Seaweed Distribution and Abundance in the Delaware Inland Bays: A declining trend documented via a simple method of collection.

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This report is an addendum to Tyler (2010) in which a full background on seaweed benefits and problems was provided.

Summary

This study's overarching conclusion is that the seaweed reduction over the 1999 to 2009 period that was documented in the parent report (Tyler 2010) continued through the end of sampling in September 2012. The reason for this reduction remains undefined. It seems reasonable to consider that perhaps the substantial public and private sector efforts to reduce nutrient inputs to the Inland Bays over the past three decades are a contributing factor. The author recognizes that there are still localized areas of the Inland Bays in which seaweed periodically becomes dense enough to be regarded as a nuisance or even detrimental to overall ecosystem health, for example the dead-end canals of South Bethany. Nonetheless, the results from this sampling during 3 of 4 recent summer seasons (2009, 2011, 2012) clearly show that there has been a downward trend in Delaware Inland Bays seaweed density overall.

Of particular notice, the density of the green seaweed *Ulva lactuca* is very light to absent in most places in Indian River Bay and Rehoboth Bay, where 15 to 20 years ago it was extremely heavy. The author recalls his first outing on the Inland Bays in the early 1990's at which time large amounts of floating *Ulva* had been deposited across the *Spartina alterniflora* marsh during high tides where it was bleached white by the sun and resembled toilet paper.

Although it would seem that seaweed in shallow waters receives adequate light to proliferate, it is also true that the absence of any type of benthic substrate stabilizing material (i.e. seaweed or seagrass) would facilitate the resuspension of fine bottom sediments into the water column thereby increasing turbidity. Resuspension does seem to be a factor in some areas of the bays, particularly with increasing distance from the Indian River Inlet.

For the past 20 years or more seaweed in the Inland Bays has often been regarded negatively. However, it also important to keep seaweed attributes in mind including habitat

provision and stabilization of bottom sediments. The optimum quantity between too much and not enough remains undefined.

Measuring and categorizing seaweed density is an arbitrary and somewhat artful endeavor. The author settled on categories of light, moderate and heavy and the thresholds for each based on visual observations in conjunction with collections during low tide periods in the 1999 study (Tyler 2000). A different investigator may have made different choices. In the future, perhaps a consortium of resource managers and researchers could independently observe seaweed beds of different density and compare their impressions. The heavy density threshold settled on by the author was a visual density such that depositional feeding by sessile organisms (e.g. clams, oysters) would likely be compromised and water circulation would be poor enough for long enough to allow the development of severe hypoxia and even anoxia near the sediment-water interface. It's a judgment based more on qualitative observation than quantitative measurement.

It continues to be recommended that the Inland Bays Scientific and Technical Advisory Committee explore a path forward to integrate seaweed sampling into the mix of routine water column variables that are collected to meet the monitoring requirements of the Clean Water Act, for the reasons stated in the parent report. The University of Delaware Citizen Monitoring Program (UDCMP) seems best positioned to assume this task as it is the only entity that presently does any seaweed monitoring in the Inland Bays other than that which has been done in this study by the author. The UDCMP presently has 6 seaweed sites that are sampled from shore in the lower Indian River Bay area although none of the sites are located near the 12 fixed sites that were sampled in this study.

Methods

Main points that are relevant to the integration of the 2009 data, with the two additional years of data, are made here otherwise readers are referred to the parent report for a more detailed assessment of the methods used for collection or additional background information on historical distribution of seaweed (Tyler 2010).

Sampling Design

Sampling in 2011 and 2012 was done using the same rapid "hook" methodology as was described in 2009. Unlike the 2009 sampling, seaweed was collected only at the 12 fixed sites, 6 in each bay (Figure 1). Location coordinates were recorded in the field during 2009 using a GPS to mark the general location and to aid in GIS mapping (Table 1). Water temperature, salinity, water clarity (Secchi depth) and seaweed type and density were documented for each site.

Data Analysis

The data were analyzed for variation within and between years. Volume (liters) of wet seaweed in a sieve bucket was again used to quantify seaweed, with the categories of density remaining as in 2009 (Light < 3, Moderate $\geq 3 < 8$ and Heavy ≥ 8). Quantities that did not cover the bottom of the sieve bucket were considered "trace" amounts and for purpose of analysis were arbitrarily assigned a value of 0.5 liters. Likewise, samples for which no seaweed was collected were arbitrarily assigned a value of 0.05 liters. The nonparametric Kruskal-Wallis test was used to examine differences between medians. The median was used rather than the mean because the data for many of the variables were not normally distributed, so a conservative decision was made to use the nonparametric approach throughout. The accepted significance level for all tests is $\alpha = 0.05$.

To understand the box and whisker plots that follow, the box represents the middle 50 percent of the total number of data points, the ends of the whiskers represent the data point that equals or falls closest to 1.5 times the range of the data within the box (i.e. the interquartile range). Small squares beyond the whiskers that are unfilled represent results that are between 1.5 and 3 times the interquartile range. Squares with a cross within are beyond 3 times the interquartile range. The squares emphasize the atypical nature of these data. The vertical line through the box represents the sample median, while the plus sign within the box is the sample mean. Because some of the data tested were normally distributed the means are shown.

Weather data (rainfall, air temperature and wind) were retrieved from the Delaware Environmental Observing System (DEOS) (http://www.deos.udel.edu/monthly_retrieval.html) for the months April – September at the Georgetown and Indian River Inlet stations for the years sampled. For rainfall, the Georgetown data was considered most representative because that station is in the watershed from where comes most of the freshwater that affects salinity in the

Bays. For temperature and wind, the Indian River Inlet data were deemed to be most representative of conditions in the study area because the seaweed stations are relatively close to that site. Monthly averages were the results used for comparison. The variables tested included rainfall (inches per month), air temperature (number of days per month ≥ 90 °F) and wind (average velocity) (see Table 2).

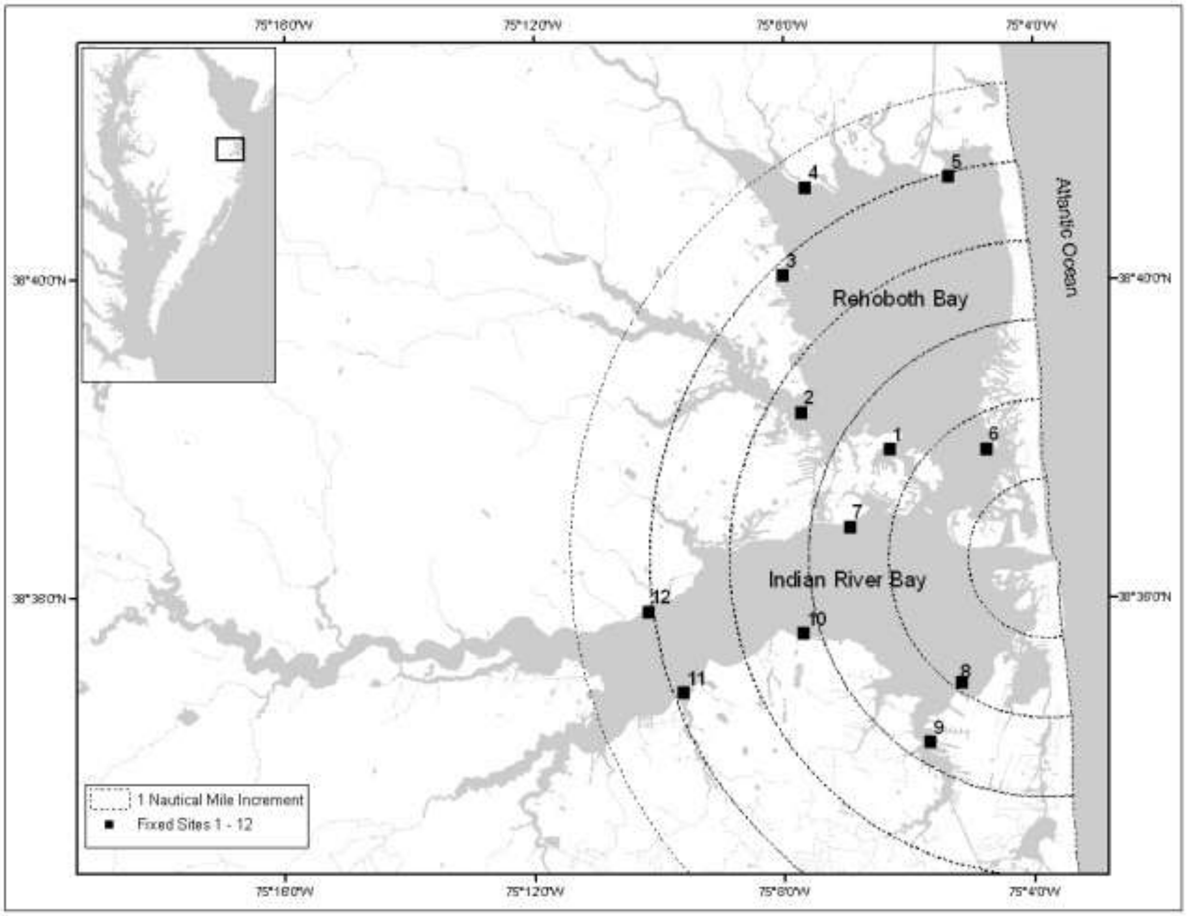

Figure 1: Indian River Bay and Rehoboth Bay, Delaware showing fixed sites sampled for seaweed during 2009, 2011 and 2012.

Table 1: Location data for the 12 fixed seaweed sampling sites in Indian River Bay and Rehoboth Bay, Delaware.

Site	Area Description	Lat.	Long.
1	Roman T Pond	38.63054	75.10469
2	Herring Creek Mouth	38.64013	75.12708
3	Shell Landing	38.66578	75.13293
4	Reh. Bay Community	38.68529	75.12783
5	Thompson Island	38.68805	75.08896
6	Savages Ditch	38.63329	75.07906
7	West of Steels Cove	38.61451	75.11496
8	Pasture Point	38.58249	75.08587
9	Whites Creek	38.56935	75.09573
10	Holts Landing	38.59279	75.12660
11	Blackwater Creek	38.58130	75.16067
12	Oak Orchard	38.59598	75.16999

Table 2: Weather data from the Delaware Inland Bays area. Rainfall data from Georgetown, Delaware. Air temperature and wind data from Indian River Inlet, Delaware.

	April	May	June	July	August	Sept.
Rainfall (total inches)						
2009	4.6	5.7	5.6	2.3	6.5	4.4
2011	2.7	2.0	1.9	2.5	9.6	4.5
2012	3.1	3.2	1.3	2.0	4.9	3.0
Air Temperature (# days > 90°C)						
2009	1	0	2	2	5	0
2011	0	2	2	6	4	0
2012	0	0	5	10	2	0
Wind Velocity (avg. mph)						
2009	9.2	7.5	7.2	6.6	5.4	10.1
2011	10.5	8.2	6.1	6.1	7.1	7.8
2012	8.9	8.7	8.6	7.2	6.3	7.2

Results

Environmental Conditions – Water

Differences between years were tested for water temperature, salinity and water clarity (Secchi depth). There was no inter-annual difference in temperature (Figure 2). Years 2009 and 2011 were similar for salinity and clarity while 2012 was higher for salinity (Fig. 3) and lower water clarity (Fig. 4) ($P < 0.001$, respectively).

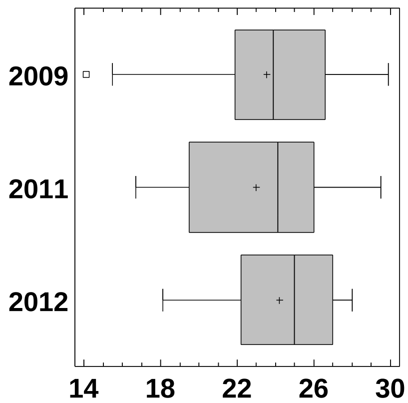

Fig. 2: Inter-annual comparison of temperature (°C) distributions in Indian River Bay and Rehoboth Bay, Delaware using monthly (May – September) sampling data from the 12 fixed seaweed sampling sites. (N = 59 samples per year)

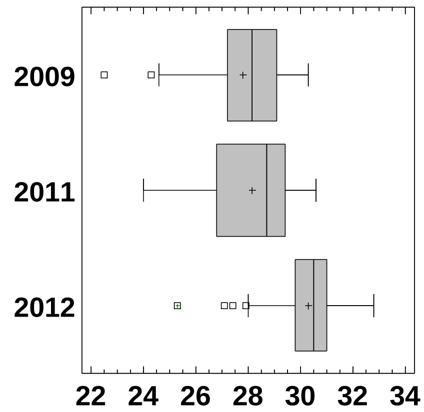

Fig. 3: Inter-annual comparison of salinity (ppt) distributions in Indian River Bay and Rehoboth Bay, Delaware using monthly (May – September) sampling data from the 12 fixed seaweed sampling sites. (N = 54 samples per year)

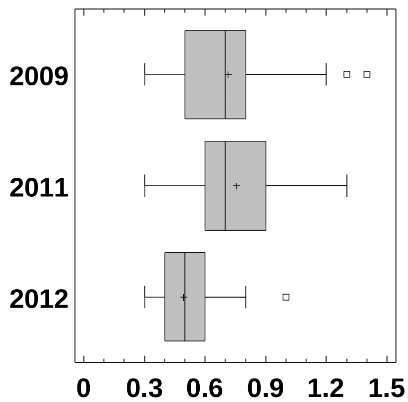

Fig. 4: Inter-annual comparison of Secchi depth (m) distributions in Indian River Bay and Rehoboth Bay, Delaware using monthly (May – September) sampling data from the 12 fixed seaweed sampling sites. (N = 54 samples per year)

Environmental Conditions - Weather

The inter-annual extremes of temperature, rainfall and the duration and timing of such extremes can result in some years being quite different than others. It is general knowledge that fluctuations in abundance, distribution and growth of all kinds of flora and fauna are to substantial extent responses to seasonal/annual weather variation. The interest in examining some key elements of weather in this study was to see if there might be something definitive, or at least suggestive regarding its' influence on seaweed fluctuation in the Inland Bays.

There were a few notable features in the weather data presented in Table 2. The period April through June, 2009 had considerably more rain than the same period during the other two years, which were similar to each other. The significantly higher salinity during 2012 (Figure 3) was the result of a 3-month period of drought (May 10 through August 9) when only 5.47 inches of rain was recorded. While the number of hot days (> 90 °C) over the 6-month period during both 2012 and 2011 was the same (24) and considerably more than in 2009 (8), this numeric difference was not enough to make a significant difference in the water temperature (Figure 2). Also, average monthly wind velocity was similar during all three years (Table 2) so at this level of analysis it does not appear that wind accounts for much of the significantly lower water clarity in 2012.

Seaweed Conditions

The main finding of this study is that the seaweed density and distribution reductions that occurred between 1999 and 2009 persisted through the end of sampling in September 2012. Analysis of all the samples collected between 2009 and 2012 (180) showed that density was mostly light (defined as < 3 liters seaweed), continued that way in all three years (Figure 5a) and was lightest in 2011 ($P = 0.028$). A comparison of samples in which seaweed of density ≥ 1 liter was collected, revealed no difference between the 3 years (Figure 5b).

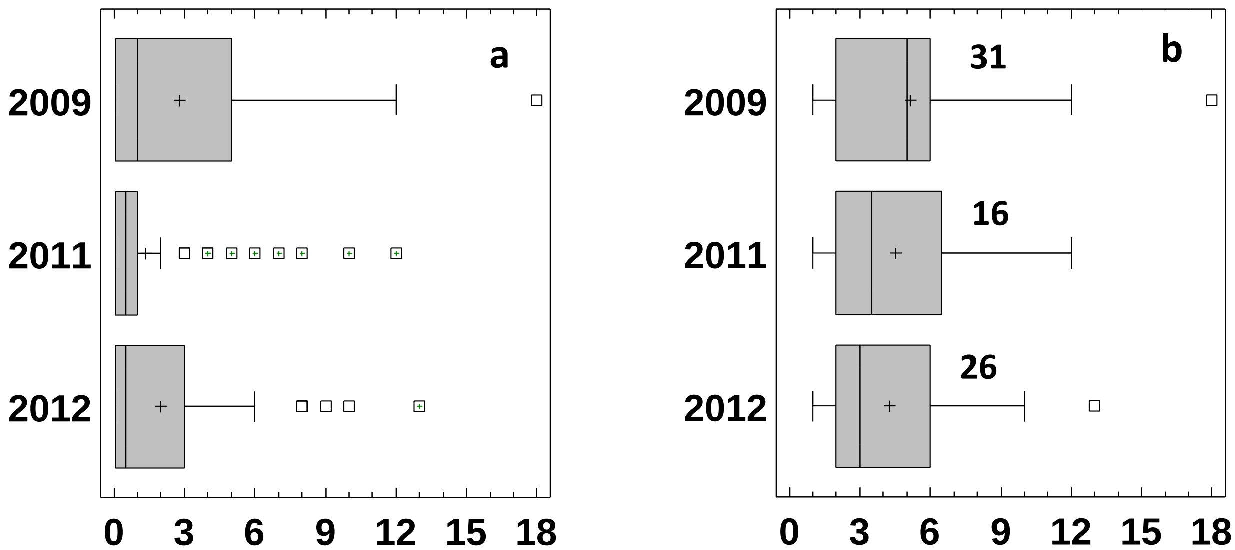

Figure 5a-b: Seaweed density (liters) from 12 near-shore sites in Indian River Bay and Rehoboth Bay, Delaware sampled monthly from May – September over 3 years. Left panel (a) N = 60, or all samples attempted regardless of whether seaweed was collected or not. Right panel (b) N = samples per year with 1 liter of seaweed. In (b) the actual N is positioned to the top right of the box for each respective year.

The preponderance of light density samples is further illustrated by Figure 6. It is important to keep in context that a criterion for selection of the 12 sites monitored in this study was that seaweed occurred there at some level of abundance during the late 1990's, when there was a relatively large public focus on related problems. At most of the sites (including 1, 3, 4, 5, 6, 7, 8, and 11) densities were such that bivalve kills and/or nuisance reports from the public occurred with some recurring routinely. In consideration of this fact, the proportion of samples over all three years (60%) for which no, or a trace amount of seaweed was collected is striking (Figure 7).

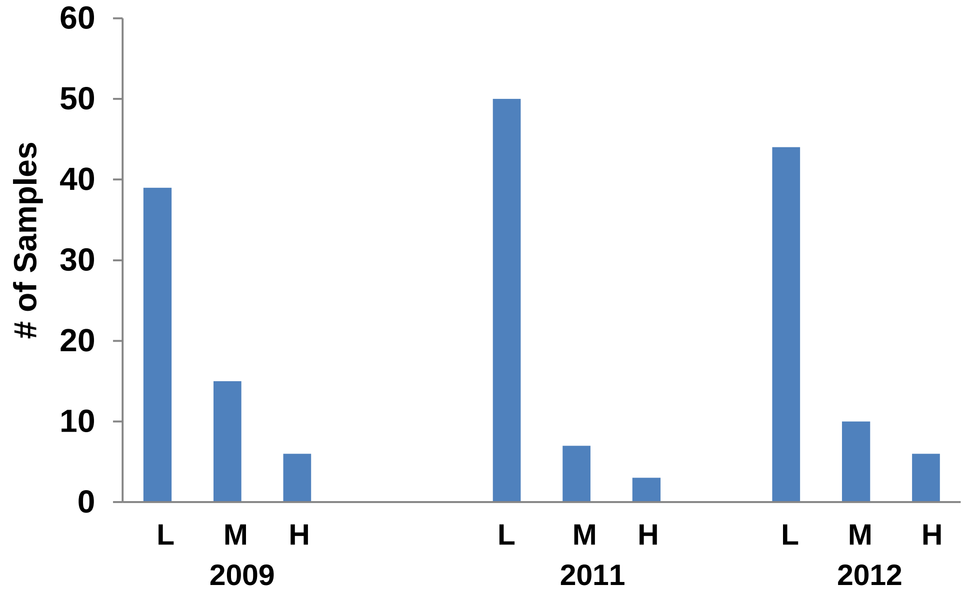

Figure 6: Seaweed density (wet volume – liters) categories - light (L < 3 liters), moderate (M ≥ 3 to < 8 liters) and heavy (H ≥ 8 liters) for each of 3 sampling seasons from Indian River Bay and Rehoboth Bay, Delaware. N = 60 samples per year.

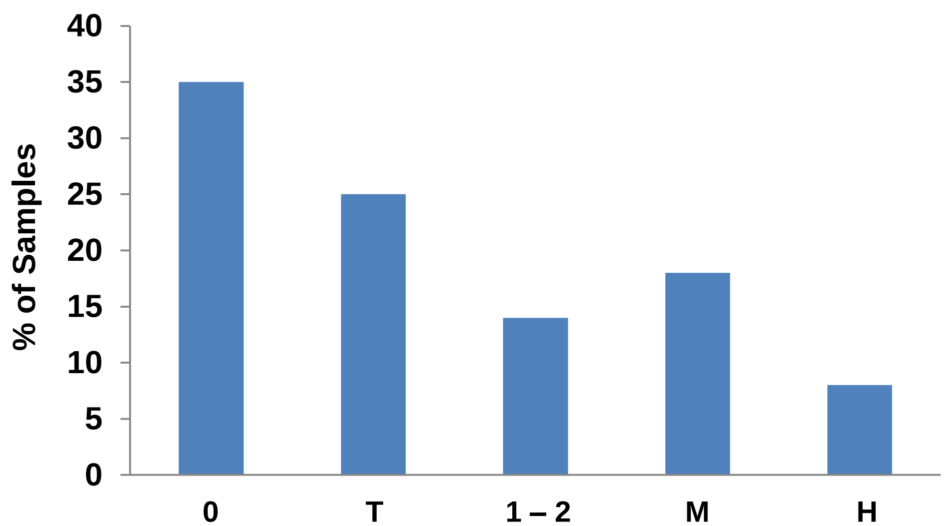

Figure 7: Proportion of seaweed samples in each density (wet volume – liters) category for all 3 sampling seasons (2009, 11 and 12) from Indian River Bay and Rehoboth Bay, Delaware. N = 180 samples. First three bars from left collectively represent the light (L) category (< 3 liters with 0 = no seaweed collected, T = some quantity < 1 and the remainder). M = moderate (3 to < 8 liters), H = heavy (≥ 8 liters).

In the parent report, the variation in seaweed density over the course of the 2009 season was examined by combining for each month the samples from the fixed sites that were in the moderate and heavy categories. This very small dataset suggested that density was highest during July when the samples from 50% of the fixed sites were in this combined group with gradual increases in May and June and gradual decreases in August and September. This pattern mostly continues when the data from all three years are pooled (Figure 8) with the only difference from the 2009 analysis being a greater number of samples joining this group in May.

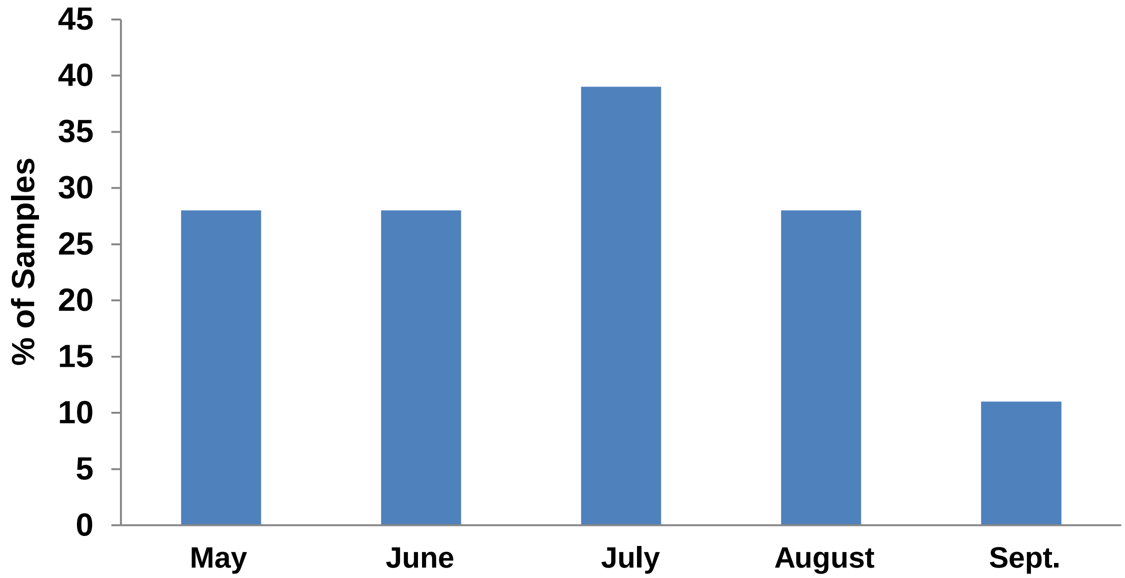

Figure 8: Percentage seaweed samples for each month in the combined moderate (3 to < 8 liters wet volume) and heavy (≥ 8 liters). Samples were collected from Indian River Bay and Rehoboth Bay, Delaware over three seasons 2009, 11 and 12. N = 36 samples per month.

For each site, pooling of the 3 seasons of data shows obvious and consistent differences in density (Figure 9). Regarding moderate to heavy density, among all 12 sites the heaviest and most consistently abundant seaweed occurred at Site 1 (Roman T. Pond). This was the only site that had at least one heavy category sample in all three years and it accounted for 7 (47%) of the 15 heavy density samples in the entire study. In combining all the moderate and heavy density samples from all 12 sites (N = 47) two sites, 1 and 8 (Pasture Point Cove) accounted for 22 (47%). Of the 30 samples collected at these two sites, 73% were in the moderate and heavy categories. Three sites, 1, 3 (Shell Landing Cove) and 5 (Thompson Island) had at least one moderate or heavy category sample in each year. At Site 2 (Mouth of Herring Creek), the first 4 samples collected in 2009 (May – August) were moderate to heavy. Of the other 11 samples beginning with September 2009, one had 1 liter while the remaining 10 had either a trace amount or no seaweed collected. This was one of the deeper sites (total depth is about 2 m) and shares this characteristic with Site 8. However, while seaweed declined at Site 8 in 2011 and 12, in comparison to 2009 it did not disappear (See attached data appendix).

Of the samples that contained only trace to absent amounts of seaweed, only one site had all 15 samples that yielded these densities, and that was Site 4 (Rehoboth Bay Community). This area had very heavy seaweed in the late 1990's, which created such a public stir that it was harvested on multiple occasions by the State of Delaware, DNREC. The seaweed conditions found in the upper half of Indian River Bay, i.e. Site 10 (Holts Landing), Site 11 (Blackbird Creek) and Site 12 (Oak Orchard) continued in 2011 and 12. Of the 45 samples collected at these three sites over all three years, 91% contained either trace amounts to a complete absence of seaweed. One moderate density sample of 3 liters was collected at Site 11 in 2012. Four other sites had over 50% of their samples accounted for by none collected or trace quantites, which included: Site 2 (as mentioned in the preceding paragraph), 6 (Savages Ditch), 7 (West of Steeles Cove) and 9 (Whites Creek).

Additionally, regarding Figure 9, when all 180 samples from the 12 sites are pooled (bottom of graph), samples of high density appear as outliers (beyond the upper whisker of the box). Also noteworthy is that of key data statistics for this pooled group of samples the overall median is the value of 0.5 assigned to trace amounts of seaweed and the mode (the sample result that occurs most frequently) is the 0.05 assigned to samples for which no seaweed was collected.

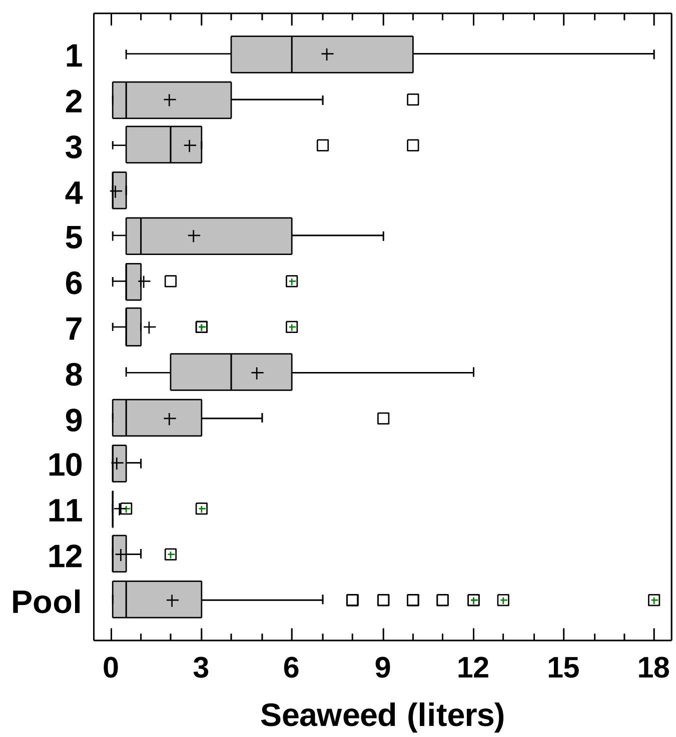

Figure 9: Comparison of seaweed density (wet volume – liters) data from 12 sites sampled monthly from May – September, 2009, 2011 and 2012 in Indian River Bay (1-6) and Rehoboth Bay (7-12), Delaware. N = 15 samples per site. Pool = all 180 samples. Density categories used in analysis are light (< 3 liters), moderate (3 to < 8) and heavy (≥ 8).

One of the main findings of the parent report (Tyler 2010) was that the historically dominant seaweed assemblage comprised of the genera *Agardhiella*, *Gracilaria* and *Ulva* was replaced in 2009 by a single species of the genus *Ceramium* (Figure 10). A point of discussion in the parent report was that the abundant appearance of *Ceramium* may represent a shift in dominant seaweed type, but, that one year of sampling was not enough to conclude such. The subsequent sharp decline of *Ceramium* in density and distribution during 2011 and 2012 was one of the main points of the study overall and the reason for it is unknown. Meanwhile *Ulva*, which during the 1990's was the seaweed type that elicited the most complaints and was most responsible for bivalve kills, was not dominant in any samples over the entire study, though it was mixed with the other types in several samples overall (Table 3). Also overall, Gracilaria was the most widely distributed and frequently occurring genera.

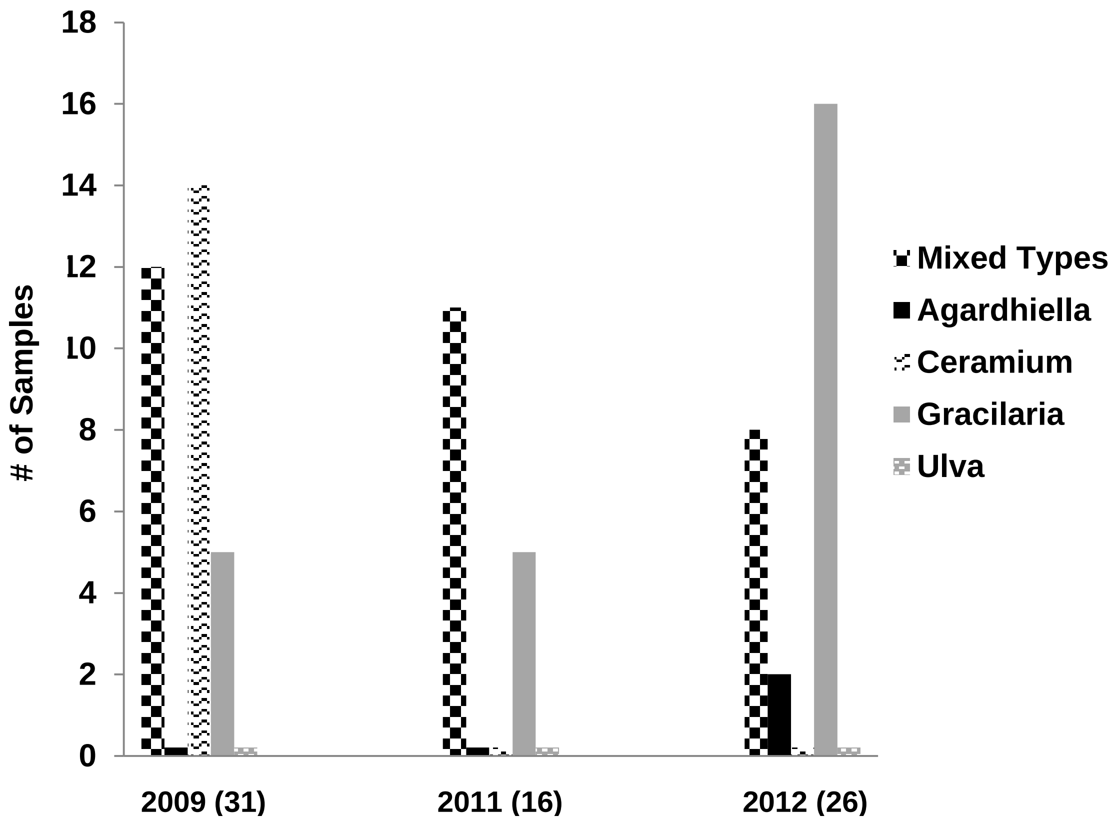

Figure 10: Partitioning of the seaweed samples of density ≥ 1 liter by dominant genera collected from Indian River Bay and Rehoboth Bay, Delaware over three seasons. Mixed types means some combination of two or more of the four dominant genera. Monthly sampling was done at 12 sites from May – September ($\sum_N = 60$ samples per year). The number in parentheses next to the year on the X axis indicates the collective number of seaweed samples ≥ 1 for that year. The very short bars, e.g. Agardhiella in 2009, indicate 0 samples in that genera and were given an arbitrary value of 0.2 to fill that space.

Table 3: Number of occurrences for the four dominant seaweed genera collected from 12 sites in Indian River Bay and Rehoboth Bay, Delaware during 2009, 2011 and 2012 (monthly May – September, 15 total samples per site). Criterion for occurrence was that the total density of seaweed in a sample must be ≥ 1 liter.

Site	Agardhiella	Ceramium	Gracilaria	Ulva	# N ≥ 1 liter
1	5	0	14	3	14
2	0	4	1	0	5
3	3	4	6	1	10
4	0	0	0	0	0
5	3	0	8	3	8
6	0	0	7	4	7
7	0	2	6	4	6
8	5	11	7	6	12
9	1	6	5	6	7
10	0	1	1	1	1
11	0	0	1	1	1
12	0	0	2	1	2
Pool	17	28	58	30	73

This study's overarching conclusion is that the seaweed reduction over the 1999 to 2009 period that was documented in the parent report (Tyler 2010) continued through the end of sampling in September 2012. The reason for this reduction remains undefined. It seems reasonable to consider that perhaps the substantial public and private sector efforts to reduce nutrient inputs to the Inland Bays over the past three decades are a contributing factor. The author continues to emphasize that integrating seaweed sampling into the mix of routine water column variables that are collected to meet the environmental monitoring requirements of the Clean Water Act remains important for the reasons stated in the parent report.

References

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