## Introduction

Seaweeds (macroalgae) are prominent aquatic plants in Indian River Bay and Rehoboth Bay (The Inland Bays), Delaware where types, distribution and abundance have been documented by Orris and Taylor (1973), Timmons and Price (1996) and Tyler (2000). Their ecological influences and relationships with people are mixed. Benefits include food and shelter for various creatures including invertebrates and fish (Wilson et al. 1990a, Wilson et al. 1990b, Sogard and Able 1991, Sogard et al. 1992, Szedlmayer and Able 1996, Epifanio et al. 2003). Several types of water birds eat seaweed and/or the creatures that live in or on it. Detriments are related to dense accumulations on shorelines and in shallow waters during the warmer months that are undesirable in appearance and odor, hinder boating and smother creatures that live in or on the bottom (White 1968, Perkins and Abbott 1972, Wharfe 1977, Dauer and Connor 1980, Rosenberg 1985, Everett 1991, Mackenzie 2000). In the Inland Bays, seaweed accumulations in shallow waters that lasted for periods of weeks to months have been associated with poor health in hard clams (Tyler 2007) and with bivalve kills (B. Anderson and R. Tyler personal observation).

In the Inland Bays, seaweed abundance dense enough to trigger public complaints and damage to aquatic creatures has been occurring since at least the 1980's. Such abundance has been attributed to human-influenced increase in the rate of eutrophication, a phenomenon driven by the loading of organic matter and nutrients (nitrogen and phosphorus) to an aquatic system (see Nixon 1995). This conclusion facilitated the inclusion of the Inland Bays in the National Estuary Program in 1989, followed by development of *The Comprehensive Conservation and Management Plan for the Delaware Inland Bays* (CCMP). The CCMP identified eutrophication and habitat loss as the two factors most responsible for declines in water quality and abundances of desirable aquatic creatures (IBEP 1995).

The CCMP led to the development of a Total Maximum Daily Load (TMDL) model for the Inland Bays (State of Delaware 1998), which established nutrient reduction targets that are to be met through implementation of a Pollution Control Strategy (PCS) (State of Delaware 2008). The PCS is a set of regulatory and voluntary actions that are focused upon reducing nutrient loading throughout the Inland Bays watershed for the purpose of reducing eutrophication symptoms, including nuisance abundance of seaweed. The nutrient reduction targets are set at levels that ecological models predict will suppress algal growth to the extent that 1) dissolved oxygen (DO) will meet standards protective of aquatic life and 2) enough sunlight will reach the bottom to allow reestablishment of seagrass (submersed vascular plants). Seaweed does not have roots whereas seagrass does.

The presence of seagrass in an estuarine system is widely regarded to be an indicator of good ecological health, and its demise an indicator of system decline (Stevenson et al. 1993, Valiela et al. 1997, Bricker et al. 1999, Nixon 1999, Nixon et al. 2001). Seagrass is indigenous to the Inland Bays but has not been observed growing there since about 1970 (Orris and Taylor 1973; Price 1998) with exception of a small replanted area of eelgrass, *Zostera marina*, in southeastern Indian River Bay that has survived for the past several years. It is hoped that the Inland Bays ecosystem will respond to the PCS actions by again supporting seagrass and greater abundance of desirable aquatic creatures, for example finfish, blue crabs, and clams.

A key indicator of whether the Inland Bays TMDL/PCS actions are having the desired effect is the concentration in the water of chlorophyll *a* (Chl *a*), a routinely used indirect measure of algal density. As it is presently being applied in the Inland Bays Chl *a* can be misleading as an indicator of ecological condition because it only represents one of multiple pools of Chl *a* in the aquatic environment. In a given waterbody there can be four pools of Chl *a* including the three main types of algae (phytoplankton, periphyton, seaweed) and seagrass (currently insignificant in the Inland Bays). The phytoplankton pool is routinely monitored by conventional methods of water sampling, whereas specialized sampling is required to measure the seaweed and periphyton pools. Knowledge of seaweed density is important in Indian River Bay and Rehoboth Bay because they tend to be the dominant flora along the shorelines and in shallow areas of the mainstems. In these areas the water can be very clear and low in phytoplankton Chl *a* even though bottom coverage by seaweed is dense enough to prohibit the growth of seagrass and cause DO to drop to levels that repel, or even kill, aquatic creatures. Thus it is not possible to know if environmental conditions are suitable for seagrass growth, let alone reestablishment, without knowledge of seaweed density.

Dissolved oxygen conditions due to heavy seaweed density can become severely hypoxic (< 2.0 mg $l^{-1}$ $O_2$) to anoxic (< 0.2 mg $l^{-1}$ $O_2$ ) under two scenarios: 1) duration of minutes to hours from the water surface to the bottom during the a.m. period of the diel (24 hr) cycle and 2) duration of days to weeks in the lower layer of a seaweed mat due to very low water circulation, with the upper layer of the seaweed mat and the overlying water having healthy concentrations of DO (D'Avanzo and Kremer 1994, Krause-Jensen et al. 1996, MacKenzie 2000). The second scenario is sometimes exacerbated by the release of hydrogen sulfide from the bottom and the decaying seaweed after DO has been completely used up. This second scenario can be quite damaging to aquatic creatures that are nonmotile or have low mobility.

If the TMDL/PCS approach succeeds in reducing nutrient levels and the Chl *a* level drops as predicted, then it is hoped that water transparency will increase and enough light will reach the bottom to allow the growth of seagrass (rooted vascular plants), specifically eelgrass or widgeon grass *Ruppia maritima*. Such growth would indicate that the PCS is working and it would set up the Inland Bays for a cascade of increases in the abundance of other aquatic creatures and water birds. It is important to recognize that creatures such as blue crabs, the various economically important finfish species and water birds may not respond as hoped to increases in seagrass in the Inland Bays due to influences of external habitats, natural cycles and various human activities upon their respective life cycles.

The main objective of this study was to explore a low-cost, low-tech sampling approach for seaweed in the Inland Bays and similar shallow waters that can be used routinely over the long-term by trained citizen volunteers to track changes in type, distribution and abundance. A second objective was to identify similarities and differences between this study and previous studies with regard to dominant seaweed types, distribution and abundance and reset the baseline for this important variable at the onset of Pollution Control Strategy implementation.

## Methods

Sampling Design

Sampling was done monthly from May through September. Seaweeds were collected, identified to genera (for example, *Aghardiella*, *Ceramium*, *Gracilaria*, *Ulva*) and quantified using the same method as in 1999 (Tyler 2000a). Samples were processed in the field. Water temperature and salinity were measured using a YSI multi-parameter sonde and water transparency was measured using a Secchi disk (20 cm diameter).

The sampling design included a mix of fixed and randomly stratified sites. During each sampling event, there were 12 fixed sites, 6 in each bay (Fig. 1) and 9 to 12 random sites, also divided between bays. Sampling site coordinates were recorded in the field using GPS and later mapped using GIS. The fixed sites were distributed to represent the main stems of both bays. Most of the fixed sites in this study were also sampled in 1999, with sites 1, 6 and 12 added. Random sites were selected from within one-nautical mile increments starting from the bridge over Indian River Inlet, landward to six miles from the inlet (Fig. 1). No samples were taken from the inlet to the one-mile increment (0-1) because there is no history of problematic seaweed in that area. Thus, there were five nautical mile increments sampled (e.g. 1-2, 2-3, etc) for each bay. To select the increments randomly for each sampling event tokens were placed into a hat (i.e. 4 tokens per distance increment * 5 increments per bay * 2 bays = 40) and 12 were drawn. Thus knowing which increments were to be sampled and the number of samples within respective increments, the principal investigator chose serendipitously while in the field where specifically to collect the “random” samples. This was done so that the random samples could be collected without losing time in going much out of the way while navigating between the fixed sites. Small-scale spatial variation in seaweed density was expected around any given site therefore at least one site was sampled in triplicate on any given day.

Sampling was conducted from late-flood through early-ebb tide so that navigation between sites would not be hindered by shallow water. Water depth at the sampling sites did not exceed 1.2 m (based on mean low water soundings – see NOAA nautical chart 12216).

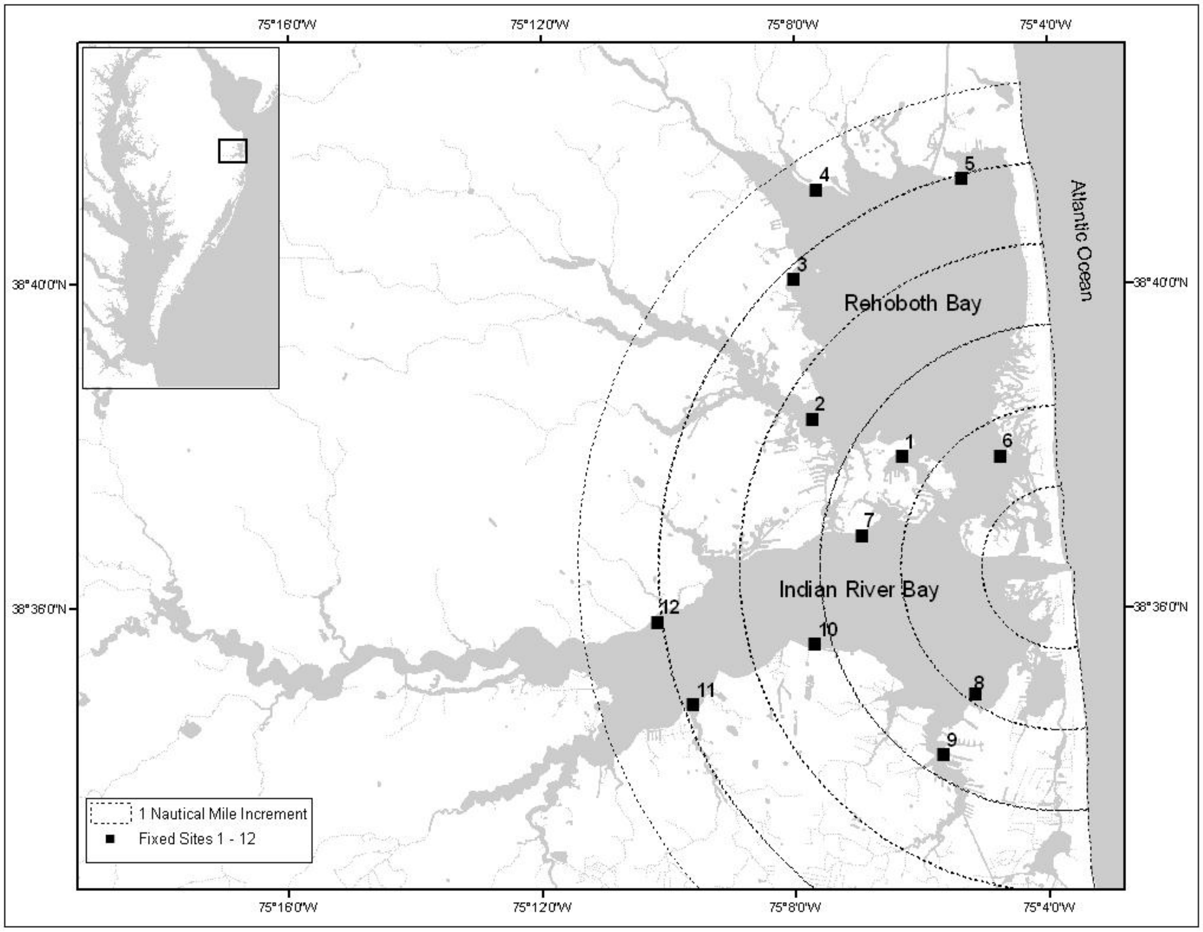


**Figure 1. Indian River Bay and Rehoboth Bay, Delaware showing fixed sites sampled for seaweed during 2009 and nautical mile increments.**

<u>Sampling Technique</u>

Seaweed was collected using a stainless steel grappling hook (Photo 1). The method was developed by the Project Manager during the 1999 seaweed study (Tyler 2000a). The hook is 25 cm long, has a width of 24.3 cm with six tines spaced about 9 cm apart and is attached to a 10 m length of 0.95 cm diameter nylon line. With the boat drifting, the hook was tossed to the windward side and allowed to settle to the bottom. On each toss the line was given five steady tugs and then the hook was hauled into the boat. A tug is described as extending one's arm straight away from the body and then contracting the elbow until the hand is even with one's side. This is a distance of about 0.5 m ± 0.1 m depending upon the arm length of the sampler. Three tosses made up a single sample that was placed into a bucket graduated in liters (Photo 2). The bucket was shaken from side-to-side a few times to settle and uniformly distribute the seaweed.

**Photo 1: Stainless steel grappling hook used to sample seaweed since 1999 by the author, R. Tyler. Hook was fabricated by William Wireman of Dover, DE.**

**Photo 2: Bucket used to measure seaweed volume. The genera of seaweed pictured is the finely bushy red seaweed, *Ceramium*. Photo Chris Bason, CIB.**

Samples of seaweed were reported as liters (volume) of algae. Density was categorized as light (0 to < 3 liters), moderate (≥ 3 to < 8 liters) and heavy (≥ 8 liters). Dominant groups were categorized according to Gosner (1978) and included the "finely bushy red seaweeds" *Ceramium* and Polysiphonia, (Photo 2) "coarsely bushy red seaweeds" *Agardhiella* and *Gracilaria* and the "green seaweed" *Ulva* (Photo 3).

**Photo 3: Frequently collected seaweed genera of the Delaware Inland Bays clockwise left to right *Agardhiella, Ulva, Gracilaria*. Photo: RobinTyler.**

The "hook method" was tested by the author (Tyler 2000a) in a side-by-side comparison against the more precise method of harvesting seaweed from a one square meter plot. Light and moderate densities of seaweed were not significantly different between the two methods. The hook method resulted in significantly lower volumes of seaweed than did the harvest method when seaweed was at heavy density (Tyler 2000a). However, the hook method still clearly identified conditions where seaweed density was heavy enough to suppress DO and harm sessile and low-motility creatures.

The hook method has limitations. First, if the wind is less than a "Light Breeze" (< 4 wind knots, see the Beaufort Wind Scale) the sampler must make sure that the line on the hook is long enough to cover the five tugs. Extending the line length to 15 m would easily resolve this occasional problem. Secondly, the hooks used in this study tend to "set" in hard bottom areas, particularly those where seaweed density is light to absent. This makes it difficult to maintain a consistent distance for each tug. It should be possible to modify the hook so that seaweeds are still collected without the hook sticking in hard bottom.  Finally, structural differences between different seaweeds may influence volume measurements and thus density.  For example, the finely bushy red seaweed *Ceramium* does not settle as compactly in the bucket as *Ulva* does.  Although this difference could be overcome by comparing seaweed dry weights rather than wet volumes, doing so would add a laboratory step to the analytical process that would probably complicate the task to the extent that volunteers would not be able to do the work.

## Results

Environmental Conditions

Salinity and light affect seaweed distribution and abundance.  Salinity ranged from 19.6 to 30.4 ppt. with a median of 28.1 ppt (Fig. 2).  Seventy percent of the measurements were ≥ 25 ppt., indicating a stable polyhaline environment, a condition which seems favorable for the dominant seaweeds of the Inland Bays.

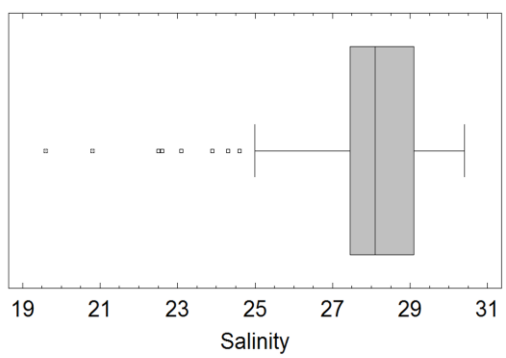


**Figure 2.  Box and whisker plot of all salinity measurements (N = 104) taken in conjunction with seaweed samples in Indian River Bay and Rehoboth Bay from May to September, 2009.  The line through the box represents the median value.**

Secchi depth is the most common and oldest way of measuring transparency in natural surface waters.  The literature regarding its use as a surrogate for direct measurements of light attenuation in the water column, the amount of photosynthetically active radiation (light) remaining at depth and the depth of the "photic zone" (1% of surface light remaining) is vast (see Poole and Atkins 1929, Beeton 1958, Tyler 1968, Megard and Berman 1989, Gattuso et al. 2006).  These studies suggest that the Secchi depth corresponds to about 10 to 20 % of the light at the water surface.  The author compared Secchi Depth with direct light measurements in a freshwater pond, within a few miles of the Delaware Inland Bays that was highly turbid due to phytoplankton and found that about 30 % of the surface light remained at the Secchi depth (Tyler 2000b).  The Secchi depth multiplied by 3.0 closely approximates the depth of the photic zone (Sharp et al. 2009).

Secchi measurements in the Inland Bays during 2009 ranged from 0.3 to 1.4 m with a median of 0.7 m (Fig. 3).  For 95 % of the samples, 3.0 times the Secchi depth exceeded the total depth, with some of the Secchi measurements equaling the total depth.  Water transparency varied among the sites, with the clearest water occurring within two nautical miles of the inlet and the murkiest water occurring on the north side of Indian River Bay around Oak Orchard.  Overall, considering that the measurements were taken around the time of high tide it is likely that at all sites the bottom was well within the photic zone during most of the day.  Thus regarding light, conditions appeared suitable to support seaweed growth even in areas where little or none was collected.

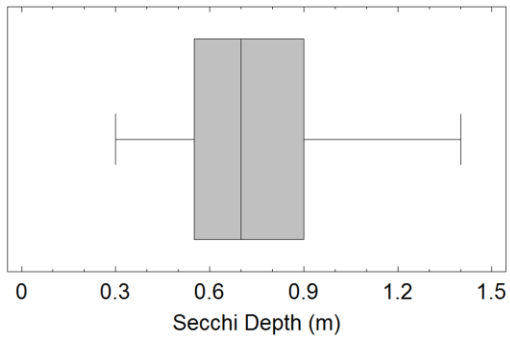


**Figure 3: Box and whisker plot of all Secchi disk measurements (N = 112) taken in conjunction with seaweed samples in Indian River Bay and Rehoboth Bay from May to September, 2009. The line through the box represents the median value.**

Bottom character may also be important to the distribution of seaweed types. In this study, bottom character ranged from hard (sand) to soft (mud) with most of the sites being hard. In the 1999 study, *Ulva* was the most dominant seaweed where the bottom was hard while *Agardhiella* and *Gracilaria* were dominant where the bottom was soft. In this study, *Ceramium* occurred over hard and soft bottom and there were not enough samples dominated by the other three seaweed types to make a comparison with 1999.

<u>Seaweed Conditions</u>

Of the 112 samples, seaweed was absent in 30.3 % while only 25.9 % fell into the moderate and heavy density categories (Fig. 4). Based on the 12 fixed sites, density appeared highest during July when half of the sites were either moderate or heavy (Fig. 5). Figure 6 shows temporal and spatial variability in seaweed density from May to September 2009. In all other months at least 8 of the fixed sites had light density. No sites, fixed or random, had heavy density seaweed in May or September. The most widely distributed and abundant type of seaweed in both bays during 2009 was *Ceramium spp.* (Fig. 7). This "finely bushy" red seaweed was also dominant during a similar one-time survey conducted during May 2008 (R. Tyler unpublished data). Fixed sites where heavy density of *Ceramium* frequently occurred were Site 2 and Site 8 (Fig 6). It sometimes occurred at heavy density at random sites along the west side of Rehoboth Bay (Fig. 6). In Indian River Bay, heavy density of *Ceramium* was collected at Site 9 and at a nearby random site.

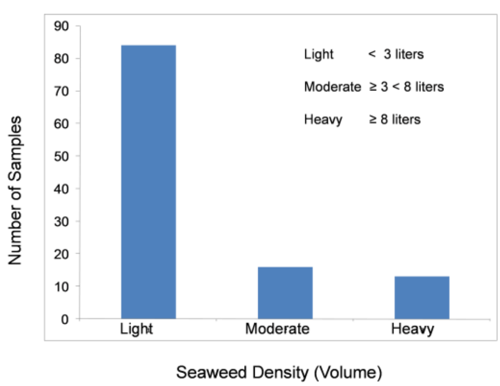


**Figure 4: Density (wet volume) categories for all seaweed samples (N = 113) collected from Indian River Bay and Rehoboth Bay, Delaware during 2009.**

*Agardhiella*, *Gracilaria* and *Ulva* were much reduced from the distributions and abundances observed in 1999 (see Tyler 2000a). The only place where these types occurred in samples at heavy density was Site 1 and in only one sample (July 13). Of these three types, *Gracilaria* was the most widely distributed and abundant. No windrowed accumulations were observed of either type that would be considered a public nuisance or threat to bottom dwelling animals. Moderate to heavy densities of *Gracilaria* with minor amounts of *Agardhiella* were sampled in upper Rehoboth Bay (R5-6) and around Site 6.

Seaweed was consistently absent in Indian River Bay samples west of the mouth of Whites Creek on the south side and Steeles Cove on the north side. In Rehoboth Bay, seaweed

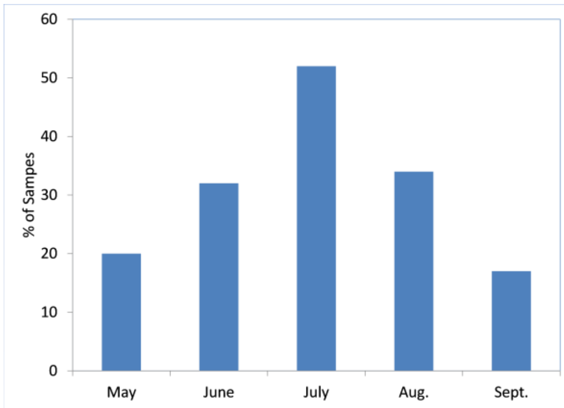


Figure 5: Monthly percentages of seaweed samples in the moderate and heavy density (wet volume) categories collected from Indian River Bay and Rehoboth Bay, Delaware during 2009. May - 20 samples, June – 25, July – 21, August – 23, September – 24.

density was absent to light in samples from the mouth of Love Creek around the northern part of the bay and all of the eastern side from lower Dewey Beach down to random sites below fixed Site 6. Some patches of *Gracilaria* that completely covered the bottom were observed within creeks penetrating into the marsh along the southeastern side of Rehoboth Bay and around Site 6, but they were not sampled.

Six fixed sites were sampled frequently enough in both 1999 (see Tyler 2000a) and 2009 for purposes of comparing differences in total volume (Table 1). At every site, average volume was less in 2009 than in 1999. The greatest differences between years (> 4.0 liters) were found at sites 4 and 11.

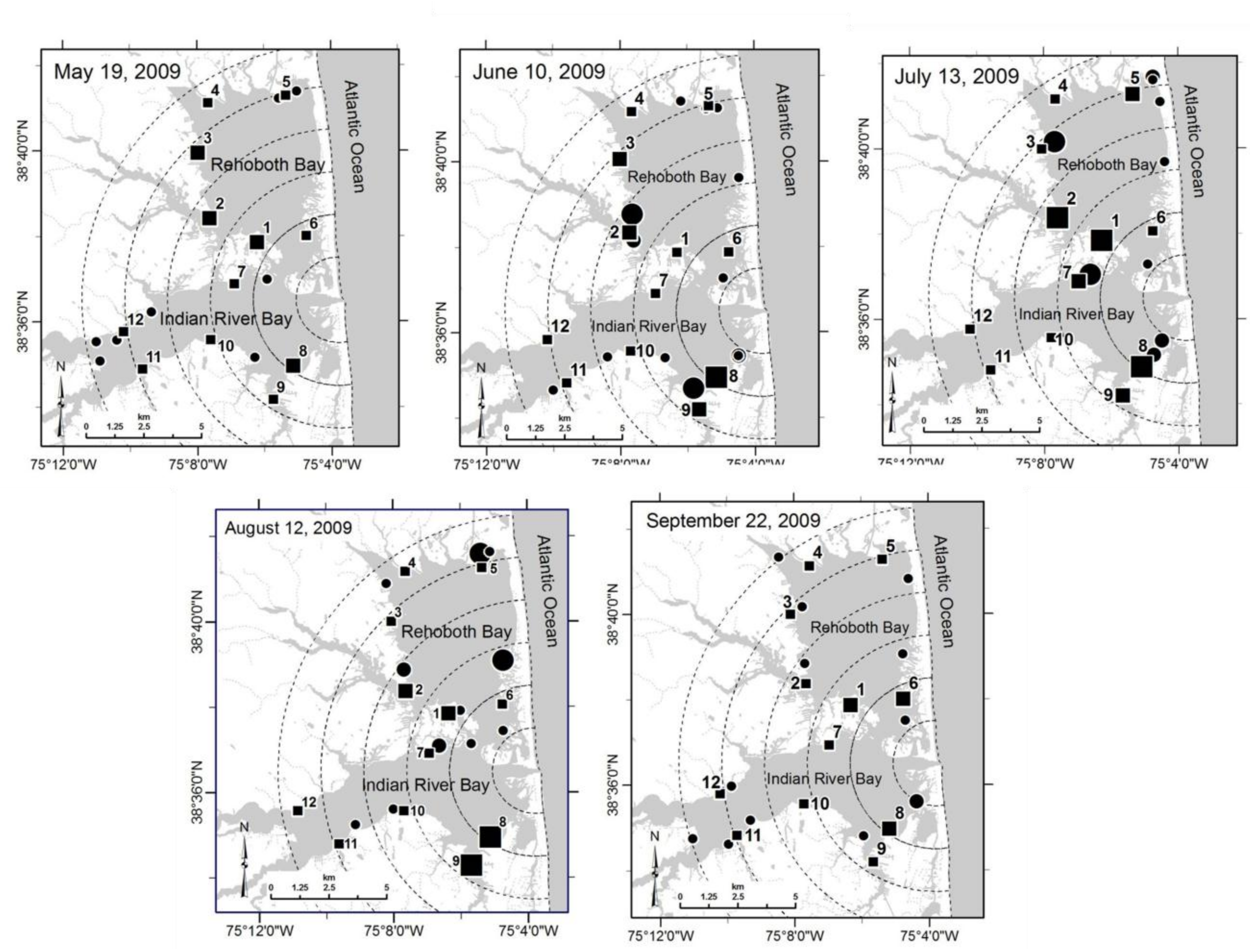


Figure 6: Figure 6: Monthly (May to September) seaweed sampling results from Indian River Bay and Rehoboth Bay, Delaware during 2009 showing fixed and random sites. Marker sizes indicate wet seaweed volume (liters) categories (absent/light, moderate and heavy).

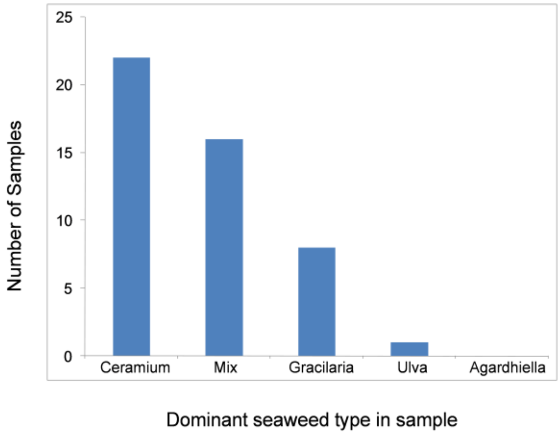


**Figure 7: Partitioning of seaweed samples collected from Indian River Bay and Rehoboth Bay, Delaware during 2009 according to the dominant type of seaweed in the sample. Includes only samples that contained 1 liter or more of seaweed (N = 47). Mix means some combination of two or more of the four dominant types.**

**Table 1. Comparison of average seaweed volume in liters collected from Indian River and Rehoboth Bay Delaware during 1999 (Tyler 2000a) and 2009 (this study).**

| Site Name | Site Number (2009) | 1999 | 2009 | Difference |
|---|---|---|---|---|
| Roman T Pond | 1 | | 7.4 | |
| Herring Creek Mouth | 2 | | 5.2 | |
| Shell Landing | 3 | 2.4 | 2.0 | -0.4 |
| Reh. Bay Community | 4 | 4.7 | 0.3 | -4.4 |
| Thompson Island | 5 | 3.7 | 1.7 | -2.0 |
| Savages Ditch | 6 | | 1.9 | |
| White House Point | 7 | 1.8 | 1.0 | -0.8 |
| Pasture Point | 8 | | 9.0 | |
| Whites Creek | 9 | | 4.0 | |
| Holts Landing | 10 | 2 | 0.1 | -1.9 |
| Blackwater Creek | 11 | 4 | 0.0 | -4.0 |
| Oak Orchard | 12 | | 0.2 | |

## Small-Scale Spatial Variability and Representativeness

Though much seaweed is unattached to any substrate and can therefore be moved by the wind, it doesn't appear to move far unless a strong storm event occurs. Seaweed distribution and density were very patchy, thus the amount collected during a sampling event may have poorly represented the amount present in a given locale. Samples taken from sites where the bottom was visible provided valuable insight regarding density variability. At some sites, there were times when sampling yielded light to no seaweed, yet amounts that would have been moderate to heavy in density were visible covering the bottom a short distance away (see Photo 4). The opposite was sometimes the case. In locations where the bottom cannot be seen, it cannot be known how spatially extensive a given density is.

**Photo 4: Ariel photo over Indian River Bay, Delaware. Note the patchy distribution of seaweed on the bay bottom. Seaweed appears as the dark areas, the light areas are sand. Photo Melanie Thymes, DNREC.**

## Sampler Variability

A comparison between two samplers collecting seaweed at the same time shows that variation due to the sampler resulted in seaweed density being placed into different categories (light, moderate or heavy) only 10 % of the time (Table 2). Even so, also note in Table 2 that the volumes collected by the two samplers were not very different.

**Table 2. Variation between two samplers in seaweed wet volume (liters) collected using identical hooks at multiple sites in Indian River Bay and Rehoboth Bay, Delaware on August 12, 2009. L (light volume, < 3 liters), M (moderate ≥ 3 < 8 liters), H (heavy ≥ 8 liters), N (no seaweed collected), T (trace < 1 liter). Far right column summarizes Sampler 1 and 2 results and shows agreement or lack thereof with regard to seaweed density category. N and T are lumped into the light seaweed category.**

| Site | Sampler 1 | Sampler 2 | Difference |
|---|---|---|---|
| 1 | 4 | 6 | M |
| 2a | 7 | 4 | M |
| 2b | T | T | L |
| 2c | 6 | 10 | M,H |
| 3 | T | T | L |
| 4 | N | N | L |
| 5a | 4 | 3 | M |
| 5b | 1 | T | L |
| 5c | T | T | L |
| 6 | T | 1 | L |
| 7 | T | T | L |
| 8 | 10 | 12 | H |
| 9 | 8 | 9 | H |
| 10 | N | N | L |
| 11 | N | N | L |
| 12 | N | N | L |
| R 1-2 | N | N | L |
| I 1-2 | T | T | L |
| R 2-3 | 10 | 7 | H,M |
| R 2-3 | N | N | L |
| I 2-3a | 7 | 5 | M |
| I 2-3b | 4 | 6 | M |
| I 2-3c | 2 | T | L |
| R 3-4 | 5 | 5 | M |
| I 3-4 | N | N | L |
| I 4-5 | N | N | L |
| R 5-6 | T | 1 | L |
| R 5-6 | 10 | 10 | H |
| R 5-6 | 3 | 1 | M,L |

**Table 3. Triplicate seaweed sampling variability for multiple sites in Indian River Bay and Rehoboth Bay, Delaware during 2009. (T) Trace quantity of seaweed < 1 liter wet volume. Rows with two numbers represent two different samplers collecting seaweed simultaneously with identical hooks.**

| Date | Rep. 1 | Rep. 2 | Rep. 3 |
|---|---|---|---|
| 6/10 | T | 6 | 9 |
| 7/13 | 4 | 3 | 2 |
| 7/13 | 7 | 3 | 6 |
| 8/12 | 2,T | 4,6 | 7,5 |
| 8/12 | T,T | 1,T | 4,3 |
| 8/12 | 6,10 | T,T | 7,4 |
| 9/12 | 1 | 2 | T |
| 9/12 | 0 | 0 | 0 |
| 9/12 | 9,8 | 9,11 | 0,0 |

Variability Within Sites

Triplication of sampling at individual sites showed that different conclusions can be drawn regarding seaweed abundance in a small area. Nine sites were sampled in triplicate (Table 3), four of which were also included in the sampler variability test, thus a total of 13 triplicate samples. For 7 of these 13 triplicates the low replicate was None or Trace with the highest replicate ranging from 2 to 11 liters of algae. This variability affirms the small-scale patchy distribution of seaweed. Notice that for the August samples, even though there was substantial within site variability 11 of the 12 paired samples (two samplers) were within the same density category.

Variability Between Sites

In this analysis the fixed and random sites are examined separately. Each of the 12 fixed sites is a group represented by 5 samples. Their variation is illustrated by Fig. 8a. The random sites are divided into 10 groups according to the nautical mile increment in which samples were collected. One random group (Indian River Bay, nautical mile increment 3-4) was represented by only two samples, neither of which yielded any seaweed therefore this group was not included in the analysis. The nine groups analyzed were not balanced and the number of samples ranged from three (Rehoboth Bay 1-2) to 11 (Rehoboth Bay 5-6). Their variation is illustrated by Fig. 8b.

Among the 12 fixed site groups, the median seaweed density values ranged from 0 to 9 liters and pooling of all the samples yielded a Grand Median of 2 liters (Fig. 8a). The sites in Fig. 8a can be sorted into groups according to the occurrence, or lack thereof, of the three density categories (light, moderate and heavy). For example, Sites 1, 2, and 9 can be considered a group because each site had at least one sample within each of the categories. Thus, over the course of the 2009 season our sampling showed that these sites had the highest density variability in the study (Fig. 8). Other groups included Sites 4, 10, 11, 12, where all samples fell into the light category, Sites 3, 5, 6 and 7 which had samples in the light and moderate categories. It is important to keep in mind that the author has chosen to include in the light category samples where no seaweed was collected. Site 8 stood out as the only area where seaweed was always in the moderate to heavy category. These spatial and monthly distributions between sites are illustrated by Fig. 6.

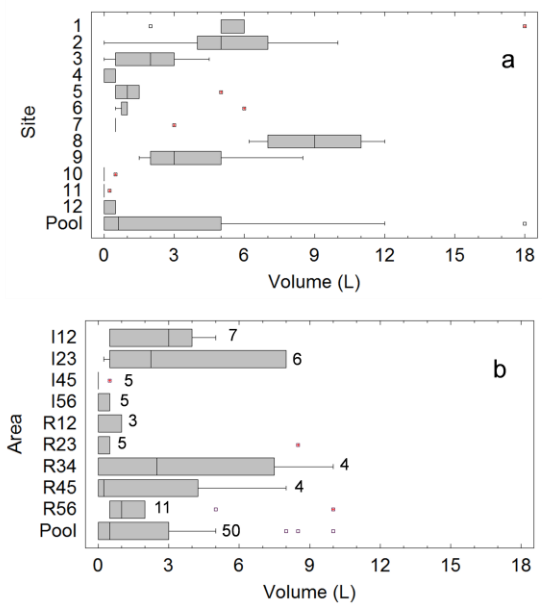


**Figure 8: (a) Box and whisker plots showing seaweed volume variability within and between 12 fixed sites in Indian River Bay and Rehoboth Bay, Delaware during 2009, plus the pooled result for all samples from the 12 sites (N = 60). The line within the box indicates median. For Site 11, note the single data point at 0.25 (L). Although there was no seaweed collected in any of the five samples at this site, the statistical software program would not process the data unless at least one of the numbers was > 0. (b) Box and whisker plots for randomly stratified samples collected in conjunction with 7a within nautical mile increments of the Indian River Inlet showing seaweed volume variability within and between increments. The number of samples varied per increment – the numbers at the end of the box or whisker for each increment indicates the number of samples. The pooled N = 50. See Fig. 1 for site location reference.**

Among the 9 random site groups, no median seaweed density values exceeded 3 liters. At the minimum end of the seaweed density range, all groups had one or more samples that were of 0.5 liters volume or less. At the maximum end of the range, seven groups also included samples that exceeded ≥ 8 liters. These extremes are further affirmation of the patchy nature of seaweed throughout the bays. One group had a maximum of 5 liters (Indian River Bay 1-2), and two groups had maximums of 0.5 liters (Indian River Bay 4-5 and Indian River Bay 5-6).

## Discussion

The main purpose of this study was to pilot a method of collecting some meaningful information regarding seaweed type, density and distribution in the Delaware Inland Bays. The lack of a logistically practical method for sampling seaweed appears to be a main reason why there is little monitoring information. In areas where the bottom is visible seaweed density can range from absent to heavy within a distance that can be seen by standing on the bow of a boat and simply looking. Thus, the naturally patchy distribution of seaweed creates a need to maximize the number of samples, rather than using field time engaged in the much slower process of quantifying how much seaweed exists in a precisely measured area, a square meter for example.

Other approaches to monitoring seaweed in the Inland Bays have been conducted. In the 1990's the University of Delaware and DNREC collaborated on an attempt to map seaweed distribution using aerial photography. Conceptually, this approach would allow for a more comprehensive assessment of seaweed distribution than manual methods. When sky conditions were favorable for photography the imagery was able to differentiate between bare bottom and seaweed-covered bottom in areas where the water was clear enough for the bottom to be seen. However, it was not possible to see the bottom over large areas of the bays due to turbidity and, even in areas where the bottom was discernible, it was necessary to do substantial ground-truth work in order to confirm seaweed type and density. The cost and logistics of implementing and sustaining such a project (i.e. flying, ground-truth, data analysis) kept the effort from gaining momentum, the people involved moved on to other endeavors, and the subject has not been raised in over 10 years.

Timmons and Price (1996) used a "dredge sled" that was pulled along the bottom from a boat for a specific amount of time (2 minutes – approximately 90 m) and a beach seine pulled over a specified distance (30 m). The dredge sled was modeled after the one used by Orris and Taylor (1973) and was determined to be only 12 % efficient. The cost of fabricating the sleds and the size; 130 cm long, 76 com wide and 30 cm deep would make it impractical for uses by volunteers. The beach seine would have collected all seaweed in its path and seems like a practical tool along shorelines, particularly if there is interest in quantifying fauna.

Important findings of this study are that in comparison to the studies of 1969 (Orris and Taylor 1973) and the 1990's (Timmons and Price 1996, Tyler 2000a) there appears to be (A) a shift in the dominant seaweed types from aggregations of *Agardhiella*, *Gracilaria* and *Ulva* to *Ceramium* and (B) perhaps an overall decline in seaweed abundance and spatial distribution. It is acknowledged that this study was for only one year and that these apparent differences may not continue. However, *Ceramium*/*Polysiphonia* was the dominant seaweed during the single bay-wide survey in 2008 (R. Tyler unpublished data) that was similar to the sampling events of 2009, indicating that its dominance was not a one-season phenomenon. The single survey in 2008 was in response to public complaints regarding a "black algae" that was washing up on shorelines thus suggesting that perhaps 2008 may have been the first season in which it was dominant.

Orris and Taylor (1973) sampled seaweed in Rehoboth Bay at approximately monthly intervals from June 1969 to July 1970. They found seaweed abundance to be greatest during summer and least during winter and early-spring with the differences being mostly attributable to changes in *Agardhiella* and *Gracilaria*. They also noted that the seaweed summer density maximum coincided more closely with maximum summer water temperature than with maximum irradiance (i.e. summer solstice). In the present study the largest number of moderate and heavy density samples occurred during July, consistent with the Orris and Taylor (1973) findings. Timmons and Price (1996) sampled seaweed quarterly (June 92 – March 93) in Indian River Bay and Rehoboth Bay and also found density to be highest in summer, with the seasonal difference driven by *Ulva* variation in Indian River Bay.

In May and June 1999 moderate to heavy densities of *Ulva* were collected around the mouth of Whites Creek, Holts Landing, Blackwater Creek and Steeles Cove and declined sharply thereafter (Tyler 2000a). These observations were consistent with Timmons and Price (1996) who also noted a sharp decline in *Ulva* between June and August at their sampling sites. In 2009 *Ulva* was absent to light in these areas throughout the season and there were no samples collected anywhere where density was moderate to heavy.

The reasons for the apparent shift in dominant seaweed type are unknown. Even though the waters of the bays were murky during 2009, at areas that had heavy density in 1999, sufficient light to support seaweed growth probably occurred at the bottom during lower tide stages (from about half ebb through half flood). Perhaps the elimination of point sources during the 1990's and substantial upgrades to the City of Rehoboth wastewater treatment plant since 2000 are yielding favorable results.

While the nuisance factors associated with seaweed tend to get attention, the habitat attributes of seaweed should be highlighted. We observed in this study that a moderate to heavy density sample of seaweed may contain hundreds of small crustaceans, and it is likely that even more are washed out while the sample is being dragged through the water toward the boat. In southeastern Rehoboth Bay north of Burton Island and east of Cedar Islands (see NOAA nautical chart 12216) we observed very light *Ulva* attached to tubeworm casings that was being used as a substrate for clusters of small ( $\approx$ 1 cm) blue mussels. These mussels are of a size that can be easily ingested by diving ducks, for example buffleheads, scaup and scoters. As for habitat function, consideration may be given to conducting a study to compare faunal abundance within beds of finely bushy red seaweed beds to abundance in beds of other seaweed types. Epifanio et al. (2003) examined differences in juvenile blue crab density between *Agardhiella*, *Gracilaria* and *Ulva* and found no correlation between the abundance of crabs and the dry-weight ratio of red to green seaweed. However, at the time of that study (summer of 1999) *Ceramium*/ *Polysiphonia* was a minor component of the seaweed assemblage.

The relatively low abundance of seaweed observed in Indian River Bay and Rehoboth Bay during 2009 was counter to conventional wisdom regarding seaweed – nutrient interaction. It might be expected that nutrient loading resulting from average rainfall during the summer of 2009 would have triggered a large amount of seaweed growth. While seaweed density was high in some places, overall density was much lower than 1999. It could be that seaweed responses to nutrient loading are being offset to some extent by increased flushing of the system resulting from a deepening of the Indian River Inlet over the past 2-3 decades.

Spatial variation can make it difficult to accurately represent some environmental phenomena and this is particularly true of seaweed. For example, seaweed abundance may be heavy on one side of a cove or point and light on the other. It may be heavy in a shoreline-fringing band several meters wide that gives way abruptly to bottom that has no seaweed coverage. One can often see such patchiness just upon looking around at a given location. Where is one to sample? The difficulty in quantifying seaweed is further compounded by limitations upon the sampling methods. Quadrat (plot) harvesting, which most accurately measures quantity in a defined area (e.g. 1 square meter), is time consuming and impractical for water deeper than one can wade. The dredge sled and grappling hook methods are fast and can be utilized over the full depth range of seaweed but both account for only a portion of the seaweed actually present on the area of bottom over which the device passes. Moreover, the distance of bottom covered by the sled or hook is imprecise in comparison to a quadrant. All three methods are proven to give an accurate representation of whether the bottom area sampled has light or heavy seaweed.

Presently, the most practical way of tracking seaweed abundance and species distribution appears to be sustained sampling of fixed locations multiple times every growing season – about May through September. We found that the difference between individuals doing the sampling is small in comparison to the spatial and temporal variability in seaweed density. This finding implies that, with training, citizen volunteers could populate a seaweed monitoring database for the Delaware Inland Bays. Because the logistics of seaweed sampling render it a poor operational fit for Delaware's routine water monitoring program, it may well be the only viable way to get the work done. The volunteers live locally, the grappling hooks are relatively inexpensive to make and the work can be done off a dock by one person or out of a small boat by, in the interest of safety, two people. Five gallon buckets are inexpensive and can be easily marked in units of volume.

Based on what is known regarding the types of dominant seaweed in the Inland Bays, citizen volunteers should be able to provide adequate identification information. The visual differences between *Agardhiella*, *Ceramium*/*Polysiphonia*, *Chaetomorpha*, *Gracilaria* and *Ulva* are substantial. Distinguishing *Ceramium* from *Polysiphonia* would be difficult and require some microscope work. However, from the standpoint of identifying a dominant type of seaweed it does not seem that important to distinguish between these two similar types. They are both in the general group of "finely bushy" red seaweed. Orris and Taylor (1973) documented a much greater number of species than reported by the studies of Timmons and Price (1996), Tyler (2000a) and this study. However, an objective of the Orris and Taylor (1973) study was to document as many types of seaweed as they could find while objectives of the more recent studies were focused upon the most dominant types. Orris and Taylor (1973) also sampled throughout the year and mentioned that the greatest number of species occurred when total seaweed was at lower abundance and vice versa.

If the method piloted in this study is adopted by citizen volunteers and a group of selected locales is sampled consistently for enough years the accumulation of a database that is sufficient to examine spatial patterns and temporal trends is foreseeable. Seaweed densities that result in ecological damage occur worldwide, thus the findings from this study can be applied broadly to other coastal bay/lagoon systems that have similar conditions.

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## Appendix 2

Descriptions of Fixed Seaweed Sampling Sites - see Figure 1. All sampling locations can be found on either a Sussex County map or NOAA navigational chart 12216, except where noted as “unnamed feature”, which are readily available via local knowledge.

1) Roman T. Pond – ~ 100 m from west edge of Masseys Ditch channel, middle of cove, soft bottom.

2) Herring Creek – mouth middle, between Burton Point and Lee Joseph Creek (unnamed feature), soft bottom.

3) Shell Landing – ~100 m east of the point delineating north side of the cove, hard bottom.

4) Rehoboth Bay Community (unnamed feature) - ~100 m from shore at the end of Old Landing Road, hard bottom.

5) Thompson Island – east side, ~100 m from shore, line up end of the point with the Rusty Rudder and/or Lighthouse Restaurants (unnamed features), hard bottom.

6) Savages Ditch (unnamed feature) - ~ 50 m south of small unnamed marsh island which is just south of Big Bacon Island, hard bottom.

7) Indian River Bay north of Buoy 20 - ~100 m from shore, halfway between Boat House Pond and Steeles Cove, hard bottom.

8) Pasture Point Cove – ~ 50 m northeast of marked oyster reef, hard bottom.

9) Whites Creek – flats off east flank of channel, ~ 100 m up creek of the large fingered canal that serves Holly Terrace Acres, soft bottom.

10) Holts Landing - ~ 50 m north of the public dock at the end of Holts Landing Road, hard bottom.

11) Blackwater Creek - ~100 m southeast of tip of the marsh point which delineates the west side of the creek, hard bottom.

12) Oak Orchard - ~ 50 m southeast of the dock at the end of State Highway 5, hard bottom.