FIELD STUDY OF WATER QUALITY IN SUPPORT OF EELGRASS HABITAT RESTORATION PLANNING IN THE ANNISQUAM RIVER

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ABSTRACT

Water clarity and chemistry were studied in the Annisquam River and Gloucester Harbor from June to October 2006. Secchi disk depth (m) was measured to provide a relative assessment of water clarity, and a hand-held water quality monitor was used to collect water chemistry data (water temperature, salinity, dissolved oxygen, and pH). The five-month study described geographic and temporal characteristics of water clarity and chemistry in the Annisquam River. Results demonstrated a gradient of relatively higher water quality in northern waters of the Annisquam River to comparatively depressed water quality in southern waters of the Annisquam River, with the poorest water clarity, highest temperature, and lowest dissolved oxygen observed in the Little River. This study is part of an effort by the Massachusetts Office of Coastal Zone Management to develop an eelgrass habitat restoration plan for the Annisquam River.

INTRODUCTION

Eelgrass (*Zostera marina*) is an underwater plant that forms valuable shallow water habitat in coastal Massachusetts. Wasting disease, caused by the slime mold *Labyrinthula*, decimated eelgrass populations in the 1930s throughout the north Atlantic Ocean, including Massachusetts. This catastrophe substantially altered coastal food webs and processes (e.g., current and sediment transport patterns), severely diminished populations of waterfowl and bay scallops, and caused the extinction of a marine snail (Carlton et al. 1991), demonstrating the ecological and economic value of eelgrass (Thayer 1984). Although site-specific information on recovery is rare (e.g., Dexter 1985), sporadic observations through time indicate eelgrass generally recovered throughout its range from this epidemic by the 1950s-60s. Areas, however, apparently did not recover, and/or more recent (1980s to present) anthropogenic threats extensively depressed eelgrass populations from historic levels. Contemporary global losses in seagrass distribution, including eelgrass on the United States east coast, is considered a crisis in coastal waters (Orth et al. 2006).

Human influences, such as eutrophication, stormwater run-off, and coastal development and perturbations (e.g., mooring fields, shellfish aquaculture), in shallow waters are often ubiquitous in coastal Massachusetts. These many influences degrade eelgrass habitat. While eutrophication is a substantial problem in Buzzards Bay and southern Cape Cod (Short and Burdick 1996; Howes et al. 1999) and requires regional strategies to limit nutrient loading to coastal waters to improve water quality, coastal waters in northern Massachusetts do not appear stressed by nutrient loading (Chandler et al. 1996; Lent et al. 1998).

The abundance of eelgrass is, nevertheless, greatly diminished from historic levels in northern Massachusetts (e.g., Dexter 1985). The record of eelgrass presence in the Annisquam River is supported by monitoring and anecdotal evidence. Addy and Alyward (1944) documented the presence of eelgrass in the Annisquam River in 1943, and Dexter (1985) monitored eelgrass around Cape Ann from 1933 to 1984, indicating recovery of eelgrass in the Annisquam River after the 1930s. Eelgrass mapping in 1995 and 2001 by the Massachusetts Department of Environmental Protection (MassDEP) shows small areas of eelgrass north of the Annisquam River between Babson Point and Annisquam Light and in Ipswich Bay (Figure 1). The areas mapped in 1995 and 2001 represent a dramatic decline in eelgrass within the Annisquam River since the 1970s and early 1980s (Dexter 1985).

While the cause of the decline in eelgrass in the Annisquam River remains unknown, evidence suggests that factors other than nutrient loading reduced eelgrass populations in coastal areas of northern

Massachusetts (Chandler et al. 1996; Lent et al. 1998). We hypothesize that either another outbreak of wasting disease after 1984 (e.g., Short et al. 1986) or contemporary anthropogenic degradation, such as increased suspended sediments in the water column, eliminated eelgrass from the majority of the Annisquam River.

The Massachusetts Office of Coastal Zone Management (CZM) is evaluating the potential to restore eelgrass in the Annisquam River. CZM's approach follows the fundamentals of Short et al. (2002) and is divided into four phases: (1) use available information to provide a preliminary assessment of restoration suitability; (2) collect field measurements, as needed, to improve the preliminary assessment and identify sites for test transplants; (3) plant test plots and monitor survival and growth of test transplants; and (4) recommend the most suitable areas for restoration.

Phase 1 was completed for the Annisquam River and Gloucester Harbor in 2005-2006 (Short and Novak 2006). Results from phase 1 identified potential restoration sites but also determined that the lack of data, particularly water quality, compromised model results (Short and Novak 2006). Shellfish contamination information (i.e., Massachusetts Division of Marine Fisheries 2000) was used as a proxy for water quality in the Annisquam River but was deemed inadequate in terms of spatial resolution or correctness in relation to eelgrass habitat (Short and Novak 2006).

The light environment in the water column (e.g., Dennison and Alberte 1985), along with other physical (e.g., substrate type and water depth) and biological features, such as the abundance of bioturbating decapod crustaceans, determines the distribution of eelgrass. Water clarity is mediated by nutrient concentration, phytoplankton abundance, and/or suspended sediments and is a critical factor limiting eelgrass distribution, since eelgrass requires light for photosynthesis (summarized by Carruthers et al. 2001). Fecal contamination information used for shellfish management was not an appropriate surrogate for water clarity.

Phase 2 of the evaluation of eelgrass habitat restoration potential was initiated by this study. The objective of this study was to examine temporal and spatial characteristics of water clarity and chemistry in the Annisquam River to support the selection of potential eelgrass habitat restoration sites.

MATERIALS AND METHODS

Study Area

The Annisquam River is located in northern Massachusetts Bay and connects Gloucester Harbor to Ipswich Bay. Eelgrass was mapped by the MassDEP along the north shore of Massachusetts in 1995 and 2001 (MassDEP 2006; Figure 1). There are also records of the historic presence of eelgrass in the Annisquam River available from 1951 aerial photography (Costello personal communication), an eelgrass monitoring study from 1933-1984 around Cape Ann (Dexter 1985), and "GRS" marks – meaning grass and interpreted as submerged vegetation – on NOAA Nautical Chart 13279. Mapping data and anecdotal information provide an indication of the current and historic occurrence of eelgrass (Figure 1).

Twenty-one stations were identified throughout the Annisquam River and Gloucester Harbor (Figure 2). The current and historic extent of eelgrass, along with geographic coverage of the Annisquam River, were used to locate sample stations (Table 1). Two stations, ANWQ1 and GLWQ1, were located within eelgrass mapped by MassDEP, and Gloucester Harbor stations were located in well-flushed areas and provided a reference to compare to the Annisquam River data.

Water Clarity

Water clarity was examined through collection of Secchi disk depth (m). Secchi disk depth (m), the point at which the human eye can not distinguish the white and black quadrangles of the disk, was measured to the nearest 0.1 m on the sunny-side of the vessel. Light visible to the human eye is similar to wavelengths that plants use for photosynthesis (photosynthetically active radiation, PAR 400-700 nm;

Carruthers et al. 2001), making Secchi disk depth an effective method for examining water clarity in relation to eelgrass habitat. Weight was added to the disk to maintain a vertical profile beneath the vessel. Secchi disk measurements are robust and comparable across stations, time, and sea conditions (Carruthers et al. 2001) and provide a spatial and temporal description of water clarity in the study area.

Water Chemistry

Water temperature (±0.15 ºC), salinity (±0.1 ppt), dissolved oxygen (±0.2 mg/l), and pH (±0.2 units) were recorded using a YSI 600 multi-parameter water quality monitor. Measurements were recorded within one meter of the water surface and seafloor. Surface and bottom measurements provided an indication of stratification. Collection of water chemistry data helped characterize spatial and seasonal variation in water quality in the Annisquam River.

Sample Dates & Sampling

Secchi disk depth and water chemistry data were collected bimonthly from June to October 2006. Samples were collected during ebb tides, starting at the turn of the tide – high to low. We assumed that ebbing tide was the period of lowest water clarity and highest run-off from the surrounding watershed and tidal creeks, representing a worst-case scenario for water clarity. Sampling occurred between 9:30 AM and 3:00 PM (on most dates; Table 2), when the sun was high and the light climate was stable. Duplicate measurements were collected at 10% of stations per sample date. The duplicates were visually examined during data analyses for data quality assurance and control.

Station locations (latitude and longitude) were loaded into a geographic position system (Garmin GPSMAP 76). The vessel was navigated to each station and anchored or hooked to a mooring, and measurements were recorded. Sampling started at the northern most station (i.e., ANWQ1) and progressed south to Gloucester Harbor. Cloud cover and weather conditions were noted for each sample (Table 2). Tidal stage was recorded relative to the nearest high tide at Gloucester Harbor (hour:minute).

Data Analysis

Data were entered into a Microsoft Excel database. Descriptive statistics (e.g., mean, standard deviation, range, etc.) were applied to describe Secchi disk depth and water chemistry measurements. Visual observation of mean and variance allowed the description of general seasonal and geographic patterns for the purposes of this study, so comparative statistics were not used to evaluate difference in mean among stations.

Seasonal patterns (June-October 2006) of water clarity and chemistry were described by calculating sample-date mean (± standard deviation) for all stations combined. Differences between stations were examined by calculating mean (± standard deviation) for the study and observing individual measurements for each sampling date. Water temperature, salinity, dissolved oxygen, and pH data were described for surface and bottom measurements for each station.

As a Secchi disk measurement is the (maximum) depth at which you cannot distinguish quadrangles, Secchi disk observations to the seafloor are not appropriate to include in the calculation of mean (±standard deviation) Secchi disk depth. Secchi disk observations to the bottom were recorded as “bottom” (water depth, m+). The frequency of observations visible to the seafloor was investigated to help differentiate water clarity among stations.

Mean and maximum Secchi disk depth were displayed for each station in the study area by inverse distance weighted (IDW) interpolation. IDW interpolation was conducted in ArcMap. IDW displays data as a gradient between data points, assuming points close to one another are more closely related than points farther apart. The default power (*p*) of 2, a ‘variable’ search radius, and a 3-meter maximum search radius were used, and no directional influences (e.g., prevailing current and wind direction) were assumed to generate the contour map. The variable radius uses a defined number of points (i.e., 21) to calculate the value of the interpolated cell, which makes the radius distance vary among points. IDW interpolation provides a foundation for classifying and creating spatial categories (i.e., polygons) of water quality to input into a site selection model for eelgrass habitat restoration (Short and Burdick 2005).

RESULTS

Water clarity and chemistry were measured at 21 stations during nine sampling events from June to October 2006. Secchi disk depth was measured 187 times, surface water chemistry was measured 188 times, and bottom water chemistry was measured 166 times during the study. The difference between the number of samples between surface and bottom measurements was a result of shallow water depths (<1.0 m) at sites on particular dates. When water was not deep enough to allow two samples, only one sample was collected approximately between the bottom and surface, and this sample was analyzed as a surface value.

Water Clarity

The Secchi disk was observable to the bottom for nearly 42% of the samples (Table 3). Samples observable to the bottom were recorded as the water depth and excluded from statistical analyses (e.g., mean ± standard deviation). The remaining 58% of the samples were used to statistically describe temporal and spatial patterns in water clarity. While observations to the bottom were excluded from statistical description, these observations were valuable at further characterizing spatial characteristics of water clarity. For example, mean Secchi depth was not calculated for ANWQ12 because every measurement was to the bottom; measurements for ANWQ12 are, however, valuable to demonstrate water clarity at this station (at water depth). Table 3 displays all Secchi disk depth measurements for this study.

Mean Secchi disk depth for the study was 2.9 ± 0.7 m. The range of Secchi disk was from 5.6 m (an observation to the bottom at ANWQ1 on 23 June) to 1.6 m (ANWQ17 on 7 August). Water clarity was relatively stable through the study, with Secchi disk depth slightly greater at the beginning of June and late September and lower from late July to early September (Figure 3).

Stations in the northern sections (ANWQ1, ANWQ2, ANWQ3, ANWQ4, and ANWQ5) of the Annisquam River generally had greater Secchi disk depth compared to southern stations, such as ANWQ17, ANWQ18, ANWQ19, and ANWQ20 (Figure 4; Table 3). IDW interpolation of mean and maximum Secchi disk depth shows the gradient between relatively clear waters in north Annisquam and less clear waters in the Little River and near the Blynman Canal (Figures 5 and 6, respectively). ANWQ4 and ANWQ5 had the greatest mean Secchi disk depth (3.6 ± 0.5 m and 3.6 ± 0.7 m, respectively). ANWQ18, the station located furthest up the Little River, had the lowest mean Secchi disk depth (2.0 ± 0.3 m). ANWQ12 was excluded from description of mean Secchi disk depth (± standard deviation) because all observations were to the bottom. ANWQ8, ANWQ9, ANWQ19, and ANWQ20 also had many measurements to the bottom due to shallow water. Water clarity at GLWQ1 and GLWQ2 (stations in outer Gloucester Harbor) did not noticeably deviate from Annisquam River stations, particularly stations from the northern stretch of the Annisquam River.

Water Chemistry

Temperature

Surface water temperature was slightly higher than bottom water temperature from June to August, and no difference in water temperature was evident in September and October (Figure 7A). Highest mean water temperature was on 24 July 2006 for surface (21.1 ± 2.0 ºC) and bottom (19.9 ± 1.5 ºC) waters.

There was an approximately 1-2 ºC difference in mean water temperature of surface and bottom waters between stations in the north-central Annisquam River and southern sections (Figure 8A). Stations in the Little River - ANWQ16 (19.4 ± 3.2 ºC), ANWQ17 (19.7 ± 3.2 ºC), and ANWQ18 (19.6 ± 3.2 ºC) - had the highest mean surface water temperature, with relatively higher mean surface water temperature also observed at ANWQ15 (18.4 ± 3.2 ºC) and ANWQ19 (18.6 ± 2.7 ºC) compared to stations in central and northern Annisquam River and Gloucester Harbor. Mean bottom water temperature was slightly lower than surface temperature at all stations, except for ANWQ19. Mean bottom water temperature was highest at ANWQ19 (19.7 ± 1.6 ºC), ANWQ18 (19.3 ± 3.1 ºC), and ANWQ15 (18.1 ± 2.6 ºC).

Salinity

Similar to water temperature, slight differences in salinity between surface and bottom waters were observed from June to August (Figure 7B). Bottom salinity was higher than surface salinity during this period. Surface and bottom salinity measurements were similar in September and October.

Salinity was stable and consistent among stations during the study (Figure 8B). The lowest mean and highest variance in surface salinity was seen at ANWQ9 (29.7 ± 3.3 ppt). ANWQ17 and ANWQ18, Little River stations, also presented relatively lower surface mean salinity for the study (29.9 ± 1.3 ppt and 29.8 ± 1.2 ppt, respectively). GLWQ2 – located in the center of the outer harbor – had the highest mean surface salinity (31.1 ± 0.8 ppt). Bottom mean salinity was also highest at GLWQ2 (31.7 ± 0.5 ppt), followed by GLWQ1 (31.4 ± 0.8 ppt) and ANWQ1 (31.0 ± 1.1 ppt). Lowest mean bottom salinity was at ANWQ18 (29.9 ± 0.9 ppt).

Dissolved Oxygen

Minimal differences between surface and bottom measurements of dissolved oxygen existed during the study (Figure 7C). The highest mean dissolved oxygen for surface and bottom waters was in June-July and October, with relatively lower dissolved oxygen in August and September.

Dissolved oxygen was highest at stations in the northern Annisquam River and lowest at stations in the Little River (Figure 8C). There was minimal difference between surface and bottom measurements for all stations. ANWQ1 had the highest mean surface (8.8 ± 0.8 mg/l) and bottom (8.9 ± 0.8 mg/l), followed by ANWQ2 (surface = 8.5 ± 1.0 mg/l; bottom = 8.4 ± 0.8 mg/l) and ANWQ5 (surface = 8.3 ± 1.2 mg/l; bottom = 8.5 ± 1.1 mg/l). The lowest mean surface and bottom dissolved oxygen was observed at ANWQ18, 6.7 ± 1.5 mg/l and 6.6 ± 1.5 mg/l respectively. Surface mean dissolved oxygen was also below 7.0mg/l at ANWQ17 (6.8 ± 1.6 mg/l), and mean bottom dissolved oxygen was 7.0 ± 1.5 mg/l. ANWQ15 (surface = 7.0 ± 1.8 mg/l; bottom = 6.9 ± 1.5mg/l), ANWQ16 (surface = 7.0±1.7 mg/l), and ANWQ20 (bottom = 7.0 ± 1.5mg/l) also demonstrated relatively lower mean dissolved oxygen levels compared to other stations. Dissolved oxygen was near or below 5.0 mg/l at ANWQ16, ANWQ17, and ANWQ18 on 21 August. All other measurements were greater than 5.0 mg/l during the study.

pH

Surface and bottom measurements of pH were virtually the same throughout the study, ranging from 7.6 ± 0.2 (bottom mean on 23 June) to 7.8 ± 0.1 (surface mean on 7 July) (Figure 7D). No noticeable station pattern existed during the study, with ANWQ1 (surface = 7.6 ± 0.3; bottom = 7.6 ± 0.2) and ANWQ16 (surface = 7.6 ± 0.3; bottom = 7.6 ± 0.3) having the lowest mean pH (Figure 8D).

DISCUSSION

Eelgrass habitat restoration is a relatively new management strategy in New England. Furthermore, eelgrass restoration is expensive. Site selection for potential restoration is, therefore, critically important to improve success rate (Short et al. 2002) and requires an understanding of spatial and temporal characteristics of water quality, along with other physical and biological features. While Short and Novak (2006) applied a restoration site-selection model to identify potential eelgrass restoration sites in the Annisquam River, the site-selection study recommended improving water quality data to better identify locations of eelgrass habitat restoration. Water clarity (Secchi disk depth) and chemistry (temperature, salinity, dissolved oxygen, and pH) were studied in the Annisquam River and Gloucester Harbor from

June to October 2006 to improve the understanding of seasonal and geographic characteristics of water quality and assist in identifying potential eelgrass restoration locations.

Water clarity was relatively stable through the study but seemed to slightly decrease from late July to early September (Figure 3). This period of lower water clarity was largely influenced by conditions in the Little River (ANWQ17 and ANWQ18; Table 3). Little River stations (ANWQ17 and ANWQ18) and ANWQ20 (located adjacent to Cape Ann Marina) showed lower Secchi disk depth compared to other stations located throughout the central and upper portions of the Annisquam River and Gloucester Harbor.

The spatial representation of Secchi disk depth (Figures 5 and 6) effectively demonstrates a gradient of relatively higher water clarity in northern waters of the Annisquam River to comparatively depressed water clarity in southern waters of the Annisquam River, particularly within the Little River tributary. Gloucester Harbor stations also presented relatively higher water clarity compared to southern waters of the Annisquam River.

Further evidence of depressed water quality in the southern Annisquam River was demonstrated by slightly higher water temperature and lower dissolved oxygen at the Little River stations and stations adjacent to the Gloucester and Cape Ann Marinas. ANWQ18, located furthest upstream in the Little River, particularly had higher water temperature and lower salinity than other sites, suggesting a relationship between freshwater inputs (e.g., run-off, stormwater discharges, or septic tank leakage) and lower Secchi depth readings.

Light extinction (attenuation coefficient; K_d) was not estimated from Secchi measurements in this study. Light extinction is a valuable estimate of light in the water column and may be an important consideration for eelgrass restoration in the Annisquam River. Carruthers et al. (2001) provide an equation to determine K_d that results in Secchi depth equal to 18% of incident light – 20% incident light is required to sustain adult shoots, and a greater percentage of light is required for successful seed production (P. Colarusso personal communication). Estimating K_d from Secchi measurements, along with the collection of continuous *in situ* light data (e.g., photosynthetically active radiation), may be warranted to better understand the light environment at locations potentially suitable for eelgrass restoration before large-scale transplanting or seeding.

Sampling for this study started later than desired, and water quality conditions from April to early June may influence the suitability of eelgrass habitat. For example, spring run-off can be a substantial source of freshwater and suspended sediments; and spring run-off often stimulates a bloom of phytoplankton, which influences water clarity and chemistry. Spring is also the beginning of the growing season of eelgrass and may influence the success of new propagules. This study did not assess spring conditions, which potentially mediates the long-term survival of eelgrass. Thus, spring water quality may need to be considered for final restoration site selection.

While additional study will be required to fully understand the suitability of areas to support eelgrass in the Annisquam River, this study provides a reasonable characterization of temporal and spatial patterns in water clarity and chemistry from late June to October 2006 and will facilitate the identification of potential eelgrass habitat restoration sites. Data gathered in this study will be combined with other data to identify sites potentially suitable for eelgrass habitat restoration in the Annisquam River. CZM will use data collected in this study, along with additional data necessary to thoroughly evaluate the potential to restore eelgrass, to develop a plan to restore eelgrass habitat restoration in the Annisquam River.

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PERSONAL COMMUNICATION

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Table 1. Station location and description of current and historic eelgrass presence. MassDEP mapped the distribution of eelgrass on the north shore in 1995 and 2001 (MassDEP 2006). Aerial photography from 1951 was used to provide an estimate of vegetated bottoms – the 1951 aerial photography should be used cautiously since there is no groundtruthing of estimated eelgrass from the images (Costello personal communication). Dexter (1985) monitored eelgrass around Cape Ann from 1933-1984. "GRS" on NOAA nautical charts indicates vegetation – possibly eelgrass. ANWQ10 was not sampled in the study.

STATION	LOCATION	EELGRASS PRESENCE
ANWQ1	Annisquam Light	2001 DEP map
ANWQ2	Annisquam Yacht Club	"GRS" on NOAA Chart
ANWQ3	Lobster Cove	Dexter observations
ANWQ4	entrance to Goose Cove	1951 estimate
ANWQ5	Main channel – north	none
ANWQ6	Wheeler Point, Mill River	"GRS" on NOAA Chart
ANWQ7	Mill River	Dexter observations and "GRS" on NOAA Chart
ANWQ8	Mill River	Dexter observations and "GRS" on NOAA Chart
ANWQ9	Jones River	Dexter observations
ANWQ11	Main channel – central	1951 estimate
ANWQ12	Main channel – central	1951 estimate
ANWQ13	Main channel – central	"GRS" on NOAA Chart
ANWQ14	Main channel – central	"GRS" on NOAA Chart
ANWQ15	Main channel – south of 128	Dexter observations and "GRS" on NOAA Chart
ANWQ16	Little River	Dexter observations and 1951 estimate
ANWQ17	Little River	Dexter observations
ANWQ18	Little River	Dexter observations
ANWQ19	Gloucester Marina	none
ANWQ20	Cape Ann Marina	none
GLWQ1	Pavilion Beach, Gloucester Harbor	2001 DEP map
GLWQ2	Outer Gloucester Harbor	none – deep water

** Central indicates stations between Wheeler Point and Rt. 128.*

Table 2. Time of high tide, tidal height, time of sampling, and weather observations for sample dates, June to October 2006.

DATE	HIGH TIDE	TIDAL HEIGHT (ft)	SAMPLING TIME	WEATHER & WIND
23 June	10:04 AM	10.2	10:30AM - 2:05PM	mostly cloudy; light wind
7 July	8:39 AM	9.0	9:00AM - 12:30PM	clear to partly cloudy; light wind
24 July	11:35 AM	9.7	12:08PM - 3:20PM	clear to few clouds; light wind
7 August	9:55 AM	9.9	10:48AM - 1:53PM	mostly cloudy until ~12:30 – then clear; SW winds @ 15 knots
21 August	10:30 AM	9.3	11:11AM - 2:11PM	mostly cloudy to sunny; light wind
7 September	11:11 AM	10.0	11:11AM - 2:00PM	partly cloudy to sunny; winds light
20 September	10:45 AM	9.0	11:15AM- 2:45PM	clear; slightly wind
4 October	9:03 AM	10.3	9:52AM - 1:50PM	clear; no wind
19 October	10:10 AM	8.7	11:10AM - 1:45PM	mostly cloudy; no wind

Table 3. Secchi disk depth (m) measurements for the Annisquam River and Gloucester Harbor, June to October 2006. “+” means that the Secchi disk was resting on the bottom; these data were not used to calculate station or sample date mean ± standard deviation.

STATION	23-Jun	7-Jul	24-Jul	7-Aug	21-Aug	7-Sep	20-Sep	4-Oct	19-Oct	Station Mean ± SD
ANWQ1	5.6+	4.1+	3.7	4.7+	3.1	3.0	3.4	2.9	4.4+	3.2 ± 0.3
ANWQ2	3.3+	4.3	3.1+	2.6+	2.8	2.8	3.0+	3.0	3.6+	3.2 ± 0.7
ANWQ3	3.3	4.2	3.0	3.0	3.4	2.4	3.6	3.2	3.7	3.3 ± 0.5
ANWQ4	5.4+	4.5	3.8	3.3	3.5+	3.0	3.5	3.2	3.3+	3.6 ± 0.5
ANWQ5	5.0	4.1+	3.3	3.3	3.5	2.7	3.5	2.9	4.2	3.6 ± 0.7
ANWQ6	4.5	4.6	2.7	3.0	3.1	3.0	3.7	3.2	3.9	3.5 ± 0.7
ANWQ7	3.6	3.3	3.1	2.6	2.8	2.3	3.2	2.1+	2.2+	3.0 ± 0.4
ANWQ8	3.2+	2.7+	2.7	2.7+	2.8+	2.5	2.9+	2.8	3.0+	2.7 ± 0.2
ANWQ9	2.2+	1.4+	2.0+	1.7+	2.1+	2.5	2.2+	2.6+	2.1+	NA
ANWQ11	3.2+	3.3+	2.1	2.7	2.6	2.6	3.3	2.7	3.3+	2.7 ± 0.4
ANWQ12	2.1+	1.3+	1.9+	1.7+	2.1+	2.4+	1.7+	1.3+	1.7+	NA
ANWQ13	3.1	2.5+	2.3+	2.1	2.5	2.5	3.2	3.0+	2.5+	2.7 ± 0.5
ANWQ14	2.4+	3.3	2.0	2.4+	3.1+	2.5	1.9+	2.9	3.7+	2.7 ± 0.6
ANWQ15	2.8	2.3	2.1+	2.6+	2.3+	2.2	3.0	1.8+	2.1+	2.6 ± 0.4
ANWQ16	2.5	2.0	1.9	2.0	2.6	2.4	3.6	2.5	3.0	2.5 ± 0.5
ANWQ17	2.1	1.9	2.1	1.6	2.3	2.2	2.9	2.1	2.4	2.2 ± 0.3
ANWQ18	2.2	2.5+	1.7	1.7	2.1+	2.2	1.9+	1.4+	2.0+	2.0 ± 0.3
ANWQ19	2.6	2.3	1.4+	1.3+	1.4+	2.3+	1.2+	1.3+	1.5+	2.5 ± 0.2
ANWQ20	1.5+	1.4+	2.1+	1.6+	2.5	2.6+	1.8	2.0+	1.4+	2.2 ± 0.5
GLWQ1	2.9	4.1+	3.2+	3.0+	2.5	2.3	3.3	2.5	3.3+	2.7 ± 0.4
GLWQ2	3.2	3.0	3.6	3.3	2.6	NA	3.5	2.7	NA	3.1 ± 0.4
Sample Date Mean ± SD	3.2 ± 0.9	3.2 ± 1.0	2.7 ± 0.7	2.6 ± 0.6	2.8 ± 0.4	2.5 ± 0.3	3.2 ± 0.5	2.8 ± 0.3	3.4 ± 0.7	2.9 ± 0.7

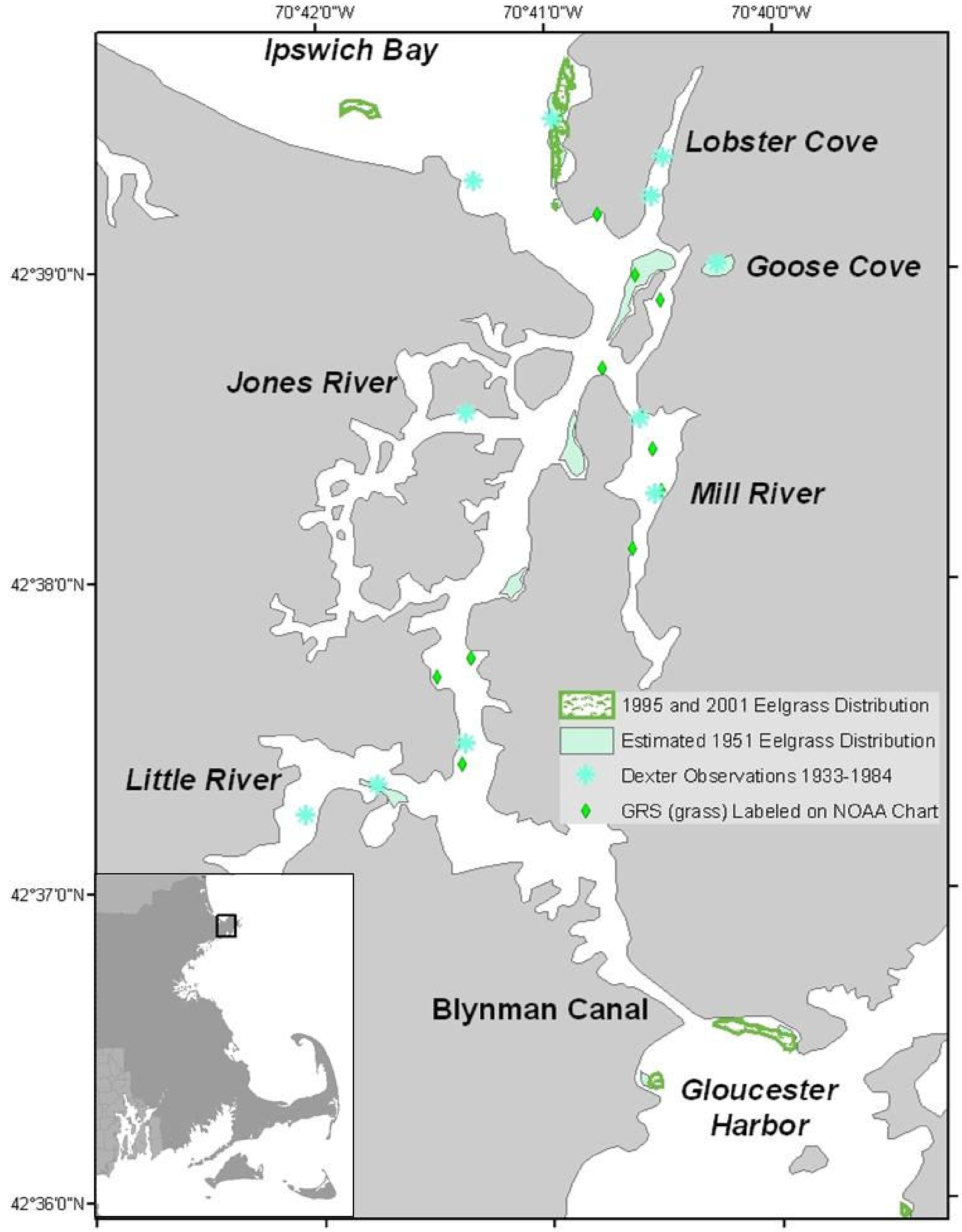

Figure 1. Study area map showing the current distribution of eelgrass in 1995 and 2001 mapped from aerial photography (MassDEP 2006), historic presence of eelgrass from 1951 (light blue polygon; Costello personal communication), observations from 1933-1984 (Dexter 1985), and NOAA nautical chart "GRS" labels.

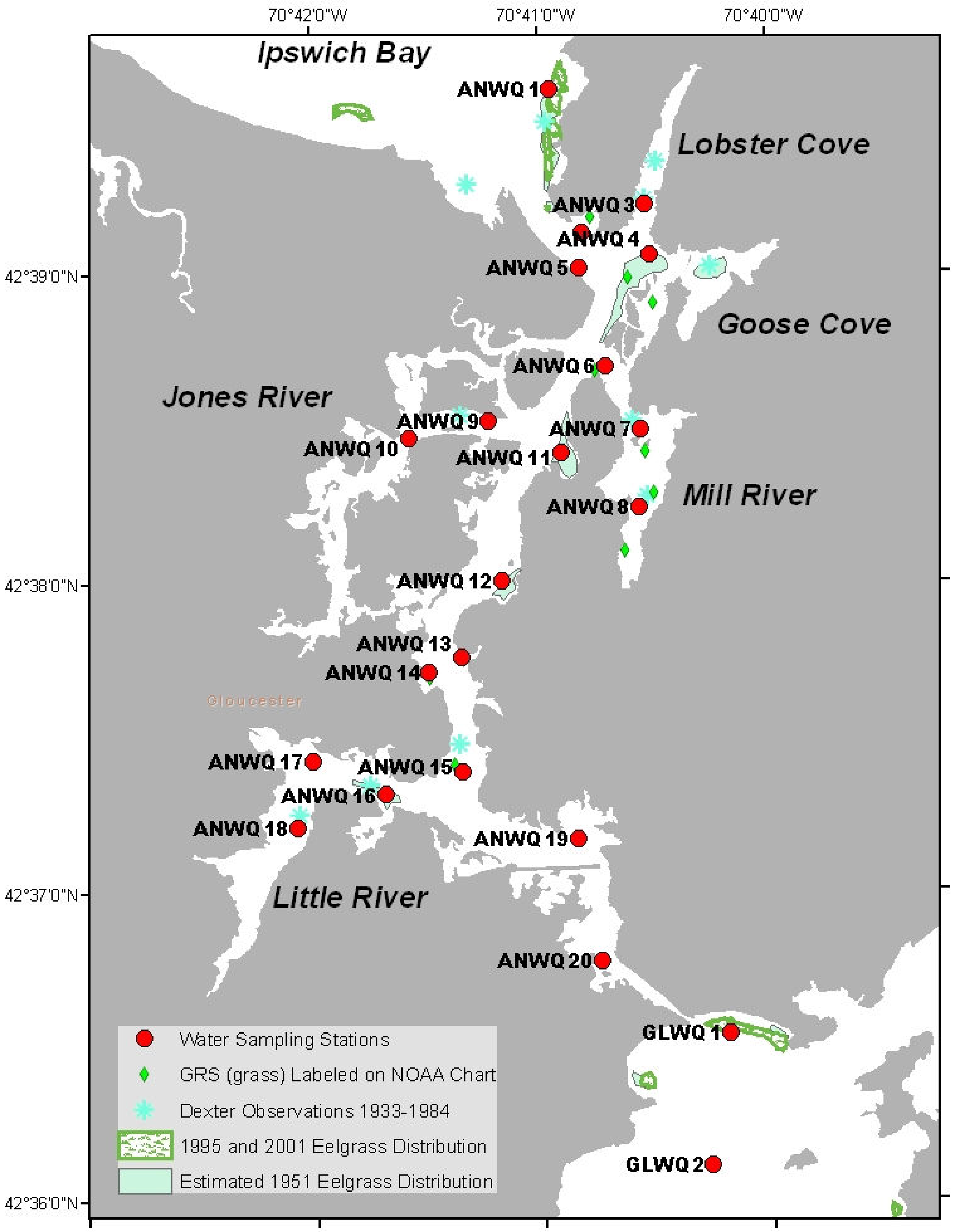

Figure 2. Water sampling stations in the Annisquam River and Gloucester Harbor. *ANWQ2 not shown on map – located offshore of Annisquam Yacht Club; ANWQ10 was not sampled in 2006.

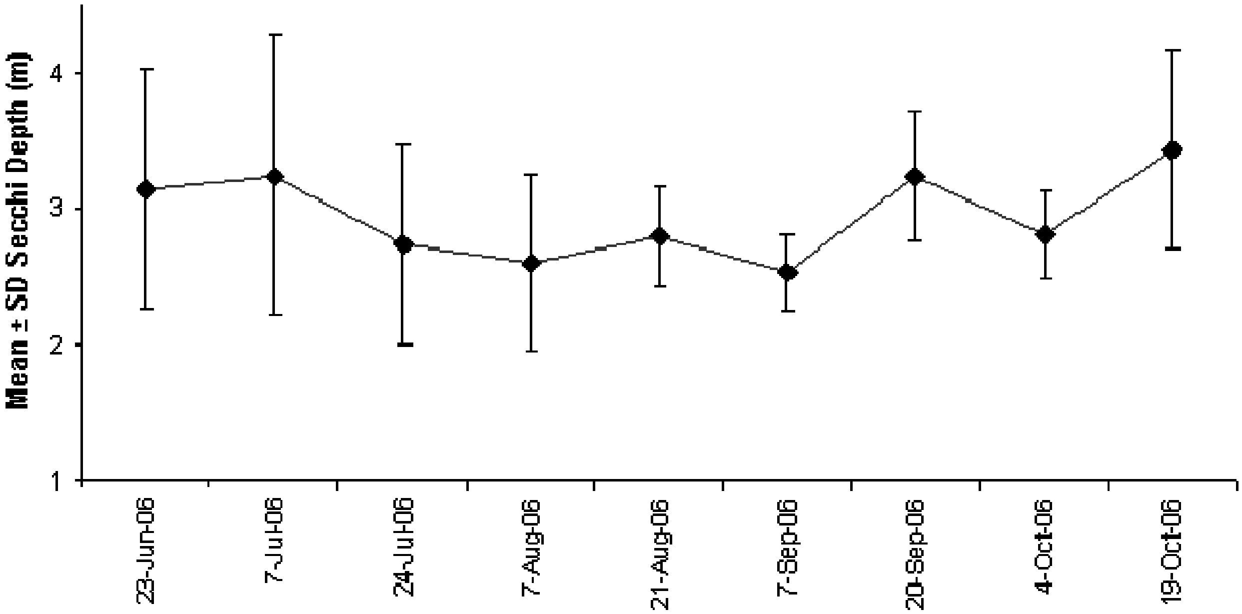

Figure 3. Sample period mean (± standard deviation) of Secchi disk depth (m), June to October 2006.

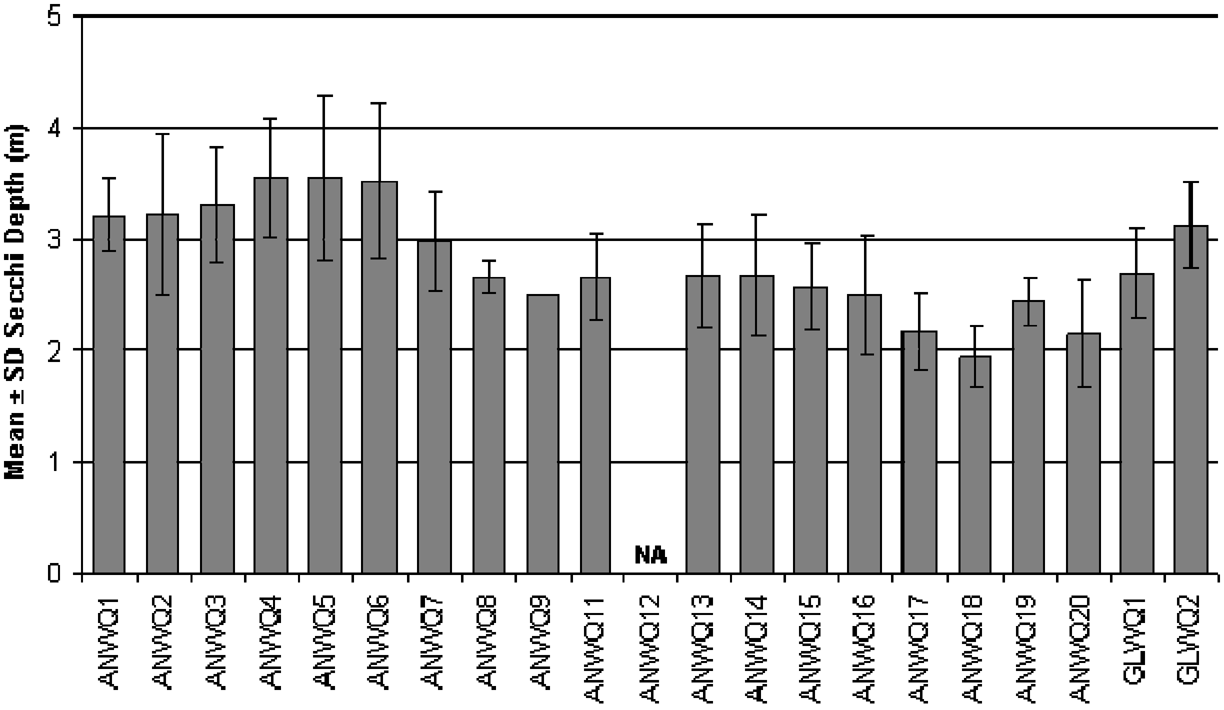

Figure 4. Station study mean (± standard deviation) of Secchi disk depth (m), June to October 2006.

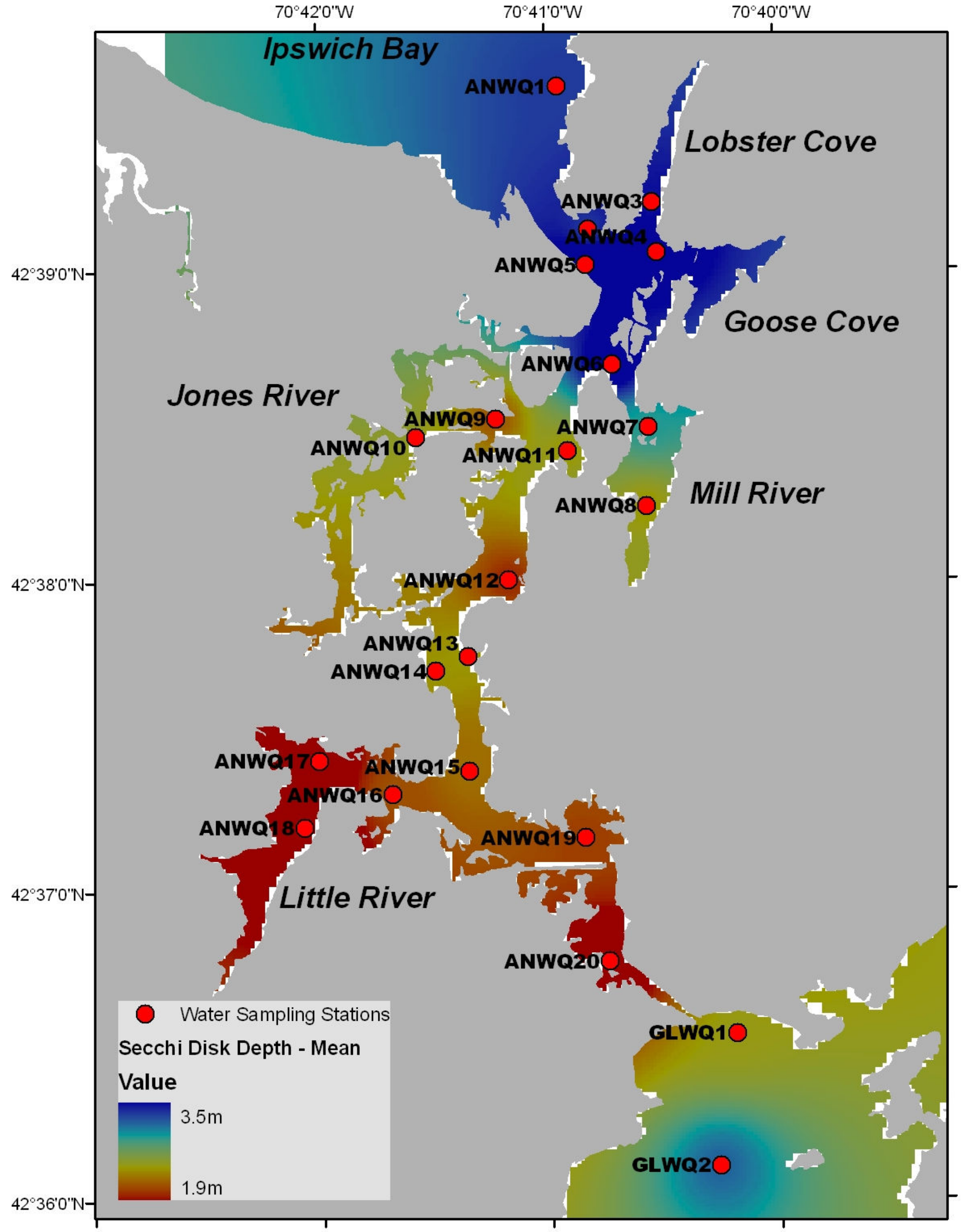

Figure 5. Mean Secchi disk depth (m) displayed by inverse distance weighted interpolation for study area.

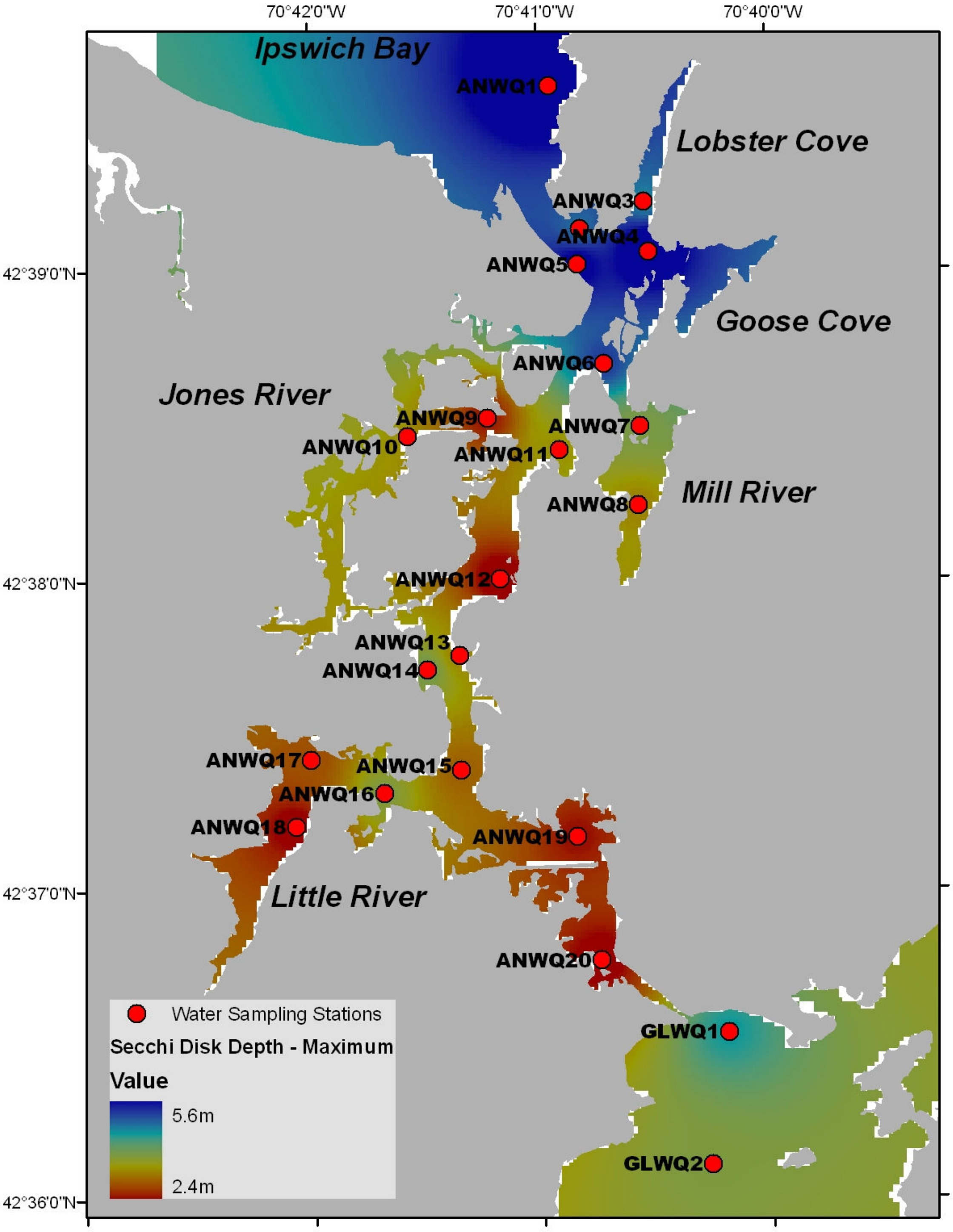

Figure 6. Maximum Secchi disk depth (m) displayed by inverse distance weighted interpolation for study area.

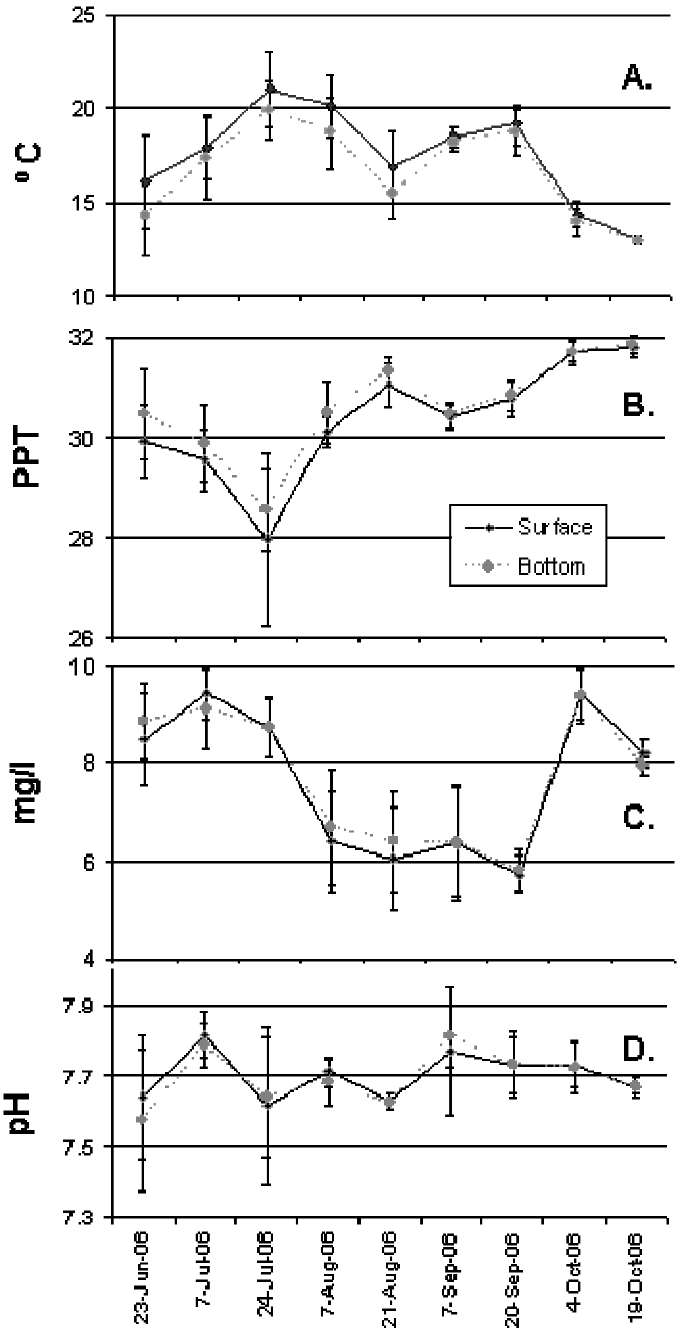

Figure 7. Sample period mean (± standard deviation) of (A) temperature, (B) salinity, (C), dissolved oxygen, and (D) pH for surface and bottom measurements in Annisquam River and Gloucester Harbor, June to October 2006.

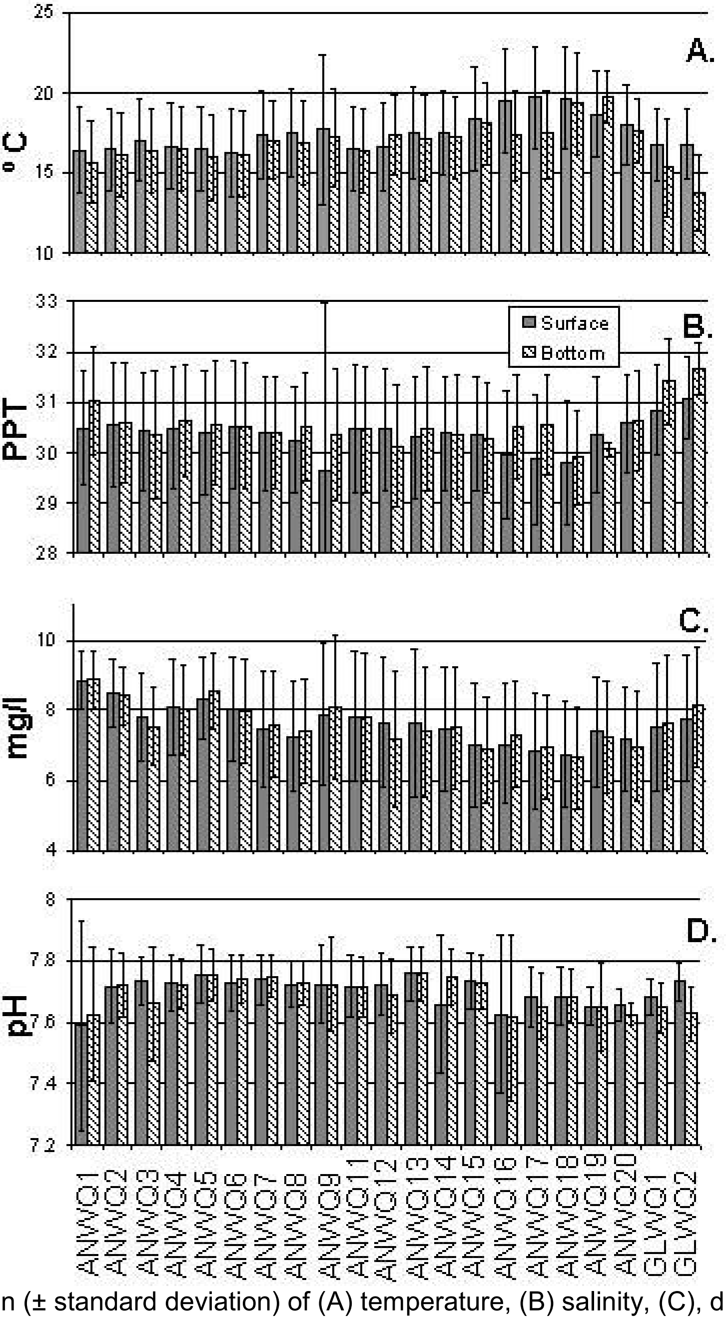

Figure 8. Station mean (± standard deviation) of (A) temperature, (B) salinity, (C), dissolved oxygen, and (D) pH for surface and bottom measurements in Annisquam River and Gloucester Harbor, June to October 2006.

Appendix A: Location of sampling stations in decimal degrees.

STATION	LATITUDE (ºNorth)	LONGITUDE (ºWest)
ANWQ1	42.65992	70.68244
ANWQ2	42.65220	70.68023
ANWQ3	42.65367	70.67555
ANWQ4	42.65097	70.67527
ANWQ5	42.65029	70.68042
ANWQ6	42.64496	70.67855
ANWQ7	42.64156	70.67599
ANWQ8	42.63734	70.67616
ANWQ9	42.64206	70.68709
ANWQ11	42.64032	70.68184
ANWQ12	42.63339	70.68623
ANWQ13	42.62930	70.68926
ANWQ14	42.62851	70.69159
ANWQ15	42.62309	70.68921
ANWQ16	42.62189	70.69485
ANWQ17	42.62372	70.70013
ANWQ18	42.62012	70.70129
ANWQ19	42.61947	70.68081
ANWQ20	42.61283	70.67913
GLWQ1	42.60890	70.66983
GLWQ2	42.60178	70.67116

CZM