A restoration goal for Chesapeake Bay phytoplankton communities

Executive Summary

A Phytoplankton Index of Biotic Integrity (PIBI) has been developed for Chesapeake Bay.[1] It is currently used to analyze monitoring data and assess phytoplankton health with respect to "reference communities"[2] found in desirable water quality conditions. The PIBI combines the scores of pollution-sensitive, biologically important metrics of the phytoplankton community into a single index. Like other multi-metric indexes, the PIBI is more sensitive to habitat conditions than its component metrics, which include chlorophyll *a*, the abundances of several potentially harmful species, and various indicators of cell function and species composition. The numeric values of the PIBI makes the index useful in assessing status of natural communities and establishing restoration goals.

A protocol for rating the P-IBI numeric scores was developed to assess status of a station or water body. Index ratings range from "Poor" (PIBI = 1.0) to "Good" (PIBI = 5.0). The highest rating is not characterized as "Excellent." This rating scheme follows U.S. Environmental Protection Agency estuarine bioassessment/biocriteria guidelines[3] that most reference sites should show a rating in the desirable range of biological conditions, but can reflect a less than ideal biological integrity. The assessment protocol acknowledges the reality that most of Chesapeake Bay is presently impaired by excess nutrients and poor water clarity, and ecologically important grazer populations have declined during the last half century. Nutrient and sediment reductions may attain Bay water quality criteria,[4] but harvest demands on living resources will continue to be high. The future, restored Chesapeake Bay will be a heavily manipulated system. The highest phytoplankton IBI rating of "Good" is intended to be the best attainable level of integrity, not the level of integrity that would be found in pristine estuaries.

Overall status of phytoplankton in the past 20 years has been Fair-Good in Susquehanna Flats and in the large mainstem segment off the mouth of the Potomac River. The remainder of the Chesapeake Bay mainstem was Fair or Fair-Poor. Overall status has been Poor or Poor-Fair in the most of the tributary rivers, with only the lower Rappahannock River and the Pamunkey reach of the upper York river attaining Fair status. Status varied across the spectrum from Poor to Good depending on seasonal and annual fluctuations in water quality.

The steps followed in developing the PIBI are well established in the literature and have been successfully applied to a variety of communities.[3] The PIBI can become a functional tool for Chesapeake Bay management and decision-making if a numeric PIBI restoration goal is approved by the Chesapeake Bay Program. The PIBI development team recommends an index value of 4.0, or Good, as a restoration goal for all Chesapeake Bay waters. Data analysis suggests this goal aligns well with attainment of the Chesapeake Bay water quality criteria and standards for dissolved oxygen and water clarity, and healthy phytoplankton communities will become increasingly evident as nutrient and sediment pollutants are reduced. If this does not happen, management is warned that other environmental factors in the complex Chesapeake ecosystem are impacting the phytoplankton community. Closer examination of the multiple phytoplankton metrics may then indicate the cause of impairment.

Recommendation: establish a PIBI restoration goal of 4.0, or "Good."

Introduction

Phytoplankton (free-floating, microscopic algae) are supported by nutrients and light in the water and form the base of the estuarine food web. Phytoplankton in Chesapeake Bay and its tidal tributaries are collected, identified, and enumerated by state partners of the Chesapeake Bay Program (CBP) as part of bay-wide water quality monitoring programs.[5] Utility of the data has been significantly enhanced by long-term efforts to measure cell dimensions and estimate biomass from counts.[6] Metrics (indicators) calculated from the data were recently used to characterize "reference communities," or populations presently living in least-degraded water quality conditions.[2] The reference communities were used to create a Phytoplankton Index of Biotic Integrity (PIBI), or quantitative scale for assessing phytoplankton community status relative to water quality.[1] The PIBI is an analytical tool that can also be used for resource management and decision-making and for communicating restoration progress to the public.

Clearing Up Some Misconceptions

Several misconceptions about chlorophyll *a* and phytoplankton (algae) are common in management and public perceptions of bay restoration. Correcting these misconceptions will encourage managers to use the PIBI as a functional tool, and will improve the general public's expectations for a restored bay.

- *"Chlorophyll* a *is a measure of algal biomass"*

False. Chlorophyll *a* is a measure of photosynthetic capability. It is a photosensitive chemical used by most primary producers to capture sunlight energy, and it comprises about 0.1 - 5 % of an algal cell's organic matter. It correlates well with algal biomass when water clarity is good. It over-estimates algal biomass when water clarity is poor because cells adapt to low light.

- *"Reducing nutrients will starve the fish"* (or "*More is Better*")

False. Data analysis suggests that lower nutrient concentrations–<u>if coupled with better water clarity</u>–will result in the same, or more, phytoplankton biomass for the food web.[2] There will be fewer and less severe algal blooms and food quality may improve. It is worth noting that present-day "reference communities" for phytoplankton and zooplankton resemble the plankton communities of the 1950's, when the bay ecosystem was considered "healthy enough" and supported much larger grazer populations.

- *"Oysters are one of the most important filter-feeders in Chesapeake Bay"*

False. They once were…they no longer are. Neither are menhaden. Zooplankton and soft-bottom benthos presently graze most of the phytoplankton in Chesapeake Bay.

- "*We can't manage the zooplankton and benthos*"

False. We can indirectly manage their communities and improve their capacity to support fish, crabs, and birds to a significant degree by reducing nutrients and improving water clarity and dissolved oxygen.

- *"We don't need to monitor phytoplankton (or zooplankton) if we are monitoring–and attaining–the water quality criteria."*

False. Chesapeake Bay has been changing physically, chemically, and biologically for a long time. Simply reversing nutrient and sediment trends, and eventually attaining the water quality criteria, does not guarantee restoration of the bay food web described in CBP agreements. Phytoplankton monitoring tracks the presence of non-native and harmful species, measures the quality and quantity of phytoplankton food for grazers, and verifies CBP water quality and ecosystem model predictions.

Calculating the PIBI

The component metrics of the PIBI are scored individually according to how similar they are to values found in reference communities: metric values are scored high (5) if they are very similar, low (1) if they are significantly different, or in the middle (3) if they are not clearly different (Figure 1). The index score is the average of the component metric scores and can range from 1, representing extremely degraded communities, to 5, representing the best of the reference communities. The PIBI correctly identified degraded and reference water quality conditions in 70.0% - 84.4% of the samples in the calibration data set, which were grouped into four salinity zones and two seasons (spring, summer). The component metrics and the overall index performed very well in two different validation efforts. The PIBI correctly identified 77.3% of all samples in an independent validation data set and had mean errors of 3.12% - 12.59%, depending on salinity and season, in a jackknife validation procedure.

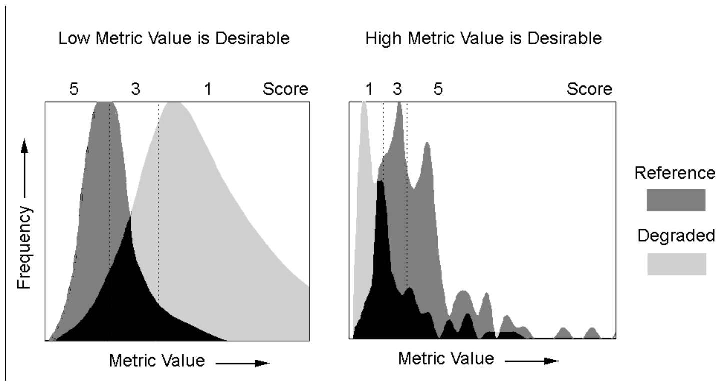

Figure 1. Examples of how metrics are scored.

Assessing Phytoplankton Status

A protocol for rating the P-IBI numeric scores was developed for the purpose of assessing the status of a station or water body.[1] The index ratings are consistent with the 1-3-5 scoring protocol for the component metrics. Index scores of 1 - 2 are given the rating "Poor," scores of 2 - 2.67 are "Fair-Poor," scores of 2.67 - 3.33 are "Fair," scores of 3.3 - 4 are "Fair-Good," and scores of 4 - 5 are "Good." None of the highest ratings were characterized as "Excellent." This rating scheme follows U.S. Environmental Protection Agency estuarine bioassessment/biocriteria guidelines[3] that most reference sites should show a rating in the desirable range of biological conditions, but can reflect a less than ideal biological integrity. The assessment protocol intentionally reflects the fact that most of Chesapeake Bay phytoplankton populations inhabit waters impaired by excess nutrients and poor water clarity, and populations of ecologically important phytoplankton grazers have declined in the Bay during the last half century. Nutrient and sediment reductions may attain Bay water quality criteria[4] and alleviate habitat stressors such as poor water clarity for underwater grasses and low dissolved oxygen. However, harvest demands on living resources will continue to be high. The future, restored Chesapeake Bay will be a heavily manipulated system. The highest phytoplankton IBI rating of “Good” is intended to be the best attainable level of integrity, not the level of integrity that would be found in pristine estuaries.

Presenting the PIBI Scores

Data can be presented spatially in maps, temporally in time series, and numerically in tables. Several options for presenting the PIBI scores are shown in Figures 2-6. Maps have the advantage of portraying spatial distributions of the PIBI scores and can indicate problem areas (Figure 2). They cannot easily indicate change over time. Times series of a seasonal or annual mean will indicate how the central tendency of the PIBI values has changed over time, but important information about changes in the range (e.g., frequency of extreme values) are lost (Figure 3). Bar graphs can bias the results positively (Figure 4) or negatively (Figure 5) if the frequency of just the highest or lowest PIBI categories are shown, respectively. The bias is removed if the frequencies of all the categories are shown in a stacked bar (Figure 6). The PIBI development team recommends this latter, "full disclosure" method of portraying PIBI scores when a time series is required. Tabular presentations of the data are useful for referencing and documenting the data's statistics for management purposes; they are usually not used for public communication purposes (Table 1).

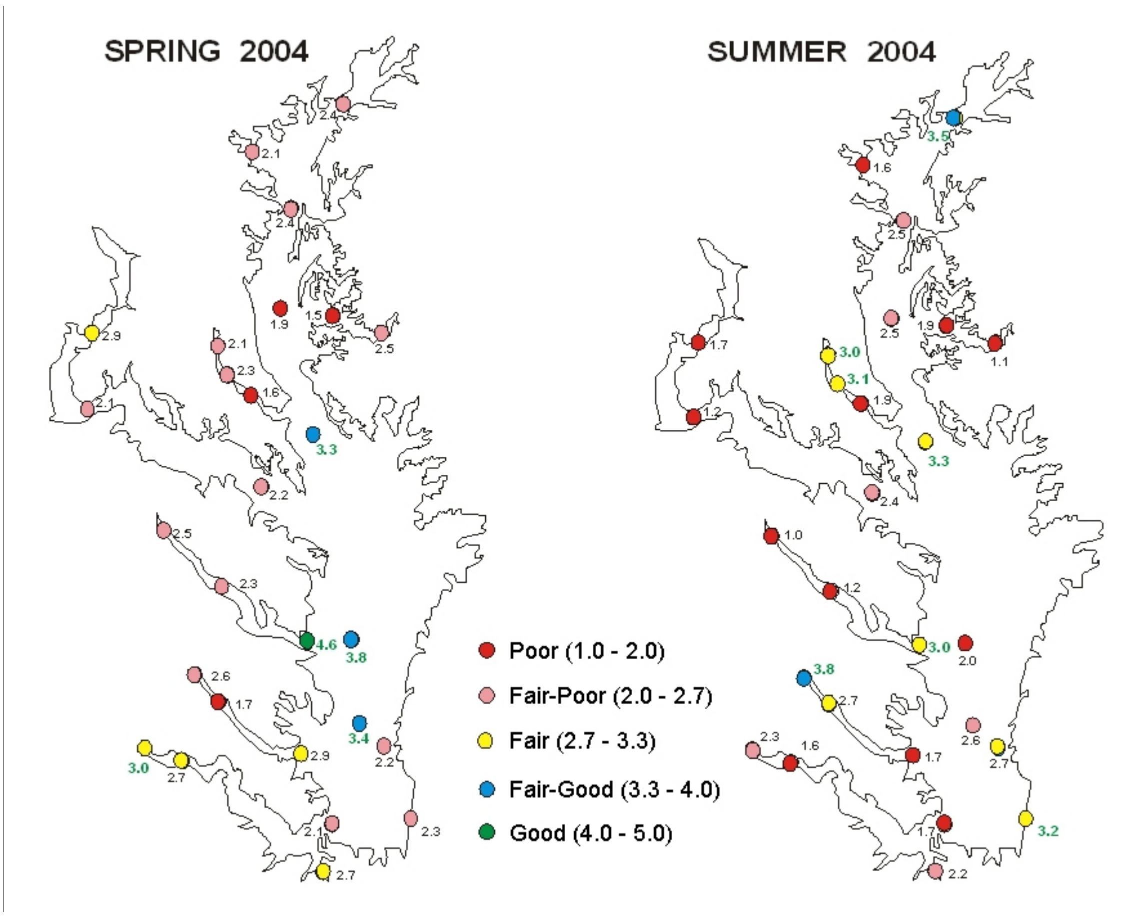

Figure 2. Spring and summer 2004 PIBI. Each point is an average based on 3 or more data points collected monthly in either spring (March - May) or summer (July - September), 2004.

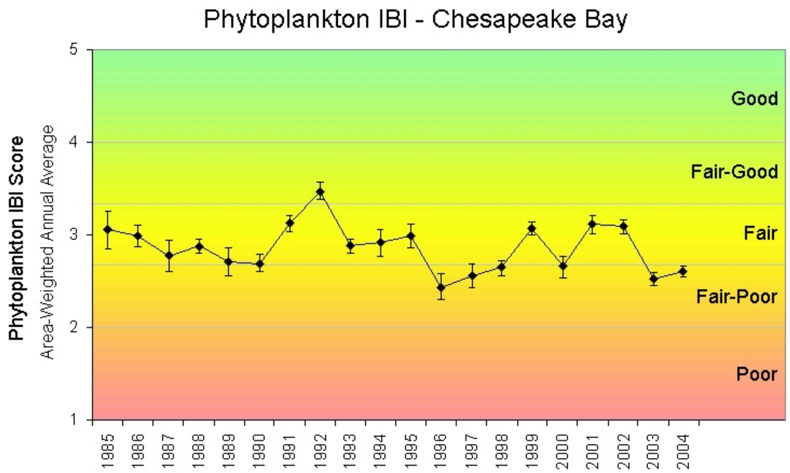

Figure 3. Annual average PIBI score ($\pm$SE), 1985-2004. Station scores are weighted by segment area, then averaged by year. Annual PIBI averages indicate the overall phytoplankton condition in Bay surface waters has been Fair since 1985.

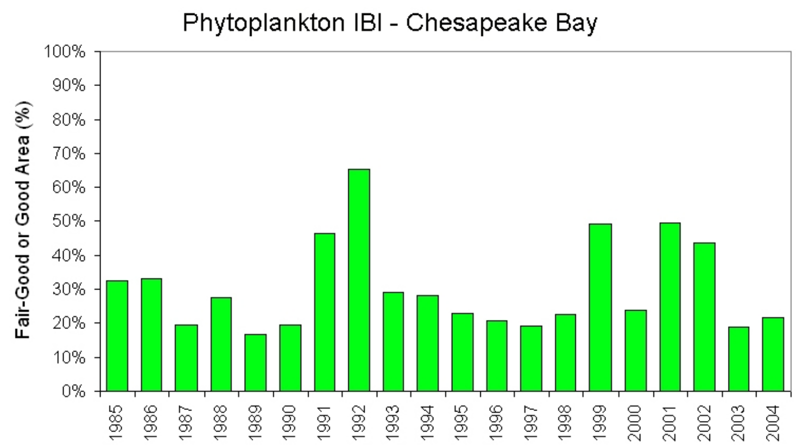

Figure 4. Frequency of PIBI $\geq$ 3.33, 1985-2004. Station scores are weighted by segment area before annual frequency is calculated. Approximately 31% of Bay surface waters are in Fair-Good or Good condition and there is no downward trend.

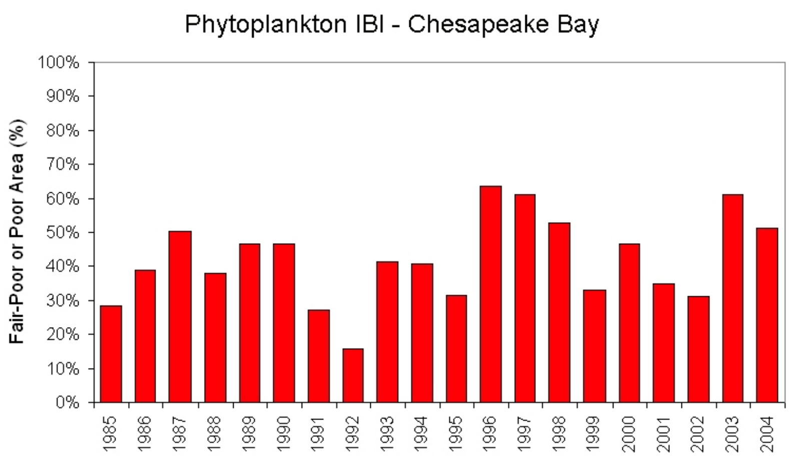

Figure 5. Frequency of PIBI $\leq$ 2.67, 1985-2004. Station scores are weighted by segment area before annual frequency is calculated. Approximately 42% of Bay surface waters are in Fair-Poor or Poor condition and there is an upward trend.

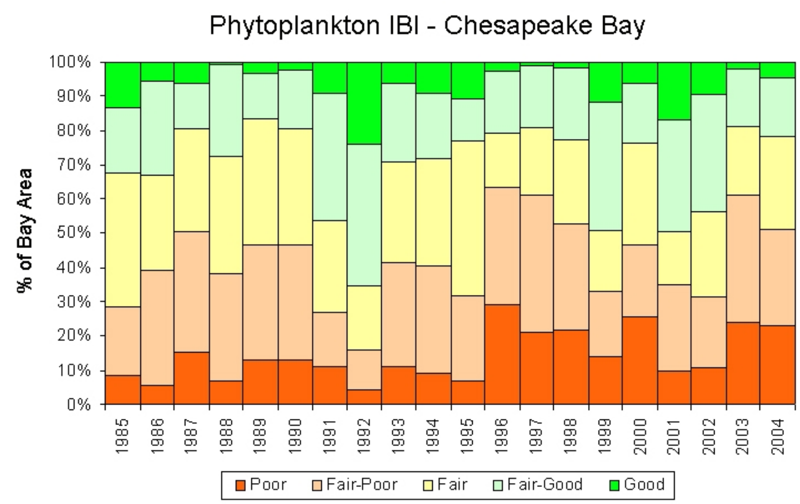

Figure 6. Frequency of each PIBI category, 1985-2004. Station scores are weighted by segment area before frequencies are calculated. There is no trend apparent in the combined Good and Fair-Good categories, however there is an upward trend in the combined Poor and Fair-Poor categories.

Table 1. Mean, standard error (SE), median, interquartile (IQ) range, and number (n) of P-IBI values experienced at the CBP monitoring stations in spring (March-May) and summer (July-September), 1985-2002. Sal., average seasonal salinity at station: F, 0-0.5 ‰; O, 0.5-5.0 ‰, M, 5.0-18.0 ‰; P, >18 ‰. p, significance of differences (Wilcoxon test) between spring and summer P-IBI scores: **, p<0.01; *, p<0.05; ns, not significant. Status is based on the station median P-IBI score: 1 - <2, "Poor;" 2 - <2.67, "Fair-Poor;" 2.67 - <3.33, "Fair;" 3.33 - <4, "Fair-Good;" 4 - 5, "Good." (from Lacouture et al. In press.)

			SPRING					SUMMER					
River Basin	Station	Sal.	Mean	SE	Median [IQ Range]	n	Status	Mean	SE	Median [IQ Range]	n	Status	p
Chesapeake Bay Mainstem													
Susquehanna	CB1.1	F	2.9	0.13	2.67 [2.6 - 3.4]	51	Poor-Fair	3.3	0.10	3.67 [3.0 - 4.0]	69	Fair-Good	**
Upper Bay	CB2.2	O	2.8	0.09	2.60 [2.0 - 3.4]	86	Poor-Fair	3.5	0.09	3.67 [3.0 - 4.0]	105	Fair-Good	**
Off Chester	CB3.3C	M	2.7	0.09	2.67 [2.2 - 3.3]	80	Poor-Fair	2.4	0.08	2.33 [1.8 - 3.0]	89	Poor-Fair	*
Off Choptank	CB4.3C	M	3.3	0.09	3.29 [2.7 - 3.9]	89	Fair	3.1	0.07	3.00 [2.7 - 3.4]	104	Fair	ns
Mid Bay	CB5.2	M	3.4	0.10	3.29 [3.0 - 4.1]	78	Fair	3.4	0.08	3.40 [3.0 - 4.0]	95	Fair-Good	ns
Off Rappahannock	CB6.1	P	3.2	0.11	3.00 [2.7 - 3.7]	48	Fair	2.9	0.08	3.00 [2.7 - 3.3]	66	Fair	ns
Off York	CB6.4	P	3.0	0.10	3.00 [2.6 - 3.7]	61	Fair	2.8	0.08	2.78 [2.3 - 3.4]	71	Fair	ns
VA Western Shore	CB7.3E	P	3.1	0.12	3.00 [2.3 - 3.7]	57	Fair	3.0	0.10	3.11 [2.3 - 3.7]	70	Fair	ns
Mouth of Bay	CB7.4	P	3.3	0.10	3.33 [2.7 - 3.9]	60	Fair-Good	3.3	0.09	3.25 [2.8 - 4.0]	71	Fair	ns
Maryland Tributaries													
Patapsco	WT5.1	M	2.6	0.11	2.43 [2.0 - 3.0]	78	Poor-Fair	1.7	0.06	1.67 [1.3 - 1.9]	99	Poor	**
Choptank	ET5.1	O	1.9	0.08	1.80 [1.3 - 2.6]	80	Poor	1.3	0.05	1.00 [1.0 - 1.3]	93	Poor	**
Choptank	ET5.2	M	2.4	0.08	2.33 [1.9 - 3.0]	79	Poor-Fair	2.5	0.08	2.33 [1.8 - 3.0]	98	Poor-Fair	ns
Patuxent	TF1.5	F	2.2	0.11	1.80 [1.0 - 2.8]	83	Poor	1.3	0.06	1.00 [1.0 - 1.7]	89	Poor	**
Patuxent	TF1.7	O	2.1	0.08	2.00 [1.7 - 2.6]	80	Poor-Fair	2.1	0.09	2.00 [1.7 - 2.4]	88	Poor-Fair	ns
Patuxent	LE1.1	M	2.6	0.08	2.67 [2.0 - 3.0]	86	Poor-Fair	2.3	0.08	2.33 [1.7 - 3.0]	97	Poor-Fair	*
Potomac	TF2.3	F	2.2	0.11	2.00 [1.7 - 2.6]	49	Poor-Fair	1.5	0.10	1.00 [1.0 - 1.7]	62	Poor	**
Potomac	RET2.2	O	1.9	0.11	1.80 [1.4 - 2.2]	54	Poor	3.1	0.13	3.17 [2.6 - 3.9]	64	Fair	**
Potomac	LE2.2	M	2.8	0.12	2.71 [2.4 - 3.3]	51	Fair	2.6	0.11	2.33 [1.7 - 3.3]	66	Poor-Fair	ns
Virginia Tributaries													
Rappahannock	TF3.3	F	2.3	0.15	2.00 [1.9 - 3.0]	30	Poor-Fair	2.3	0.17	2.20 [1.5 - 3.0]	33	Poor-Fair	ns
Rappahannock	RET3.1	O	2.5	0.16	2.50 [1.9 - 3.2]	31	Poor-Fair	2.0	0.13	2.00 [1.7 - 2.5]	31	Poor-Fair	*
Rappahannock	LE3.6	M	3.3	0.13	3.29 [2.7 - 3.9]	47	Fair	2.8	0.09	2.69 [2.3 - 3.3]	66	Fair	**
Pamunkey (York)	TF4.2	F	2.4	0.18	2.55 [1.6 - 3.0]	26	Poor-Fair	3.4	0.14	3.40 [3.0 - 3.8]	30	Fair-Good	**
York	RET4.3	M	2.4	0.19	2.00 [1.5 - 3.0]	28	Poor-Fair	1.9	0.09	1.67 [1.7 - 2.2]	26	Poor	ns
York	WE4.2	P	2.8	0.13	2.60 [2.2 - 3.5]	43	Poor-Fair	2.5	0.11	2.50 [1.9 - 3.0]	59	Poor-Fair	ns
James	TF5.5	F	2.3	0.17	2.00 [1.8 - 3.0]	32	Poor-Fair	1.4	0.11	1.00 [1.0 - 1.5]	31	Poor	**
James	RET5.2	O	2.2	0.14	2.00 [2.0 - 2.5]	32	Poor-Fair	1.8	0.14	1.80 [1.0 - 2.0]	31	Poor	**
James	LE5.5	P	2.2	0.10	2.33 [1.7 - 2.7]	61	Poor-Fair	2.6	0.08	2.50 [2.0 - 3.0]	73	Poor-Fair	*
Elizabeth	SBE2	M	2.2	0.19	2.00 [1.8 - 2.6]	18	Poor-Fair	1.8	0.14	1.66 [1.5 - 1.9]	18	Poor	*
Elizabeth	SBE5	M	2.2	0.13	2.20 [1.7 - 2.7]	37	Poor-Fair	2.2	0.11	2.25 [1.7 - 2.8]	39	Poor-Fair	ns

Comparing PIBI Scores and Water Quality Criteria Attainment

Each phytoplankton sample has associated with it water quality data collected at the same time. Water quality corresponding to different PIBI values can thus be examined and compared to CBP water quality criteria. The PIBI is a spring-summer index specific to the above-pycnocline layer of open water environments, so comparisons to the water clarity criteria which apply only to nearshore environments, and to the dissolved oxygen criteria which apply year-round to all environments, are necessarily indirect.

Recommendations for numeric chlorophyll *a* criteria were not made by CBP in the 2003 criteria document,[4] although the Commonwealth of Virginia is presently moving to adopt numeric criteria.[7] Table V-6 of the criteria document summarizes chlorophyll *a* concentrations reported in the literature for waters with desirable (mesotrophic) status. Average values range from 1 - 10 µChl *a* l^{-1}. Median and average chlorophyll *a* values for three overlapping groups of PIBI values, PIBI $\geq$ 3.0, $\geq$ 3.5, and $\geq$ 4.0, are well within this range, with the exception of spring oligohaline waters.[8] Chlorophyll *a* values are lowest in PIBI $\geq$ 4.0, with 90% of their values below 10 µChl *a* l^{-1} in all season-salinities except spring oligohaline.

Dissolved oxygen concentrations typically do not fail DO criteria in surface waters and tributary spawning reaches in the bay. A weak, positive correspondence between surface DO and PIBI is found in the 1985-2002 data. Table V-10 of the criteria document[4] shows model-simulated seasonal mean and salinity regime-specific chlorophyll *a* concentrations that are expected to support attainment of DO criteria at *all* locations and depths in the bay. In six of the eight season-salinity groups, chlorophyll *a* medians for PIBI $\geq$ 4.0 align more closely with the simulated concentrations than those for PIBI $\geq$ 3.0, and chlorophyll *a* concentrations show significant reductions ($p<0.05$) as PIBI changes from $\geq$ 3.0 to $\geq$ 4.0 (Figure 7, top panel).

The 2003 water clarity criteria target submerged aquatic vegetation (SAV) and their light requirements. The criteria were derived from complex formulations of light attenuation in the water column and through the settled sediment and epiphyte growth on SAV leaves.[4] An earlier document identified the water column light requirements for SAV as Secchi depth > 0.7 m (low salinity) and > 1.0 m (high salinity) during the SAV growing season.[9] In five of the eight season-salinities, Secchi depths associated with PIBI $\geq$ 4.0 are significantly closer to achieving the SAV light requirement than those associated with PIBI $\geq$ 3.0 (Figure 7, bottom panel).

Overall, water quality conditions associated with P-IBI $\geq$ 4.0 are more likely to meet the CBP DO and water clarity criteria than those associated with P-IBI $\geq$ 3.0. If numeric chlorophyll *a* concentrations are established for the Bay, chlorophyll *a* levels in PIBI $\geq$ 4 are more likely to fully meet the criteria.

Choosing a Restoration Goal

The underlying intent of a restoration goal influences where the goal is set. In the case of phytoplankton, the goal is likely to be set at one of three possible levels:

- PIBI $\geq$ 3.0

Nine of the 29 biomonitoring stations currently have overall average PIBI scores of 3.0 or greater (Table 1), and seasonal PIBI scores in low (tidal fresh, oligohaline) and high (mesohaline, polyhaline salinities presently range just below 3.0 (Figure 8). Significant progress could be demonstrated over the short-term if the goal is PIBI $\geq$ 3.0. This may inspire rather than daunt

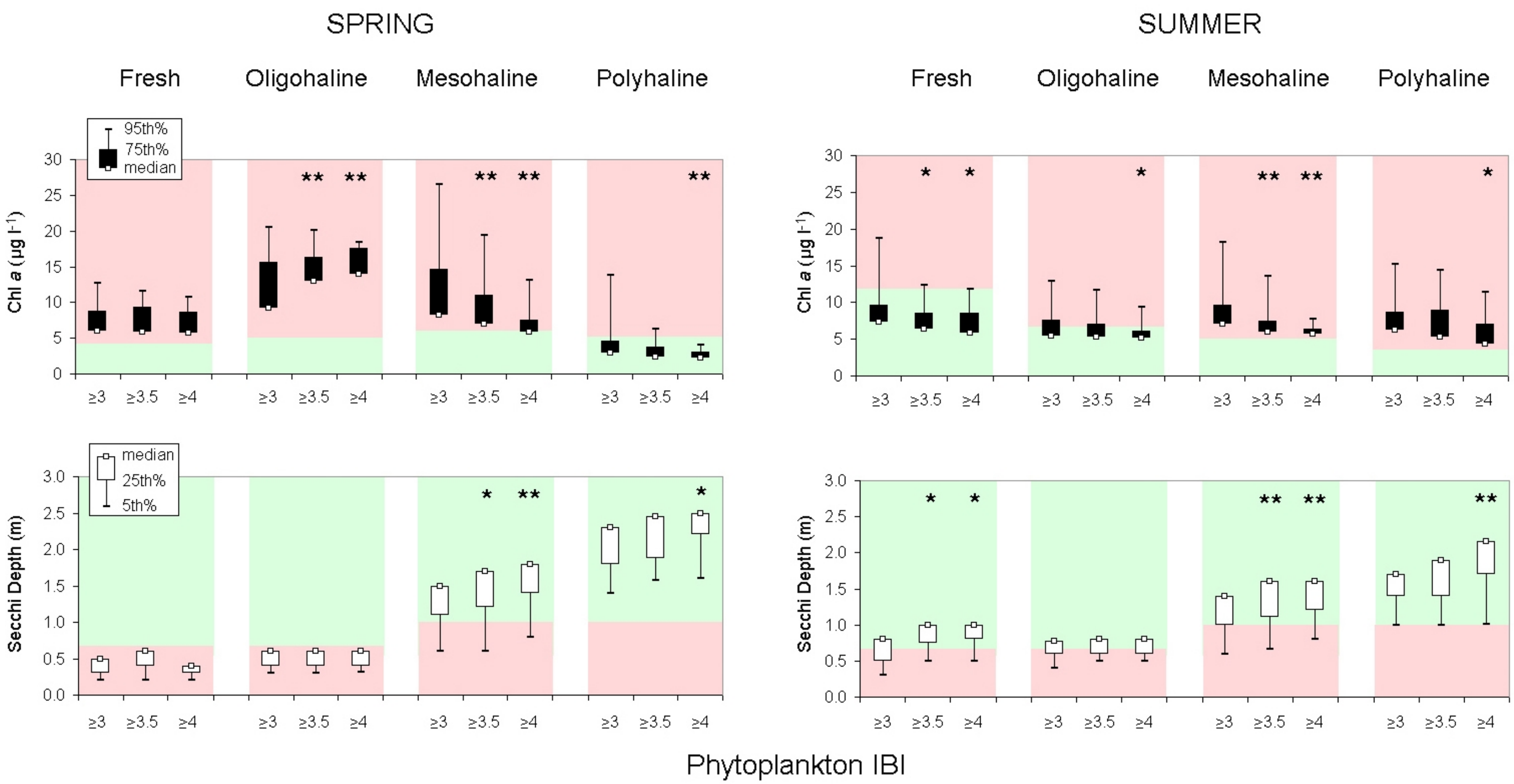

Figure 7. Chlorophyll *a* and Secchi depth values associated with P-IBI ≥ 3.0, ≥ 3.5, and ≥ 4.0 in the 1985 - 2002 CBP biomonitoring station data. *Top panel*: 95th%, 75th%, and median chlorophyll *a* concentrations are shown; red areas, model-simulated mean chlorophyll *a* concentrations that do not support attainment of Chesapeake Bay dissolved oxygen criteria in all bay environments[4]; green areas, mean chlorophyll *a* concentrations that support attainment; *bottom panel*: the 5th%, 25th%, and median Secchi depth are shown; red areas, Secchi depths do not meet Chesapeake Bay habitat requirements for submerged aquatic vegetation; green areas, supportive of SAV.[9] Student t-tests were used to compare values associated with P-IBI ≥ 3.0 to values associated with P-IBI ≥ 3.5 and ≥ 4.0; *, $p < 0.5$; **, $p < 0.01$.

management action and public/political commitment. Achieving 3.0, however, will not remove harmful algal blooms (HABs) or reduce variability (uncertainty) in the PIBI scores, and its ecological benefit is debatable. CBP would have to make clear to the public that a restoration goal of PIBI ≥ 3.0 aims at a minimum of Fair, not Good, to avoid misunderstandings.

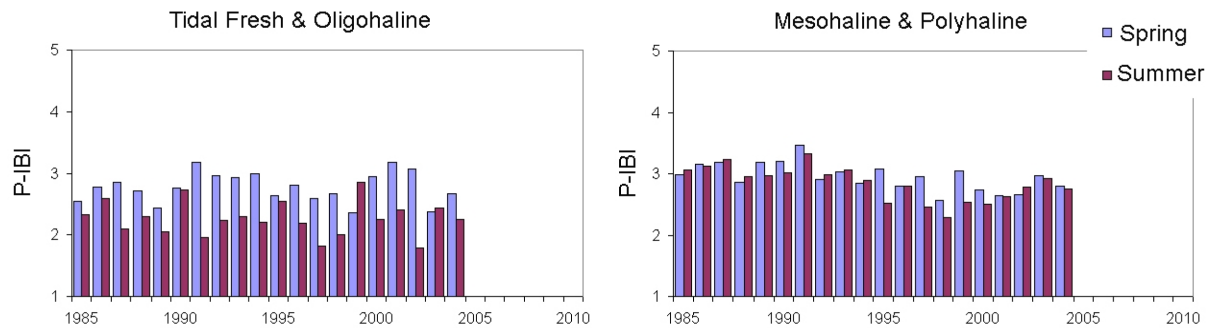

Figure 8. Seasonal average PIBI scores for tidal fresh/oligohaline and mesohaline/polyhaline salinity zones, weighted by segment area.

- Between PIBI 3.0 and 4.0

Spring and summer reference communities have median IBI values of 3.4 - 3.7, and an overall IBI interquartile range (middle 50%) of 2.7 to 4.0. Reference communities have infrequent algal blooms, desirable species compositions with relatively low blue-green algae and HABs, and chlorophyll *a* concentrations somewhat higher than concentrations experienced in the 1950s (Table 2). Reference communities occur in just 17% of Chesapeake samples over all seasons. Only 2.7% of these reference communities have all their component metrics scoring 5 (highest). On average, about half of the metrics in the index score 5 while another third score 1 (lowest), indicating population features are still variable. Good water quality conditions are too transient for these communities to last long at one site.

A restoration goal of PIBI ≥ 3.5 has many reference community features, with a higher percentage of the index metrics scoring 5. About 19% of Chesapeake samples, or ~1/5, currently have IBI ≥ 3.5. Of these, more than half occur in water quality conditions conducive to algal blooms, i.e. excess nutrients and poor water clarity.

To avoid misunderstandings, CBP should make it clear to the public that a PIBI restoration goal between 3.0 and 4.0 is aiming at Fair-Good, not Good, and year-to-year variability in a segment's PIBI can be expected. A PIBI goal set between 3.0 and 4.0 may be useful as an interim goal, until some modest level of water quality restoration produces better, more stable habitat conditions and recovering grazer populations (zooplankton, benthos, oysters, menhaden) exert stronger top-down controls on the phytoplankton.

- PIBI ≥ 4.0

A restoration goal set at 4.0 will be difficult to achieve but is expected to reflect attainment of the Chesapeake Bay water quality standards (see above). Approximately 10% of spring and summer Bay samples, collected mostly in the mainstem, had PIBI scores ≥ 4.0 in the past 20 years.   In these samples, roughly 3/4 of the metrics in the index scored 5 and only 1/12 scored 1. Phytoplankton communities with PIBI ≥ 4.0 exhibit strong reference community quality, with very few algal blooms, low pheophytin and Chl:C ratios (indicates cells are not light-stressed), desirable species compositions, and–according to the literature–sufficient biomass for zooplankton grazers. Chlorophyll *a* concentrations are closest to 1950's levels.[10] The reference communities have a high certainty of co-occurring with desirable water quality conditions (nitrogen, phosphorus, water clarity, dissolved oxygen). CBP will be able to communicate to the public that a goal of PIBI $\geq$ 4.0 aims at a Good status.

	1950's[10]			**PIBI $\geq$ 4.0**		**PIBI $\geq$ 3.5**		**PIBI $\geq$ 3.0**	
						Average concentrations			
	Spr	Sum		Spr	Sum	Spr	Sum	Spr	Sum
F	1.1	1.1	F	6.5	6.3	6.7	6.7	6.4	9.0
O	2.3	2.0	O	13.7	5.3	12.8	5.8	11.0	8.5
M	3.7	4.4	M	6.6	5.6	8.8	6.6	11.3	6.4
P	3.9	-	P	2.4	5.6	3.6	6.7	4.7	6.9
						Median concentrations			
				Spr	Sum	Spr	Sum	Spr	Sum
			F	5.7	5.8	5.9	6.3	6.0	7.4
			O	13.9	5.2	12.9	5.2	9.1	5.4
			M	5.8	5.7	6.9	6.0	8.2	7.1
			P	2.2	4.4	2.5	5.3	2.9	6.2

Table 2. Comparison of average seasonal surface layer chlorophyll *a* concentrations (μg liter^{-1}) in the 1950's[10] with average and median concentrations calculated for PIBI $\geq$ 3.0, $\geq$ 3.5, and $\geq$ 4.0, for 1985 - 2002 biomonitoring station data. Salinities: F, tidal fresh; O, oligohaline; M, mesohaline, P polyhaline. In all but spring oligohaline, chlorophyll *a* concentrations in PIBI $\geq$ 4.0 are closest to those observed in the 1950's.

Goal Recommendation

Key features of phytoplankton populations at different PIBI levels are summarized in Table 3. A restoration goal of PIBI $\geq$ 4.0 or "Good" is recommended for Chesapeake Bay because it is commensurate with attaining state water quality standards and it targets the most desirable populations in present-day Chesapeake Bay. Important phytoplankton features such as chlorophyll *a* are closest to 1950's levels in populations.

A restoration goal of a median PIBI ~ 3.5 would reflect the present-day reference communities; a goal of PIBI $\geq$ 3.5 would reflect the most desirable fifth of present-day communities. Samples with median PIBI ~ 3.5 and PIBI $\geq$ 3.5 occur during comparatively short periods of good water quality exposure and have little opportunity to equilibrate with the long-lived grazer populations. They exhibit favorable scores for many of their metrics (3, 5), but as a whole they represent less than ideal biological integrity.

Goal Attainment

Attainment of a PIBI restoration goal needs to account for the strong, unpredictable influence of annual variability in freshwater flow and its effect on water quality. Attainment of the PIBI goal could be measured as a) an area-weighted, average or median value above the PIBI

PIBI Goal	Status at Goal	Features	Effort*	%**
≥ 4.0	Good	Algal blooms[b] rare (1.4%) Most desirable species composition Blue-green algae biomass low, HABs very rare (0.2%) Sufficient biomass for grazers Most water quality criteria would be met	Hardest	10%
≥ 3.5	Fair-Good	Algal blooms[b] infrequent (5.2%) Desirable species composition Blue-green algae biomass low, HAB's rare (1%) Many chlorophyll criteria and some water clarity & DO criteria would be met	Hard	19%
Ref. Comm.[a] median PIBI: 3.4 - 3.7	Fair-Good	Algal blooms[b] infrequent (5%) Blue-green algae biomass low, HAB's rare (0.4%) Low biomass variability; desirable species composition; 2.7% of IBI scores = 5 (highest) Known association with adequate light & relatively low nutrient concentrations Many chlorophyll criteria and some water clarity & DO criteria would be met	Hard	17%
≥ 3.0	Fair	Algal blooms[b] somewhat common (9.5%) Blue-green algae biomass increasing, HAB's infrequent (1.8%) Higher variability in biomass and species composition Many water quality criteria would not be met	Easier	40%
Present status, 1984-2004 (based on median)	Fair-Poor	Algal blooms[b] frequent (29%) Blue-green algae biomass often high; HAB's somewhat frequent (6.9%); 1% of IBI scores = 5 (highest) High variability in biomass and species composition Most variability in seasonal IBI scores Water quality criteria not met (except surface and spawning area DO criteria) Median index score of all samples is 2.5 Area-weighted average index score is 2.9		

Table 3. Phytoplankton features at different PIBI restoration goals, 1984-2002 data. The PIBI index is on a scale of 1 to 5. [a], present-day reference communities; [b], chlorophyll levels greater than the 95^{th}% of the season- and salinity-specific reference communities; HABs, harmful algal species (the common HABs, *Microcystis aeruginosa* and *Prorocentrum minimum*, were used to gauge rareness); *, level of effort needed to raise median IBI values to PIBI Goal; **, percentage of 1984-2002 phytoplankton samples. Note: PIBI ≥ 3.0 includes all PIBI ≥ 4.0, etc.

goal, or b) a specified high percent of bay surface waters at or above the PIBI goal. These decisions need to be made by CBP after a numeric restoration goal is approved.

Citations

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[8] Spring chlorophyll *a* concentrations in the oligohaline, near the estuarine turbidity maximum, behave differently than those in other season-salinities, i.e., chlorophyll *a* concentrations become *higher*, not lower, as P-IBI approaches 4.0. This suggests a) improving water quality could rehabilitate the spring bloom that is thought to drive much of the bay's summer productivity, and b) the phytoplankton kinetics module of the CBP Eutrophication Model might need to be refined to more accurately portray this important feature of estuarine ecosystems.

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