VII. ASSESSMENT OF EMBAYMENT NUTRIENT RELATED ECOLOGICAL HEALTH

The nutrient related ecological health of an estuary can be gauged by the nutrient, chlorophyll and oxygen levels of its waters and the plant (eelgrass, macroalgae) and animal communities (fish, shellfish, infauna) which it supports. For Chatham's five embayment systems our assessment is based upon data from the water quality monitoring database and our surveys of eelgrass distribution, benthic animal communities and sediment characteristics conducted during the summer and fall of 2000. These data form the basis of an assessment of these systems' present health, and when coupled with a full water quality synthesis and projections of future conditions based upon the water quality modeling effort, will support complete nitrogen threshold development for these systems.

VII.1 OVERVIEW OF BIOLOGICAL HEALTH INDICATORS

There are a variety of indicators that can be used in concert with water quality monitoring data for evaluating the ecological health of embayment systems. The best biological indicators are those species which are non-mobile and which persist over relatively long periods if environmental conditions remain constant. The concept is to use species which integrate environmental conditions over seasonal to annual intervals. The approach is particularly useful in environments where high-frequency variations in structuring parameters (e.g. light, nutrients, dissolved oxygen, etc.) are common, making adequate field sampling difficult.

As a basis for a nitrogen thresholds determination, MEP focused on major habitat quality indicators: (1) bottom water dissolved oxygen (Section VII.2), (2) eelgrass vs. macroalgal distribution (Section VII.3) and (2) benthic animal communities (Section VII.4). Dissolved oxygen depletion is frequently the proximate cause of habitat quality decline in coastal embayments (the ultimate cause being nitrogen loading). However, oxygen conditions can change rapidly and frequently show strong tidal and diurnal patterns. Even severe levels of oxygen depletion may occur only infrequently, yet have important effects on system health. To capture this variation, MEP deployed dissolved oxygen sensors within the upper regions of the embayments to record the frequency and duration of low oxygen conditions during the critical summer period. Eelgrass is a sentinel species for indicating nitrogen over-loading to a coastal embayment. It is also a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. Mapping of each embayment's eelgrass beds was conducted for comparison to historic records. Temporal trends in habitat quality were determined by comparison with previous eelgrass distribution data collected in the Chatham embayment systems by DEP (C. Costello, personal communication). Temporal changes in eelgrass distribution provides a strong basis for evaluating recent increases (nitrogen loading) or decreases (increased flushing-new inlet) in nutrient enrichment.

In areas that do not support eelgrass beds, benthic animal indicators were used to assess the level of habitat health from "healthy" (low organic matter loading, high D.O.) to "highly stressed" (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of their habitat. Benthic animal species from sediment samples were identified and the environments ranked based upon the fraction of pristine, intermediate stress, and stress indicator species. The analysis is based upon life-history information on the species and a wide variety of field studies within southeastern Massachusetts waters, including the Wild Harbor oil spill, benthic population studies in Buzzards Bay (Woods Hole Oceanographic Institution) and New Bedford (SMAST), and more recently the WHOI Nantucket Harbor Study (Howes *et al.* 1997).

VII.2 BOTTOM WATER DISSOLVED OXYGEN

Dissolved oxygen levels near atmospheric equilibration are important for maintaining healthy animal and plant communities. Short-duration oxygen depletions can significantly affect communities even if they are relatively rare on an annual basis. For example, for the Chesapeake Bay it was determined that restoration of nutrient degraded habitat requires that instantaneous oxygen levels not drop below 3.8 mg L^{-1}. Massachusetts State Water Quality Classification indicates that SA (high quality) waters maintain oxygen levels above 6 mg L^{-1}.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. The result is that lowest oxygen levels (mg L^{-1}) are found in the warmest summer months. In addition, biological processes which consume oxygen from the watercolumn vary directly with temperature. The result is that the highest rates of oxygen uptake are in the summer. It is not surprising, then, that the largest levels of oxygen depletion (departure from atmospheric equilibrium) and lowest absolute levels (mg L^{-1}) are found during the summer in southeastern Massachusetts embayments. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically underestimate the frequency and duration of low oxygen conditions within shallow embayments (Taylor and Howes 1994). To more accurately capture the degree of bottom water dissolved oxygen depletion during the critical summer period, autonomously recording oxygen sensors were placed within key sub-embayments to the 5 embayment systems. The sensors (YSI 6600) were first calibrated in the laboratory and checked with standard oxygen mixtures, then placed in the field with calibration samples collected at the sensor depth and assayed by Winkler titration (potentiometric analysis, Radiometer). Each mooring was serviced and field oxygen samples collected at the sensor, at least biweekly and sometimes weekly during a minimum deployment of 30 days during July and August. All of the mooring data from the 5 embayment systems is from summer 2002.

In addition to the oxygen sensors, chlorophyll a sensors (fluorescence) were also part of the moorings (YSI 6600). The chlorophyll a sensors were maintained as for the oxygen sensors, except that field samples were collected for chlorophyll a and pheophytin analysis by cold acetone (90%) extraction and fluorometric assay (Turner AU10). Like oxygen levels, chlorophyll a is an indicator of habitat health relating to nitrogen loading. Chlorophyll a serves as a proxy for phytoplankton biomass.

Similar to other embayments in southeastern Massachusetts, the 5 embayment systems in this assessment showed high frequency variation, apparently related to diurnal and sometimes tidal influences. The high degree of temporal variation in bottom water dissolved oxygen concentration at each mooring site, underscores the need for continuous monitoring within these systems.

Nitrogen enrichment of embayment waters can manifest itself in the dissolved oxygen record, both through oxygen depletion and through the magnitude of the daily excursion. This phenomenon is best seen in the upper Muddy Creek record., where dissolved oxygen levels drop to less than 1 mg L-1 during the night and reach levels in excess of atmospheric saturation during the day time (Figure VII-1a). A confirmation that the low dissolved oxygen levels result from nitrogen enrichment of embayment waters is seen in many of the records where the temporal pattern of oxygen depletion is inversely correlated with the timing of phytoplankton blooms (chlorophyll a levels). This is relationship was seen in the Upper Muddy Creek (Figure VIII-1a), Mill Pond (Figure VIII-2)and to a lesser extent in Oyster Pond (Figure VIII-3), Stage Harbor (Figure VIII-4), Sulphur Springs (Figure (VIII-6). In addition, systems which generally had lower chlorophyll levels (<15 ug L^{-1}), tended to show less oxygen depletion. This is clearly seen in the comparison of the Bassing Harbor System (Figures VII-7,8,9,10) to Muddy Creek, Mill Pond, Oyster Pond, and Sulphur Springs sub-embayments (Figures VII-1,2,3,6). It is also seen within the Bassing Harbor System, which show an inverse gradient in oxygen minima to chlorophyll levels moving from Ryder Cove to Crows Pond to Bassing Harbor.

The dissolved oxygen and chlorophyll a records were analyzed to determine the percent of the deployment time (29-64 days) that oxygen was below various benchmark concentrations (Table VII-1) or above various chlorophyll concentrations (Table VII-2). These data indicate not just the minimum or maximum levels of these critical nutrient related constituents, but the intensity of the low oxygen circumstances or of the phytoplankton blooms. It is clear that systems with higher chlorophyll had lower and more prolonged oxygen depletion.

Muddy Creek (upper and lower) are clearly eutrophic with frequent and prolonged oxygen declines below 3 mg L^{-1} (half of the record) and chlorophyll a levels exceeding 25 ug L^{-1} on over half of the days. In addition, it appears that upper Muddy Creek built and sustained a large late summer bloom with exceedingly high chlorophyll a levels, >80 ug L^{-1}.

Within Stage Harbor System, only Mill Pond showed very low oxygen levels (<3 mg L^{-1}), Oyster Pond and upper Stage Harbor (lower Mitchell River) consistently had oxygen levels >5 mg L^{-1} and chlorophyll a levels < 15 u L^{-1} (generally <10 mg L^{-1}). None of these systems showed the very high bloom conditions of Muddy Creek. However, both parameters clearly indicate nutrient enrichment in Mill Pond and to a lesser extent in the other 2 sub-embayments.

A single mooring was placed in the terminal drowned kettle pond, Taylors Pond, in the Taylors Pond System. Mill Creek is very shallow with parts becoming emergent at low tide. In addition, Mill Creek functions primarily as a salt marsh a high proportion of the tidal reach being vegetated by *Spartina* grasses. Taylors Pond also showed indications of nitrogen enrichment, with dissolved oxygen levels declining below 5 mg L^{-1} almost 10% of the time (and <4 mg L^{-1} 2% of the time) and chlorophyll a levels exceeding 10 ug L^{-1} almost 10% of the deployment period.

Sulphur Springs showed a similar level of nitrogen related habitat quality to Mill Pond, both exchanging tidal waters with Nantucket Sound. Sulphur Springs is much shallower than Mill Pond, but still showed significant oxygen depletion, <3 mg L^{-1} on 6% of time and with chlorophyll a levels exceeding 25 ug L^{-1}. Sulphur Springs is the shallow upper basin within the Sulphur Springs, Cockle Cove, Bucks Creek composite embayment. There are signs that Sulphur Springs is currently transitioning to salt marsh.

The Bassing Harbor System is part of the Pleasant Bay Estuary. Bassing Harbor receives nitrogen inputs from its adjacent watershed as well as some nitrogen on the incoming tide which originated within the greater watershed to Pleasant Bay. At present it appears that the Bassing Harbor System overall supports relatively high oxygen levels and moderate chlorophyll a levels, except for the upper reach of Ryder Cove. Ryder Cove receives the highest nitrogen load from its watershed of the sub-embayments to this system. Upper Ryder Cove is approaching Mill Pond relative to its nitrogen response. The difference is that upper Ryder Cove still supports eelgrass, whereas Mill Pond has lost its beds.

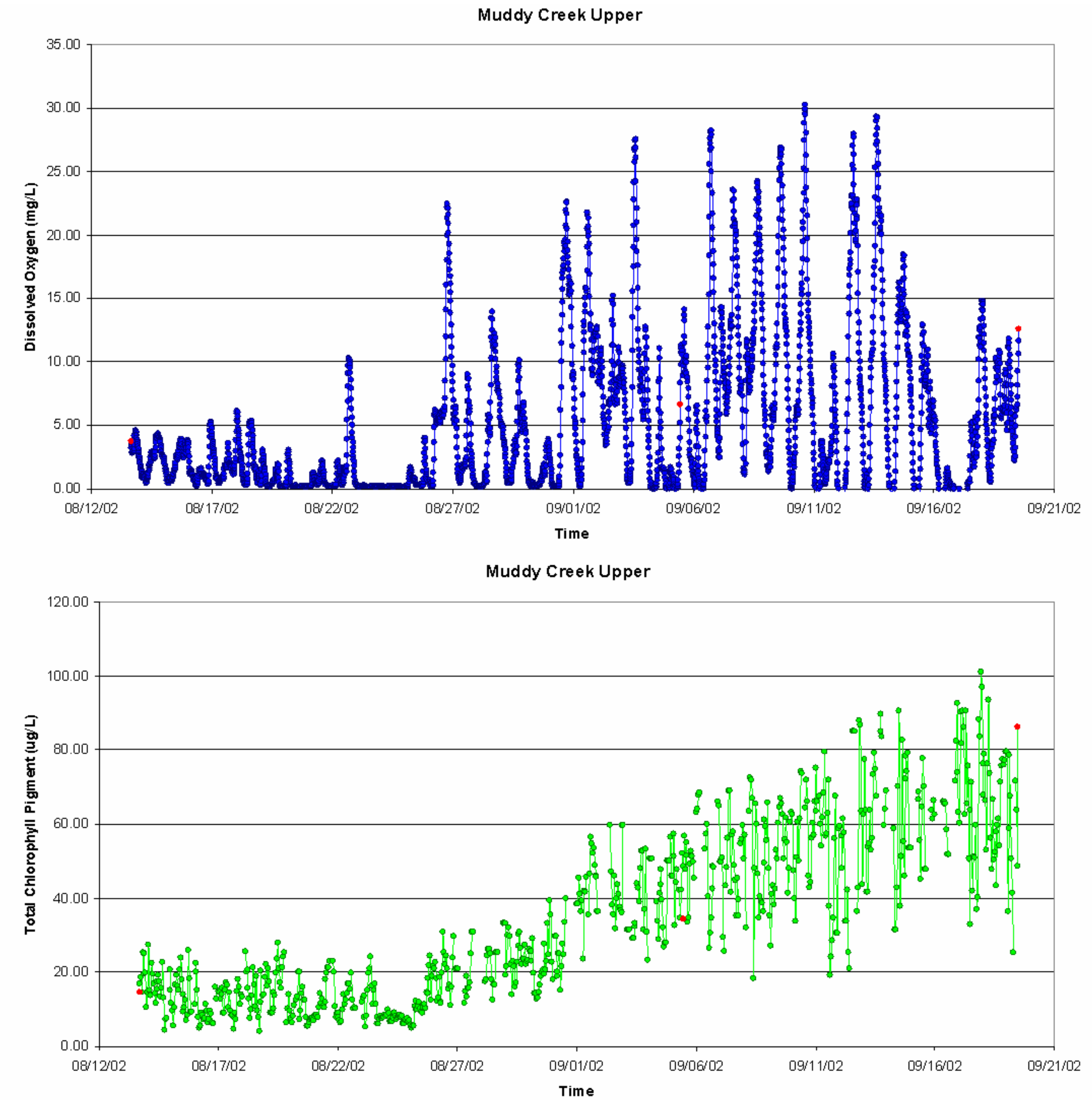


Figure VII-1a. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Upper Muddy Creek, Summer 2002. Calibration samples represented as red dots.

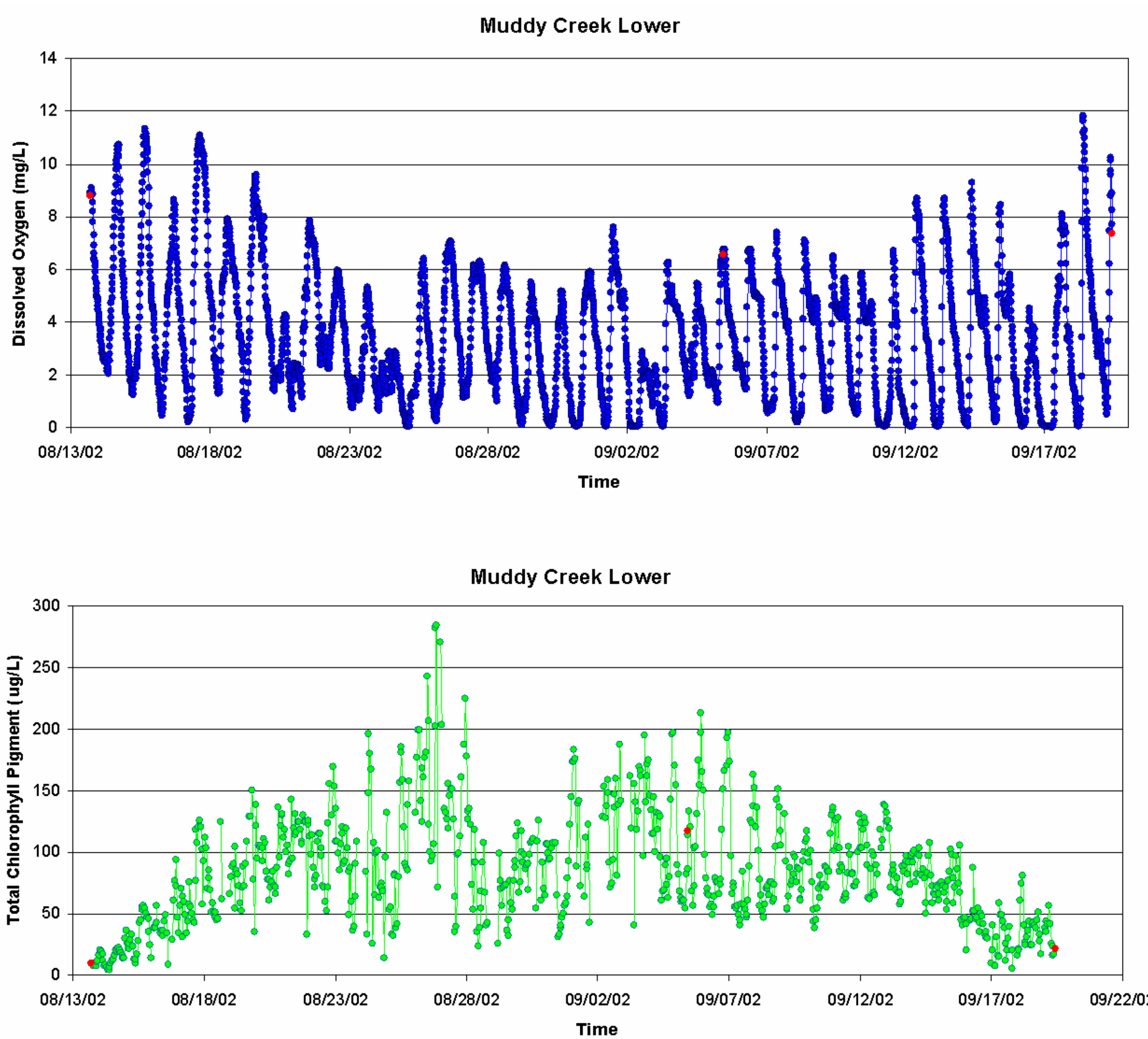


Figure VII-1b. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Lower Muddy Creek, Summer 2002. Calibration samples represented as red dots.

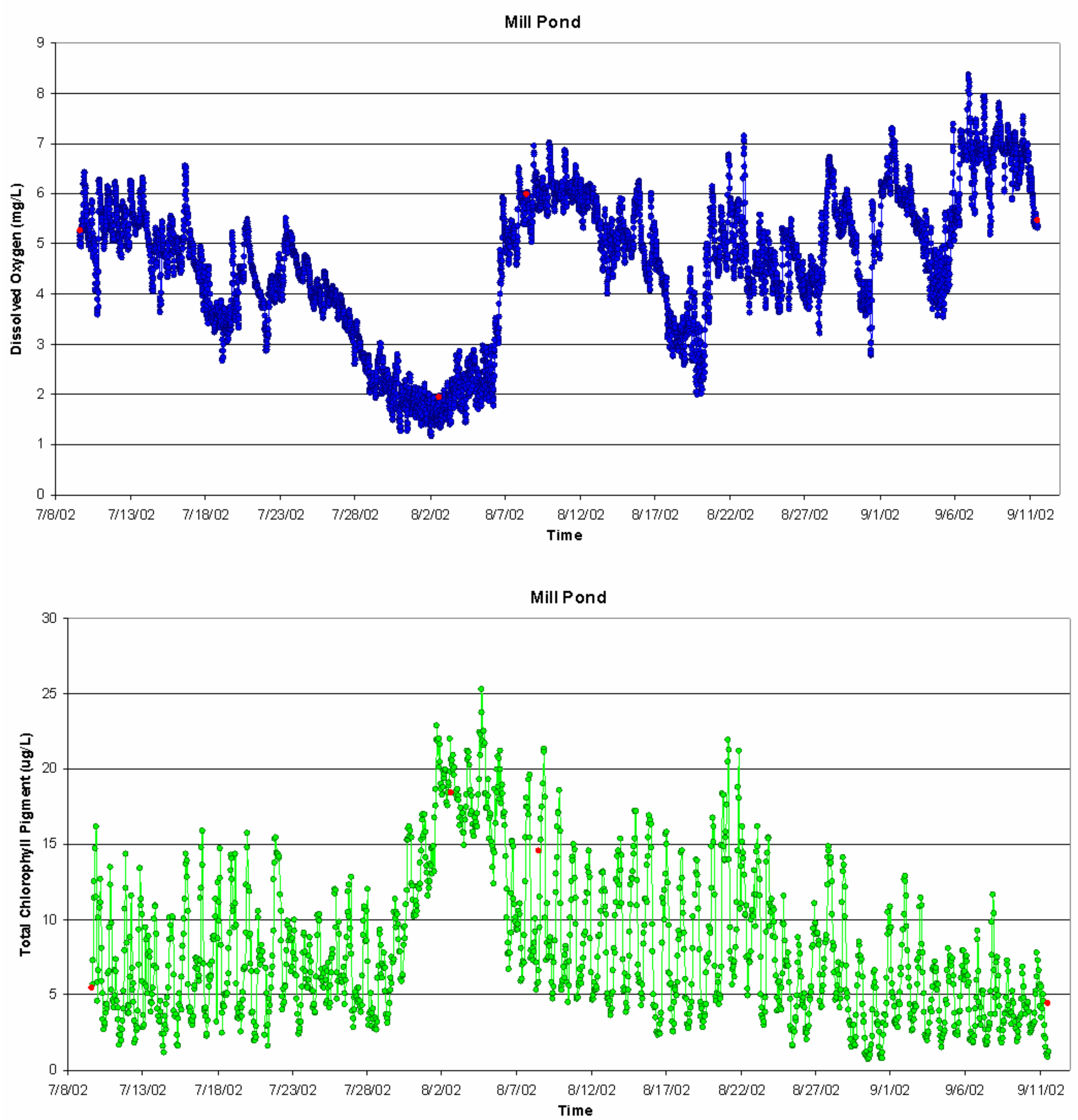


Figure VII-2. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Mill Pond (Stage Harbor System), Summer 2002. Calibration samples represented as red dots.

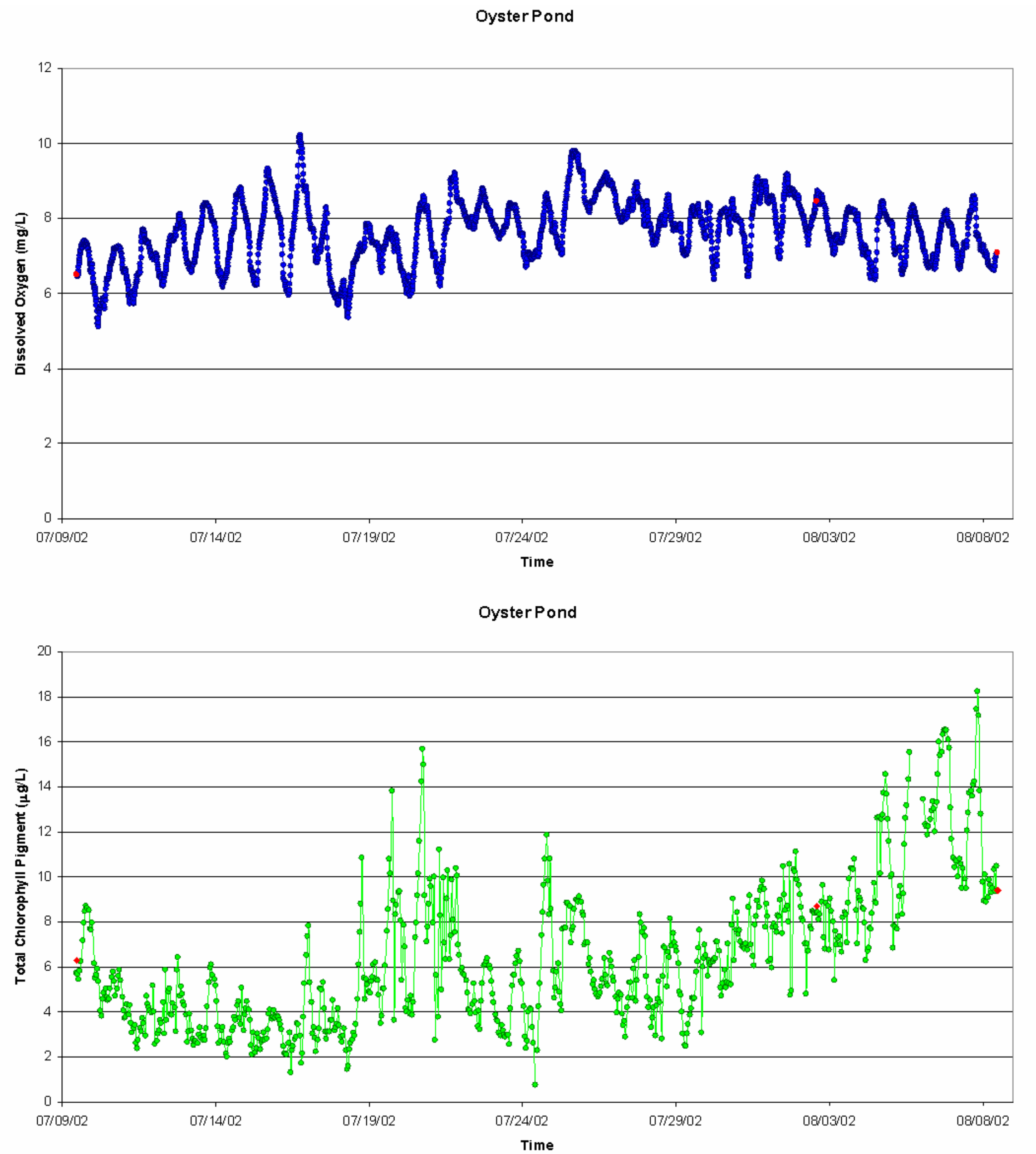


Figure VII-3. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Oyster Pond (Stage Harbor System), Summer 2002. Calibration samples represented as red dots.

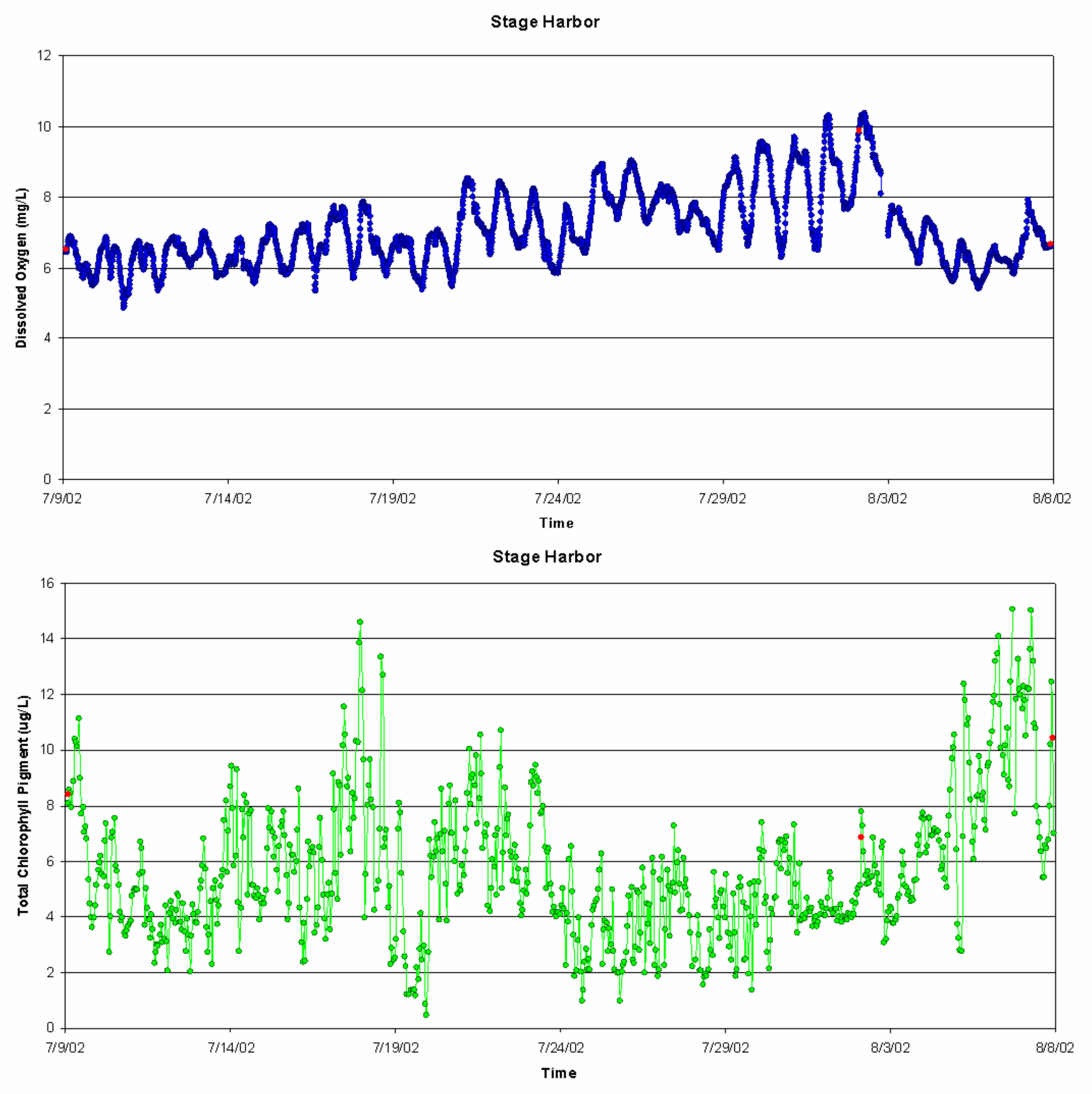


Figure VII-4. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Stage Harbor (Stage Harbor System), Summer 2002. Calibration samples represented as red dots.

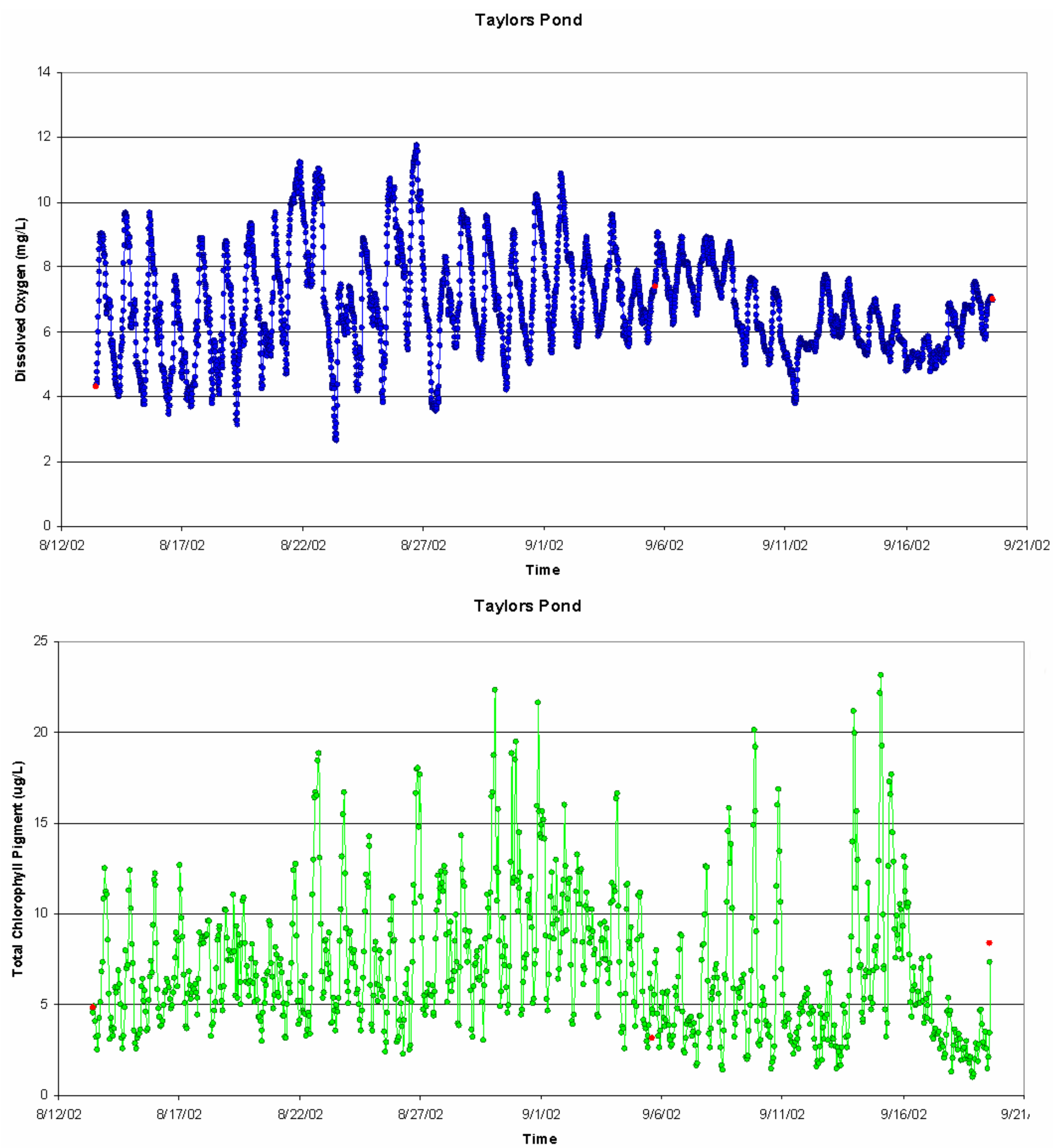


Figure VII-5. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Taylors Pond, Summer 2002. Calibration samples represented as red dots.

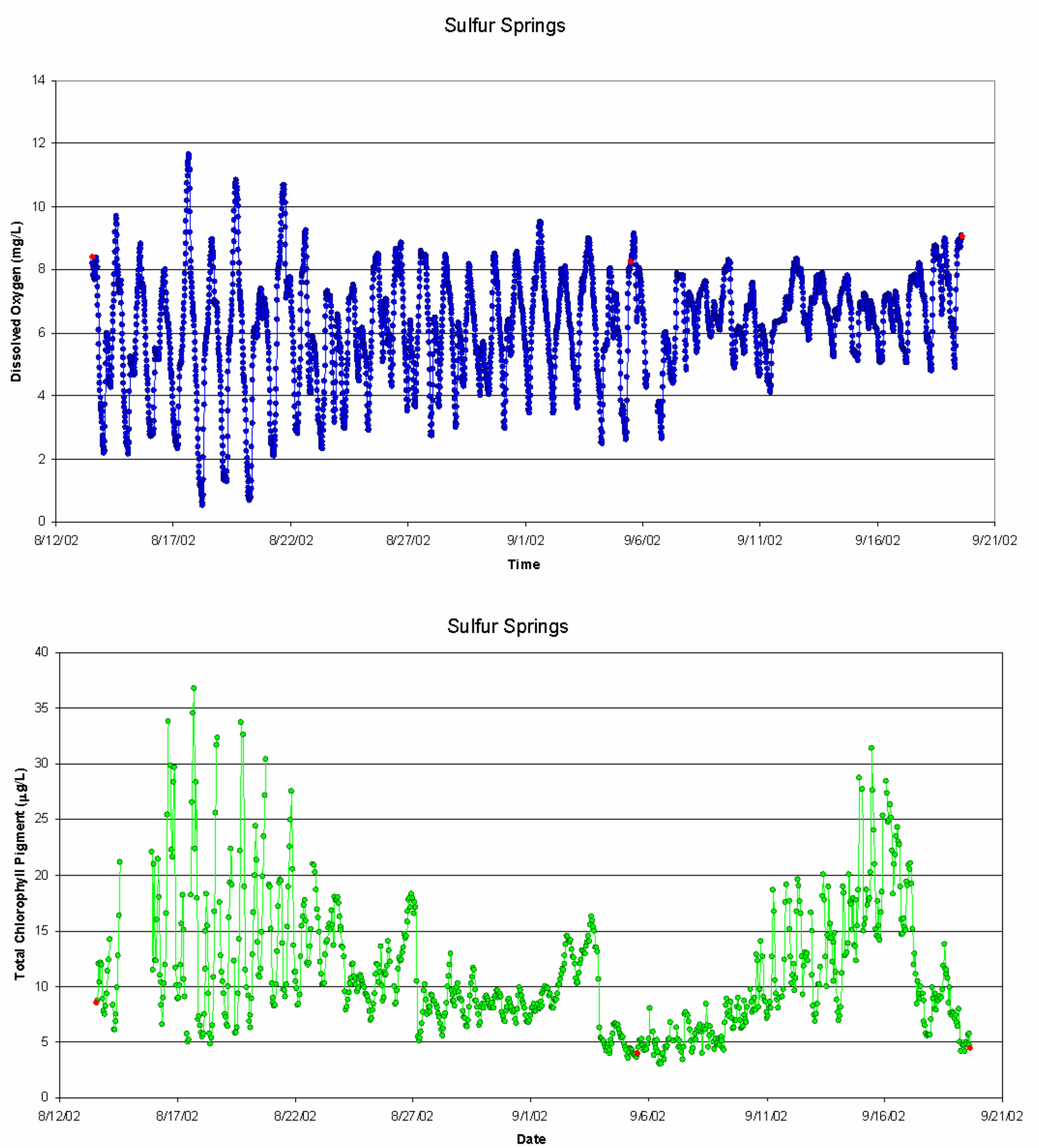


Figure VII-6. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Sulphur Springs, Summer 2002. Calibration samples represented as red dots.

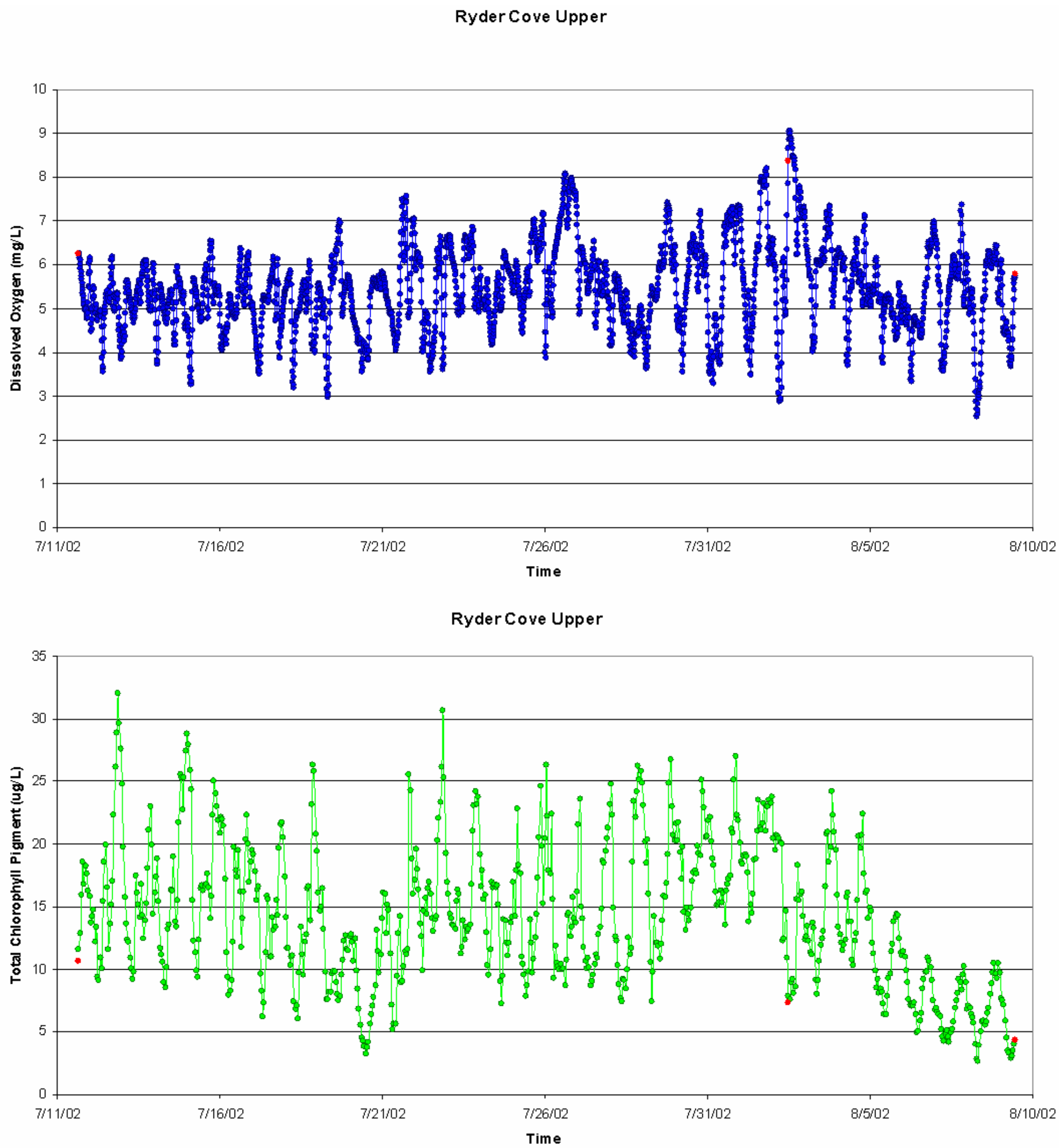


Figure VII-7. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Upper Ryder Cove (Bassing Harbor System), Summer 2002. Calibration samples represented as red dots.

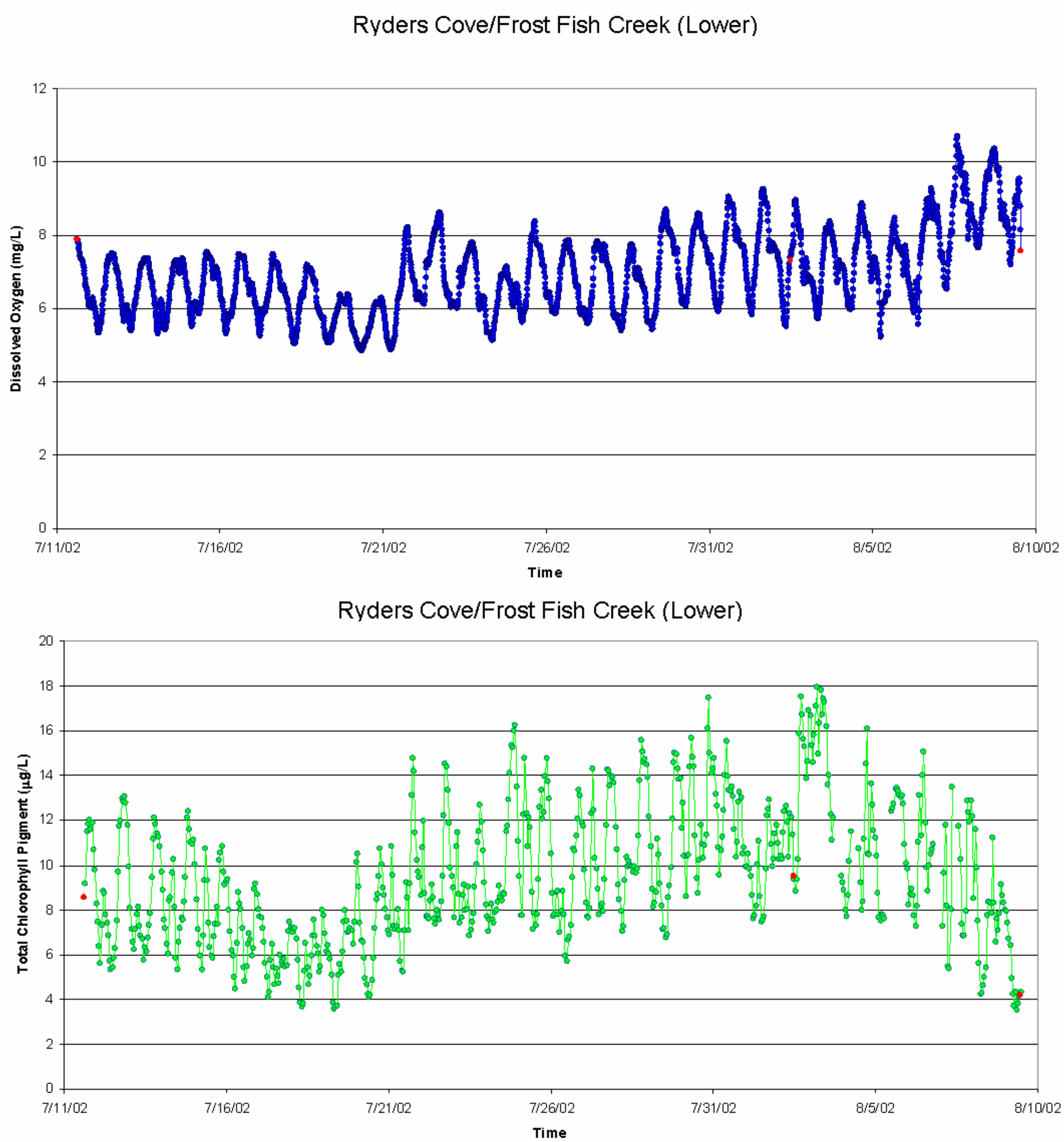


Figure VII-8. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Lower Ryder Cove (Bassing Harbor System), Summer 2002. Calibration samples represented as red dots.

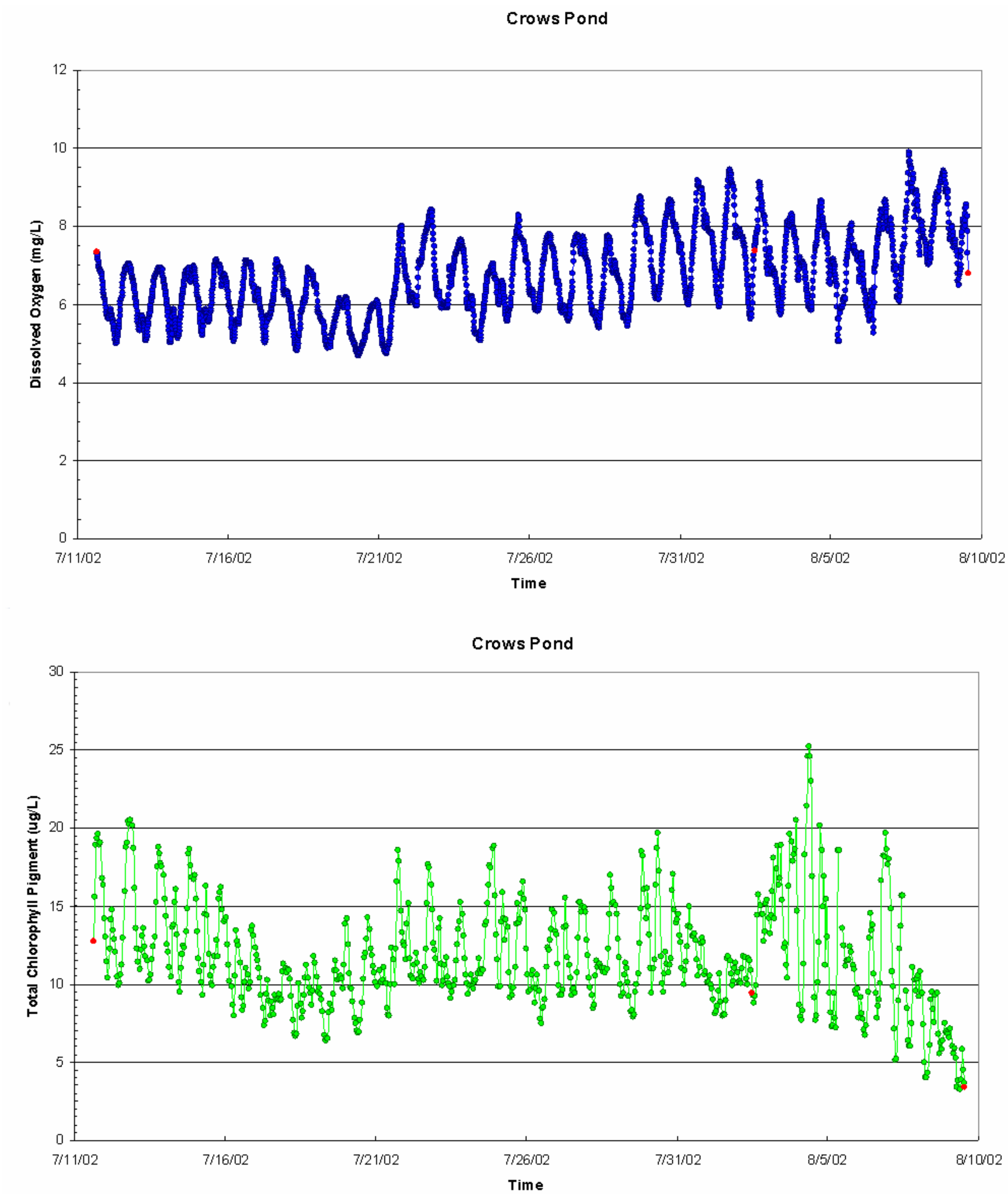


Figure VII-9. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Crows Pond (Bassing Harbor System), Summer 2002. Calibration samples represented as red dots.

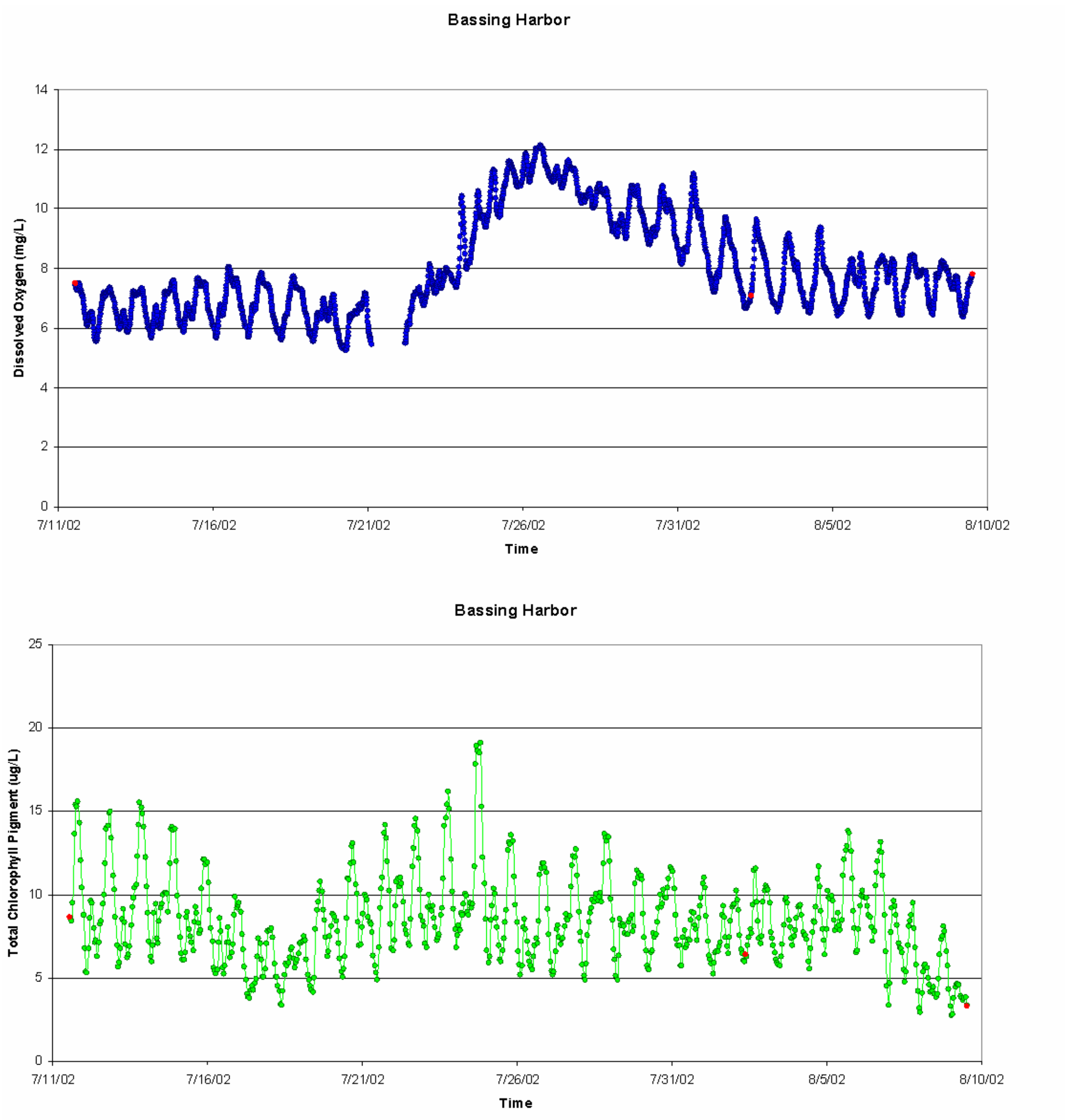


Figure VII-10. Bottom water record of dissolved oxygen (top panel) and chlorophyll-a (bottom panel) in Bassing Harbor, Summer 2002. Calibration samples represented as red dots.

Table VII-1. Percent of time during deployment that bottomwater oxygen levels recorded by the in situ sensors were below various benchmark oxygen levels.

Massachusetts Estuaries Project **Town of Chatham: 2002**	**Dissolved Oxygen: Continuous Record, Summer 2002**				
	Deployment Days	**<6 mg/L (% of days)**	**<5 mg/L (% of days)**	**<4 mg/L (% of days)**	**<3 mg/L (% of days)**
Muddy Creek System:					
Muddy Creek-Upper	29	88%	81%	76%	69%
Muddy Creek-Lower	37	85%	74%	60%	49%
Stage Harbor System:					
Mill Pond	64	84%	56%	30%	16%
Oyster Pond	64	6%	1%	0%	0%
Stage Harbor-Upper	30	14%	0%	0%	0%
Taylor's Pond System:					
Taylor's Pond	37	21%	9%	2%	0%
Sulphur Springs System:					
Sulphur Springs-Basin	37	41%	22%	12%	6%
Basing Harbor System:					
Ryder Cove-Upper	29	73%	32%	7%	1%
Ryder Cove-Lower	29	21%	1%	0%	0%
Crows Pond	29	28%	3%	0%	0%
Bassing Harbor	29	7%	0%	0%	0%

Table VII-2. Frequency (number of events during deployment) and duration (total number of days over deployment) of chlorophyll a levels above various benchmark levels within the 5 embayment systems.

Embayment System	Start Date	End Date	Total Deployment (Days)	Duration (cumulative days) >5 ug/L (Days)	>10 ug/L (Days)	>15 ug/L (Days)	>20 ug/L (Days)	>25 ug/L (Days)	Frequency (# events) >5 ug/L (#)	>10 ug/L (#)	>15 ug/L (#)	>20 ug/L (#)	>25 ug/L (#)
Basing Harbor System													
Bassing Harbor	7/11/02	8/9/02	29	26.833	6.625	0.583	0.000	0.000	11	33	4	0	0
			Mean	2.439	0.201	0.146	N/A	N/A					
			Min	0.208	0.042	0.083	0.000	0.000					
			Max	8.667	0.417	0.250	0.000	0.000					
			S.D.	3.053	0.116	0.072	N/A	N/A					
Ryder's Cove Up	7/11/02	8/9/02	28.8	27.833	21.333	12.167	5.167	1.125	6	33	44	27	12
			Mean	4.639	0.646	0.277	0.191	0.094					
			Min	0.042	0.042	0.042	0.042	0.042					
			Max	16.833	4.125	1.000	0.542	0.208					
			S.D.	6.808	0.779	0.234	0.136	0.062					
Ryder Cove Low	7/11/02	8/9/02	28.9	26.458	10.833	1.292	0.000	0.000	11	44	12	0	0
			Mean	2.405	0.246	0.108	N/A	N/A					
			Min	0.083	0.042	0.042	0.000	0.000					
			Max	17.708	1.125	0.250	0.000	0.000					
			S.D.	5.234	0.224	0.072	N/A	N/A					
Crows Pond	7/11/02	8/9/02	28.9	28.375	19.833	4.917	0.458	0.042	3	49	34	4	1
			Mean	9.458	0.405	0.145	0.115	0.042					
			Min	0.042	0.042	0.042	0.042	0.042					
			Max	27.417	2.000	0.375	0.208	0.042					
			S.D.	15.559	0.400	0.107	0.086	N/A					

Table VII-2. (continued)

Embayment System	Start Date	End Date	Total Deployment (Days)	Duration (cumulative days) >5 ug/L (Days)	>10 ug/L (Days)	>15 ug/L (Days)	>20 ug/L (Days)	>25 ug/L (Days)	Frequency (# events) >5 ug/L (#)	>10 ug/L (#)	>15 ug/L (#)	>20 ug/L (#)	>25 ug/L (#)
Muddy Creek System													
Muddy Creek Low	8/13/02	9/19/02	36.8	32.833	32.292	31.667	31.042	30.333	2	7	12	13	16
			Mean	16.417	4.613	2.639	2.388	1.896					
			Min	0.625	0.042	0.083	0.042	0.042					
			Max	32.208	28.042	20.542	20.542	16.708					
			S.D.	22.333	10.341	5.992	5.796	4.366					
Muddy Creek Up	8/13/02	9/11/02	29	30.958	26.458	22.625	19.417	16.667	6	23	36	35	28
			Mean	5.160	1.150	0.628	0.555	0.595					
			Min	0.958	0.042	0.042	0.042	0.042					
			Max	20.583	20.125	16.167	6.250	5.500					
			S.D.	7.787	4.143	2.670	1.476	1.308					
Taylors Pond System													
Taylor's Pond	8/13/02	9/19/02	37.2	23.833	7.250	1.750	0.250	0.000	66	42	19	5	0
			Mean	0.361	0.173	0.092	0.050	N/A					
			Min	0.042	0.042	0.042	0.042	0.000					
			Max	1.417	0.458	0.208	0.083	0.000					
			S.D.	0.299	0.110	0.047	0.019	N/A					
Mill Pond	7/9/02	9/11/02	63.9	43.125	19.208	7.500	1.500	0.042	78	64	24	10	1
			Mean	0.553	0.300	0.313	0.150	0.042					
			Min	0.042	0.042	0.042	0.042	0.042					
			Max	10.917	6.792	1.958	0.375	0.042					
			S.D.	1.228	0.838	0.510	0.111	N/A					

Table VII-2. (continued)

Embayment System	Start Date	End Date	Total Deployment (Days)	Duration (cumulative days) >5 ug/L (Days)	>10 ug/L (Days)	>15 ug/L (Days)	>20 ug/L (Days)	>25 ug/L (Days)	Frequency (# events) >5 ug/L (#)	>10 ug/L (#)	>15 ug/L (#)	>20 ug/L (#)	>25 ug/L (#)
Sulphur Springs System													
Sulphur Springs	8/13/02	9/19/02	37.1	31.208	15.667	7.208	2.542	1.083	22	36	35	19	12
			Mean	1.419	0.435	0.206	0.134	0.090					
			Min	0.042	0.042	0.042	0.042	0.042					
			Max	16.167	3.000	0.750	0.333	0.125					
			S.D.	3.854	0.588	0.150	0.088	0.030					
Stage Harbor System													
Stage Harbor	7/9/02	8/8/02	29.9	15.875	2.208	0.083	0.000	0.000	60	14	2	0	0
			Mean	0.265	0.158	0.042	N/A	N/A					
			Min	0.042	0.042	0.042	0.000	0.000					
			Max	2.750	0.625	0.042	0.000	0.000					
			S.D.	0.407	0.161	0.000	N/A	N/A					
Oyster Pond	7/9/02	9/11/02	64	17.958	3.625	0.583	0.000	0.000	40	22	4	0	0
			Mean	0.449	0.165	0.146	N/A	N/A					
			Min	0.042	0.042	0.042	0.000	0.000					
			Max	5.792	1.333	0.375	0.000	0.000					
			S.D.	0.953	0.289	0.158	N/A	N/A					
Mill Pond	7/9/02	9/11/02	63.9	43.125	19.208	7.500	1.500	0.042	78	64	24	10	1
			Mean	0.553	0.300	0.313	0.150	0.042					
			Min	0.042	0.042	0.042	0.042	0.042					
			Max	10.917	6.792	1.958	0.375	0.042					
			S.D.	1.228	0.838	0.510	0.111	N/A					

VII.3 EELGRASS ANALYSIS

A detailed, eelgrass survey was conducted of the five embayments of the Town of Chatham in the Fall of 2000. The survey was conducted by shallow draft boat with direct observation of the embayment bottom. In addition to coverage information (presence or absence), the density of the eelgrass beds were assessed in order to determine the role of this resource in system function. Density relates to the amount of bottom covered with eelgrass within the boundary of region of eelgrass bed colonization. This latter density value allows for future tracking of changes in eelgrass bed health, which is frequently not possible from bed delineation alone. This detailed study, when combined with the mapping program by DEP in support of MEP (C. Costello), provides a view of temporal trends in eelgrass distribution from 1951 to 1994/5 to 2000. This temporal information can be used to determine the stability of the eelgrass community.

The fact that each of the eelgrass data sets was collected by a different method reduces the extent to which quantitative rates of change in eelgrass coverage within a basin can be determined. However, the primary use of the data is to indicate (a) if eelgrass once or currently colonizes a basin and (b) if large-scale system-wide shifts have occurred. The historical eelgrass data (presence/absence) was derived from 1951 aerial photos, but with only anecdotal validation, while the 1994/5 and 2000 data had field validation. Furthermore, the fact that the trend from 1951 to 1994/5 was consistent with the trend from 1994/5 to 2000 lends credence to the earlier data set.

In 2000 only the larger embayment systems contained notable eelgrass coverage. Eelgrass was not observed within Taylors Pond/Mill or Creek, Cockle Cove/Sulphur Springs/Bucks Creek. Muddy Creek was devoid of eelgrass except for a small patch (about 10% density) adjacent the inlet. The eelgrass survey data from the Stage Harbor and Bassing Harbor Systems was used to produce the eelgrass coverage maps shown in Figures VII-11 and VII-12. Within these 2 larger systems, eelgrass was not observed within the upper regions of the Oyster Pond and Little Mill Pond/Mill Pond/Mitchell River sub-embayments in the Stage Harbor System and in Frost Fish Creek in the Bassing Harbor System.

Due to our concern over potential recent changes in nutrient conditions within the major embayment systems resulting from watershed loading and changes in flushing (inlet shifts), we examined Massachusetts DEP eelgrass mapping data collected in 1994 for Chatham's coastal waters. These data confirmed the absence of eelgrass within the smaller embayments and agreed in general distribution within the two large embayment systems. Figure VII-13, VII-14, and VII-16 show the distribution of eelgrass coverage in 1994/5.

The 1951 eelgrass distribution maps for the Stage Harbor System (Figure VII-15) and Bassing Harbor System (Figure VII-16) suggest that eelgrass coverage was significantly greater in some of the sub-embayments compared to present conditions. Most notably both Oyster Pond and Mill Pond had extensive coverage in 1951. These systems still had coverage in 1994 and the near complete loss by 2000. In fact, it appears that most of these 2 embayment systems was capable of supporting relatively dense eelgrass stands in 1951.

It is possible to determine a general idea of short and long term rates of change in eelgrass coverage from the mapping data. However, since the 2000 mapping program was done fully by on-site transect surveys it was able to detect sparse eelgrass beds, not typically seen by aerial mapping (Table VII-3). Therefore, while the 2000 study may represent more fully the eelgrass situation, it is not directly comparable to the historical data. Therefore, to determine historical changes we used the distributions shown in Figures VII-15, VII-16, which were all generally collected using a similar approach (Table VII-4). The latter data represent relatively established beds and therefore the areal coverage's are less than observed in the transect study. None-the-less, it is clear that each of the sub-embayments to the Stage Harbor (Figure VII-15) and Bassing Harbor (Figure VII-16) Systems have lost coverage. Comparison of coverage's based upon maps derived from aerial surveys suggests that there has been significant reduction in eelgrass coverage over the past 50 years in both embayment systems (Table VII-4). That this change is still occurring is seen in the aerial mapping data (Table VII-4) and by comparing the 1994/5 and 2000 maps for each system. Since the 2000 maps (Figures VII-11, 12) use a more sensitive technique than the 1994/5 maps (Figures VII-14, 16), the lower coverage in 2000 suggests a "true" loss of bed area.

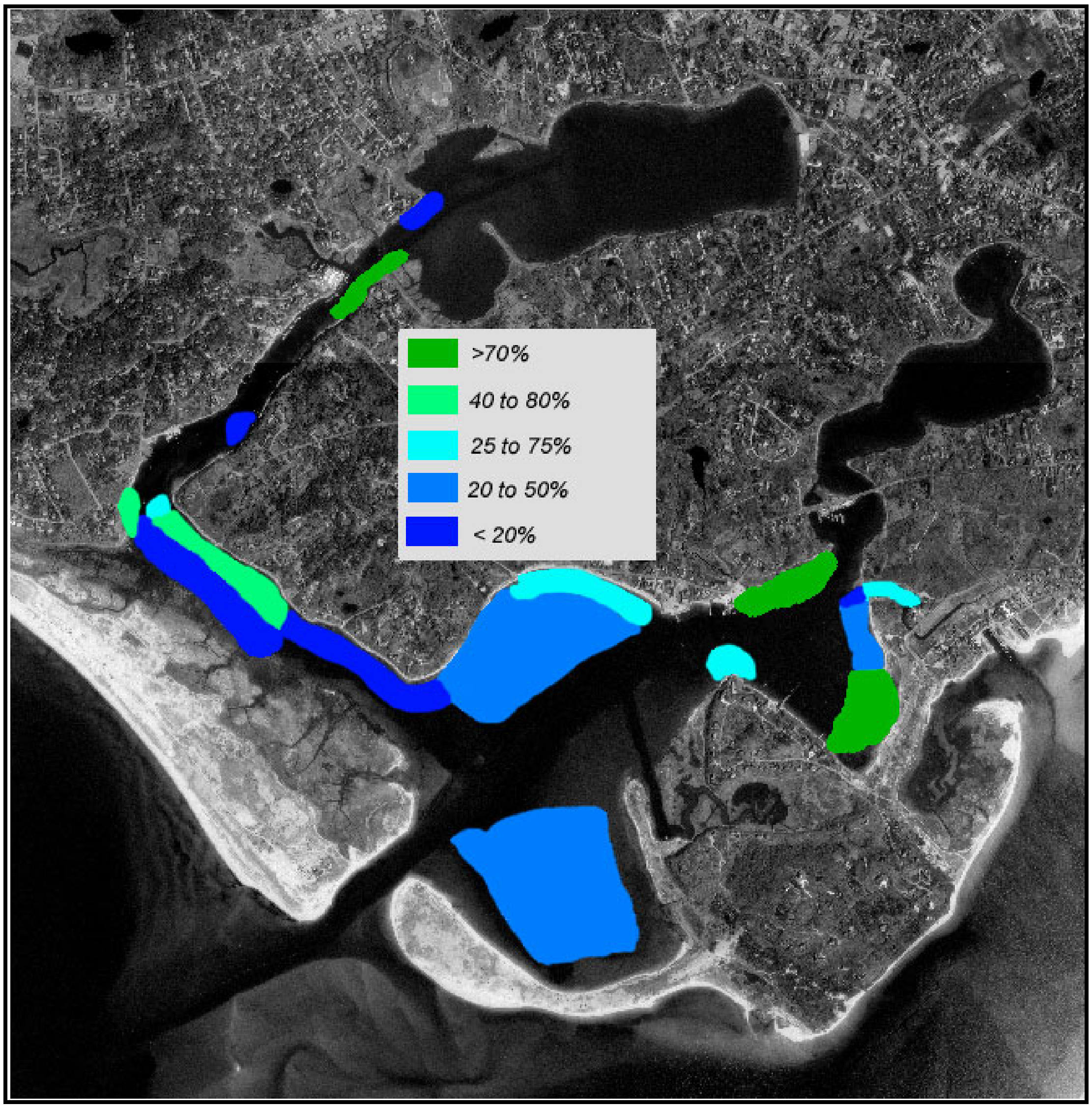


Figure VII-11. Map of Stage Harbor eelgrass distribution as observed in 2000.

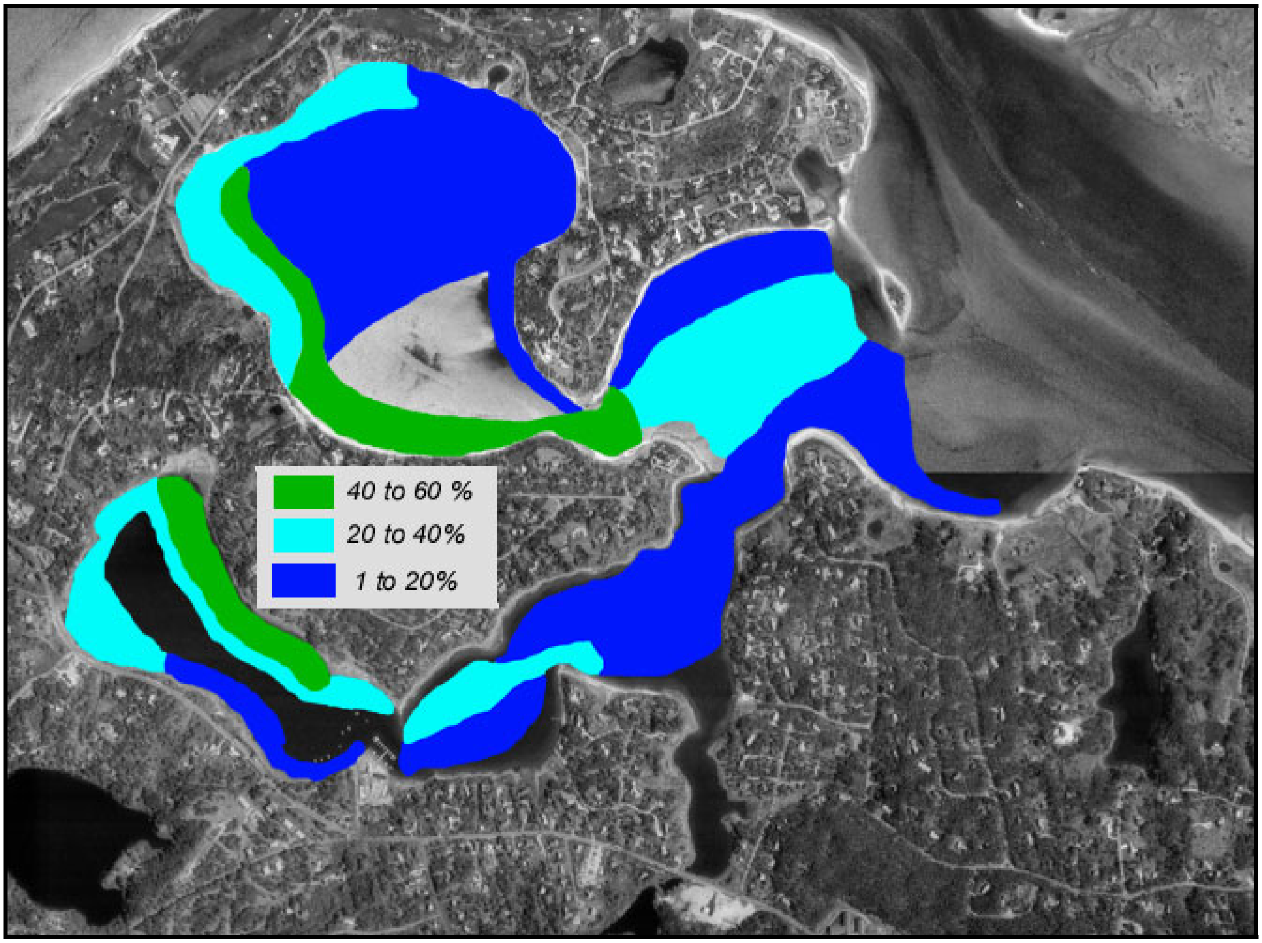


Figure VII-12. Map of Bassing Harbor eelgrass distribution as observed in 2000.

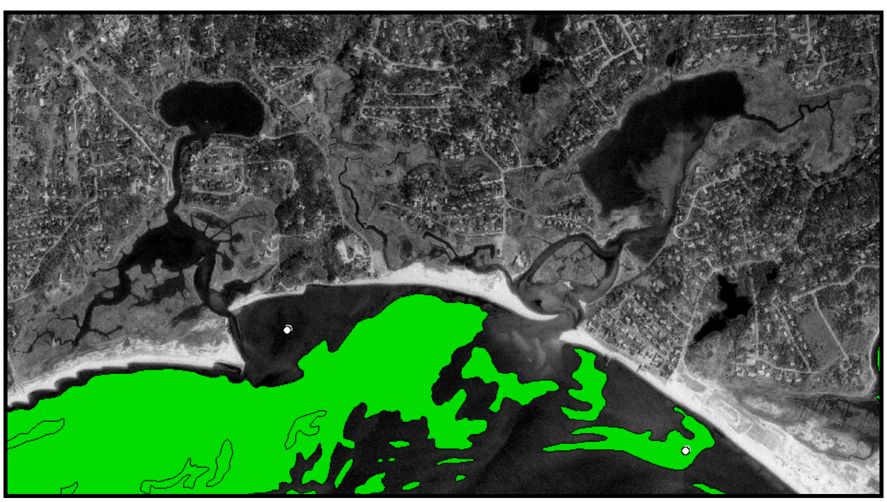


Figure VII-13. Map of Taylors Pond and Sulphur Springs area eelgrass distribution (green shaded area) as determined by Massachusetts DEP in 1994 by analysis of aerial photographs. White circles indicate sites where eel grass coverage was field-confirmed.

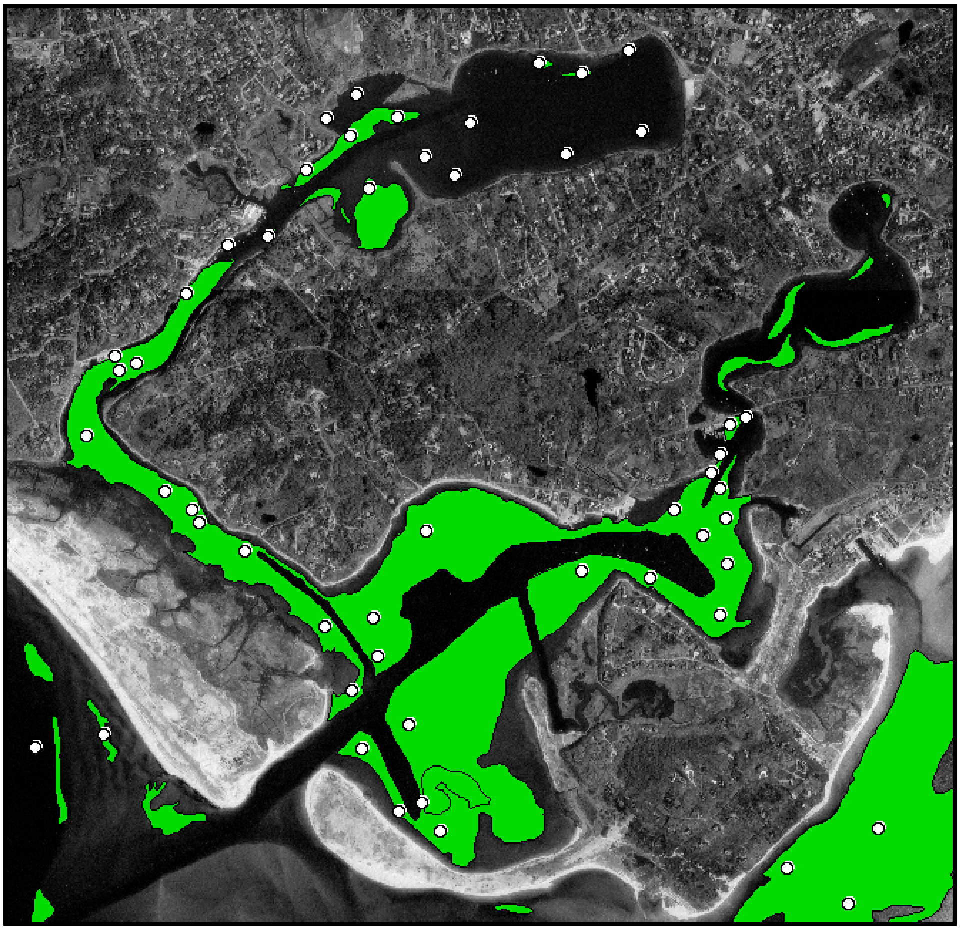


Figure VII-14. Map of Stage Harbor area eelgrass distribution (green shaded area) as determined by Massachusetts DEP in 1994 by analysis of aerial photographs. White circles indicate sites where eel grass coverage was field-confirmed.

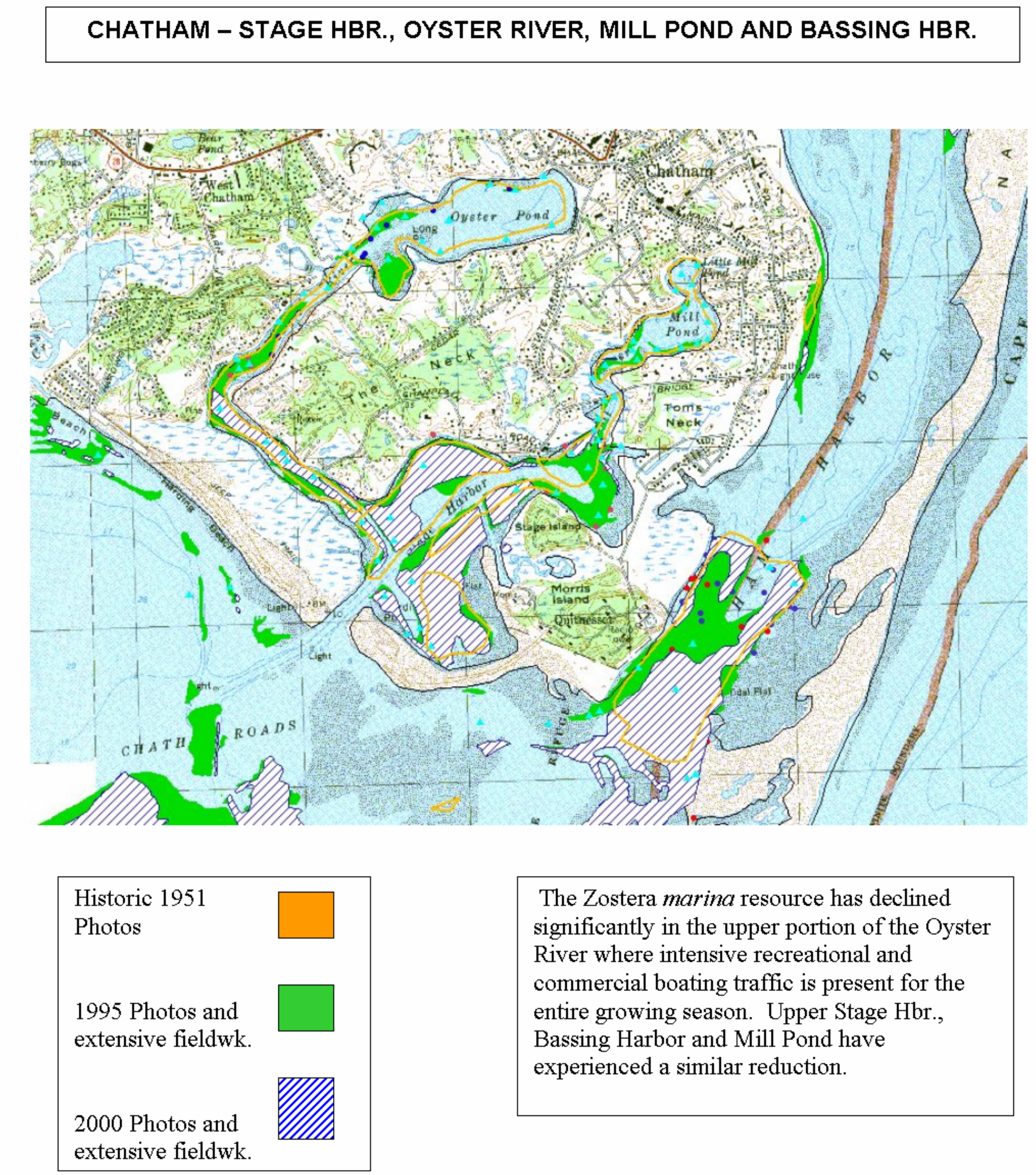
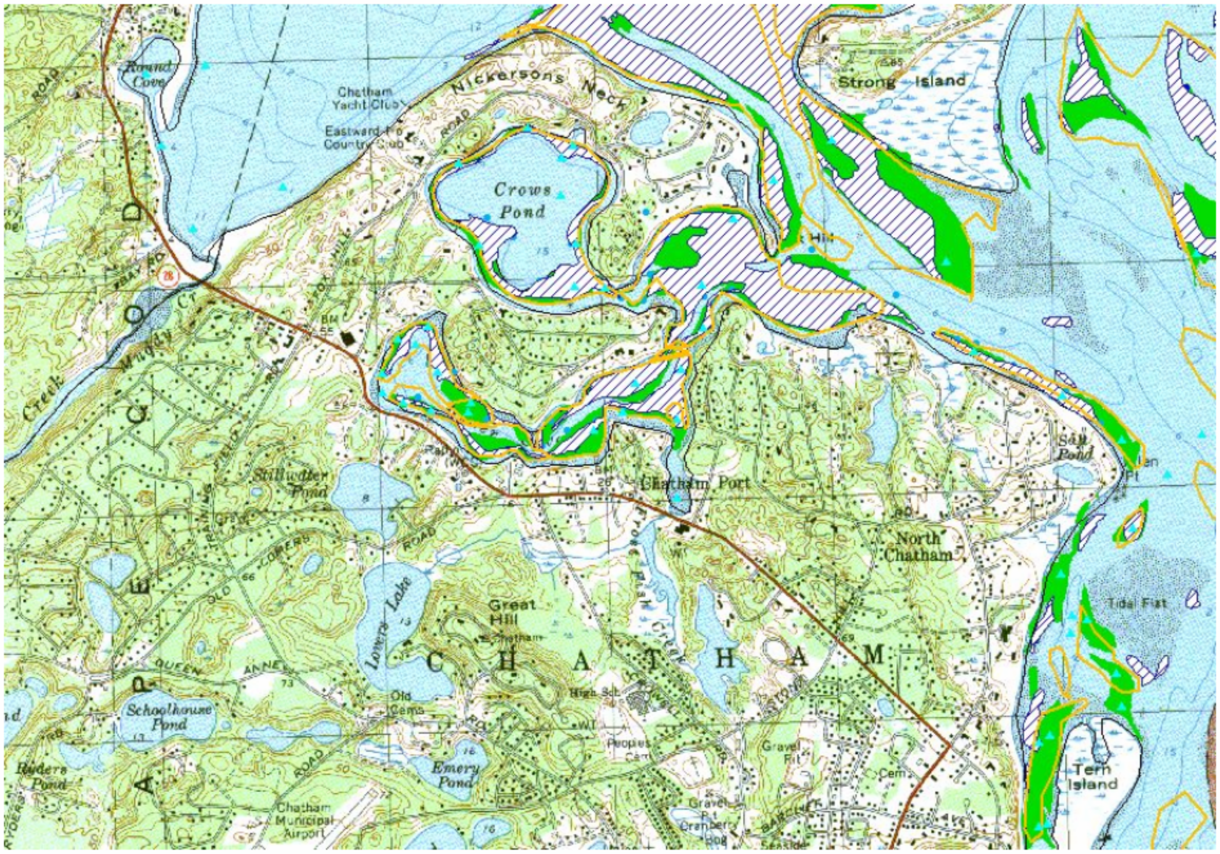


Figure VII-15. Historical eelgrass coverages with the Stage Harbor System. The 1951 coverage is depicted by the orange outline inside of which is the eelgrass beds. The green solid and blue hatched areas depict the bed areas in 1995 and 2000, respectively.

CHATHAM – RYDERS COVE



Historic 1951 Photos	(orange)
1995 Photos and extensive fieldwk.	(green)
2000 Photos and extensive fieldwk.	(blue hatched)

The Zostera *marina* resource has been relatively stable in the Ryder's Cove area. The Frost Fish Creek area was not included in our survey. Present resources seem to be close to what the historic imagery revealed.

Figure VII-16. Historical eelgrass coverages with the Bassing Harbor System. The 1951 coverage is depicted by the orange outline inside of which is the eelgrass beds. The green solid and blue hatched areas depict the bed areas in 1995 and 2000, respectively.

Table VII-3. Eelgrass coverage in Chatham embayments in 2000 assayed by visual transect surveys. This approach can record the distribution of eelgrass at low density. Therefore the values represent maximum areal coverage.

Embayment (total surface area)	Eel Grass Density	Area (ac)	Coverage Area percentage of total embayment area
Stage Harbor System			
Inner Stage Harbor (76.1 ac)	> 70%	20.3	26.6
	25 to 75%	5.9	7.8
	20 to 50%	4.8	6.4
	< 20%	0.8	1.1
Stage Harbor (268.2 ac)	25 to 75%	9.6	3.6
	20 to 50%	97.5	36.4
	< 20%	2.8	1.0
Oyster Pond River (88.1 ac)	> 70%	3.9	4.4
	40 to 80%	13.2	15.0
	25 to 75%	1.1	1.3
	< 20%	31.3	35.6
Stage Harbor system Total Surface area: 640 ac Stage Harbor system total Eel grass coverage: 191 ac Percent coverage total system: 29.9%			
Bassing Harbor System			
Crows Pond (115.7 ac)	40 to 60%	17.2	14.8
	20 to 40%	17.3	14.9
	1 to 20%	65.4	56.5
Ryder Cove (46.9 ac)	40 to 60%	9.5	20.3
	20 to 40%	15.1	32.1
	1 to 20%	5.1	10.9
Outer Ryder Cover (54.2 ac)	20 to 40%	6.9	12.8
	1 to 20%	34.1	62.9
Bassing Harbor (86.5 ac)	40 to 60%	3.7	4.3
	20 to 40%	26.1	30.1
	1 to 20%	30.8	35.6
Bassing Harbor system Total Surface area: 320 ac Bassing Harbor system total Eel grass coverage: 231 ac Percent coverage total system: 72.2%			

Table VII-4. Changes in eelgrass coverage in the 2 major embayment systems within the Town of Chatham over the past half century (C. Costello). Note: data from Table VII-3 collected by different approach not included.

Embayment*	1951 (acres)	1995 (acres)	2000 (acres)	% Difference (1951 to 2000)
Stage Harbor System	**320**	**267**	**162**	**51%**
Bassing Harbor System	**246**	**153**	**114**	**46%**

*No Eelgrass in the Following Embayment Areas: Sulphur Springs, Muddy Creek, Taylors Pond, Frost Fish Creek.

The pattern of eelgrass loss in these systems is consistent with bed loss from nutrient enrichment. As embayments receive increasing nitrogen inputs from their watersheds, there is typically a resulting gradient in nitrogen levels within embayment waters. In systems like those in Chatham, the general pattern is for highest nitrogen levels to be found within the innermost basins with concentrations declining moving toward the tidal inlet. This pattern is also observed in nutrient related habitat quality parameters, like phytoplankton, turbidity, oxygen depletion, etc. The consequence is that eelgrass bed decline typically follows a pattern of loss in the innermost basins (and sometimes also from the deeper waters of deep basins) first. The temporal pattern is a “retreat” of beds toward the region of the tidal inlet. This is the pattern observed in the 2 major systems in the Town of Chatham.

Other factors which influence eelgrass bed loss in embayments may also be at play in Chatham waters, although the pattern of loss seems diagnostic of nitrogen enrichment. However, a brief listing of non-nitrogen related factors is useful. Eelgrass bed loss does not seem to be directly related to mooring density, as some of the highest mooring areas still support eelgrass, while other areas of low mooring density have lost eelgrass. Similarly, pier construction and boating pressure may be adding additional stress in nutrient enriched areas, but do not seem to be the overarching factor. It is not possible at this time to determine the potential effect of shellfishing on eelgrass bed distribution, although the loss of eelgrass from the smaller shallower embayments, which do not support significant shellfishing pressure would suggest again that this is not the overarching stress. In fact both the loss from the smaller embayments and pattern of loss within the larger embayments is consistent with nitrogen enrichment as the primary stressor for eelgrass throughout these five of Chatham’s estuaries.

There are several additional conclusions relative to nutrient related habitat quality which can be derived from an examination and comparison of the Year 2000, Year 1994, and Year 1951 eelgrass maps and coverage data (Tables VII-3 and VII-4 show changes to eelgrass coverage). They can be summarized as follows:

- Eelgrass does not presently colonize the smaller embayment systems, most likely due to their high nitrogen levels and periodic depletion of oxygen in these systems. These conditions existed prior to 1994.

- Eelgrass coverage is declining within the Stage Harbor System. Oyster Pond and Oyster Pond River appear to have had bed loss between 1994 and 2000. It is likely that the eelgrass beds within Oyster Pond were relatively extensive in recent times (1970's or 1980's) based upon the apparent rapid rate of loss in other parts of the system and coverage in 1951. Similar to Oyster Pond the Mill Pond tributary to Stage Harbor also appears to be losing eelgrass. The pattern of loss is also similar, with loss beginning in the innermost reaches with migration toward the lower parts of the System. The loss of eelgrass from 1994 to 2000 from Mill Pond, Mitchell River and upper Stage Harbor mirrors the loss from Oyster Pond and Oyster River over the same period.

- It is almost certain that a primary cause of the observed eelgrass decline results from increasing watercolumn nitrogen levels within these environments over the past decades. Areas of loss are generally associated with the higher chlorophyll sites recorded by the moored instruments (Section VII-2).

- Eelgrass coverage does appear to be declining within the overall Bassing Harbor System. Although no eelgrass bed density data was available from the 1994 mapping study, comparison of similar approaches for determining bed coverage indicates a decline from 1951 to 1994 to 2000.

- Eelgrass within portions of Bassing Harbor (near Bassing Island) are colonized by 2 species of tunicates which appear to be causing localized damage to the beds. It appears that both may be introduced bioinvasive organisms (*Botrylloides diegensis* and *Diplosoma sp.*). These beds need to be monitored to the extent that this biological interaction effects their distribution.

- It should be noted that the density of eelgrass in many of the existing coverage areas is relatively sparse (less than 20%). This may indicate a thinning of beds.

- The Sulphur Springs region of the Sulphur Springs/Bucks Creek System (or Cockle Cove System) is currently a region of high production and accumulation of macro-algae. The basin bottom is completely covered during summer with dense accumulations. In addition, the shallow nature of the system has resulted in the colonization of even the main basin by clumps of *Spartina alterniflora*. It appears that this system is beginning to transition to salt marsh.

The relative pattern of these data is consistent with the results of the benthic infauna analysis and the patterns of eelgrass loss are typical of nutrient enriched shallow embayments (see below).

VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling was conducted at 15 locations within 4 of the embayment systems. Tidal salt marsh creeks and shallow pools were excluded. Samples were collected from: Ryder Cove, Bassing Harbor, Frost Fish Creek, Crows Pond, Muddy Creek, Stage Harbor, Oyster Pond, Mill Pond, Little Mill Pond, and Taylors Pond. Figure VII-17 shows the benthic infauna sampling stations. In all areas and particularly those that do not support eelgrass beds, benthic animal indicators can be used to assess the level of habitat health from healthy (low organic matter loading, high D.O.) to highly stressed (high organic matter loading-low D.O.). The basic concept is that certain species or species assemblages reflect the quality of the habitat in which they live. Benthic animal species from sediment samples are identified and ranked as to their association with nutrient related stresses, such as organic matter loading, anoxia, dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano 1986). Assemblages are classified as representative of excellent or healthy conditions, intermediate in stress, or highly stressed conditions. Both the distribution of species and the overall population density are taken into account. The assemblage was then classified as representative of pristine or healthy conditions, intermediate in stress, or highly stressed conditions. Both the distribution of species and the overall population density were taken into account.

The Infauna Study indicated that most of the upper regions of the embayments are currently supporting habitats under either intermediate or high stress (Table VII-5, VII-6). The lower regions (those nearest the inlets) show higher habitat quality, intermediate to low stress, most likely as a result of the greater dilution of watershed nitrogen inputs by tidal source waters.

The inner "deep" basins, apparently drowned kettle ponds, showed the poorest habitat conditions. Little Mill Pond, Mill Pond (and upper Mitchell River) and Taylors Pond were dominated by stress indicator species. In addition, these systems were supporting low numbers of individuals (except nematodes), indicative of poor nutrient related water quality.

Similar to the "deep" basins, the tidally restricted systems of Muddy Creek and Frost Fish Creek showed very poor habitat quality. This was evidenced by the species present and their low numbers. These systems are heavily nutrient and organic matter loaded. The sediments of Frost Fish Creek and upper Muddy Creek are fluid organic-rich muds, and the assemblages are typical of this type of condition.

The larger basins within the Stage Harbor and Bassing Harbor Systems generally registered as intermediate habitat quality. Only the upper Stage Harbor region and a portion of Crows Pond approached healthy conditions.

Analysis of the evenness and diversity of the benthic animal communities yields a similar evaluation to the natural history information and the evaluation of the number of individuals. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. The highest quality habitat areas, as shown by the oxygen and chlorophyll records and eelgrass coverage, have the highest diversity (generally ~3) and evenness (~0.7). These areas are found in the lower regions of the Stage Harbor and Bassing Harbor Systems (for example Crows Pond, Lower Mitchell River, Bassing Harbor). The converse is also true, with poorest habitat quality found in upper Muddy Creek (H'=1.35, E=0.52), Taylors Pond (H'=1.46, E=0.52), Frost Fish Creek (H'=1.53, E=0.66) and Oyster Pond ((H'=1.42, E=0.40)

These results indicate a moderate to high level of nutrient related stress throughout almost all upper regions of Chatham's embayments (Cockle Cove/Sulphur Springs System not measured). These infauna indicator analysis results are consistent with the levels of nitrogen and oxygen depletion within these systems. In addition, the sediment survey results generally supported the concept of high organic matter loading within the upper poor quality regions of these embayments. The majority of the area within the 2 major embayment systems (Stage Harbor, Bassing Harbor) appear to be experiencing only a moderate level of ecological stress and are supportive of productive and diverse benthic animal communities. These results are also consistent with the water quality monitoring and sediment characteristics data sets.

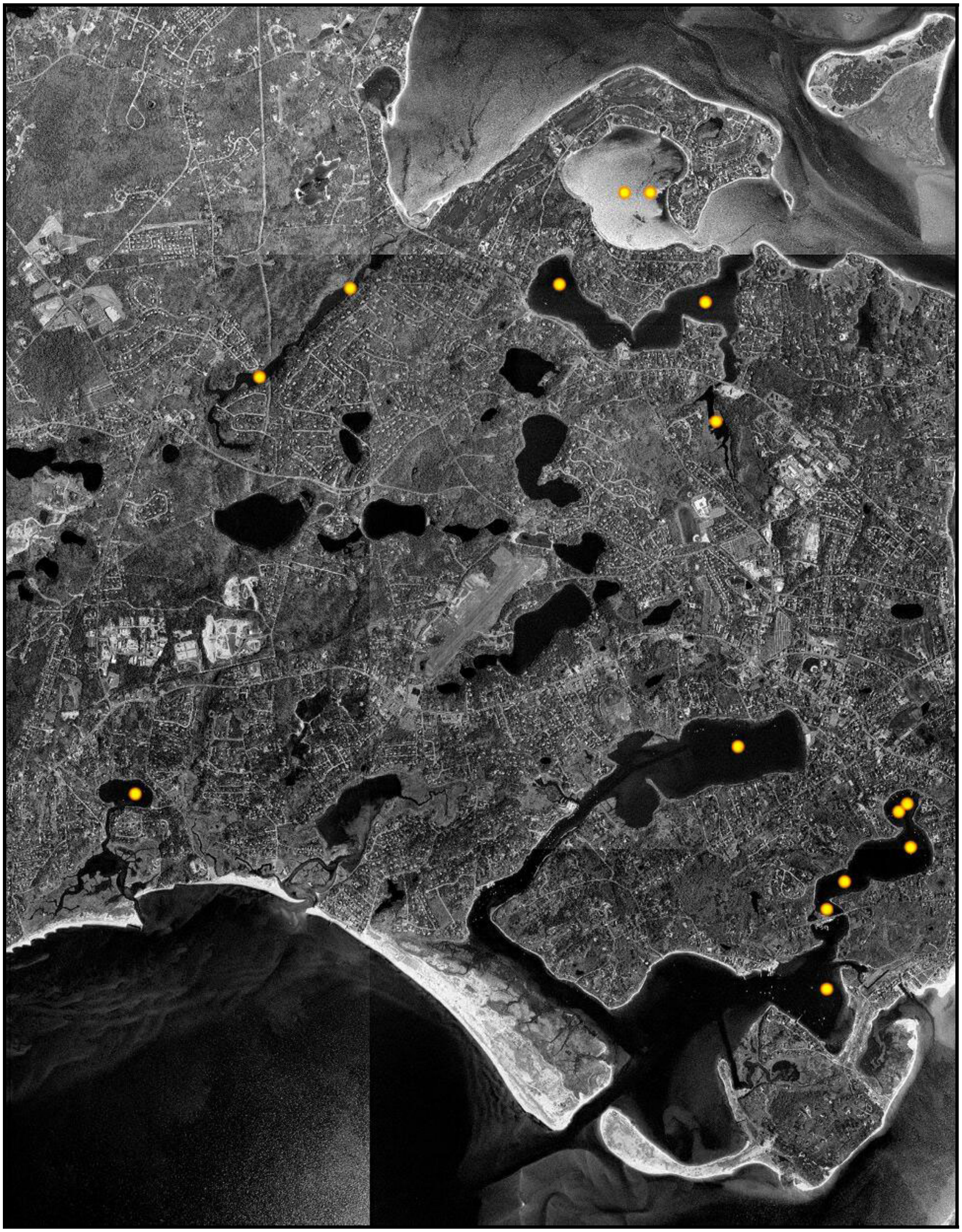


Figure VII-17. Aerial photograph of Chatham showing location of benthic infaunal sampling stations (yellow circles).

Table VII-5. Benthic Infaunal Community Assessment for Chatham Embayments. Samples collected Summer and Fall of 2000. All data is represented as per 1/25 m2. Indicator assessment based upon life history information (G.R. Hampson, SMAST).

Embayment	Total	Total	Benthic Infaunal Community - Indicators						Classification
			Healthy	Healthy	Intermediate	Intermediate	Stressed	Stressed	
	#Species	#Individuals	#Species	#Individuals	#Species	#Individuals	#Species	#Individuals	
Stage Harbor System:									
Oyster Pond	12	1090	6	109	3	962	3	19	Intermediate
Little Mill Pond - Rep 1	2	>600	0	0	1	Abundant	1	Abundant	Stressed
Little Mill Pond - Rep 2	2	>600	0	0	1	Abundant	1	Abundant	Stressed
Mill Pond	2	317	0	0	0	0	2	317	Stressed
Mitchell river Upper	17	506	9	55	4	435	4	16	Intermediate
Mitchell river Lower	23	1037	15	469	6	555	2	13	Intermediate/Healthy
Stage Harbor Upper	20	470	12	62	4	337	4	71	Intermediate/Healthy
Basing Harbor System:									
Bassing Harbor	17	137	11	28	4	73	2	36	Intermediate
Crows Pond – I	29	287	23	186	4	87	2	14	Intermediate/Healthy
Crows Pond – O	29	373	22	180	4	28	3	165	Intermediate
Ryder Cove	19	634	14	131	3	339	2	164	Intermediate
Frost Fish Creek	5	125	1	1	3	64	1	60	Stressed
Taylors Pond	6	43	3	3	3	40	0	0	Stressed

Table VII-6. Benthic infaunal community data for the 5 embayment systems. Estimates of the number of species adjusted to the number of individuals and diversity (H') and Evenness (E) of the community allow comparison between locations.

System	Location	Total Actual Species	Total Actual Individuals	Species Calculated @75 Indiv.	Weiner Diversity (H')	Evenness (E)
Muddy Creek System						
Muddy Creek	Upper	6	77	6	1.35	0.52
Muddy Creek	Lower	8	200	7	2.02	0.67
Stage Harbor System						
Little Mill Pond	Rep 1	1	17	NA	0.00	NA
	Rep 2	No Infauna	NA	NA	NA	NA
Mill Pond	Mid	2	317			
Mitchell River	Upper	18	520	11	1.91	0.46
	Lower	23	1037	14	3.10	0.69
Stage Harbor	Upper	20	470	10	1.86	0.43
Oyster Pond	Mid	12	1090	6	1.42	0.40
Bassing Harbor System						
Ryder's Cove		18	633	11	1.81	0.43
Bassing Is.		16	136	13	3.06	0.77
Crows Pond	Inner	29	287	18	3.76	0.77
Crows Pond	Outer	30	374	18	3.63	0.74
Frost Fish Creek		5	125	15	1.53	0.66
Taylor's Pond System						
Taylor's Pond	Basin	7	44	NA	1.46	0.52