000	-70.2544000	MDEP BLWQ MARINE
128992	NA	FORE RIVER - FRLW	43.6552590	-70.2523060	FRIENDS OF CASCO BAY
127582	NA	FORE RIVER - BT090	43.6493790	-70.2512670	FRIENDS OF CASCO BAY
135496	NA	PRESUMPSCOT RIVER - PR-11	43.7141150	-70.2506250	MDEP BLWQ MARINE
90576	Marine Waters	BANDM RAILROAD TRESTLE - BMR02	43.6763160	-70.2500020	FRIENDS OF CASCO BAY
128303	Lower Estuarine	FORE RIVER - FR08	43.6561100	-70.2500000	MDEP BLWQ MARINE
90592	Lower Estuarine	CUSTOM HOUSE WHARF - CST15	43.6566830	-70.2499670	FRIENDS OF CASCO BAY
127849	NA	TROUT BROOK - TB01	43.6366300	-70.2493400	MDEP BLWQ MARINE
91359	NA	CASCO BAY - PRESUMPSCOT RIVER - CBPR01 - NCCA	43.6863000	-70.2492000	EPA
128996	NA	FORE RIVER - FRSP	43.6566280	-70.2487960	FRIENDS OF CASCO BAY
134753	Upper Estuarine	PRESUMPSCOT RIVER - PR-17	43.7059900	-70.2472300	MDEP BLWQ MARINE
142541	NA	PRESUMPSCOT RIVER - PR-13	43.7131600	-70.2471500	MDEP BLWQ MARINE
131213	Lower Estuarine	PRESUMPSCOT RIVER - PR-28	43.6906700	-70.2464200	MDEP BLWQ MARINE
142543	NA	PRESUMPSCOT RIVER - PR-19	43.7036400	-70.2439800	MDEP BLWQ MARINE
90649	Lower Estuarine	PORTLAND YACHT SERVICES - PYS44	43.6625000	-70.2425000	FRIENDS OF CASCO BAY
90596	Marine Waters	EAST END BEACH - EEB18	43.6712200	-70.2419450	FRIENDS OF CASCO BAY
136090	Lower Estuarine	PORTLAND HARBOR - PH1	43.6565350	-70.2406530	MDEP BLWQ MARINE
97798	NA	PRESUMPSCOT RIVER - 6	43.6870700	-70.2392200	MER
142703	Marine Waters	CASCO BAY - CBEE	43.6684540	-70.2383100	MDEP BLWQ MARINE
110328	Marine Waters	PRESUMPSCOT RIVER - CBPR	43.6798950	-70.2371560	MDEP BLWQ MARINE
90615	Marine Waters	MACKWORTH ISLAND CAUSEWAY - MAC30	43.6922220	-70.2369440	FRIENDS OF CASCO BAY

SITESEQ	CLASS	CURRENT_SITE_NAME	LATITUDE	LONGITUDE	Source
127581	**NA**	**FORE RIVER - BT077**	**43.6585470**	**-70.2363290**	**FRIENDS OF CASCO BAY**
128305	**Lower Estuarine**	**FORE RIVER - FR09**	**43.6577000**	**-70.2353900**	**MDEP BLWQ MARINE**
91376	**NA**	**CASCO BAY - EAST END - CBEE01 - NCCA**	**43.6731000**	**-70.2353000**	**EPA**
90657	**Marine Waters**	**SOUTHERN MAINE COMMUNITY COLLEGE PIER - SMT50**	**43.6505560**	**-70.2294440**	**FRIENDS OF CASCO BAY**
90633	**Marine Waters**	**FORT GORGES - P6FGG**	**43.6622220**	**-70.2263890**	**FRIENDS OF CASCO BAY**
142707	**Marine Waters**	**CASCO BAY - CBFG**	**43.6650420**	**-70.2211730**	**MDEP BLWQ MARINE**
131221	Upper Estuarine	YORK RIVER - YR-02	43.1577100	-70.7381100	MDEP BLWQ MARINE
131219	Upper Estuarine	SMELT BROOK - SB00	43.1801400	-70.7349400	MDEP BLWQ MARINE
92788	NA	YORK RIVER - YORK-06	43.1644910	-70.7235650	WELLS NERR
93312	Upper Estuarine	YORK RIVER - YR6	43.1622660	-70.7219710	WELLS NEER
92787	NA	YORK RIVER - YORK-05	43.1603730	-70.7096930	WELLS NERR
128405	Lower Estuarine	YORK RIVER - YR-33	43.1598300	-70.7094080	FRIENDS OF CASCO BAY
93311	Lower Estuarine	YORK RIVER - YR5	43.1590840	-70.7085490	WELLS NEER
91563	NA	YORK HARBOR - YORK RIVER - YHYR01 - NCCA	43.1566000	-70.7059000	EPA
93310	Lower Estuarine	YORK RIVER - YR4	43.1427310	-70.6931320	WELLS NEER
92786	Lower Estuarine	YORK RIVER - YORK-04	43.1422710	-70.6929850	WELLS NERR
131223	Lower Estuarine	YORK RIVER - YR-50	43.1413600	-70.6925200	MDEP BLWQ MARINE
131225	Lower Estuarine	YORK RIVER - YR-64	43.1361100	-70.6761800	MDEP BLWQ MARINE
93309	Lower Estuarine	YORK RIVER - YR3	43.1362600	-70.6721000	WELLS NEER
92785	Lower Estuarine	YORK RIVER - YORK-03	43.1364360	-70.6614520	WELLS NERR
93308	Lower Estuarine	YORK RIVER - YR2	43.1361500	-70.6535980	WELLS NEER
92784	Lower Estuarine	YORK RIVER - YORK-02	43.1357820	-70.6487760	WELLS NERR
131227	Lower Estuarine	YORK RIVER - YR-84	43.1294800	-70.6450800	MDEP BLWQ MARINE
93307	Marine Waters	YORK RIVER - YR1	43.1279230	-70.6441080	WELLS NEER
92783	Marine Waters	YORK RIVER - YORK-01	43.1277490	-70.6422440	WELLS NERR
91564	NA	YORK HARBOR - WESTERN POINT - YHWP01 - NCCA	43.1278000	-70.6287000	EPA

SITESEQ	CLASS	CURRENT_SITE_NAME	LATITUDE	LONGITUDE	Source
99901	NA	YORK RIVER - YR-1	43.1295830	-70.6237000	EPA REGION 1
111554	Upper Estuarine	MOUSAM RIVER - MR00	43.3811570	-70.5413700	MDEP BLWQ DEA
124462	NA	MOUSAM RIVER - MR-03	43.3748610	-70.5356820	MDEP BLWQ RIVERS MODELING
111556	Upper Estuarine	MOUSAM RIVER - MR-11	43.3706230	-70.5328160	MDEP BLWQ DEA
131217	Upper Estuarine	MOUSAM RIVER - MR-25	43.3591200	-70.5217000	MDEP BLWQ MARINE
124464	Lower Estuarine	MOUSAM RIVER - MR-31	43.3513410	-70.5182760	MDEP BLWQ RIVERS MODELING
100512	Upper Estuarine	SACO RIVER - SC1	43.4921790	-70.4398840	WELLS NERR
91496	NA	SACO BAY - SACO RIVER - SBSC02 - NCCA	43.4920000	-70.4397000	EPA
100542	Upper Estuarine	SACO RIVER - N2	43.4943020	-70.4393590	WELLS NERR
91490	NA	SACO BAY - SACO RIVER - SBSC01 - NCCA	43.4919000	-70.4378000	EPA
100520	Upper Estuarine	SACO RIVER - SC2	43.4876760	-70.4324580	WELLS NERR
100544	NA	SACO RIVER - N3	43.4864120	-70.4311590	WELLS NERR
100521	Upper Estuarine	SACO RIVER - SC3	43.4840380	-70.4282440	WELLS NERR
100522	Upper Estuarine	SACO RIVER - SC4	43.4819640	-70.4207770	WELLS NERR
100603	NA	SACO RIVER - S5	43.4807750	-70.4207480	MDEP BLWQ DWM
100523	Upper Estuarine	SACO RIVER - SC5	43.4788300	-70.4102980	WELLS NERR
100611	Upper Estuarine	SACO RIVER - S6	43.4733560	-70.4080200	MDEP BLWQ DWM
100524	Upper Estuarine	SACO RIVER - SC6	43.4743930	-70.4075480	WELLS NERR
100561	NA	SACO RIVER - S7	43.4719040	-70.4001390	MDEP BLWQ DWM
100546	NA	SACO RIVER - N8	43.4756940	-70.3985050	MDEP BLWQ DWM
100525	Upper Estuarine	SACO RIVER - SC7	43.4711290	-70.3980580	WELLS NERR
100526	Upper Estuarine	SACO RIVER - SC8	43.4661640	-70.3950630	WELLS NERR
100557	NA	SACO RIVER - N10	43.4652160	-70.3900070	MDEP BLWQ DWM
100658	NA	SACO RIVER - S10	43.4600100	-70.3892470	MDEP BLWQ DWM
100555	NA	SACO RIVER - N9	43.4634130	-70.3836950	WELLS NERR
100527	Upper Estuarine	SACO RIVER - SC9	43.4611000	-70.3807880	WELLS NERR
124466	NA	ROYAL RIVER - RR00	43.7986630	-70.1784150	MDEP BLWQ RIVERS MODELING

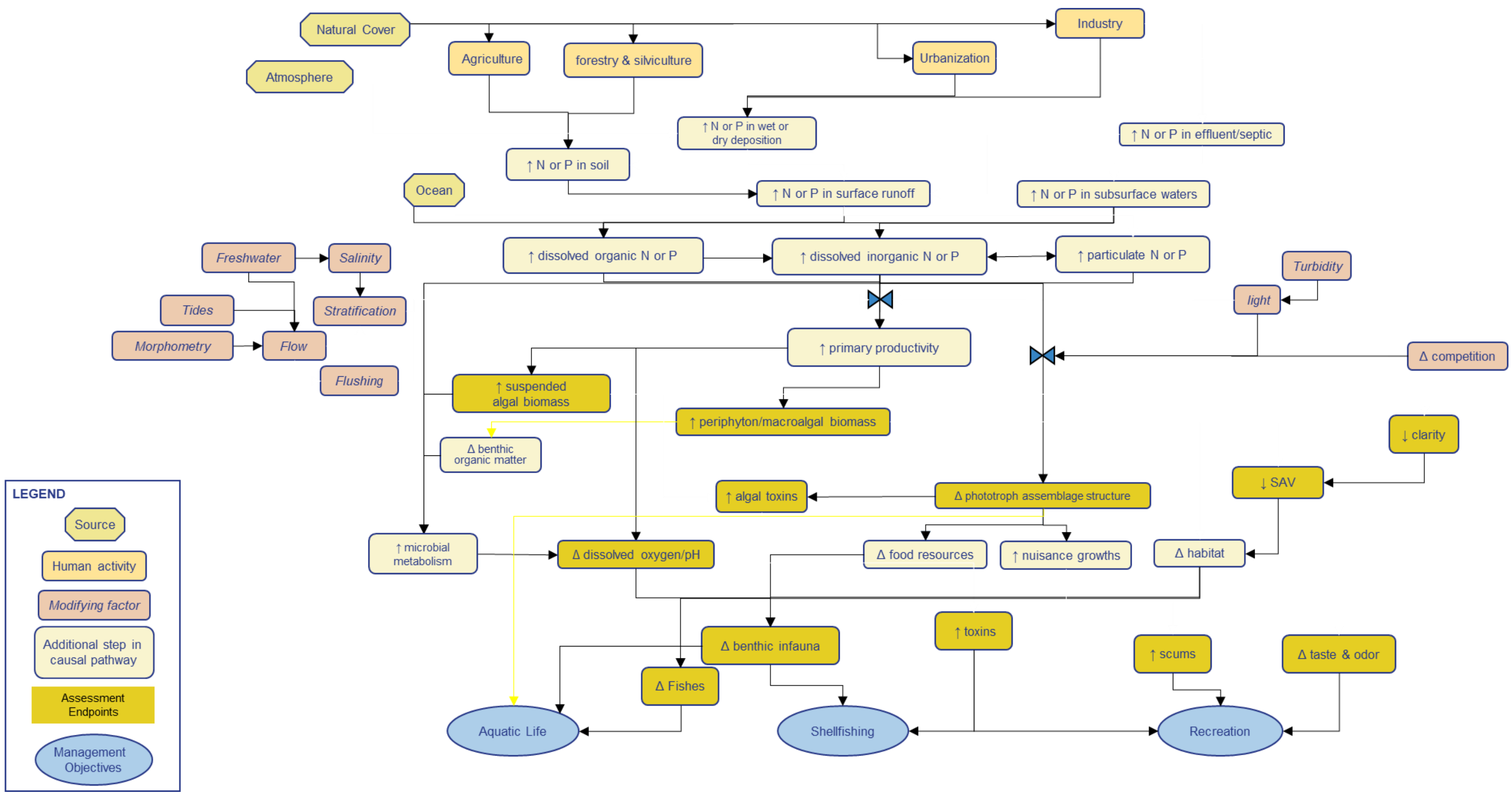
SITESEQ	CLASS	CURRENT_SITE_NAME	LATITUDE	LONGITUDE	Source
131278	Upper Estuarine	ROYAL RIVER - RR-01	43.7980780	-70.1777300	MDEP BLWQ MARINE
90651	Upper Estuarine	ROYAL RIVER YANKEE MARINA - RRY47	43.7952780	-70.1730560	FRIENDS OF CASCO BAY
124468	Lower Estuarine	ROYAL RIVER - RR-06	43.7946040	-70.1680160	MDEP BLWQ RIVERS MODELING
131207	Upper Estuarine	COUSINS RIVER - CRTRIB0	43.8212000	-70.1612600	MDEP BLWQ MARINE
128347	Lower Estuarine	ROYAL RIVER - RR-13	43.7901800	-70.1563810	MDEP BLWQ MARINE
128407	Upper Estuarine	COUSINS RIVER - CR-31	43.8120100	-70.1534150	FRIENDS OF CASCO BAY
90590	Upper Estuarine	COUSINS RIVER MUDDY RUDDER - CRV63	43.8122220	-70.1533330	FRIENDS OF CASCO BAY
92735	Upper Estuarine	COUSINS RIVER - COUS-02	43.8120640	-70.1532820	MDEP BLWQ DEA
97759	NA	ROYAL RIVER - 10	43.7919500	-70.1522800	MER
131211	Lower Estuarine	COUSINS RIVER - CR-44	43.7973100	-70.1460700	MDEP BLWQ MARINE
92734	NA	COUSINS RIVER - COUS-01	43.7972680	-70.1460530	MDEP BLWQ DEA
131209	Upper Estuarine	COUSINS RIVER - CR00	43.8292200	-70.1458200	MDEP BLWQ MARINE
124470	Lower Estuarine	ROYAL RIVER - RR-19	43.7955180	-70.1454650	MDEP BLWQ RIVERS MODELING
131792	Marine Waters	ROYAL RIVER - RR-20	43.7960110	-70.1437150	MDEP BLWQ MARINE
90650	Lower Estuarine	ROYAL RIVER CAN 5 - RRC46	43.7888890	-70.1380560	FRIENDS OF CASCO BAY
110334	Marine Waters	ROYAL RIVER - CBRR	43.7891400	-70.1346000	MDEP BLWQ MARINE
97760	NA	ROYAL RIVER - 11	43.7939100	-70.1328600	MER
97762	NA	HARRASEEKET RIVER - 13	43.8121000	-70.1083800	MER
90656	Lower Estuarine	SOUTH FREEPORT TOWN LANDING - SFP51	43.8203630	-70.1058850	FRIENDS OF CASCO BAY
92741	Lower Estuarine	HARRASEEKET RIVER - HR04-5	43.8128100	-70.1045950	MDEP BLWQ DEA
128321	Lower Estuarine	HARRASEEKET RIVER - HR04	43.8199500	-70.1044000	MDEP BLWQ MARINE
97767	NA	HARRASEEKET RIVER - 18	43.8113300	-70.1039700	MER
70615	NA	CASCO BAY - HARRASEEKET RIVER - CBHR03 - NCCA	43.8154000	-70.1038333	MDEP BLWQ SWAT
97763	NA	HARRASEEKET RIVER - 14	43.8243100	-70.1013600	MER
128314	NA	HARRASEEKET RIVER - HR01	43.8423900	-70.0999400	MDEP BLWQ MARINE
97766	NA	HARRASEEKET RIVER - 17	43.8223800	-70.0991200	MER
128323	Marine Waters	HARRASEEKET RIVER - HR05	43.8043800	-70.0983300	MDEP BLWQ MARINE

SITESEQ	CLASS	CURRENT_SITE_NAME	LATITUDE	LONGITUDE	Source
91403	NA	CASCO BAY - HARRASEEKET RIVER - CBHR01 - NCCA	43.8321000	-70.0973000	EPA
93418	Lower Estuarine	HARRASEEKET RIVER - HR01-2	43.8420340	-70.0958750	FRIENDS OF CASCO BAY
91404	NA	CASCO BAY - HARRASEEKET RIVER - CBHR02 - NCCA	43.8307000	-70.0958000	EPA
128319	Lower Estuarine	HARRASEEKET RIVER - HR03	43.8294900	-70.0953700	MDEP BLWQ MARINE
97764	NA	HARRASEEKET RIVER - 15	43.8327900	-70.0950900	MER
110336	Marine Waters	HARRASEEKET RIVER - CBHR	43.8130600	-70.0938700	MDEP BLWQ MARINE
90571	Lower Estuarine	BARTOL ISLAND CAUSEWAY - BAR48	43.8380560	-70.0897220	FRIENDS OF CASCO BAY
97765	NA	HARRASEEKET RIVER - 16	43.8360300	-70.0876200	MER
128317	Lower Estuarine	HARRASEEKET RIVER - HR02	43.8397890	-70.0858100	MDEP BLWQ MARINE
91544	NA	PENOBSCOT BAY WEST - ROCKPORT HARBOR - PWRH02 - NCCA	44.1599000	-69.0756000	EPA
115201	NA	ROCKPORT HARBOR-RH0-VRMP	44.1866861	-69.0733972	ROCKPORT CONSERVATION COMMISSION
110100	Marine Waters	ROCKPORT HARBOR-RH1-VRMP	44.1850000	-69.0731000	MDEP BLWQ DEA
110101	Marine Waters	ROCKPORT HARBOR-RH2-VRMP	44.1826330	-69.0718830	MDEP BLWQ DEA
110102	Marine Waters	ROCKPORT HARBOR-RH3-VRMP	44.1776000	-69.0695000	MDEP BLWQ DEA
89414	NA	WEST PENOBSCOT BAY - PEN-9	44.1593330	-69.0648830	EPA
110098	Marine Waters	ROCKPORT HARBOR-RO-VRMP	44.1579550	-69.0533930	MDEP BLWQ DEA
91542	NA	PENOBSCOT BAY WEST - ROCKPORT HARBOR - PWRH01 - NCCA	44.1653000	-69.0525000	EPA
87860	NA	BELFAST BAY - BEL1	44.4410170	-69.0205830	SAQUISH SCIENTIFIC LLC
92733	Lower Estuarine	BELFAST BAY - BELF-03	44.4388300	-69.0131800	MDEP BLWQ DEA
92732	Lower Estuarine	BELFAST BAY - BELF-02	44.4305000	-69.0084700	MDEP BLWQ DEA
139250	Lower Estuarine	BELFAST BAY - BB01	44.4301500	-69.0039200	MDEP BLWQ MARINE
87861	NA	BELFAST BAY - BEL2	44.4301500	-69.0039170	SAQUISH SCIENTIFIC LLC
92731	Marine Waters	BELFAST BAY - BELF-01	44.4224600	-68.9877900	MDEP BLWQ DEA
87862	NA	BELFAST BAY - BEL3	44.4189830	-68.9824000	SAQUISH SCIENTIFIC LLC
91549	NA	PENOBSCOT BAY WEST - BELFAST BAY - PWBB01 - NCCA	44.4148000	-68.9817000	EPA

SITESEQ	CLASS	CURRENT_SITE_NAME	LATITUDE	LONGITUDE	Source
139252	Lower Estuarine	BELFAST BAY - BB02	44.4148000	-68.9817000	MDEP BLWQ MARINE
139260	Lower Estuarine	WEST PENOBSCOT BAY - PB02	44.3851000	-68.9729800	MDEP BLWQ MARINE
139262	Marine Waters	WEST PENOBSCOT BAY - PB03	44.3768900	-68.9525600	MDEP BLWQ MARINE
139266	Marine Waters	WEST PENOBSCOT BAY - PB04	44.3654200	-68.9333600	MDEP BLWQ MARINE
89406	Marine Waters	WEST PENOBSCOT BAY - PEN-1	44.3654160	-68.9333580	EPA
91548	NA	PENOBSCOT BAY WEST - NORTH ISLESBORO - PWNB01 - NCCA	44.3563000	-68.9253000	EPA
91543	NA	PENOBSCOT BAY WEST - MARSHALL POINT - PWML01 - NCCA	44.3815000	-68.9202000	EPA
90146	Marine Waters	PENOBSCOT BAY WEST - MOOSE POINT - PWMP01 - NCCA	44.4131120	-68.9166930	EPA
139256	Lower Estuarine	WEST PENOBSCOT BAY - PB01	44.4131100	-68.9166900	MDEP BLWQ MARINE
91509	NA	PENOBSCOT BAY WEST - SEARSPORT HARBOR - PWSP01 - NCCA	44.4467000	-68.9157000	EPA
91540	NA	PENOBSCOT BAY WEST - TURTLE HEAD - PWTH01 - NCCA	44.4025000	-68.8902000	EPA
90142	Marine Waters	PENOBSCOT BAY WEST - STOCKTON HARBOR - PWSH01 - NCCA	44.4711280	-68.8708830	EPA
91550	NA	PENOBSCOT BAY WEST - TURTLE HEAD - PWTH02 - NCCA	44.4029000	-68.8680000	EPA
91552	NA	PENOBSCOT BAY WEST - SEARS ISLAND - PWSS02 - NCCA	44.4133000	-68.8674000	EPA
91557	NA	PENOBSCOT BAY WEST - SEARS ISLAND - PWSS01 - NCCA	44.4278000	-68.8644000	EPA
91449	NA	PENOBSCOT RIVER - INDIAN POINT - PNIP01 - NCCA	44.5834000	-68.8210000	EPA
71304	Upper Estuarine	PENOBSCOT RIVER - PNE11	44.5903100	-68.8200220	MDEP BLWQ DEA
91447	NA	PENOBSCOT RIVER - INDIAN POINT - PNIP02 - NCCA	44.5799000	-68.8164000	EPA
94169	Upper Estuarine	PENOBSCOT RIVER - P1	44.5924730	-68.8148990	MDEP BLWQ MARINE
90171	Lower Estuarine	PENOBSCOT RIVER - FORT POINT COVE - PNFP01 - NCCA	44.4907360	-68.8101440	EPA
94181	Upper Estuarine	PENOBSCOT RIVER - P7	44.5524360	-68.8039910	MDEP BLWQ MARINE
71305	Upper Estuarine	PENOBSCOT RIVER - PNE12	44.5702650	-68.8019230	MDEP BLWQ DEA

SITESEQ	CLASS	CURRENT_SITE_NAME	LATITUDE	LONGITUDE	Source
94173	Upper Estuarine	PENOBSCOT RIVER - P2	44.5712920	-68.7983290	MDEP BLWQ MARINE
91448	NA	PENOBSCOT RIVER - SANDY POINT - PNSP01 - NCCA	44.5077000	-68.7957000	EPA
91446	NA	PENOBSCOT RIVER - VERONA ISLAND - PNVN01 - NCCA	44.5117000	-68.7903000	EPA
70614	NA	PENOBSCOT RIVER - VERONA ISLAND - PNVN02 - NCCA	44.5047333	-68.7892500	MDEP BLWQ SWAT
139564	Upper Estuarine	PENOBSCOT RIVER - P3A	44.5665300	-68.7764000	MDEP BLWQ MARINE
94175	Upper Estuarine	PENOBSCOT RIVER - P3	44.5654070	-68.7729500	MDEP BLWQ MARINE
94180	Lower Estuarine	PENOBSCOT RIVER - P6	44.5004070	-68.7711310	MDEP BLWQ MARINE
94178	Upper Estuarine	PENOBSCOT RIVER - P4	44.5442280	-68.7655700	MDEP BLWQ MARINE
94179	Upper Estuarine	PENOBSCOT RIVER - P5	44.5229820	-68.7577330	MDEP BLWQ MARINE
94168	Upper Estuarine	ORLAND RIVER - O3	44.5393670	-68.7518890	MDEP BLWQ MARINE
94165	Upper Estuarine	ORLAND RIVER - O2	44.5508430	-68.7462860	MDEP BLWQ MARINE
94162	Upper Estuarine	ORLAND RIVER - O1	44.5616010	-68.7457710	MDEP BLWQ MARINE
128325	NA	MACHIAS RIVER - MR01	44.7136700	-67.4585200	MDEP BLWQ MARINE
128337	NA	MIDDLE RIVER - MIR01	44.7201600	-67.4499400	MDEP BLWQ MARINE
128327	Lower Estuarine	MACHIAS RIVER - MR02	44.7171500	-67.4359900	MDEP BLWQ MARINE
128329	Lower Estuarine	MACHIAS RIVER - MR03	44.7135400	-67.4118000	MDEP BLWQ MARINE
128341	Lower Estuarine	EAST MACHIAS RIVER - EMR02	44.7232400	-67.3975000	MDEP BLWQ MARINE
91425	NA	MACHIAS BAY - MACHIAS RIVER - MCMR01 - NCCA	44.6956000	-67.3916000	EPA
128339	NA	EAST MACHIAS RIVER - EMR01	44.7347100	-67.3915200	MDEP BLWQ MARINE
128333	Marine Waters	MACHIAS RIVER - MR05	44.6956100	-67.3910300	MDEP BLWQ MARINE
128331	Lower Estuarine	MACHIAS RIVER - MR04	44.7107000	-67.3903300	MDEP BLWQ MARINE
128335	Marine Waters	MACHIAS RIVER - MR06	44.6815500	-67.3805300	MDEP BLWQ MARINE
91424	NA	MACHIAS BAY - ROUND ISLAND - MCRN01 - NCCA	44.6689000	-67.3460000	EPA
91410	NA	MACHIAS BAY - HOLMES BAY - MCHB01 - NCCA	44.6796000	-67.3380000	EPA

APPENDIX 2 – DETAILED CONCEPTUAL MODEL


Natural Cover
Industry
Atmosphere
Agriculture
forestry & silviculture
Urbanization
↑ N or P in wet or dry deposition
↑ N or P in effluent/septic
↑ N or P in soil
Ocean
↑ N or P in surface runoff
↑ N or P in subsurface waters
Freshwater
Salinity
↑ dissolved organic N or P
↑ dissolved inorganic N or P
↑ particulate N or P
Turbidity
Tides
Stratification
light
Morphometry
Flow
↑ primary productivity
Δ competition
Flushing
↑ suspended algal biomass
↑ periphyton/macroalgal biomass
↓ clarity
Δ benthic organic matter
LEGEND
Source
Human activity
Modifying factor
Additional step in causal pathway
Assessment Endpoints
Management Objectives
↑ algal toxins
Δ phototroph assemblage structure
↓ SAV
↑ microbial metabolism
Δ dissolved oxygen/pH
Δ food resources
↑ nuisance growths
Δ habitat
↑ toxins
Δ benthic infauna
↑ scums
Δ taste & odor
Δ Fishes
Aquatic Life
Shellfishing
Recreation