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. The MEP assessment of the Oyster Pond embayment system in the Town of Falmouth, Cape Cod, MA, has been adjusted to accommodate the brackish water nature of this tidal system. For example, the absence of eelgrass (*Zostera marina*), which generally is associated with nutrient enrichment in most southeastern Massachusetts estuaries cannot be employed in the assessment of Oyster Pond. Oyster Pond has generally supported a salinity of 2-4 ppt over the past 60 years, except for 9 years, 1987-1995, (B.L. Howes personal communication, Figure VII-1). While eelgrass does form beds over a wide salinity range, it is generally considered to be distributed in areas of 10-39 ppt (Davison and Hughes 1998), although it does germinate well at 10 ppt. Surveys in the United Kingdom generally indicate eelgrass in areas of 18-40 ppt (Tyler-Walters 2004). Therefore, there is little physiological support for targeting the establishment of eelgrass as the restoration goal for Oyster Pond. Similarly, there is no support for the occurrence of eelgrass in Oyster Pond over the past century (since it freshened). As a result, habitat assessment of this system is based upon data from the water quality monitoring database (chlorophyll and dissolved oxygen) and MEP surveys of benthic animal communities and sediment characteristics and previous studies undertaken to reorient the salinity regime of the Oyster Pond system. These data form the basis of an assessment of this system's 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 this system (Section VIII). Note that based upon site-specific evidence from bioassays and the elemental ratio method (Redfield Ratio), the MEP Technical Team concluded that nitrogen should be targeted as the key nutrient for management of the habitat quality of this estuarine system (see Section II).

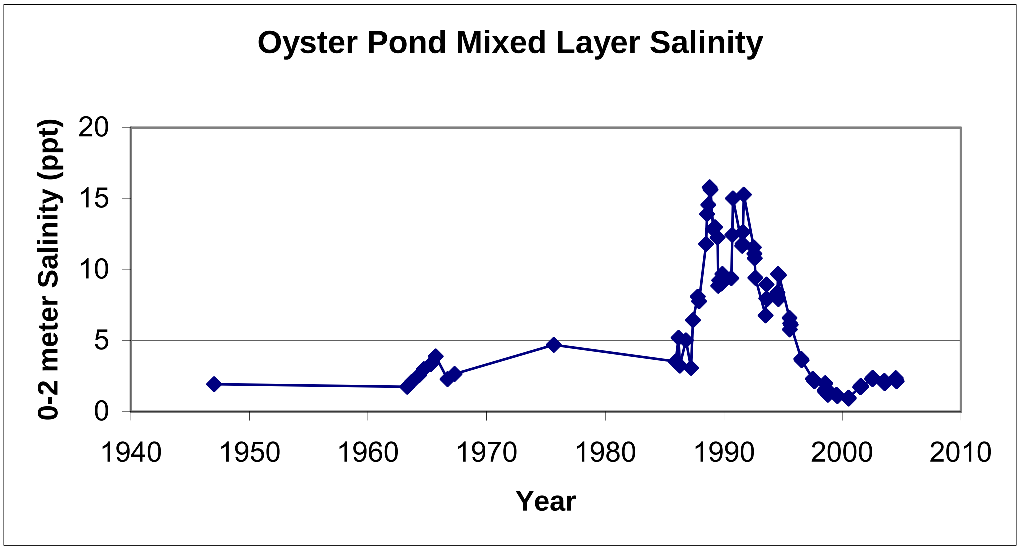

Figure VII-1. Salinity of Oyster Pond surface waters over the past 60 years. The salinity increase over 4 ppt from 1987-1995 resulted from the installation of a new culvert in the tidal channel between the Lagoon and the main basin. The recent lowering and stabilization of the salinity has resulted from the installation of a salinity control/fish weir upgradient of the culvert. Salinity reconstruction courtesy of B.L. Howes.

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 nitrogen thresholds determination, MEP focuses on major habitat quality indicators: (1) bottom water dissolved oxygen and chlorophyll a (Section VII.2), (2) eelgrass distribution over time (Section VII.3) and (3) 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. In the micro-tidal system of Oyster Pond oxygen depletion tends to be associated with periodic stratification by temperature (above 4 meters) and by salinity (below 4 meters in the southern basin only). The MEP Technical Team used the July and August dissolved oxygen levels (determined from grab samples) as the record of the frequency and extent of low oxygen conditions during the critical summer period. The MEP habitat analysis normally uses eelgrass as a sentinel species for indicating nitrogen over-loading to coastal embayments. Eelgrass is a fundamentally important species in the ecology of shallow coastal systems, providing both habitat structure and sediment stabilization. Mapping of the eelgrass beds throughout southeastern Massachusetts is conducted for comparison to historic records (DEP Eelgrass Mapping Program, C. Costello). Temporal trends in the distribution of eelgrass beds are used by the MEP to assess the stability of the habitat and to determine trends potentially related to water quality. Eelgrass beds can decrease within embayments in response to a variety of causes, but throughout almost all of the embayments within southeastern Massachusetts, the primary cause appears to be related to increases in embayment nitrogen levels. However, for the reasons stated above, the absence of eelgrass in Oyster Pond is the result of low salinity and linkage to nitrogen levels is therefore not possible in this system.

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 healthy, transitional, and stressed 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 Woods Hole Oceanographic Institution Nantucket Harbor Study (Howes *et al.* 1997). These data are coupled with the level of diversity (H’) and evenness (E) of the benthic community and the total number of individuals to determine the infaunal habitat quality.

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}. The tidal waters of the Oyster Pond System are currently listed under this Classification as SA. It should be noted that the Classification system represents the water quality that the embayment should support, not the existing level of water quality. It is through the MEP and TMDL processes that management actions are developed and implemented to keep or bring the existing conditions in line with the Classification.

Dissolved oxygen levels in temperate embayments vary seasonally, due to changes in oxygen solubility, which varies inversely with temperature. In addition, biological processes that consume oxygen from the water column (water column respiration) vary directly with temperature, with several fold higher rates in summer than winter (Figure VII-2). It is not surprising 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 when water column respiration rates are greatest. Since oxygen levels can change rapidly, several mg L^{-1} in a few hours, traditional grab sampling programs typically require several years of sampling in order to accurately capture the minimum oxygen conditions within shallow embayments (Taylor and Howes, 1994). Given the oxygen profiling throughout Oyster Pond at relatively short intervals (2 week) during the period of lowest dissolved oxygen (mid-July to late August) and given that Oyster Pond operates primarily as a brackish water lake, the multi-year grab sample data should yield an excellent estimate of minimum oxygen levels. Oyster Pond, unlike more tidally dominated systems, tends to have oxygen minima proximately caused by periodic stratification. Without the tidal currents, this stratification is only broken down by wind-driven mixing and therefore low oxygen events appear to persist for longer periods (to the extent that they occur) than in better flushed estuaries (Howes and Hart, 1997). This lends further support to the use of the high frequency grab sampling approach over several years for finding the oxygen minima for this system. Note that all oxygen data were collected ~7-8 AM, when oxygen level levels are generally at their lowest for a day in these estuaries (Taylor and Howes, 1994).

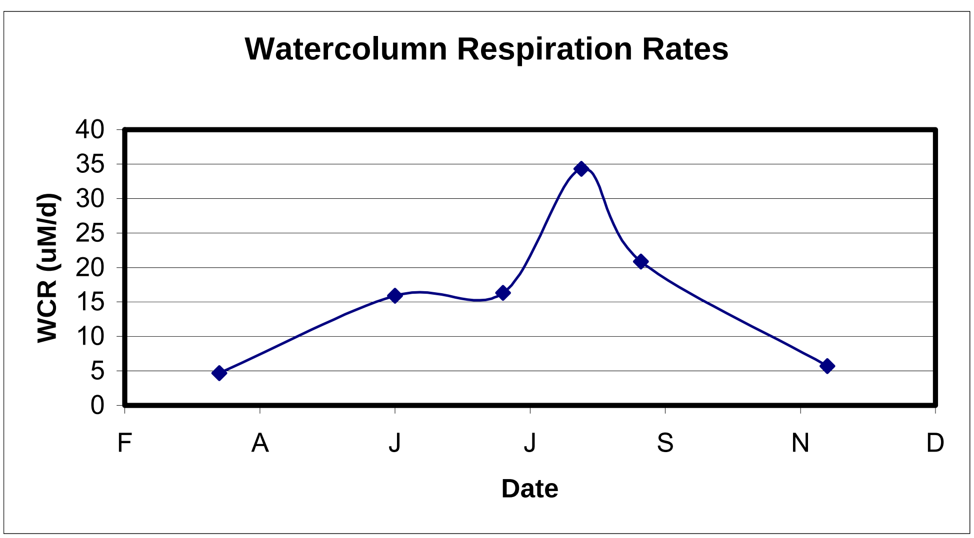

Figure VII-2. Average watercolumn respiration rates (micro-Molar/day) from water collected throughout the Popponesset Bay System (Howes et al., 2004). Rates vary ~7 fold from winter to summer as a result of variations in temperature and organic matter availability.

Unlike many of the other embayments in southeastern Massachusetts, Oyster Pond showed a relatively consistent pattern of low oxygen in its bottom waters throughout its basins (Figure VII-3). The deep, southern basin (6 meters) is consistently anoxic during summer months due to its salinity stratification which persists for months to years. However, this represents only ~10% of the pond bottom. The remaining areas, ≤4 meters depth are only periodically anoxic or hypoxic. The northern basin was periodically anoxic between 1998-2004. However, this basin is enclosed and this anoxia is driven mainly by stratification. The majority of the sediments in the pond (~80%) are represented by the oxygen levels observed in the upper and lower main basin (OP-2 3.25 m, OP-3 4 m). These regions are more open to wind-driven mixing and showed oxygen levels 3 mg/L or above in 96% of samplings and 2 mg/L as a minimum level. Restoration of this system will require an improvement of oxygen levels in this lower basin, which represents most of the benthic habitat and which does not appear to support long periods of stratification shallower than 4 meters depth (as opposed to the northern basin).

Nitrogen enrichment of embayment waters generally manifests itself in the dissolved oxygen record. However, the effect of nitrogen enrichment is magnified in bottomwaters which periodically stratify, like Oyster Pond. Nitrogen enrichment affects oxygen levels by increasing the amount of phytoplankton and algae within estuarine waters. This increased organic matter results in increased rates of oxygen uptake from the water either when the plants die and decay, or at night when they do not photosynthesize. Stratification affects oxygen levels by preventing significant oxygen transport to bottom waters from the generally well oxygenated surface waters. In Oyster Pond the level of nitrogen enrichment watershed inputs is relatively low, as reflected in the moderate total chlorophyll a levels in summer (Table VII-1). In estuaries with vertically well mixed waters, these chlorophyll levels would likely not produce the consistently low summer bottom water oxygen levels. However, the depth of Oyster Pond supports periodic stratification during summer months and the resulting loss of oxygen transport from the surface to bottom waters results in the observed oxygen depletions at even these biomass levels. Note that the ultimate cause of the oxygen depletion is still nitrogen enrichment, stratification only makes the system more sensitive to its effects on oxygen levels.

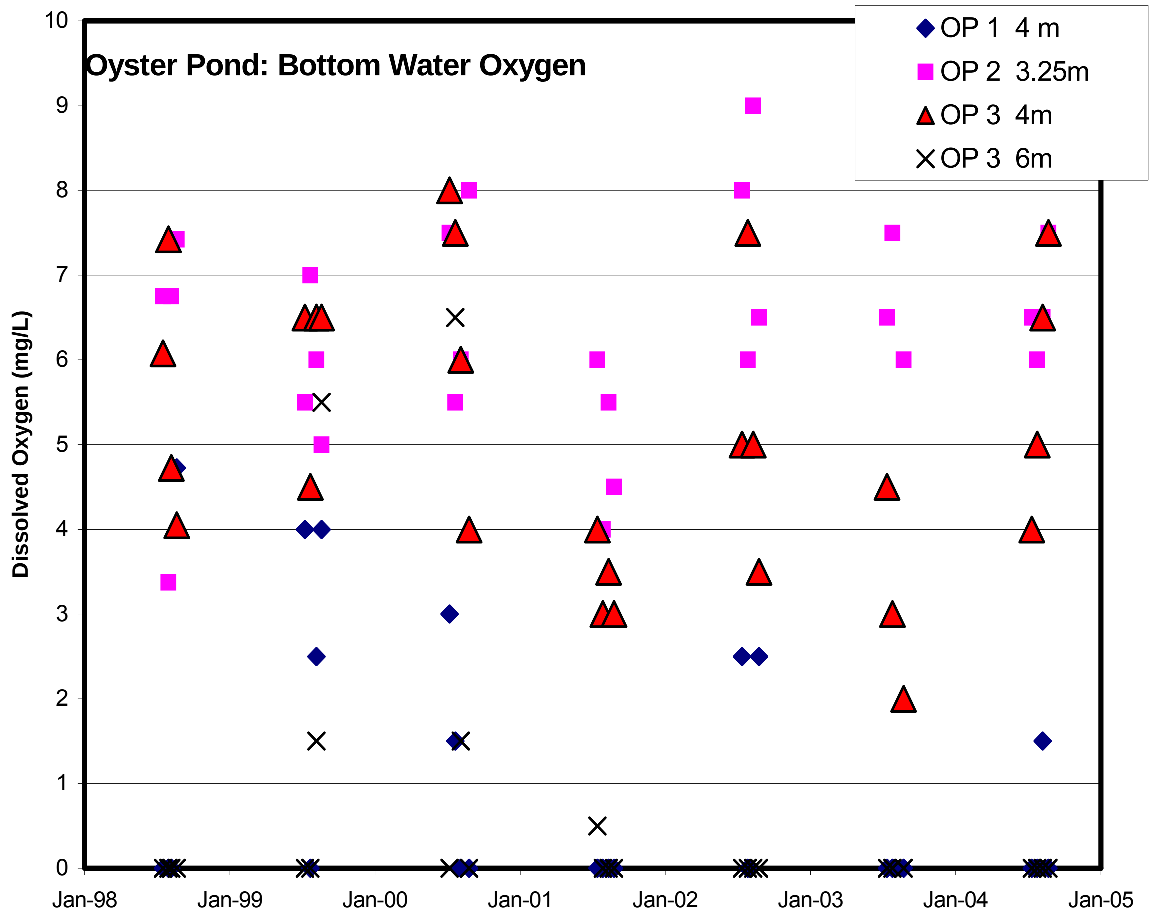

Figure VII-3. Bottom water dissolved oxygen levels measured by Falmouth PondWatch during July and August, determined from grab samples and Winkler Titrations (to 0.5 mg/L). Note that OP 1, 4 m (within the enclosed northern basin) and OP 3, 6 meters (within the deep southern basin) periodically go anoxic. The benchmark for the threshold analysis is OP-3 at 4 meters, this site had D.O. > 3 mg/L on 96% of sampling dates.

Table VII-1. Frequency of grab samples for summer chlorophyll a levels above various benchmark levels within the surface waters (0-3.5m) of the Oyster Pond System. Data courtesy of the Falmouth PondWatch Water Quality Monitoring Program and Coastal Systems Program, SMAST. Geometric averages were used to estimate "average" conditions, given the periodic phytoplankton blooms.

		Frequency						Statistics		
Sub-Embayment	**Sta ID**	**<5 ug/L %**	**5-10 ug/L %**	**10-15 ug/L %**	**15-20 ug/L %**	**20-25 ug/L %**	**>25 ug/L %**	**Geo Mean ug/l**	**Geo s.d. ug/L**	**N**
Oyster Pond System: 2000 – 2004										
Main Basin	OP1-3	57	37	1	1	1	1	4.9	1.9	134

VII.3 EELGRASS DISTRIBUTION - TEMPORAL ANALYSIS

As stated above, the low salinity waters of Oyster Pond are not supportive of eelgrass bed formation. The DEP Eelgrass Mapping Program has conducted no surveys in Oyster Pond. However, observations have been made by PondWatch from 1987 to present which support the lack of eelgrass in this system. Similarly, a complete system data collection and analysis effort conducted in the 1960's throughout the main basin of Oyster Pond did not indicate the presence of eelgrass (Emery, 1997). This latter effort included a census of submerged aquatic vegetation, which did not indicate eelgrass, but did indicate that the dominant SAV in 2004, *Ceratophyllum demersum*, was also dominant in the 1960's. Therefore, the most likely reason for the absence of eelgrass in the main basin of Oyster Pond is the low salinity. This indicates that eelgrass cannot be used as a habitat restoration indicator for this system.

VII.4 BENTHIC INFAUNA ANALYSIS

Quantitative sediment sampling to determine infaunal animal communities was conducted at 6 locations throughout the Oyster Pond System (Figure VII-4). Sites were selected at 1, 2, and 4 meter depths and in 5 of 6 cases duplicate samples were collected. Since Oyster Pond does not support the use of eelgrass as a habitat quality indicator (or as a restoration target), benthic animals were the primary biological indicator employed in the habitat quality assessment. 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, and dissolved sulfide. The analysis is based upon life-history information and animal-sediment relationships (Rhoads and Germano, 1986). Assemblages are classified as representative of healthy conditions, transitional, or stressed conditions. Both the distribution of species and the overall population density are taken into account, as well as the general diversity and evenness of the community. It should be noted that, given the low oxygen levels in the bottom waters (4 meters) of Oyster Pond, the system is clearly impaired by nutrient overloading. However, to the extent that it can still support healthy infaunal communities, the benthic infauna analysis is important for determining the level of impairment (moderately impaired→significantly impaired→severely degraded). This assessment is also important for the establishment of site-specific nitrogen thresholds (Chapter VIII).

Analysis of the evenness and diversity of the benthic animal communities was also used to support the density data and the natural history information. The evenness statistic can range from 0-1 (one being most even), while the diversity index does not have a theoretical upper limit. In general, the highest quality habitat areas, as shown by the oxygen and chlorophyll records and eelgrass coverage (in other estuaries), have the highest diversity (generally >3) and evenness (~0.7). The converse is also true, with poorest habitat quality found where diversity is <1 and evenness is <0.5.

The Benthic Infaunal Study (Table VII-2) indicated that Oyster Pond is not presently supportive of either diverse (H' 0-1.12, mean 0.65) or evenly distributed (mean E = 0.46) benthic infauna. More telling is the low number of species (0-6, mean=3) compared to nearby healthy estuarine areas (~30 species per sample). Due to its brackish waters, Oyster Pond sediments supported both freshwater and estuarine invertebrate populations. The freshwater species were generally insect larvae and these tended to dominate the community. Also notable was that almost half of the samples (5 of 11) had only 0-84 individuals, indicative of an impoverished community. Although the remaining samples had dense populations, they were distributed among a very few species, 6 or less, indicating a stressed community. There was also a potential pattern of more stressed communities in the shallow (1 meter) and deep (4 meter) depths. Overall, the infauna community was consistent with the low dissolved oxygen and organic matter deposition observed in this relatively closed estuarine basin. The lack of a clear spatial pattern is consistent with the generally horizontally well mixed nature of this system (Section 6).

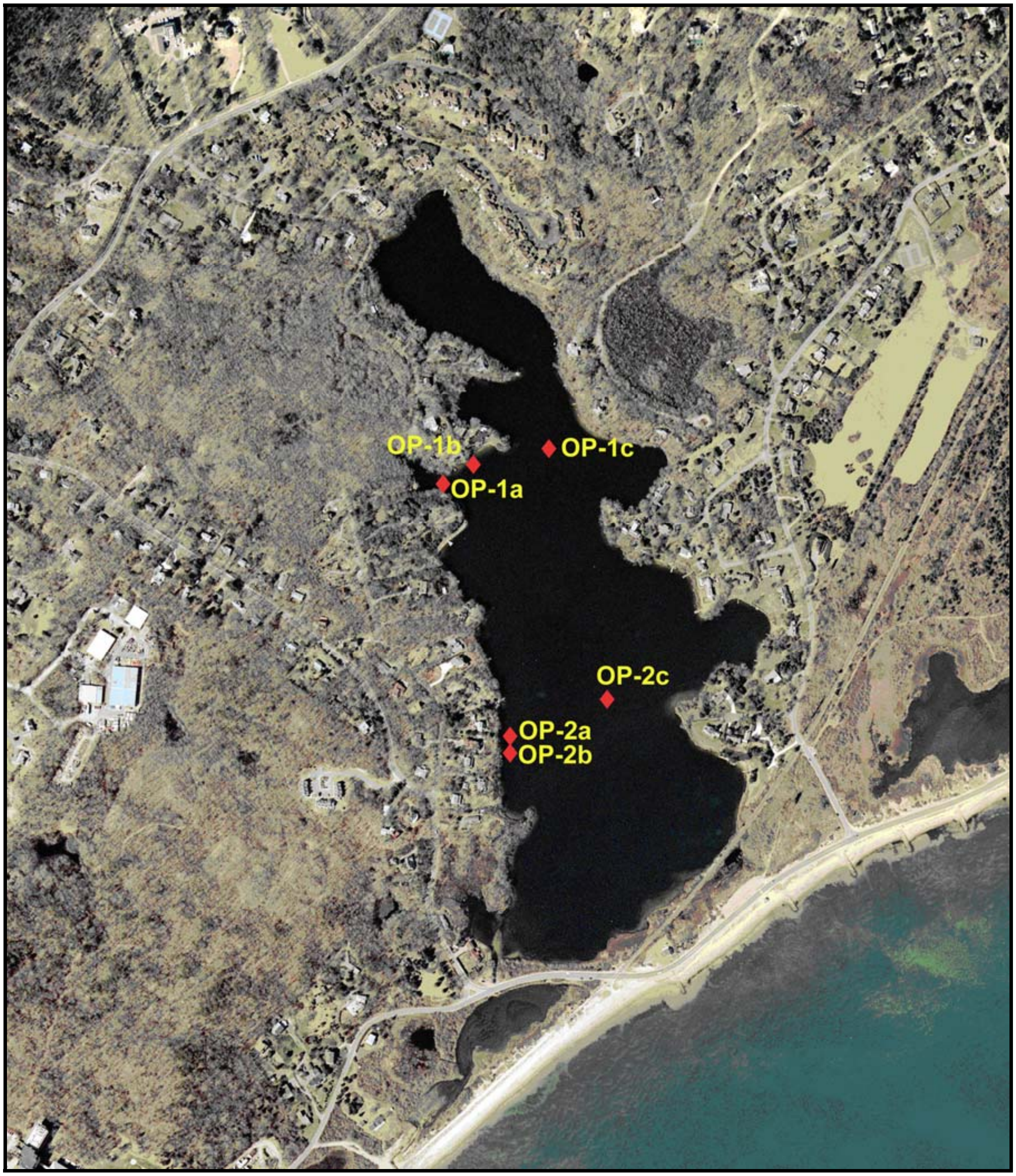

Figure VII-4. Aerial photograph of Oyster Pond showing location of benthic infaunal sampling stations (red symbol).

Table VII-2. Benthic infaunal community data for the Oyster Pond embayment system. 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 (Samples represent surface area of 0.0625 m2).

Marine Adults+All Freshwater Organisms					
Location	**Total Actual* Species**	**Total Actual* Individuals**	**Species Calculated @75 individuals**	**Weiner Diversity (H')**	**Evenness (E)**
Oyster Pond System					
OP-1-a 1m	6 (2)	1165 (241)	3.1	0.87	0.34
OP-2-a 1m	1 (0)	4 (0)	N/A	0.00	N/A
OP-2-a 1m	3 (0)	24 (0)	N/A	0.50	0.31
OP-1-b 2m	5 (1)	1200 (510)	3.0	1.12	0.48
OP-2-b 2m	5 (2)	1368 (441)	2.2	0.94	0.40
OP-1-b 2m	4 (0)	84 (0)	4.0	1.04	0.52
OP-2-b 2m	2 (1)	1271 (412)	2.0	0.91	0.91
OP-1-c 4m	4 (0)	676 (0)	1.7	0.10	0.05
OP-2-c 4m	0	0	N/A	N/A	N/A
OP-1-c 4m	1 (0)	5 (0)	N/A	0.00	N/A
OP-2-c 4m	3 (1)	1613 (12)	2.4	1.05	0.66
Overall:	**3**	**674**	**2.6**	**0.65**	**0.46**

* values are totals of marine and freshwater organisms, values in (#) are for marine organisms only.