Assessment of Submergent Macrophytes in the Bay of Quinte, Lake Ontario, August 2004, Including Historical Context

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ASSESSMENT OF SUBMERGENT MACROPHYTES IN THE BAY OF QUINTE, LAKE ONTARIO, AUGUST 2004, INCLUDING HISTORICAL CONTEXT

by

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ABSTRACT

From 1972 to 2000, twenty macrophyte surveys were conducted in the Bay of Quinte to monitor the response of submerged aquatic vegetation (SAV) to two major perturbations; the reduction in point source phosphorus (P) loadings from sewage treatment plants commencing in 1978 and the invasion by zebra mussels in 1994. In 2004, the second macrophyte survey post zebra mussel invasion was conducted along reference transects at Trenton, Belleville, Big Bay, Hay Bay and Conway to record macrophyte cover, SAV bed extent, maximum depth of colonization and species composition. The reference transects were sampled acoustically using a BioSonics DT4000, with rake tosses at intermittent sample points along the transects for echogram verification and to determine species composition. Historically, the upper Bay of Quinte had experienced sparse SAV density in the pre-P control time stanza with a slight increase in the post-P period. When the first macrophtye survey after the invasion of zebra mussels was conducted in 2000, it was found that both cover and SAV bed extent had substantially increased in the upper bay, the SAV beds expanded in the middle bay and there was little response in the lower bay. When compared to the 2000 survey, mean percent cover has declined by 16, 10 and 4% to current cover values of 55, 57 and 64% for the upper, middle and lower bays respectively in 2004. Despite this decrease in cover, the SAV beds that had expanded post-ZM have generally remained intact. Trenton North predominates all the reference transects, extending 1.16 km offshore, three times further than the next longest transect at Hay Bay East. There continues to be limited changes in SAV response in the lower bay which are likely due to restrictions imposed by basin morphometry and exposure.

RÉSUMÉ

De 1972 à 2000, vingt relevés des macrophytes ont été entrepris dans la baie de Quinte pour surveiller la réaction de la végétation aquatique submergée (VAS) à deux perturbations majeures : la réduction des charges de phosphore (P) de source ponctuelle des usines de traitement des eaux usées à compter de 1978 et l'invasion des moules zébrées en 1994. En 2004, le deuxième relevé des macrophytes après l'invasion des moules zébrées a été entrepris avec des transects de référence à Trenton, Belleville, Big Bay, Hay Bay et Conway pour consigner le

couvert de macrophytes, l'étendue du lit de la VAS, la profondeur maximale de la colonisation et la composition des espèces. Les transects de référence ont été échantillonnés acoustiquement à l'aide d'un BioSonics DT4000, avec des plongements à des points d'échantillonnage intermittents le long des transects pour la vérification des échogrammes et déterminer la composition des espèces. Historiquement, la partie supérieure de la baie de Quinte connaissait une densité éparse de la VAS dans la tranche temporelle de contrôle avant-P avec une légère augmentation dans la période après-P. Lorsque le premier relevé des macrophytes après l'invasion des moules zébrées a été entrepris en 2000, on a constaté que le couvert et l'étendue du lit de la VAS avait augmenté considérablement dans la partie supérieure de la baie, que les lits de la VAS s'étendaient dans le milieu de la baie et qu'il y avait peu de réponse dans la partie inférieure de la baie. Comparativement au relevé de 2000, le couvert moyen a diminué de 16, 10 et 4 % aux valeurs de couvert actuelles de 55, 57 et 64 % pour les parties supérieure, intermédiaire et inférieure de la baie, respectivement, en 2004. Malgré cette diminution du couvert, les lits de la VAS qui se sont étendus après l'invasion de la moule zébrée sont généralement demeurés intacts. Le nord de Trenton prédomine tous les transects de référence, s'étendant à 1,16 km au large, trois fois plus loin que le transect le plus long suivant à l'est de Hay Bay. Il continue de se produire des changements limités de la réaction de la VAS dans la baie inférieure qui sont probablement attribuables aux restrictions imposées par la morphométrie et l'exposition du bassin.

INTRODUCTION

Historically, the Bay of Quinte has experienced changes in its trophic state, with subsequent impacts on submerged aquatic vegetation (SAV) abundance and distribution. Prior to the late 1800's, sediment cores from the lower bay indicated slight to moderate oligotrophic conditions with a shift to a eutrophic state by 1890 (Sly 1986). Water quality noticeably deteriorated after 1930 and by the 1950s, the Bay was considered to be hypereutrophic. In the 1960's, algal blooms occurred in the upper and middle bays with recorded Secchi disc depths of less than 0.3 m (Johnson and Hurley 1986).

In 1972, a long-term, ecosystem-wide, scientific monitoring program called Project Quinte was established through collaboration among federal and provincial agencies, and some Ontario universities. The major goal was to monitor ecosystem response to significant reductions in point source phosphorus loadings due to upgrades at sewage treatment plants that began in 1978. Monitoring continued into the 1990's, capturing the Bay's response to the 1994 invasion by zebra mussels.

SAV monitoring was an important part of Project Quinte with 20 surveys conducted between 1972 and 2000 (Table 1). SAV is a valuable component of a healthy ecosystem. Fish use SAV for spawning and nursery habitat (Lane, Portt et al. 1996; Lane, Portt et al. 1996), a refuge from predation (Savino and Stein 1982) and a food source since macrophytes provide habitat for macroinvertebrates (Keast 1984; Eklov 1997). SAV also serves as nutrient sinks or sources (Carpenter and Lodge 1986), anchor sediments and slows water velocity (Pettigrew and Kalff 1992), thus improving water clarity. Increasing eutrophication initially increases SAV growth, which subsequently decreases due to shading by epiphytes and phytoplankton (Phillips, Eminson et al. 1978). In the Bay of Quinte, SAV beds were described as lush in the 1950s with subsequent declines during the 1960s to half of their estimated extent (Crowder and Bristow 1986). In the 1970's SAV were sparse and restricted to a euphotic zone of 2 m in the upper bay and 4 m in the lower bay.

In 1985, the Bay of Quinte was designated an Area of Concern by the International Joint Commission (IJC) due to impairment of ten of 14 beneficial uses, including eutrophication or undesirable algae and loss of fish and wildlife habitat. In response to the AOC designation, a federal/provincial Coordinating Committee was tasked to oversee the development of a remedial action plan (RAP). Problem definition, the first phase of the RAP, was completed in 1990. By 1993, an action plan with 80 recommendations to restore and protect the Bay of Quinte ecosystem was developed (Bay of Quinte RAP Coordinating Committee, 1993). Implementation began in 1993 and by 2000, the RAP Restoration Council updated its delisting targets. By 2003, the RAP Restoration Council was conducting a delisting review (German and Stride 2003) and Impaired Beneficial Uses (IBU) targets were developed, including one for SAV abundance.

There were two objectives to the 2004 macrophyte survey. The primary objective was to re-survey the original reference transects for key macrophyte measures, such as percent cover, extent of the SAV bed, maximum depth of colonization and species composition. These measures could then be compared to the historical record going back to 1972. The second objective was to obtain an independent dataset to verify predictions derived from the Bay of Quinte macrophyte model (Seifried, 2002). This model is currently used to provide input into an ecosystem model for the Bay of Quinte.

In support of the Fish Habitat Management Plan, an Ecopath ecosystem model is being developed within GLLFAS in collaboration with other federal and provincial agencies and universities. A macrophyte model was developed (Seifried 2002) for the Bay of Quinte to quantify the SAV contribution to the primary productivity of the Bay. The dependent variable in the model was percent cover values derived from the 1972 to 2000 dataset. The model was subsequently incorporated into a GIS and maps were produced illustrating the predicted percent cover for the entire bay. Surveying additional areas in 2004 outside of the reference transects could provide a valuable independent dataset to verify model predictions. The model could be used to assess whether the delisting target (IBU #8.3) of a 20% increase in SAV area has occurred in the upper bay when compared to the 1986 to 1994 baseline (German and Stride 2003). The verification of model predictions will be presented in a separate document.

MATERIALS AND METHODS

STUDY AREA

The Bay of Quinte is a Z-shaped bay that opens out to the northeastern shore of Lake Ontario West of Kingston. The 254 km^2 Bay is 64 km in length with a maximum width of 3.5 km. The 18200 km^2 watershed is formed of Precambrian Shield in the north and Paleozoic limestones in the south (Johnson and Hurley 1986). Major rivers are located in the upper bay area along the north shore entering at Trenton, Belleville, Big Bay and Napanee. This upper bay, from Trenton to the Telegraph Narrows, is 34 km long with a maximum depth range of 4 to 8 m. The highest concentration of population of the Bay is contained along its north shore in the urban centers of Trenton (amalgamated into Quinte West with a 2001 population of 41,400) and Belleville (2001 population 46,000). The middle bay extends from Telegraph Narrows to the restriction at Glenora, a total length of 13 km. Water depths of the middle bay increase from 6 m in the north to 17 m in the south. The lower bay area below Glenora is 16 km long with depths increasing to 52 m by the Bay mouth. The opening into Lake Ontario is split by Amherst Island into a lower and upper gap.

Water generally flows west to east in the Bay with an overall flushing rate of approximately two to three times per year with peak flows occurring March to April (Minns, Owen et al. 1986). Flushing is dominated by the flow from the Trent River by Trenton and annual flushing rates in the upper bay range from 9.2 to 14.6 (Johnson 1986). The Bay is usually ice-covered from the end of December to the beginning of April. In the summer, the shallow upper bay is well mixed with no permanent stratification, but during calm periods, the sediments and bottom waters can become temporarily anoxic, thus increasing P release from the sediments (Sly 1986). At Hay Bay and Conway, in the middle and lower bays, stratification begins near the end of April with turnover occurring in late September or early October. Significant water exchange occurs between Lake Ontario and the lower bay through the upper gap. During the summer, there is backflow at depth through the Glenora gap with upwelling in the middle bay (Minns, Owen et al. 1986).

HISTORICAL MACROPHYTE SURVEYS

Twenty macrophyte surveys were conducted in the Bay of Quinte between 1972 and 2000 (Table 1) (Crowder and Bristow 1986; Bristow and Crowder 1988; Crowder 1988;

Crowder, Bristow et al. 1988; Limnos 1989; McLaughlin and Crowder 1989; Dushenko 1990; Loftus, Sayer et al. 1992; Minns, Cairns et al. 1993; Marshall, Macklin et al. 1995; Valere 1996; Seifried 2002). These surveys generally focused on submerged macrophytes located in water deeper than a half meter with sampling typically occurring once during the year at the time of peak biomass. Macrophyte percent cover was the principal metric derived from these surveys and it is an estimate of how much of the bottom within a designated area is covered by SAV. It was assessed using four different methods: intersections with a knotted line (hereafter referred to as knotted line), point sampling, echosounding and a visual survey along electrofishing transects (hereafter referred to as electrofishing). Sampling varied both temporally and spatially depending on the sampling protocol (Figure 1). Both knotted line and echosounding were conducted at the same location with transects beginning in 0.5 to 1.0 m of water and extending perpendicular to the shoreline beyond the edge of the SAV bed.. They are designated the reference transects since records at these locations extend back to 1972. Biomass sampling was conducted at points along these reference transects in 1988, 1994 and 2000. Refer to Appendix 1 for a detailed description of the historical sampling methodologies.

2004 MACROPHYTE SURVEY

The 2004 macrophyte survey was conducted over 3 weeks beginning August 16th, September 7th and September 13th. Refer to Appendix 2 in the PDF version of this document for the specific date each transect was surveyed and associated field observations. The survey design combined both point sampling with echosounding along the historical transects at Trenton, Belleville, Big Bay, Hay Bay and Conway. Three transects were surveyed at each site: transect 3 which has been surveyed since 1972, and transects 1 and 5, surveyed in 1988, 1994 and 2000. These transects are located 500 m on either side of transect 3. The 2000 biomass sampling sites were revisited in 2004.

Point Sampling

Operational restrictions prevented any form of in-water sampling of SAV, so sampling occurred from the boat using two garden rake heads with welded together and attached to a rope. Each rake head was 36 cm long and had fourteen, 6 cm long tines spaced 2 cm apart. Point sampling occurred along the transects at the sites where biomass was sampled in 2000. The number of sample points per transect varied according to transect length, with a minimum of 3 and maximum of 6 points (Appendix 3). At each of the sample points, a series of visual estimations were made from the boat. A photograph and an estimation of percent cover and species composition was made through a 15 by 30 cm glass aquarium. Additionally, an estimate (sparse, moderate, heavy) of any epiphyte, algal or calcareous coating on the SAV was made and it was noted if water clarity was sufficient to make the bottom visible. GPS coordinates were recorded along with Secchi and water depths, (Appendix 2, PDF version).

Three rake tosses were made at each of the sampling sites, the first further offshore, the second in line with the sample point and the third towards shore. The length of the rope was adjusted according to the water depth at the site in an attempt to make the length of the rake swath consistent between sites. The macrophytes were placed in a plastic tub and quickly sorted to species thus if a species was only represented by a few stems in the sample, there was a possibility that it could be missed. Identification was performed according to (Fassett 1968) and (Gleason and Cronquist 1991). Species that were difficult to quickly identify, such as *Myriophyllum spicatum* and *M. exalbescens* and *Najas flexilis* and *N. guadalupensis* and *Chara braunii* and *C. globularis* were grouped by genus. Overall density (very sparse, sparse, moderate, dense, very dense), and percent species composition were noted and estimates of coatings and presence of zebra mussels were made as detailed in Appendix 4 of the PDF version of this document. A photograph was taken of the SAV retrieved from every rake toss.

Echosounding

Two systems were used for echosounding, the Lowrance X-16 system that was used in the 1994 and 2000 surveys and a BioSonics DT4000 system. All transects were sampled with the BioSonics unit while both the BioSonics and the Lowrance were run concurrently on 9 transects (one transect per location, with the exception of Hay Bay West). Refer to Appendix 5 for a description of the advantages of the digital DT4000 system, instrument settings for both systems and a comparison of percent cover values derived from each system.

The BioSonics data was analyzed with the software BioPlant version 1.0 and the data was imported into ArcView 3.2a where maps of percent cover overlaying water depth were created. Ground truthing was conducted by comparing the rake toss SAV densities (none, sparse, moderate and dense) to the percent cover data determined by BioPlant at locations closest to the rake toss site. The echosounding data, converted into the 4 categories was compared with the rake toss results to see if they fell within the same category. In the upper bay, the same category of SAV density was recorded at 51% of the sites while 35% of the sites were within 1 category (i.e. rake toss = sparse, BioSonics = moderate). Refer to Appendix 6 for additional information regarding analysis.

Sampling Protocol

Each transect began with point sampling. The 2000 GPS coordinates were used to locate the sample sites and a buoy was dropped to mark the location. Many of the start locations were inaccessible in 2004 due to low water levels and were not sampled. Due to time restrictions, some of the 2000 sample sites were not re-surveyed in 2004. Effort was concentrated on transect 3, which has a historical record back to 1972. Generally if a sample site was in close proximity to another site, it was deleted when time was limited. Visual observation of percent cover, plant height and species composition were made along the transect between sample sites (Appendix 2: PDF version). Point sampling did not occur along transect 5 at Conway South because a gill net had been set in this area.

The end point of the transect was determined by running the Lowrance X-16 from the last sample site to the point where the echosounder indicated no more macrophytes. A buoy was then dropped and 3 rake tosses were made at this location to confirm macrophyte absence. If any macrophytes were retrieved in the rake tosses, the procedure would repeat until no macrophytes were obtained.

Once all the buoys for the sampling locations were in place, the boat, a 4 m McKee, was positioned near the start point of the transect with echosounding equipment set to begin recording. Due to concerns of damaging the BioSonics transducer, echosounding was generally limited to water depths in excess of 1 m or deeper if rocks were present. Boat speed was approximately 3.5 km/hr. When the boat passed the sampling site buoys, the ping number was recorded for the BioSonics unit and the paper trace was marked on the Lowrance in order to provide field verification. Echosounding continued well past the end of the transect since some transects had very patchy SAV in deeper water. Gaps of no cover were permitted along the transect as long as they were less than 90 m in length. Thus if additional plants were detected at distances greater than 90 m, they were not considered part of the transect. This was the same transect definition used by Crowder from 1972 to 1988 in the knotted line technique. In the shallow upper bay areas, a complete traverse from North to South shores was made while in the deeper middle and lower bay areas, a zigzag pattern was employed to delineate the edge of the beds in locations near the transects.

When time permitted, echosounding was also conducted in other areas. Macrophyte models developed for the Bay of Quinte by Seifried in 2002 predicted large expanses of heavy macrophyte cover in the area around Indian Island near Trenton and in the Muscote and Hay Bay areas. The macrophyte survey was an ideal time to verify model predictions, as data from the model was used to assess IBU delisting targets (German and Stride, 2003). Time restrictions limited surveying to a few transects in both the Trenton and Muscote Bay areas.

RESULTS

PERCENT COVER

The maps in Figure 2 to Figure 16 illustrate both percent cover and the length of the transect derived from the BioSonics data for transects that were sampled in 2004, including the point sample locations. Transect and site codes are listed in Appendix 3. Water depths using IGLD 85 datum are shown in conjunction with the cover data since light availability is generally the dominant factor in determining the maximum depth of SAV colonization and irradiance is attenuated with increasing water depth. IGLD 85 datum for Lake Ontario is 74.2 m while the mean water levels at Kingston during the time of the survey (August 16th to September 17th) was 74.94 m. Thus the water depths illustrated on the maps should be 0.74 m deeper.

There are many abiotic and biotic factors that affect SAV establishment and growth which can result in SAV patchiness. Abiotic factors include irradiance and water clarity (Engel and Nichols 1994), sediment composition (Barko and Smart 1986), slope (Duarte and Kalff 1986), exposure (Hudon, Lalonde et al. 2000), temperature (Best 1987), water chemistry (Harvey, Pickett et al. 1987), hydrostatic pressure (Davis and Brinson 1980) and water level fluctuation (Blindow 1992). Biotic factors include periphyton abundance (Weisner, Strand et al. 1997), grazing by invertebrates (Kornijow 1996) and waterfowl (Knapton and Petrie 1999), uprooting by fishes such as carp (Sager, Whillans et al. 1998), plant diseases and invasion by exotic SAV (Boylen, Eichler et al. 1999). Additionally, SAV growth may be anthropogenically controlled through mechanical, chemical or biological means.

Response to these stressors can vary by SAV species due to differences in reproduction, life histories and morphologies. Many of the above factors are themselves influenced by the presence of SAV. Such is the case in shallow water systems that alternate between clear and turbid states, where abundant SAV maintain clear water by preventing the resuspension of sediments, providing a refuge for zooplankton and taking up nutrients (Scheffer, Hosper et al. 1993).

Patterns of SAV establishment and growth can vary depending on the causal mechanisms, which in turn are influenced by factors such as land use or basin morphometry. One such pattern is sparse SAV cover in the extreme nearshore, denser cover at intermediate depths and sparser cover at the deepest portion of the transect, as seen in HBW3, Figure 13. The processes affecting SAV growth typically associated with the shallow nearshore may include wave action (Chambers 1987) and ice scouring while in the deepest waters, these processes are generally light availability (both in terms of quantity and quality) (Chambers and Prepas 1988), temperature (Dale 1986) and hydrostatic pressure. Several of the other factors listed above are not strictly associated with water depth and can result in patchy SAV growth along the entire transect. Single or multiple stressors can result in patchiness along transects, as seen at TN5 (Figure 2).

At some sites, sparse cover was not encountered by the nearshore, as at Trenton South (Figure 6) and this may be due to inadequate sampling at the extreme nearshore since acoustics can only sample in waters deeper than 1 m. Shorelines with steeper slopes are particularly difficult to sample acoustically due to restricted manoeuvrability with a rapid change in bottom depth. Alternatively, nearshore processes such as wave exposure may not be dominant on some of the transects. A gradual diminishment to sparse cover was not encountered at the end of some of the transects and could indicate an abrupt change in depth, such as the dredged channel by the Trenton North 3 transects (Figure 4) or the steep drop off at Conway South (Figure 16). The Trenton map (Figure 2), indicates moderate to dense SAV growth beyond the dredged channel on TN1 with sparse growth at deeper waters on TN3 and TN5. This difference in SAV density could be due to changes in substrate or other biotic and abiotic factors, or as a result of gradual eastern expansion of western mid-channel SAV beds.

Dense cover at intermediate depths was experienced on some transects, such as Trenton N1 (Figure 3), TN3 (Figure 4), TS5 (Figure 6), Belleville S1 (Figure 9), Hay Bay W1 and HBW3 (Figure 13), Hay Bay East (Figure 14), Conway N1 and CN3 (Figure 15) and Conway South (Figure 16). Other sites had very patchy cover in the middle of the transect, such as BN1 (Figure 8), BBN (Figure 11), BBS (Figure 12) and CN5 (Figure 15). As detailed above, the causal mechanisms for SAV patchiness can be quite varied, with both abiotic and biotic factors affecting SAV growth and establishment.

As the maps illustrate, there are differences between the last plant derived from the BioSonics data and the end point that was determined through rake tosses in the field. This difference is generally due to the difficulty in detecting sparse SAV near the end of the transects. Half the transects had the field derived end point further offshore than the last plant detected through echogram analysis, with a mean difference in length of 35 m. Just over 36% of the transects located the end point before the last plant with a mean difference in length of 60 m. Given the definition of transect length (gaps of <90m of no SAV growth permitted), cover values derived for the entire transect may be unduly influenced by very patchy cover at the end of the transect. This is particularly the case for transects TS3, TS5, BS1 and BBN1 where over 25% of the cover values for the entire transect are 0 and are located just prior to the last plant.

Summary statistics of percent cover (1st quartile, median, mean and 3rd quartile) for each of the transects can be found in Figure 17. Cover statistics were calculated using the BioSonics data from the point that was closest to the start of the transect to the last point that had a cover value greater than 0, with gaps of < 90 m of no cover included. As Figure 17 illustrates, means and medians were generally similar, with the exception of TS1, TS3, TS5 and BS1 and BS5 where the difference was greater than 15. In Trenton South 1 and 3, the means were substantially greater than the median, indicating extensive patchiness in conjunction with smaller areas of dense cover. TS5, BS1 and BS5 had medians higher than the mean signifying a greater amount of high cover values in combination with large areas of no cover. Over 80% of the transects had a wide range of cover values, with quartile ranges (Q1 to Q3) greater than 50.

Variation in percent cover did occur between the 3 transects at the same location (i.e. within Hay Bay West). In 8 out of 10 locations, mean cover values were within the same category (sparse: 1 to 33%, moderate: 34 to 67% or dense: 68 to 100%) or were very close in value (<5%) to the same category as the other transects from that location. The only exceptions were Hay Bay West and Conway North and this variation may be associated with differences in morphometry, substrate and exposure along each transect.

Only 13% of the transects had mean cover values within the dense category (>67%), these being TN3, HBW5, HBE5 and CN1. Moderate cover was found in 70% of the transects while sparse cover was typically found in the Big Bay area at BBN1, BBN5, BBS5 and also at BN1 and HBW1. The mean cover values for transects TS5, BS1, HBW3, HBE1 and CN3 would be reclassified from moderate to dense and BBN1 and BBS5 would be reclassified from sparse to moderate if the patch of zero cover before the final plant was excluded from the calculation.

The relationship between percent cover and water depth is illustrated in the scatter plots of Figure 18. The parabolic pattern with low cover at both shallow and deeper depths in conjunction with higher cover at intermediate depths is most readily apparent at CN3. Restrictions regarding the minimum depth required by acoustical systems to sample outside their near field may have excluded low cover in water than was less than 1 m. Some sites, such as TN3 and TS3 had a wide range of cover values at or very near the deepest depths while other sites such as HBW3 had a more gradual diminishing of cover values as depth increased. This abrupt cut-off in cover may indicate some type of threshold, such as excessive slope or a change in sediment. Patchy cover at the intermediate depths is evident in both Big Bay scatter plots.

The transects with the greatest total exposure were those of Trenton North, Big Bay South and Conway North (Figure 19). Depending on the length of the transect, mean fetch at the start and end of the transect could vary substantially, as in BN1. A scatter plot of mean fetch and cover reveals moderate cover over a wide range of fetch with no strong relationship.

SAV BED EXTENT

Figure 20a illustrates the variation in SAV bed extent. It was determined by measuring in ArcView, the length of a straight line from the start of the transect (using the 2000 start points since water levels were lower in 2004) to the last plant, as previously defined under percent cover. To attempt to capture some of the transects with very patchy growth near the end of the transect, the graph also shows the SAV bed extent to the last plant whose cover value was greater than 10%. Using this criteria, the SAV bed extent on half the transects was reduced in length by a minimum of 2 m at BS3 to a maximum of 88 m at TS3.

The largest extent of SAV beds was found at all transects in Trenton North, Belleville N1 and BS5 and these beds were on average six times longer than the mean of all the other transect lengths. Most of the variation in SAV bed extent within a location is due to basin morphometry, as is the case in Belleville South (Figure 8), where transect 5 is substantially longer due to its location in a shallow bay. Transect lengths were most consistent for Conway and this is due to the sharp drop off to deeper depths that do not support macrophyte growth.

Some transects were quite patchy at the end, but had last plant cover values greater than 10% and therefore were not highlighted in the initial screening criteria. On average, patchiness at the end of all transects accounted for less than 23 m of its length. BS5 was the transect that was most affected by patchiness with a gap of approximately 150 m near the end. BBN1 had a gap of 132 m while the gaps in TS5 and BS1 were 61 and 69 m respectively. The gap at the end of all other transects was less than 40 m.

MAXIMUM DEPTH OF COLONIZATION

The deepest water depth that supported plant growth was determined for each transect, Figure 20b. In 87% of the cases, the maximum depth of occurrence corresponded to the end of the transect while in the remaining cases, water depth fluctuated along the transect. The maximum depth was similar for transects in the upper and middle bays, ranging from 3.0 to 4.6 m. SAV growth extended much deeper at Conway, between 5.1 and 7.5 m. Nearshore mean Secchi disc depths measured at the point sampling locations were also deeper at Conway, ranging from 3.9 to 5.4 m while the upper and middle bays had Secchi depths between 1.2 and 2.4 m.

Offshore Secchi depths at the Project Quinte stations were either measured on the same day (as in the case of BN1, BS1and BS3) or within a 2 week period from the date of the macrophyte survey. With Secchi depths measured on the same day in Belleville, the nearshore Secchi depths were consistently deeper, ranging from 1.3 to 1.6 m while the offshore Secchi depth was recorded at 1.25 m. In Hay Bay, all but one of the eight nearshore Secchi depths was greater than the offshore Secchi depth of 1.5 m. This pattern was reversed at Conway, where all nearshore Secchi depths (3.6 - 5.4 m) were less than the mean 5.6 m offshore Secchi depth.

SPECIES FREQUENCY

Figure 21 to 23 illustrates the percent frequency of species occurrence for the six most abundant species found in the Bay of Quinte during the 2004 survey. It was calculated for each transect by summing the number of rake tosses that the species was found divided by the total number of rake tosses for that transect, excluding the end point. The three most frequent species were *Vallisneria americana, Heteranthera dubia* and *Myriophyllum spp.*, occurring in 30, 28 and 27 of the 30 transects sampled in 2004. *Ceratophyllum demersum* was found in 83% of the transects while *Najas spp*. occurred in 80% of the transects. *Elodea canadensis* was located in 57% of the transects, including all Conway transects.

Vallisneria americana (Figure 21a) was the most frequent species, being present on all transects and very common (% frequency > 67) in 63% of the transects and only sparse (% frequency < 33) at BS3, a very short transect. This species is widely distributed in North America and is fairly tolerant of turbid waters, high nutrient loading and wave action. It is a perennial plant that can reproduce asexually via stolons or winter buds or sexually by seed.

Heteranthera dubia (Figure 21b) was absent on both short HBW transects but was very common on 57% of the 30 transects, including all of the Big Bay and Conway South transects and sparse at the same short transect of BS3 and at CN1. *H. dubia* is widely distributed in both North and Central America and this species has a high tolerance to degraded conditions and is well suited to survive low water periods. Reproduction is either sexually by seed or asexually via broken stem fragments.

Myriophyllum spp. (Figure 22a) was not found at BS3, HBE1 and CN5 and very common on 30% of all transects. It was sparse on 17% of the transects that included the remaining two Hay Bay East transects and 2 transects in Belleville. Both *M. spicatum* and *M. exalbescens* were found in the Bay of Quinte, but time restrictions prohibited sorting to species at each site. *M. spicatum* is an invasive species and is one of the most widely distributed nonindigenous aquatic plants, occurring in British Columbia, Ontario, Quebec and the United States. After initial introduced in Washington, D.C. in 1942, it spread quickly and was considered a weed problem in many areas by the 1970s. In Canada, it was first collected at Rondeau Provincial Park in 1962 and was already present in the Bay of Quinte by 1972 (Crowder and Bristow 1986). The earliest documented occurrence of *M. spicatum* in the Quinte area was in 1966 at Hill Island in Leeds County, approximately 50 km east of the Bay of Quinte (Queen's University Herbarium).

M. spicatum is tolerant of degraded conditions and is particularly problematic in disturbed water bodies that have experienced nutrient loading, intense SAV management, or heavy motor boat use. Local expansion of *M. spicatum* occurs via stolons while longer range expansion is through stem fragments. This species has been known to begin growth under the ice in February (Crowder and Bristow 1986) and quickly forms a dense canopy which overtops and shades native SAV, thus reducing native plant abundance and diversity (Smith and Barko 1990; Boylen, Eichler et al. 1999). Several studies have noted that *M. spicatum* expands rapidly, reaches a peak in 5 to 10 years, then subsequently declines (Trebitz, Nichols et al. 1993; Knapton and Petrie 1999).

Ceratophyllum demersum (Figure 22b) was absent on 5 of the 30 transects with 3 of these transects in Hay Bay. It was very common on 30% of transects including the three Trenton North and sparse on 10% of the transects, particularly in Big Bay. This species is common worldwide and tolerates moderate to high nutrient concentrations and low light levels. It is a rootless perennial that reproduces mainly via plant fragments, but occasionally by seed.

Najas spp. (Figure 23a) was not located on 6 of the transects, including 4 transects at Belleville. It was very common on 27% of all transects, including the three Conway North transects and sparse on 20% of the transects. Both *N. flexilis* and *N. guadalupensis* were found in the Bay of Quinte, although they were not sorted to species at each location. *N. flexilis* is both common and widespread in northern North America while *N. guadalupensis* is more common in the southern states down to South America, but is local in the northeast and central states. Both plants are annuals and reproduce by seed and can tolerate relatively low light conditions.

Elodea canadensis (Figure 23b) was absent on 13 of the 30 transects, including all of the Big Bay South and Hay Bay East transects. It was very common on 13% of the transects, including two transects in Belleville South. *E. canadensis* was sparse on 4 of the 30 transects, including TN3 and TS3. Distribution of this species is from Nova Scotia to southern British Columbia and south to California, Iowa and North Carolina. It grows in a wide range of conditions, from very shallow to very deep waters and in a variety of sediments. Reproduction is by stem fragments, over wintering buds and rarely by seed.

SPECIES RICHNESS

Only 2 species were found at both HBW5 and BS3 (Figure 24a), while a maximum of 11 species were found at BS5 and BBN1. A total of 17 species were identified in the Bay of Quinte in 2004 (Appendix 7). Conway had the highest richness, closely followed by Trenton whereas the least number of species was found in Hay Bay. It should be noted that sampling effort did vary across transects with the number of sites generally increasing with the length of the transect. Richness on the three very short transects (< 20 m length) was between 2 and 3 and these sites had between 1 and 3 point samples. Conversely, CS5 recorded 6 species using a single sample point. The next shortest transect was TS1 at 57 m where 7 species were found. The scatter plot in Figure 24b illustrates the variation in richness as a function of sample size. Linear regression of the dataset indicates a weak relationship ($r^2 = 0.29$, df = 28, p = 0.002) between sample size and richness.

DISCUSSION

The Bay of Quinte has experienced two major perturbations since the initial macrophyte survey was conducted under Project Quinte in 1972. The first was the reduction in phosphorus point source loading due to upgrades at sewage treatment plants that began in 1978. The second was the invasion of zebra mussels into the Bay, commencing in 1994. Both these events impacted the macrophyte community in the Bay of Quinte to various degrees and the 2004 survey provides another dataset to the historical record. It is the second macrophyte survey to be conducted after the invasion of zebra mussels into the Bay. This discussion will begin with a review of the trends in trophic and water clarity variables in the Bay of Quinte from 1972 to 2004. The response of submergent macrophyte to these changes from 1972 to 2000 will then be examined. The discussion will conclude with a comparison of results between the 2000 and 2004 SAV surveys.

TROPHIC AND TRANSPARENCY VARIABLES: 1972 TO 2004

Measurement of total phosphorus, Chl *a* and εpar (the light extinction coefficient for photosynthetically active radiation: 400-700nm) were conducted at the Project Quinte stations of Belleville, Hay Bay and Conway from 1972 to 2004 (Nicholls and Millard 2005) as in Figure 25.

Measurements were also taken at Napanee during most of the time period, except for the years 1983 to 1988. For over 88% of the monitoring period, the upper bay stations recorded the highest values for TP, Chl *a* and εpar. The middle bay station generally recorded slightly lower values than the upper bay while the lower bay values were substantially lower.

From 1972 to 2004, total phosphorus concentrations tended to decrease through the three time stanzas, although there were inter-annual fluctuations. Between the pre-P and the post-P period, there was a 44% decline in total phosphorus for the Belleville station with a pre-P seasonal mean of 78 μg L^{-1}. TP was reduced an additional 13% in the post-ZM period to a mean of 33 μg L^{-1}. The upper bay station at Napanee exhibited a similar trend in TP with a pre-P mean of 70 μg L^{-1} and post-ZM mean of 32 μg L^{-1}. The pre-P mean for total phosphorus for the middle bay was slightly less than the upper bay stations, at 52μg L^{-1}, decreasing by 30% in the post-P period and a further 19% in the post-ZM to 27 μg L^{-1}. Mean total phosphorus concentrations in the pre-P period for the lower bay was 21μg L^{-1} and declined to 17μg L^{-1} and 11μg L^{-1} for the post-P and post-ZM periods respectively.

Chl *a* concentrations also tended to decrease through the three time stanzas, although year to year fluctuations are readily apparent. Belleville experienced a 35% reduction in mean Chl *a* from the pre-P to post-P time period and an additional decline of 30% into the post-ZM period, with means of 38μg L^{-1} and 13μg L^{-1} for pre-P and post-ZM respectively. Mean Chl *a* concentrations in Hay Bay were 29μg L^{-1} for the pre-P period, decreased by 13% to 25μg L^{-1} post-P and declined another 52% to 10μg L^{-1} in the post-ZM period. In the lower bay, mean Chl *a* concentrations were 10μg L^{-1} in the pre-P period, decreasing to 7 and 3μg L^{-1} post-P and post-ZM respectively.

The mean light extinction coefficient followed similar trends, declining through pre-P to post-ZM, but again inter-annual fluctuations are present. In Belleville, εpar decreased by 22 % between the pre-P to post-P period, with a further decline of 21% to the post-ZM period. Mean εpar for pre-P Belleville was 1.9, decreasing to 1.1 post-ZM. At Hay Bay, the mean εpar value pre-P was 1.4, declining by 14% in the post-P period and an additional 32% to the post-ZM to 0.77. Conway mean εpar pre-P was 0.64, declining by 14% to the post-P period and a further 28% to 0.37 post-ZM.

MACROPHYTES PRE-P (1972 TO 1977)

Historically, sparse cover was encountered in the upper Bay of Quinte in the early 1970’s (Figure 26) due to excessive shading by algae which flourished in the Bay’s nutrient rich waters. Prior to upgrades at sewage treatment plants, offshore Secchi depths at that time were less than 1.3 m. Examined on an individual transect basis (Appendix 8), the majority of upper bay transects had extremely sparse cover during the pre-P time stanza with the exception of dense cover found on TN3 in 1973. Percent cover is an indication of SAV density but does not account for its distribution so cover should always be viewed in conjunction with SAV bed extent (Figure 27).

The mean extent of the upper bay SAV beds in the pre-P time stanza are larger than the post-P period, but this data is somewhat misleading since very sparse cover at or near the end of the SAV bed comprise much of it’s length. If cover values less than 10% near the end of the transect were excluded, the mean SAV bed width would be reduced by half (Figure 27). When SAV bed extent is examined on an individual transect basis (Appendix 9), there is generally high inter-annual variability within a site. These sites typically have very sparse cover so the variability could be a result of abiotic or biotic impacts on these weakly established SAV beds combined with the difficulty in measuring transect lengths in very sparse cover. In the pre-P time stanza, TN3 dominates the upper bay transects both in terms of SAV density (mean cover between 28 and 76%) and extent (SAV bed width fluctuated between 380 and 175 m).

The mean maximum depth of SAV colonization in the upper bay for the pre-P time stanza ranged from 2.5 to 2.7 m (Figure 28), with sparse cover at transect BN3 recording depths to 4.8 m in 1972 (Appendix 10). For the knotted line method (1972 – 1988), the only water depth data available is the mean depth calculated from depths measured at the start and end of a sub-transect (

Appendix 1). Thus the maximum depth of colonization for this time period is only an approximation, not the actual water depth measured at the last plant on the transect.

During the pre-P time stanza, the middle bay experienced higher Secchi depths (1.1 to 1.6 m) than the upper bay. Consequently, SAV cover was higher in the middle bay when compared to the upper bay (Figure 26), but the width of the SAV beds were shorter (Figure 27). Cover values were consistently in the moderate range for the middle bay with HBE3 having both higher cover (Appendix 8) and a larger SAV bed width (Appendix 9) than HBW3. The extent of SAV beds in the middle bay are more restricted by basin morphometry than those of the upper bay (Figure 13 and 14). The mean maximum depth of colonization in the middle bay ranged from 2.2 to 2.9 m (Figure 28), with the deepest depth of 3.4 m occurring on HBW3 in 1972 (Appendix 10).

Throughout the entire time period, environmental parameters in the lower bay were substantially different that the other two bays (Figure 25). In the pre-P time stanza, Secchi depths were higher than the other two bays with a range of 2.5 to 3.6 m. During this time period, mean cover in the lower bay ranged from moderate to dense, with CS3 having slightly higher cover than the more exposed CN3 transect. SAV beds did not extend more than 145 m offshore and basin morphometry in this location has a considerable effect on the ultimate size of the SAV beds (Figure 15 and 16). The mean maximum depth of colonization ranged from 2.4 to 5.0 m (Figure 28) with both CN3 and CS3 recording a maximum depth of 5.0 m in 1972 (Appendix 10).

MACROPHYTES POST-P (1978 -1994)

It should be noted that during this time stanza, there was a change in the methodology used to determine both percent cover, SAV bed extent and maximum depth of colonization along the reference transects. This change occurred between 1988 and 1994 when the methodology moved from the knotted line transect to echogram interpretation. It is difficult to assess if results from these two methods are equivalent, or what, if any, type of correction is required. For lack of sufficient data, no type of correction has been made between the two methods. Refer to Appendix 1 for additional details regarding how these metrics were determined for each methodology.

After upgrades to the sewage treatment plants, the upper bay experienced a 44% decrease in TP and a 35% decrease in Chl *a* concentrations while Secchi depths increased up to 1.7 m. Compared to the pre-P time period, SAV cover increased slightly into the moderate range, but never exceeded 47% mean cover for the six reference transects. These higher cover values were generally experienced on the Trenton, BN3 and to some extent, the BBS3 transects. The data also shows high inter-annual variability in cover (Appendix 8), particularly on the shorter transects which may not have the same resiliency to abiotic and biotic impacts as larger, well established SAV beds.

From the pre-P to post-P time stanza, the mean SAV bed extent to the last plant of the six reference transects in the upper bay decreased (Figure 27) by a maximum of 196 m in 1979 and a minimum of 116 m in 1988, although these values would both be 83 m and unchanged if cover <10% near the end of the transect was excluded. Only TN3 and BBS3 saw an expansion of their SAV beds in most years of the post-P period relative to the pre-P time stanza (Appendix 9). The TN3 transect continued to dominate in the post-P period, with the widest bed width (522 m) and cover values consistently in the moderate range.

The mean maximum depth of colonization in the upper bay during the post-P time stanza ranged from 1.6 to 2.4 m (Figure 28), with a maximum depth of 3.3 m occurring on TN3 in 1982 (Appendix 10). These depths were generally shallower than those experienced in the pre-P period, but many of the pre-P depths were associated with very sparse cover (<10%) for much of the deeper offshore sections of the transects.

Thus despite substantial decreases in total phosphorus and increases in Secchi depth, the SAV beds of the upper bay in the post-P period did not show a significant response. Nutrient budgets calculated for the Bay of Quinte (Minns, Owen et al. 1986) indicate that reflux of phosphorus from the sediments was equal or greater than its sedimentation from the water column. This internal loading was predicted to decline slowly since the accumulation of new sediments required to reduce the amount of phosphorus available for reflux would occur gradually. It was predicted that internal P loading from the upper bay could delay SAV recovery and evidence indicates that macrophytes did not increase substantially in the upper bay until after the invasion by zebra mussels. Additionally, the resuspension of nearshore sediments due to wave action in sparse SAV beds could play a role in suppressing SAV growth during the post-P period.

The middle bay experienced a 30% decrease in total phosphorus and an increase in Secchi depth (1.2 to 2.0 m) between the pre-P and post-P time stanzas. When compared to the pre-P time period, SAV density did increase in 1979 and 1984, but for the majority of the post-P period, cover typically remained within pre-P levels (Figure 26). Moderate to dense mean SAV cover for the two reference transects in the middle bay predominated during this time stanza (Figure 26) with HBE3 usually recording higher cover than HBW3 (Appendix 8). A substantial decrease in cover occurred at HBE3 in 1994 and this was due to very sparse cover in the first half of the transect for that year, a pattern which was not evident in any previous years.

The middle bay mean SAV bed extent did not change appreciably between the pre-P and post-P time period. (Figure 27). The mean bed extent for the two middle bay reference transects remained relatively stable for the majority of the time period, with the highest increase of 70 m occurring in 1994. When the transects are examined individually, HBW3 had expanded fourfold by 1988 to 116 m and added another 52 m in 1994. The HBE3 SAV bed fluctuated in size over the post-P time stanza with a final SAV bed width of 200 m in 1994. The mean maximum depth of colonization during the post-P period ranged from 1.8 to 2.3 m (Figure 28) with the maximum depth of 3.1 m occurring on HBE3 in 1985. This is shallower than the pre-P depths and is influenced by sparse cover in deep water on HBW3 in 1972 and a very shallow depth on the same transect in 1985.

The change in environmental parameters in the lower bay between pre- and post-P time stanzas was less drastic with 20% decrease in TP and Secchi depths between 2.5 and 4.0 m after phosphorus control had been implemented. As in the pre-P period, SAV mean cover fluctuated between the moderate to dense category in the post-P period (Figure 26). The mean SAV bed extent for the two lower bay reference transects did not change substantially between the pre- and post-P period, fluctuating between 58 and 103 m during the post-P time stanza. Individually, the expansion and contraction of the CN3 transect was less than 41 m with a final length in 1994 of 46 m. The CS3 SAV bed increased over 2.5 times it's width between 1982 and 1994, with a final length of 160 m. The maximum depth of colonization ranged from 2.4 to 5.7 m with the deepest depth recorded at CS3 in 1988. These mean post-P depths were within the same range as found in the pre-P time period.

MACROPHYTES POST-ZM (2000)

There was a substantial macrophyte response in the upper bay after the invasion by zebra mussels, both in terms of SAV density and distribution. This type of response after zebra mussel invasion has been recorded elsewhere (Skubinna, Coon et al. 1995; Knapton and Petrie 1999). In the post-ZM time stanza, Secchi depths increased up to 2.3 m and total phosphorus decreased an additional 13% from the post-P period. Mean SAV cover along all 6 reference transects increased 1.7 times and the mean SAV bed width tripled between the 1994 and 2000 surveys. As water clarity increased, SAV were able to increase in density and also move further offshore due to the gently sloping sites in some locations that allowed for a rapid expansion into large areas that were only slightly deeper.

On an individual transect basis, mean cover increased on all transects between 1994 and 2000; by 1.6 times on the Trenton transects, 1.8 times on BN3 and BBN3 and doubled on BBS3. SAV was re-established on the 16 m transect at BS3, increasing in cover from 2 to 90% between the years 1994 and 2000. Transect lengths also increased by at least 1.7 times at the majority of locations with the exception of the short BS3 transect. SAV beds expanded from at least 1.7 times at BN3 to 5.5 times their previous width at BBN3. Again the TN3 transect dominated the upper bay in 2000, recording a 3.5 times increase in width to just under 1.2 km. The mean maximum depth of colonization increased by 1.4 m with 5 of the 6 transects experiencing an increase in depth of greater than 1.1 m between 1994 and 2000.

The middle bay experienced an additional 19% decrease in TP and an increase in Secchi depths up to 3.3 m from the post-P to post-ZM periods. Mean SAV cover did increase from 1994 to 2000, but cover did not change appreciably in 2000 when compared to the entire post-P period, although the SAV bed extent did expand by 130 m. When comparing the transects on an individual basis, most of the SAV bed expansion took place at HBE3, which had recovered some of its former density (Appendix 8). The mean maximum depth of colonization increased by 0.8 m between 1994 and 2000 with both transects expanding into deeper water.

Although mean total phosphorus concentrations were reduced 23% and Secchi depths increased by approximately 2 m between the post-P time period and 2000, SAV in the lower bay showed little response after the invasion by zebra mussels. In 2000, SAV cover and the maximum depth of colonization were similar to those found throughout most of the time period. The mean bed width did decrease by 50 m between 1994 and 2000, which was due to CS3.

COMPARISON BETWEEN THE 2000 AND 2004 MACROPHYTE SURVEYS

Although high SAV inter-annual variability has been observed in some studies (Blindow 1992), it appears that the majority of the transects in the Bay of Quinte that experienced substantial SAV bed extension after the invasion of zebra mussels have managed to retain most of their SAV bed 4 years later. This is not true of SAV density, which has declined between 2000 and 2004 on 8 of the 10 reference transects.

In the upper bay between the 2000 and 2004 survey, the mean cover of all six reference transects decreased by 16%, but the mean transect length remained constant. Examination by individual transect revealed that the largest decrease (58%) in SAV cover occurred on the shortest transect, BS3, whose length was reduced by half to 6m in 2004. This transect historically had zero or very sparse cover and is located on an exposed point. Two other transects, BN3 and BBS3, experienced reductions of 46 and 37% in SAV cover, yet had their bed extent, which was greater than 225 m, decrease by less than 10 m. It is unclear why these larger, stable sized beds would experience a substantial decrease in cover. BBN3 recorded an 18% decrease in cover and the bed extent at this location was almost reduced by half, to 130 m in 2004. At TS3, the bed extent increased by 150 m to 210 m and cover declined by 21%, but this decline could be a result of sparser cover encountered in the newly colonized area. Only at the relatively stable, dominant upper bay transect of TN3 did percent cover increase slightly in 2004, but the SAV bed here contracted by 30 m, extending 1.16 km offshore. Even so, TN3 was still just under 4.5 times bigger than the next longest upper bay reference transect at BBS3. The maximum depth of colonization did increase slightly on all upper bay transects, even those whose bed extents were reduced, since on several of the transects, the maximum depth did not coincide with the last plant on the transect.

Between 2000 and 2004, the middle bay experienced a 10% decline in mean SAV cover in conjunction with a 44 m decrease in mean bed extent. HBW3 recorded the highest decrease in cover at 16%, but only lost 15 m in bed extent with a 2004 length of 175 m. The bed at HBE3 was reduced by approximately 75 m to 360 m, but the SAV density remained relatively stable, declining by 8%. The maximum depth of colonization increased slightly on both transects.

Between 2000 and 2004, the SAV beds expanded at both Conway transects, but neither SAV bed extended farther than 160 m offshore at any point in time. CN3 saw a 23% increase in cover, but remained in the moderate cover category, while CS3 experienced a 37% decrease in cover, moving from dense to moderate cover. Increased water clarity in the Conway area during the post-ZM period has not had a substantial impact on SAV. The steep drop off in this area restricts a substantial increase in the SAV beds and the variation in density may be partly due to SAV attempting to establish on steeper slopes with subsequent sloughing in these areas. There is a substantial increase in the maximum depth of colonization in the lower bay, mainly due to a 3.5 m increase at CN3 between 2000 and 2004. There is difficulty in detecting low lying macrophytes, particularly in deeper waters and it is recommended that a visual assessment via a video camera be employed whenever possible to confirm the end of the SAV bed.

RELATIONSHIP BETWEEN PERCENT COVER AND SECCHI DEPTH

The relationship between offshore Secchi depth and mean percent cover by bay for the full historical record is examined in the scatter plots in Figure 29. In the upper bay, the data appears to cluster by time stanza, with the pre-P data point recording sparse cover, the post-P data clustered around low values of moderate cover and the post-ZM data at higher moderate cover. Both the sparse and low moderate cover occur over the same range of Secchi depths which implies there may be other factors involved in determining SAV density in this range of water clarity. The offshore Secchi depths may not be representative of nearshore water clarity at that time, particularly if sparse SAV was not effective in reducing suspended sediments in this shallower water.

Secchi depths for the upper bay post-ZM data are at least 0.7 m deeper and percent cover values are a minimum of 10% higher than the post-P group. Additionally, it is during the post-ZM period that several of the SAV beds greatly expanded. Perhaps there is a threshold in water clarity in the upper bay where SAV can increase in density to the point where the initial SAV beds are fully established and can rapidly colonize new deeper areas as increased light availability converts them to suitable habitat. This may be the case in the Big Bay transects, but the TN3 transect were already relatively well established with moderate cover for most of the post-P period, although both increases in density and SAV bed extent occurred at TN3 post-ZM.

In the middle bay, the data in the scatter plot does not readily cluster into the 3 time stanzas, although 2000 and 2004 are nearest neighbours due to their Secchi depths. The two highest cover values are related to some of the lowest Secchi disc depths. In this case, increased water clarity appears to be more related to the expanded SAV beds at HBE3 than any changes in

SAV density. The same case hold true for the lower bay, although it appears basin morphometry has limited SAV bed expansion even when water clarity has greatly increased.

Macrophyte models were developed by Seifried, 2002 to predict SAV density in the Bay of Quinte using depth, epar, fetch, sediment and slope as independent variables. A model was developed for each bay and in the upper bay and middle bays models, depth and epar were the most significant variables to predict cover. In the lower bay, only depth and slope were deemed necessary to predict cover. These models confirm that depth and light availability are the principle factors in SAV distribution and density in the upper and middle bays while basin morphometry predominates in the lower bay.

TRENDS IN SPECIES COMPOSITION: 1972 TO 2004

The percent frequency of occurrence on the northern reference transects for the five dominant submergent macrophyte species found in the Bay of Quinte has varied through time (Figure 30). When viewing these graphs, it is important to recall the temporal evolution of each transect since some transects, such as BN3 and BBN3, had sparse cover and relatively small SAV beds for much of the historical record. Other transects, such as TN3 and HBE3 have typically experienced moderate cover most of the time and fluctuating bed extents with substantial expansions in the post-ZM period. Throughout the entire time period, CN3 has remained relatively stable in terms of SAV cover and bed extent.

The species that are most tolerant of eutrophic conditions, *Myriophyllum spp*. and *H. dubia*, occur more frequently in the upper bay than in the middle or lower bay transects. In the Bay of Quinte, the only years *M. spicatum* was differentiated from the native *M. exalbescens* was from 1979 to 1982. Despite other studies indicating a rapid expansion and subsequent decline in *M. spicatum*, (Trebitz, Nichols et al. 1993; Knapton and Petrie 1999), *Myriophyllum spp*. have been generally increasing on TN3 where it was very common from 1994 to 2004. On the other upper bay transects, *Myriophyllum spp*. was initially common and after fluctuating over the years on these transects that had sparse cover, recorded relatively low levels in 2004. Low to moderate frequencies of *Myriophyllum spp*. were found on the middle and lower bay transects, with the frequency gradually increasing through time on CN3. Until 1982, the occurrence of *H.dubia* was generally low on all transects, except for BBN3. It has subsequently become very common in the upper bay, moderate in the middle bay and at lower levels in the lower bay.

The most consistent change has been the expansion of *V. americana* in the Bay of Quinte. In the upper and middle bays, *V. americana* occurred at low levels until 1988 and until 1974 in the lower bay. This species had gradually increased at TN3 and BN3 and had a generally increasing trend on the other 3 transects, with some inter-annual fluctuation. Although *V. americana* is fairly tolerant of turbid water and high nutrient loading, it has been known to compete poorly with *M. spicatum* (Titus and Adams 1979). This is not evident on TN3, where both species have increased since 1994.

TN3 was the only transect where *E. canadensis* was consistently found throughout the entire time period, and these were at low frequencies, except in 1994. It was generally persistent at both HBE3 and CN3, but at low to moderate levels. *C. demersum* is most frequently found on TN3, where it has been increasing since 1988 and was common by 2004. It was present at low levels at both BN3 and BBN3 in 2004 and at moderate levels at BN3 in 2000, It was generally absent throughout the middle and lower bays (except at CN3 in 2004).

SPECIES RICHNESS: 1972 TO 2004

Species richness on the same transect generally varied between surveys (Table 2). TN3 and HBE3 typically had the highest species richness. Prior to 2000, BBN3 had the lowest richness, but it should be noted that this transect also recorded sparse cover during this time period. Richness increased substantially on BBN3 from 1988 to 2000 and maintained it's diversity into 2004.

CONCLUSIONS AND RECOMMENDATIONS

Macrophytes are an important component of fish habitat and the depth to which they grow can be used as an indicator of water quality. The long historical record of many aspects of the Bay of Quinte ecosystem provides an invaluable dataset to explore the response of submergent macrophytes. The three distinct bays provide variation in both trophic status, basin morphometry and exposure and macrophyte response has varied depending on location.

In the pre-P period in the upper bay, SAV were generally very sparse with relatively small beds. There was a slight increase in density after phosphorus control was implemented and substantial response in both density and areal extent in several upper bay locations after the invasion by zebra mussels. These larger SAV beds have generally remained intact into 2004, although there has been a decrease in cover since 2000. Macrophytes in the middle bay in the pre-P period were already at moderate density and they have fluctuated between dense and moderate cover through the entire time period, with a substantial increase in areal extent occurring post-ZM. There were slight decreases in both cover and areal extent in the middle bay between the 2000 and 2004 surveys. There has been little response by SAV in the lower bay from 1972 to 2004, with moderate to dense cover throughout the time period. It appears that many of the SAV beds in the Bay of Quinte are now well established and it will be interesting to examine how resilient these beds will be in the future.

Macrophyte surveys should continue at Trenton, Belleville, Big Bay, Hay Bay and Conway with particular emphasis on transect 3 to provide continuity for the historical record. Surveys should be conducted at least every 4 years to assess annual variability since some previous macrophyte surveys reported in the literature have experienced high inter-annual variability (Blindow 1992; Rea, Karapatakis et al. 1998). The 4 year sampling period would also allow a somewhat timely capture of SAV response to new perturbations and may provide an early warning to researchers of deteriorating conditions .

SAV percent cover, bed extent, maximum depth of colonization and species composition should continue to be monitored in the Bay of Quinte. Comparison of three different macrophyte survey methods (percent cover, stem density and quadrat sampling) was conducted by Minns et al., 1993, in three Great Lakes Areas of Concern between 1988 and 1991. They found significant agreement between these three methods and recommended percent cover for the assessment of fish habitat.

In the surveys, macrophytes should be identified to species where possible, particularly when dealing with an aggressively invasive species such as *M. spicatum*. Some researchers have noted both the loss of particular species (Nichols and Mori 1971) and other species that may be indicators of suitable *M. Spicatum* habitat (Nichols and Buchan 1997).

The macrophyte surveys should aim for consistency in the sampling methodology, locations and equipment to be able to directly compare results across years. With advances in technology, there will be changes to the methodology for sampling submergent macrophytes. In the year that changes are made to the methodology, simultaneous use of both the old and new protocols is recommended to assess the equivalency of the methods and to develop correction factors as necessary.

The RAP delisting objective for submerged macrophytes in the Bay of Quinte includes targets for both the areal extent of the beds and the density of cover in the upper bay (German and Stride 2003). The macrophyte model developed by Seifried in 2002 predicts large SAV beds in the Trenton area that is currently being surveyed, and also in areas by Indian Island and Muscote Bay. For future macrophyte surveys in the Bay of Quinte, it is recommended that additional transects be established in these new areas since these areas are predicted to be major contributors to achieving the delisting targets. Furthermore, the three existing transects at Trenton North should be surveyed continuously from the north to south shore to capture possible eastern expansion of mid-channel SAV beds.

ACKNOWLEDGEMENTS

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Table 1. Summary of macrophyte surveys in the Bay of Quinte from 1972 to 2000.

Date (mo)	(Yr)	Location	# of Sites Sampled	Sampling Protocol	Method to determine % macrophyte cover	Biomass Sampling	Sources
Jul	'72	T, B, BB, HB, C[a]	10	PT to 90 m beyond beds	P/A		(Crowder and Bristow 1986),
			5	RS[n]		RQ	(Loftus, Sayer et al. 1992)
Jul	'73	T, B, BB[a]	3	PT to 90 m beyond beds	P/A		(Crowder and Bristow 1986),
			16	RS[n]		RQ	(Loftus, Sayer et al. 1992)
Jul	'74	B, HB, C[a]	5	PT to 90 m beyond beds	P/A		(Crowder and Bristow 1986),
							(Loftus, Sayer et al. 1992)
Jul	'79	T, B, BB, HB,C[a]	10[m]	PT to 90 m beyond beds	P/A		(Crowder and Bristow 1986),
			17	RS[n]		RQ	(Loftus, Sayer et al. 1992)
Jul	'82	T, B, BB, HB, C[a]	9[l]	PT to 90 m beyond beds	P/A		(Crowder and Bristow 1986),
			19	RS[n]		RQ	(Loftus, Sayer et al. 1992)
	'85	T, B, BB, HB, C[a]	9[k]	PT to 90 m beyond beds	P/A		(Crowder, Bristow et al. 1988),
			26	RS[n]		RQ	(Loftus, Sayer et al. 1992)
Aug	'87	B, BB, BI, D, HB[f]	46	PS from 0.5 to 3.6 m	single VE		(Dushenko 1990), LGL Ltd. files
Jul, Aug	'88	B, T, BI[b,c,e]	31	EFT at 1.5 to 2 m depth	single VE over the transect		(Crowder 1988),
			31	RS near transects[o]		RQ	(Crowder, Bristow et al. 1988),
							(Minns, Cairns et al. 1993), LGL files
Jul, Aug	'88	T, B, BB, HB, C[a]	8	PT to 90 m beyond beds	P/A		(Crowder, Bristow et al. 1988),
							(Loftus, Sayer et al. 1992)
Jul - Aug	'88	T, B, BB, HB, C[a]	46	PT to 30 m beyond beds	echogram interpretation		(Limnos 1989)
			57	BSS on 20 of the transects		3Q/SS	

Table 1 (continued). Summary of macrophyte surveys in the Bay of Quinte from 1972 to 2000.

Date (mo)	(Yr)	Location	# of Sites Sampled	Sampling Protocol	Method to determine % macrophyte cover	Biomass Sampling	Sources
Jul, Sep	'88	B, BB, BI, D, HB, T [f]	48 [j]	PS at depths from 1.1 to 4.1 m	single VE		(Dushenko 1990), LGL Ltd. files
Jul	'89	B, BI, T [b,c,e]	33	EFT at 2 to 3 m depth	single VE over the transect		(McLaughlin and Crowder 1989),
			30	BSS on 30 of the transects		2Q/T	(Minns, Cairns et al. 1993), LGL files
Jun, Jul	'89	B, BB, BI, D, HB [f]	8 [i]	PS from 1.3 to 3.3 m	single VE		(Dushenko 1990), LGL Ltd. files
Aug	'90	B, BI [b,e]	12	EFT at 1.5 m depth	single VE over the transect		(Minns, Cairns et al. 1993)
Aug	'91	B, BI, T [b,e]	11	EFT at 1.5 m depth	VE every 10 m along transect		(Minns, Cairns et al. 1993)
	'92	CB [d]	7	EFT at 1.5 m depth	VE every 10 m along transect		DFO dataset
	'92	CB [d]	23	EFT at 1.5 m depth	echogram interpretation		DFO dataset
Sep	'94	T, B, BB, HB, C [a]	50	PT to 30 m beyond beds	echogram interpretation		(Marshall, Macklin et al. 1995)
			62	BSS on 23 of the transects		3Q/SS	
	'95	B, BI, T [c]	21	EFT at 1.5 m depth	VE every 10 m along transect		DFO dataset
Jun - Oct	'99	B, BI, CB, T [b]	26 [h]	EFT at 1.5 m depth	single VE over the transect		DFO dataset
Aug	'00	T, B, BB, HB, C [a]	46 [g]	PT to 30 m beyond beds	echogram interpretation		U of T/DFO dataset
			82	BSS on 21 of the transects	single VE at BSS	3Q/SS	

Table 1 (continued). Summary of macrophyte surveys in the Bay of Quinte from 1972 to 2000.

Location

Abbreviations for locations: B - Belleville, BB - Big Bay, BI - Big Island, C = Conway, CB - Carnachan Bay, D - Deseronto, HB - Hay Bay, T - Trenton

[a,b,c,d,e,f] - > 50% of the data was collected at the same location as in previous surveys having the same letter code

<u># of Sites Sampled</u>

[g] - 5 of the 40 transects were replicated a total of 3 times

[h] - the 26 transects were sampled 3 to 4 times over the season, single replicates on 2 of the transects

[i] - the 8 sample points were sampled twice over the season

[j] - 28 of the 48 transects were sampled again during the season

[k] - 4 of the 7 transects were replicated a total of 2 times

[l] - 4 of the 7 transects were replicated a total of 2 times

[m] - 5 of the 8 transects were replicated a total of 2 times

<u>Sampling Protocol</u>

PT - perpendicular transects

RS - random sample throughout the Bay (sampling site locations are unknown)

PS - point sampling (range of water depths of sampling sites given)

EFT - electrofishing transects 100 m parallel to the shoreline

BSS - biomass sample sites

[n] - only the mean and range are available for this dataset. Sampling site locations are unknown.

[o] - only the mean and range are available for this dataset

<u>Method to Determine Percent Macrophyte Cover</u>

P/A - knotted line used to determine presence absence at 1 m intervals along the transect

VE - visual estimate

<u>Biomass Sampling</u>

RQ - random 0.0625 m^2 quadrat (sampling location unknown)

3Q/SS - three 0.25m^2 quadrats per sample site

2Q/T - two 0.5 m^2 quadrats per transect

Table 2. Species richness on northern and eastern transects from 1972 to 2004. Data from 1972 to 1982 was obtained from Crowder and Bristow (1986) who calculated S per 116 transect points. In 1979 and 1982, replicate transects 1 m apart were sampled. Richness from 1988 to 2004 was determined at all the point sampling sites whose number varied by transect.

	1972	1973	1974	1979	1982	1988	1994	2000	2004
TN3	8	11	NS	6 - 8	8 - 9	7	9	7	9
BN3	5	4	NS	5 - 6	2 - 5	5	2	7	4
BBN3	2	3	NS	3	1 - 1	2	NS	8	8
HBE3	11	NS	6	7 - 8	6 - 6	7	7	9	5
CN3	8	NS	10	5 -7	3 - 5	6	6	5	8

NS: transect not sampled that year

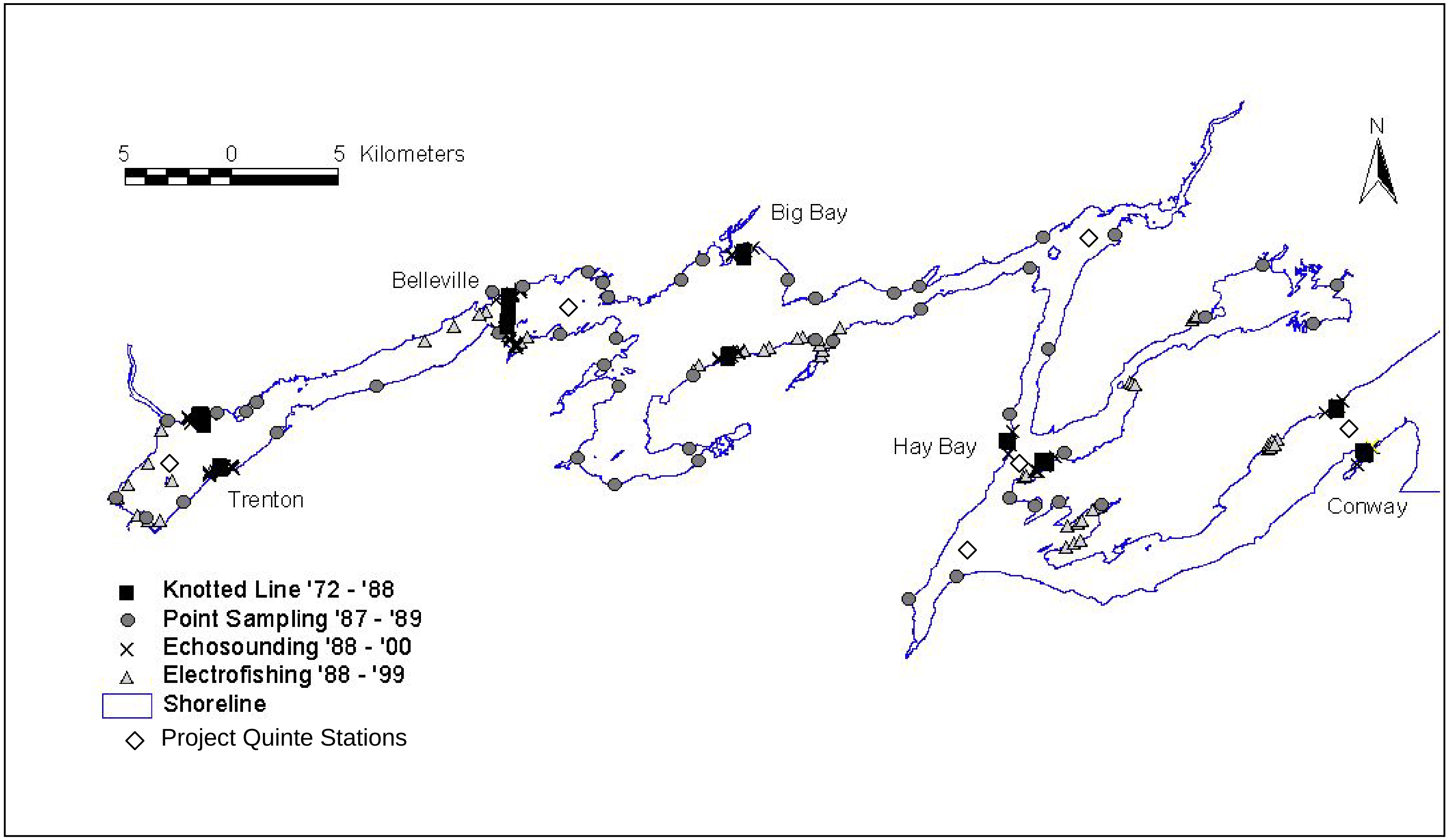


Figure 1. Macrophyte sampling locations in the Bay of Quinte from 1972 to 2000.

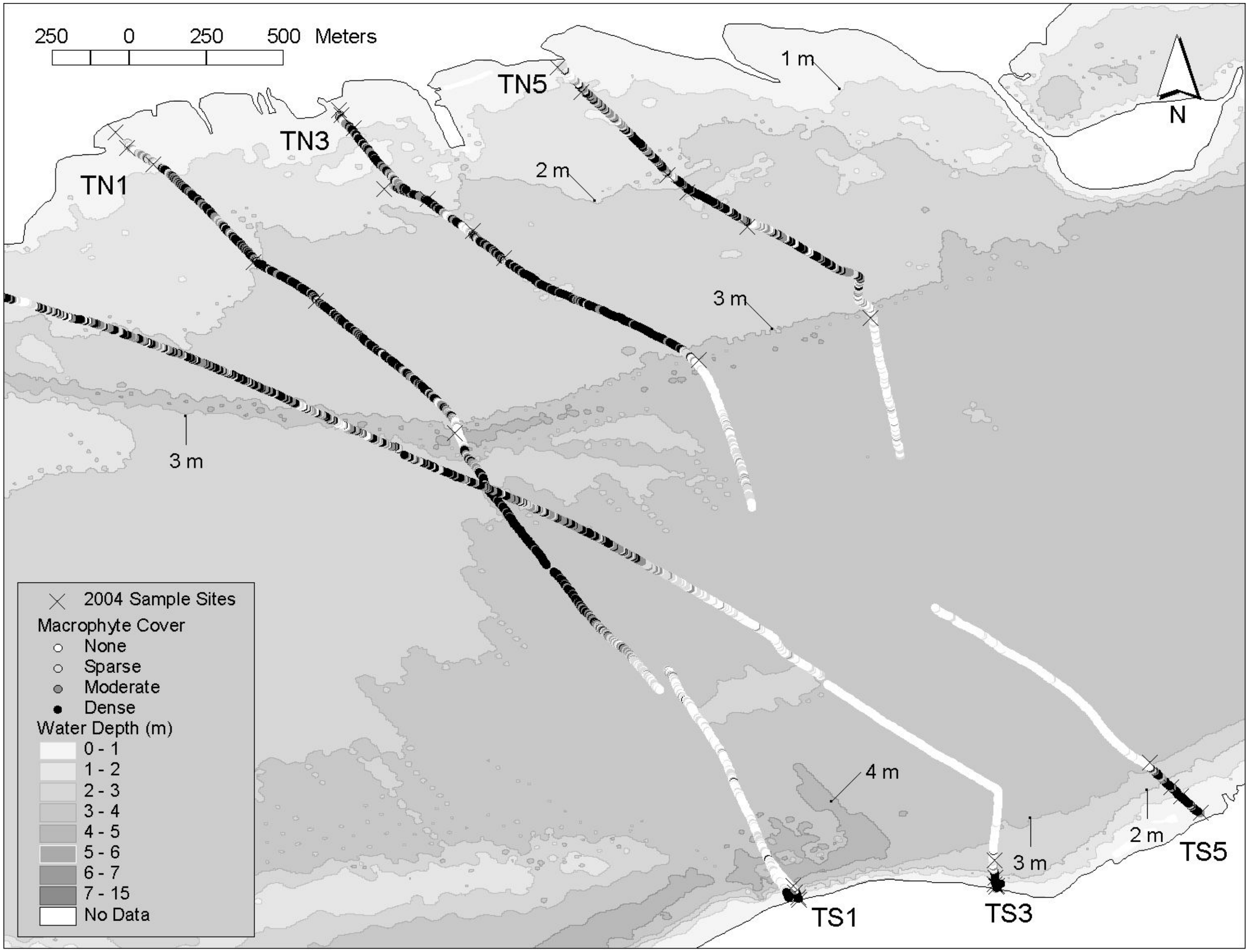


Figure 2. 2004 submerged macrophyte cover for Trenton transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

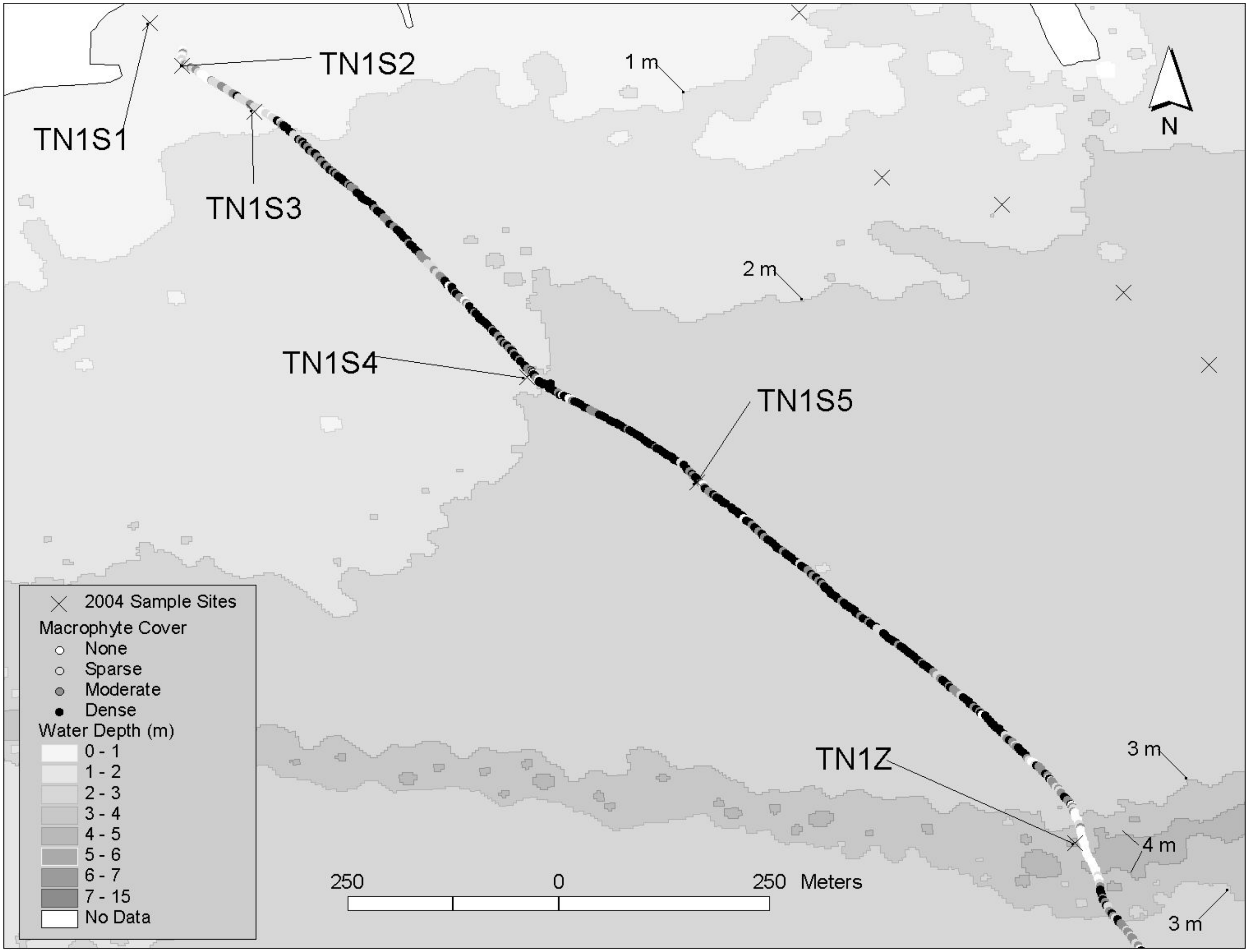


Figure 3. 2004 submerged macrophyte cover for Trenton North transect 1 based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

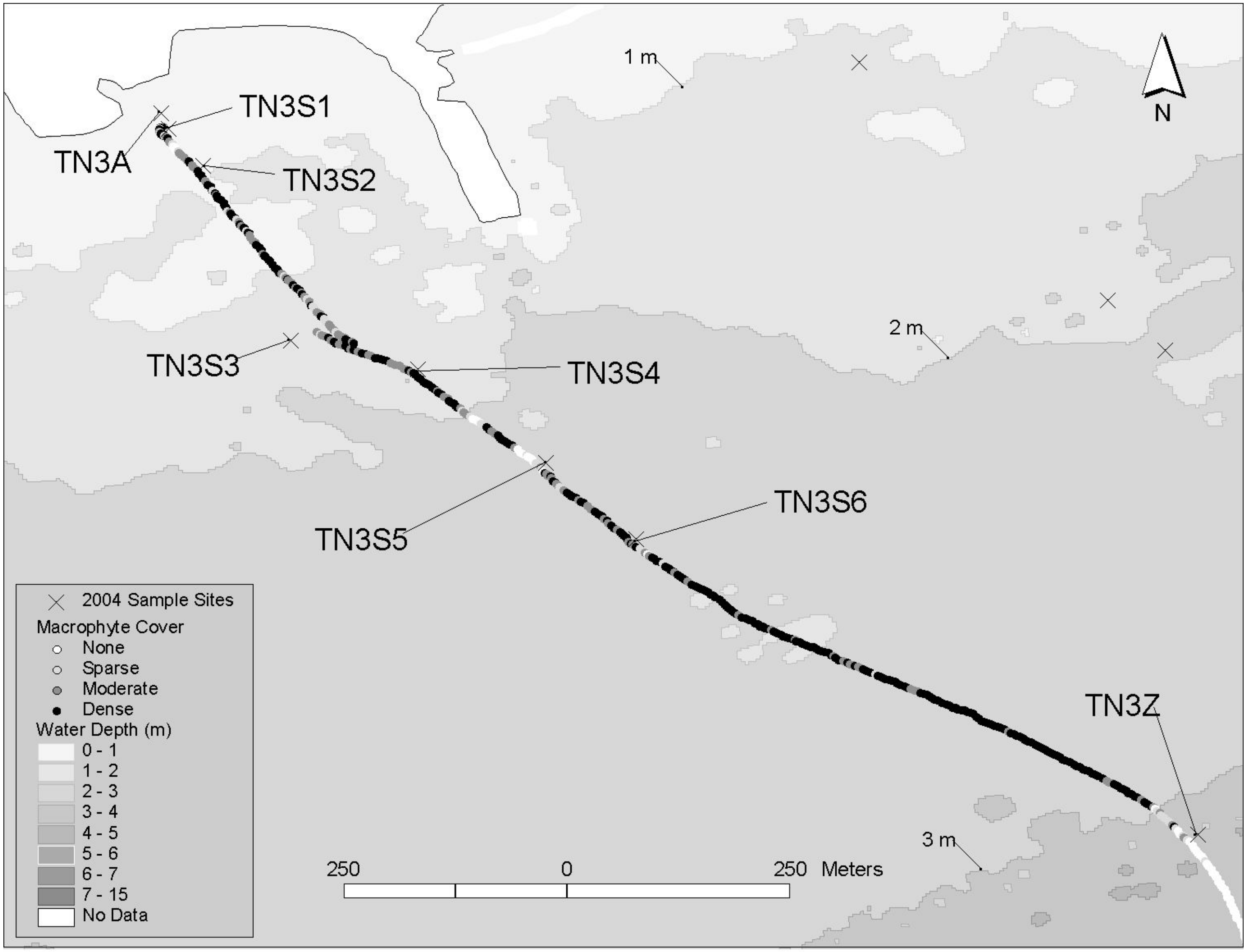


Figure 4. 2004 submerged macrophyte cover for Trenton North transect 3 based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

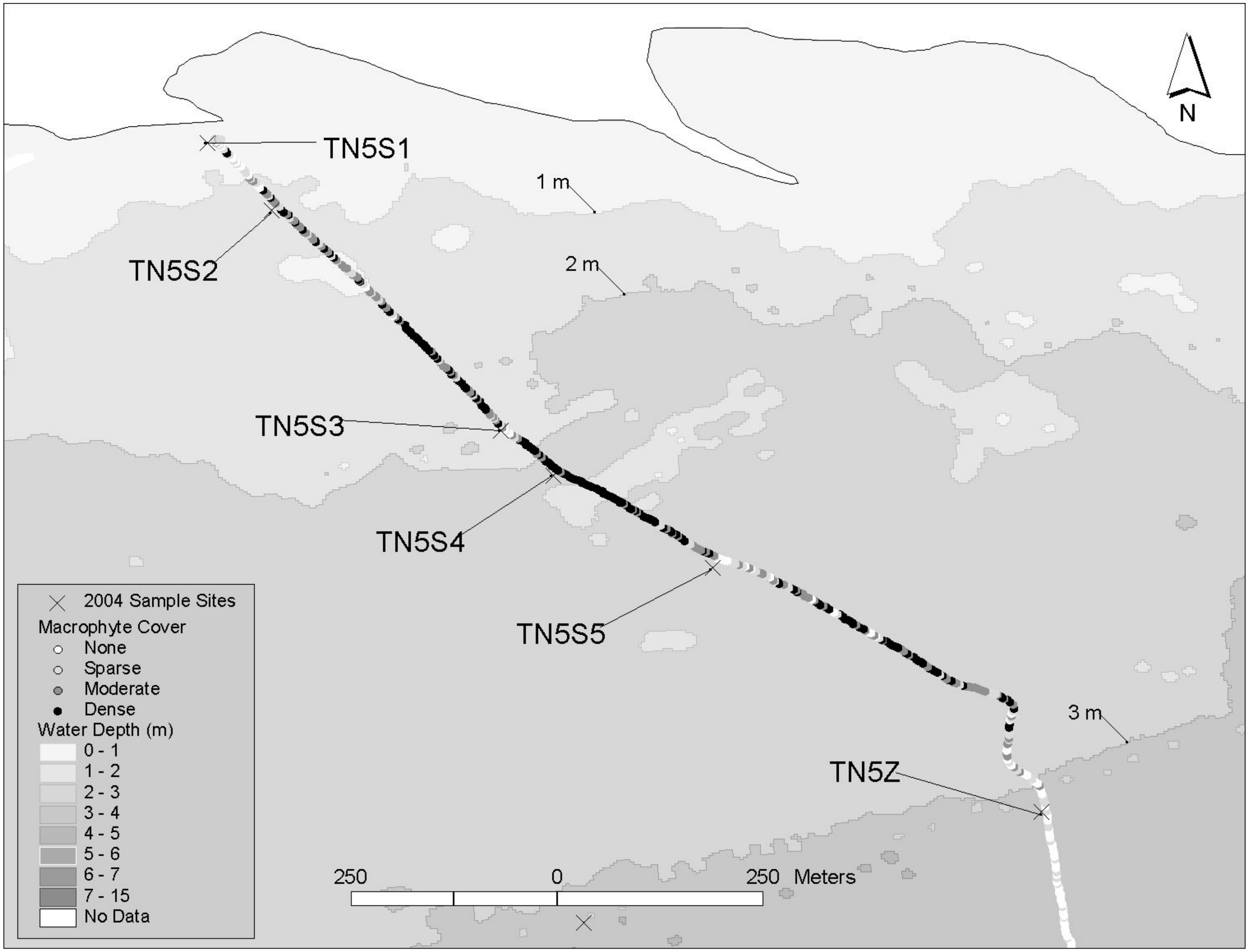


Figure 5. 2004 submerged macrophyte cover for Trenton North transect 5 based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

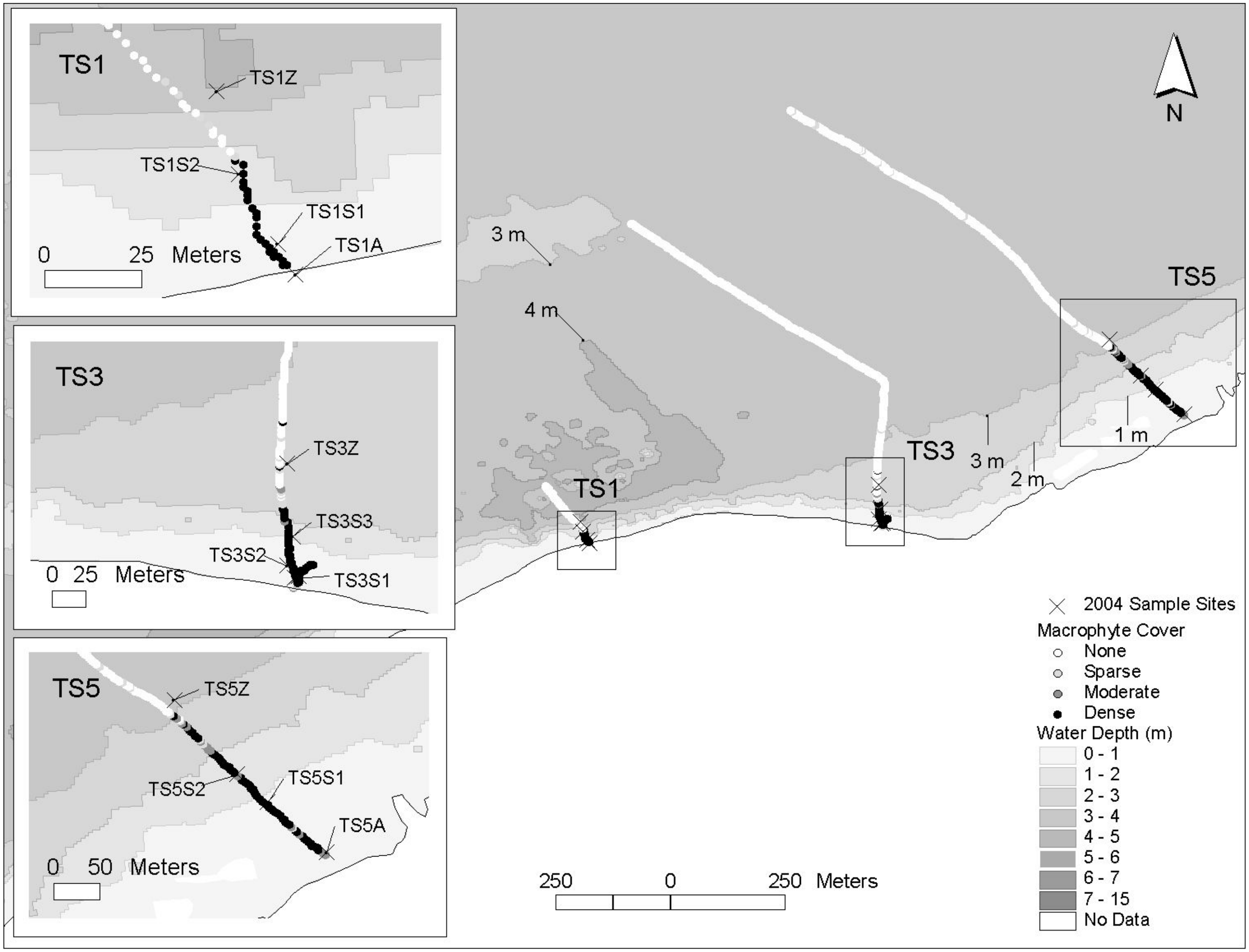


Figure 6. 2004 submerged macrophyte cover for Trenton South transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

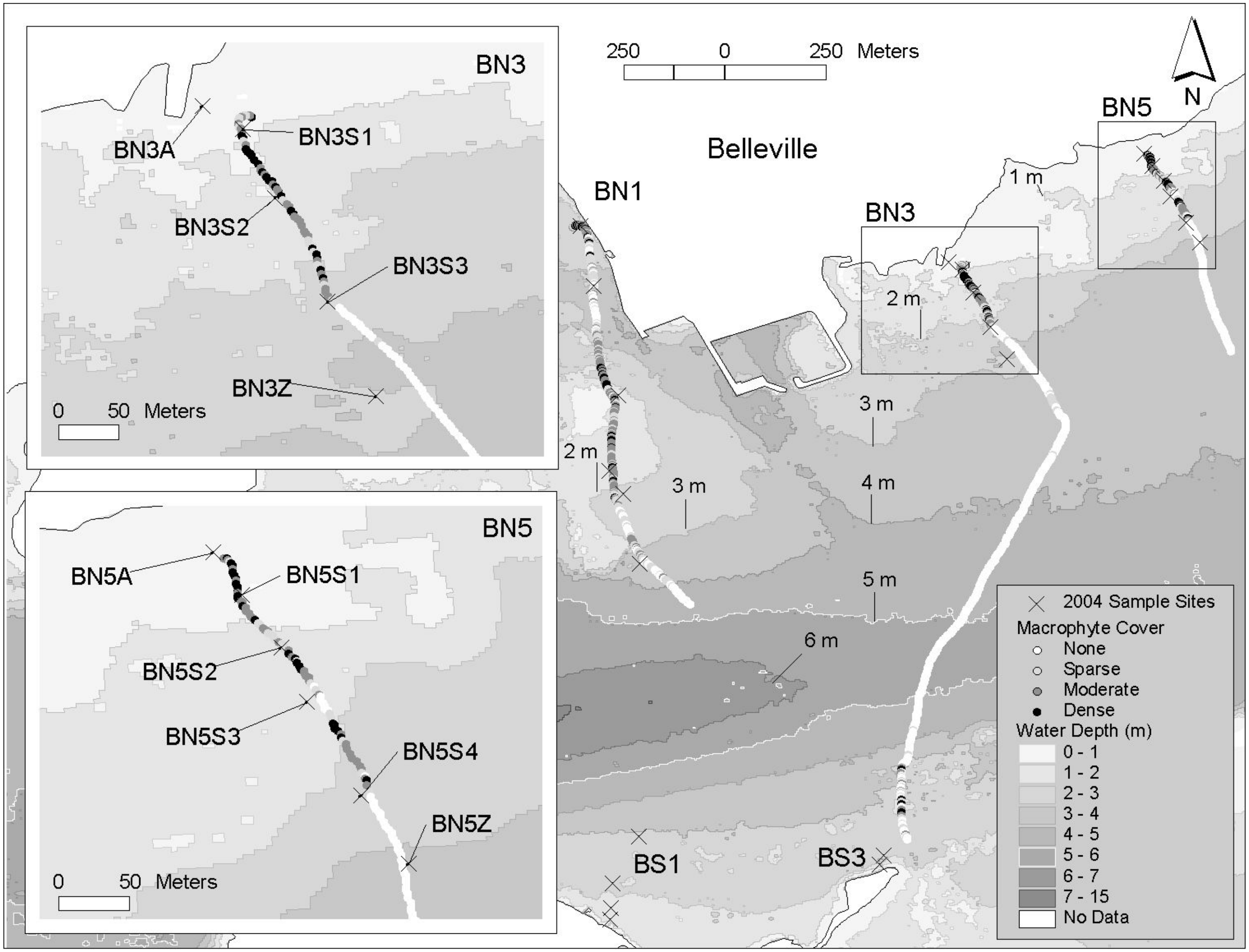


Figure 7. 2004 submerged macrophyte cover for Belleville North 3 and 5 transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

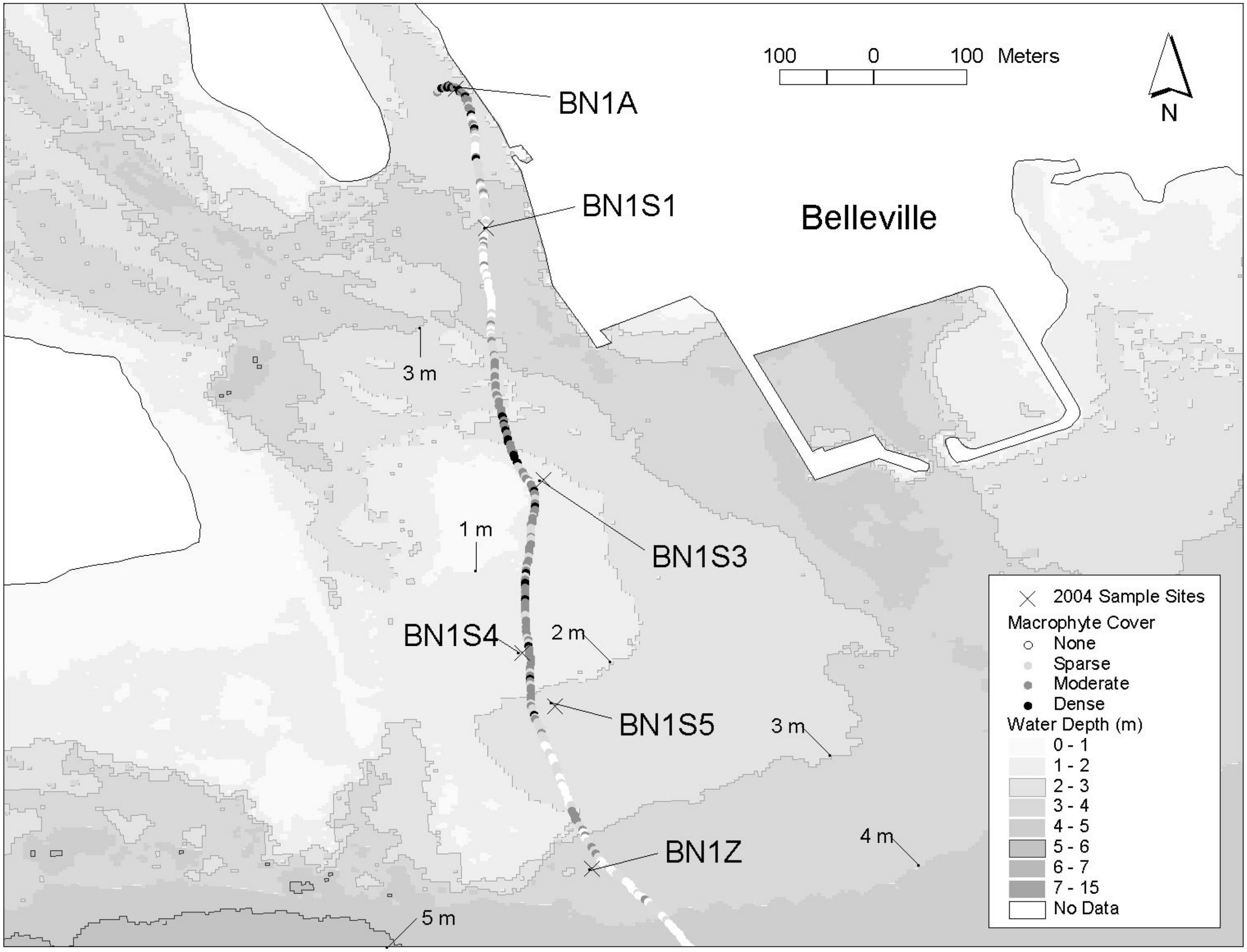


Figure 8. 2004 submerged macrophyte cover for Belleville North 1 transect based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

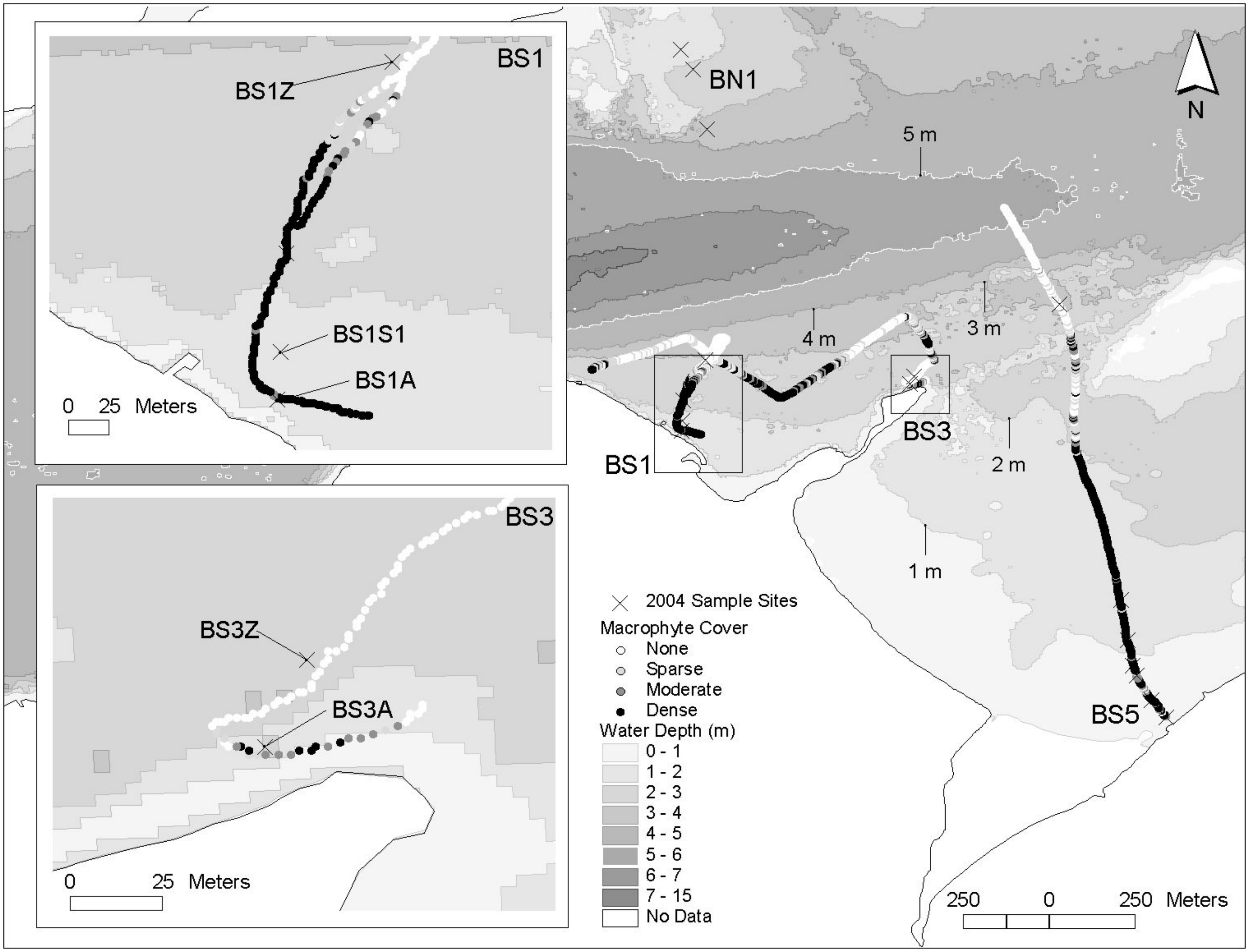


Figure 9. 2004 submerged macrophyte cover for Belleville South 1 and 3 transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

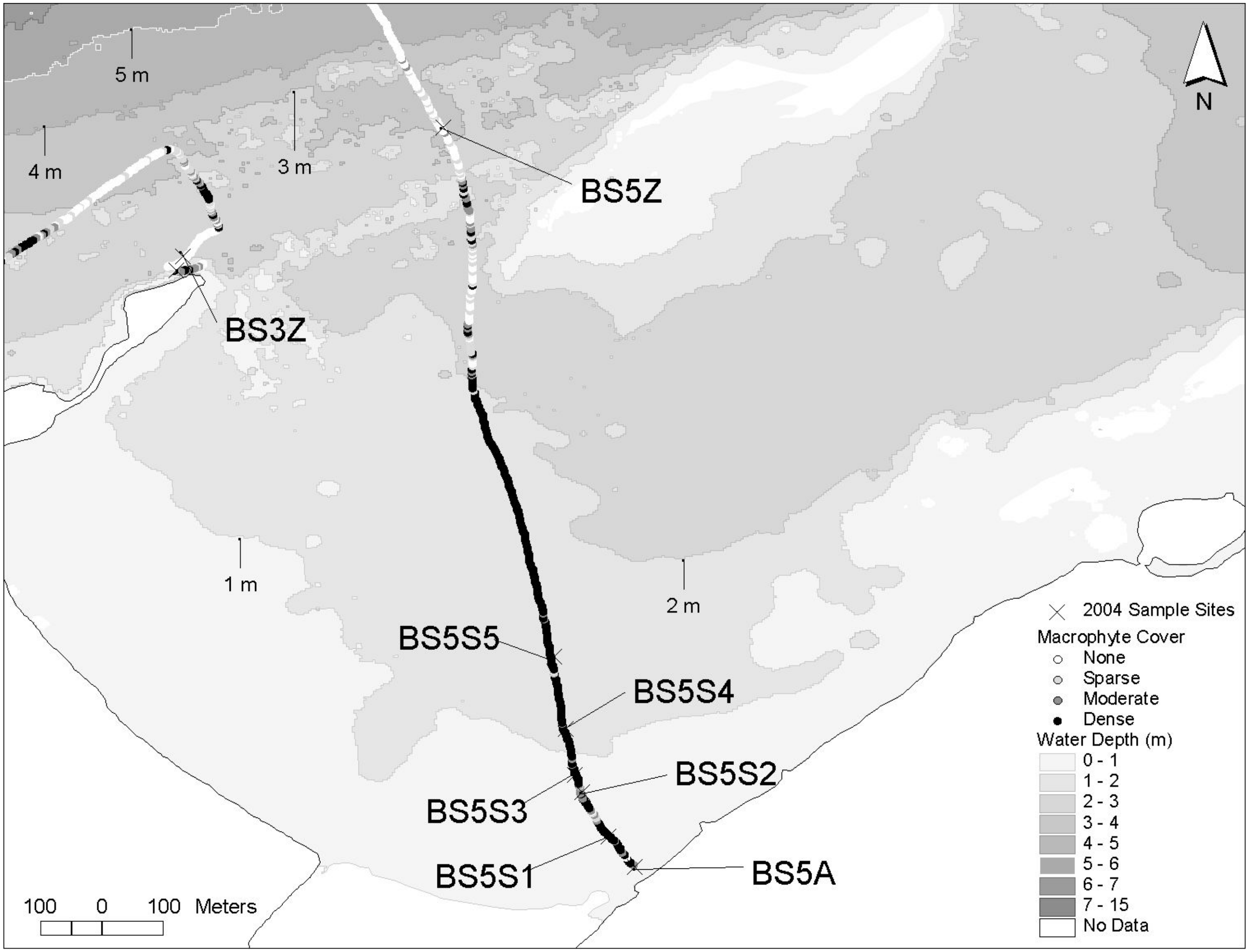


Figure 10. 2004 submerged macrophyte cover for Belleville South 5 transect based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

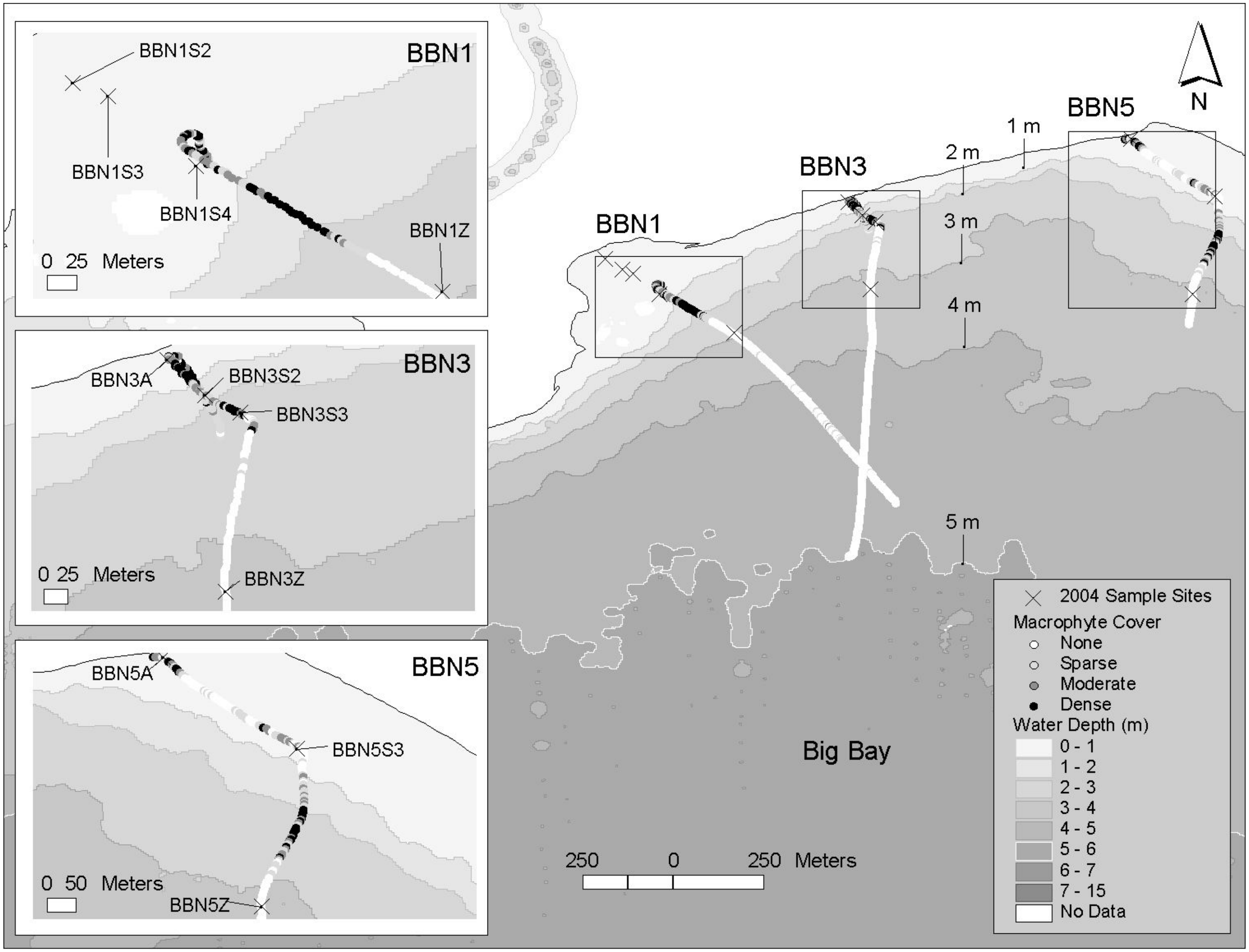


Figure 11. 2004 submerged macrophyte cover for Big Bay North transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

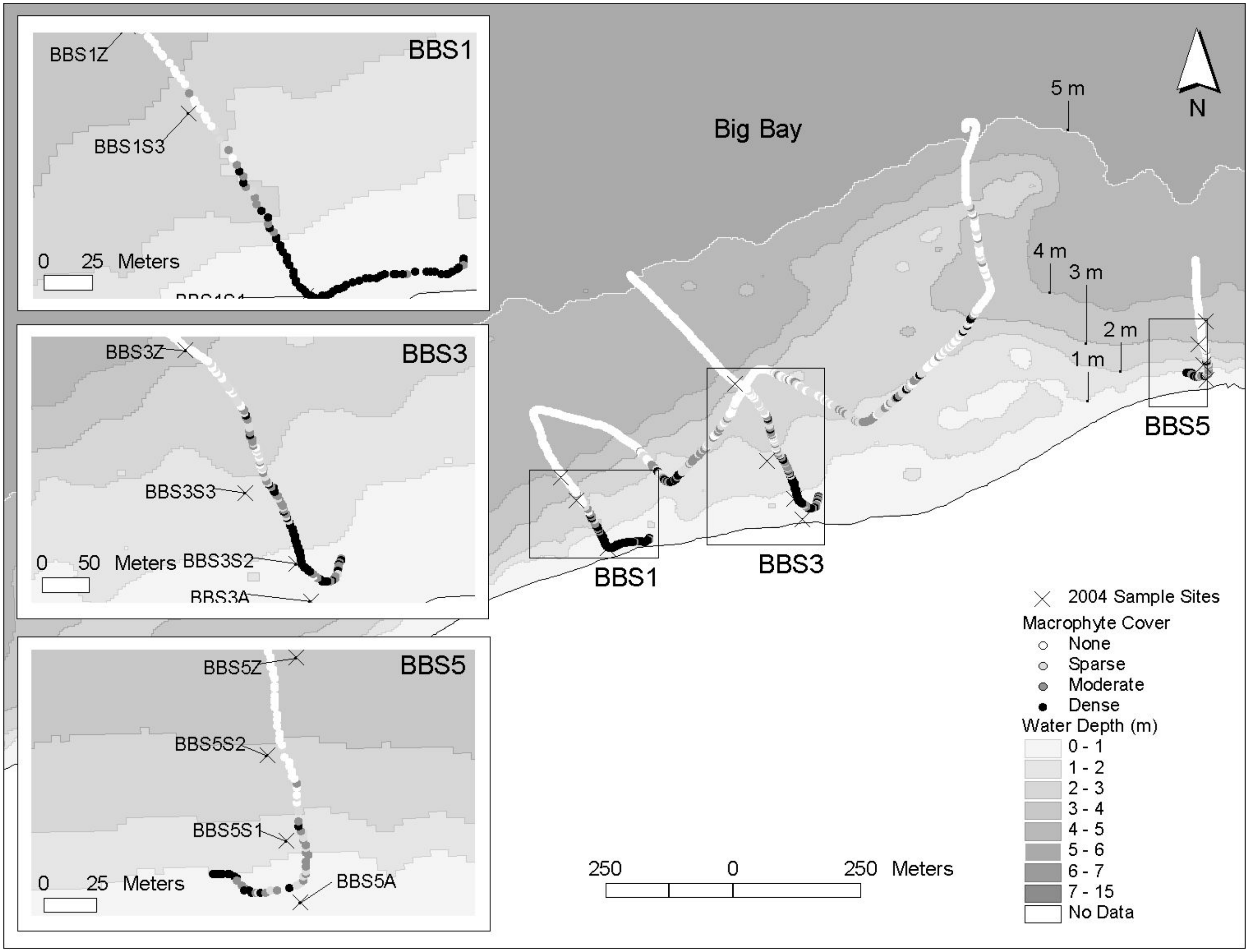


Figure 12**.** 2004 submerged macrophyte cover for Big Bay South transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

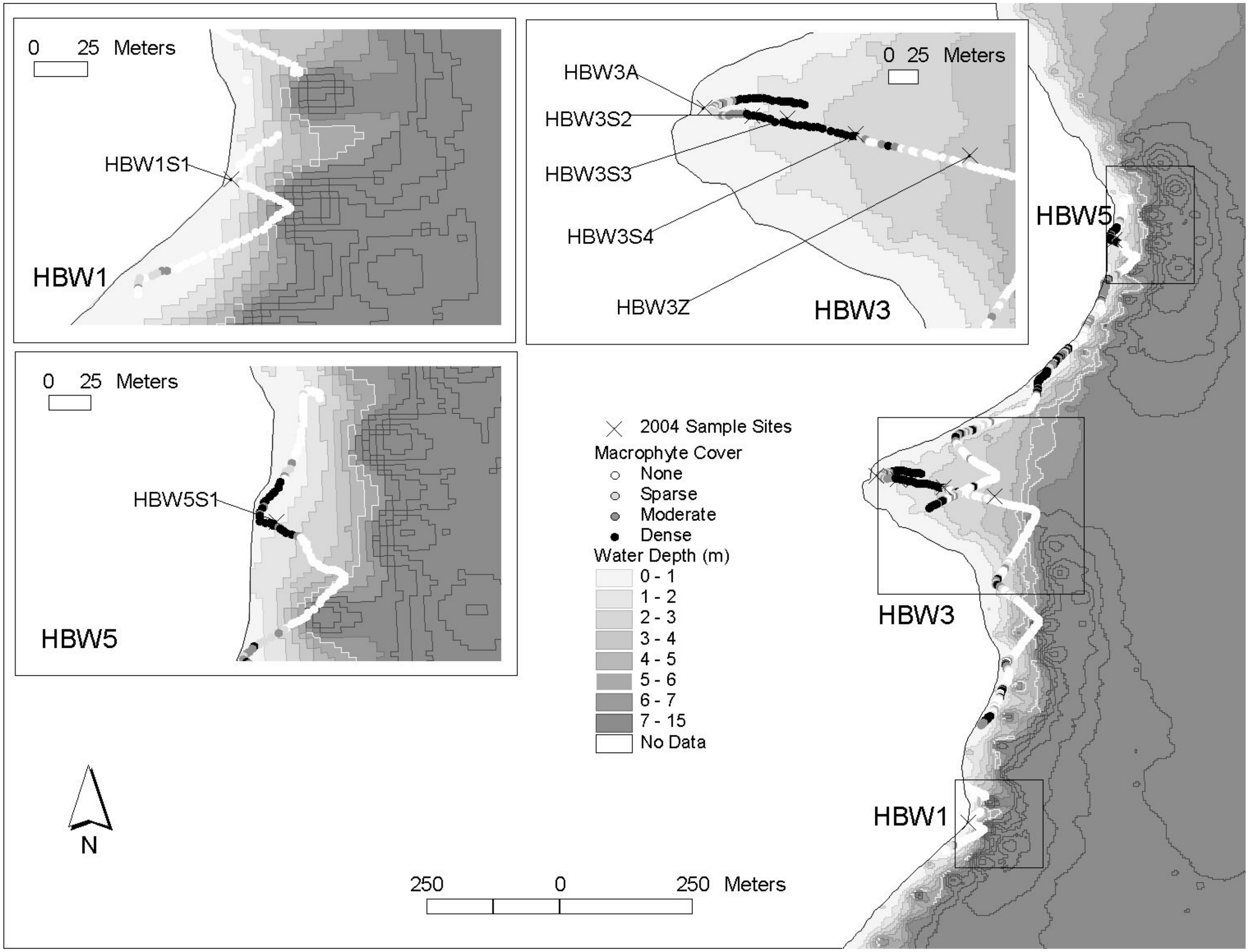


Figure 13. 2004 submerged macrophyte cover for Hay Bay West transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

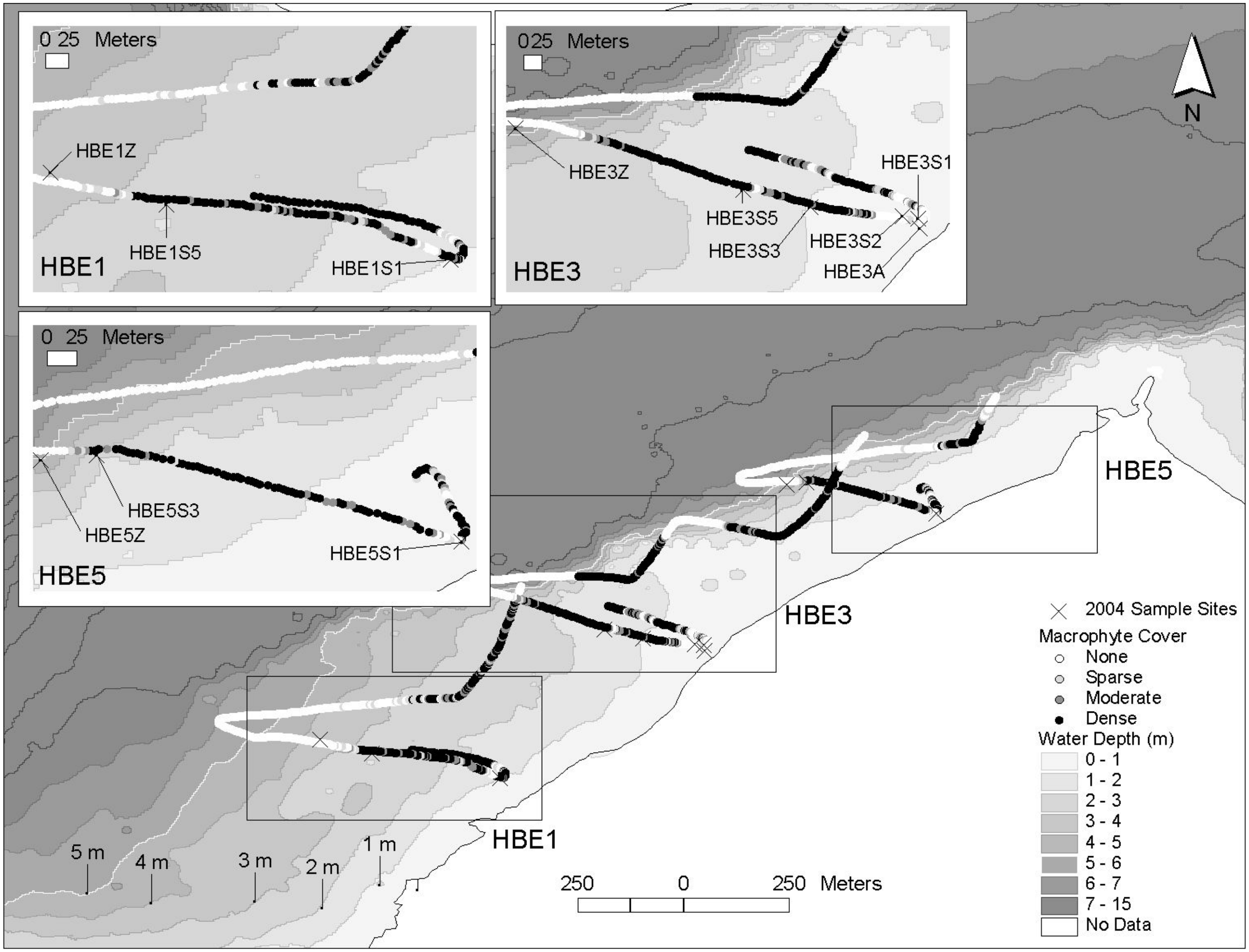


Figure 14. 2004 submerged macrophyte cover for Hay Bay East transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

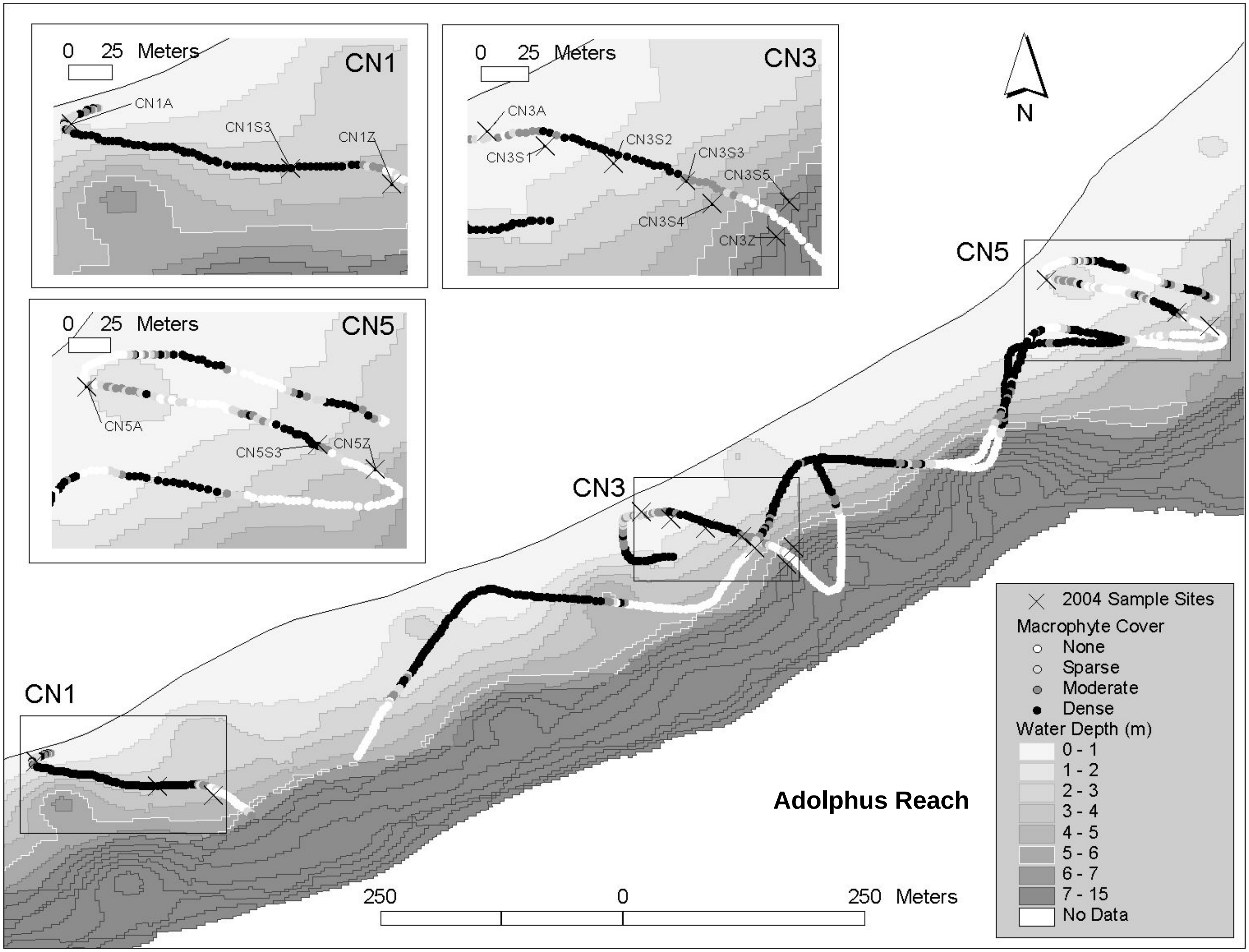


Figure 15. 2004 submerged macrophyte cover for Conway North transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

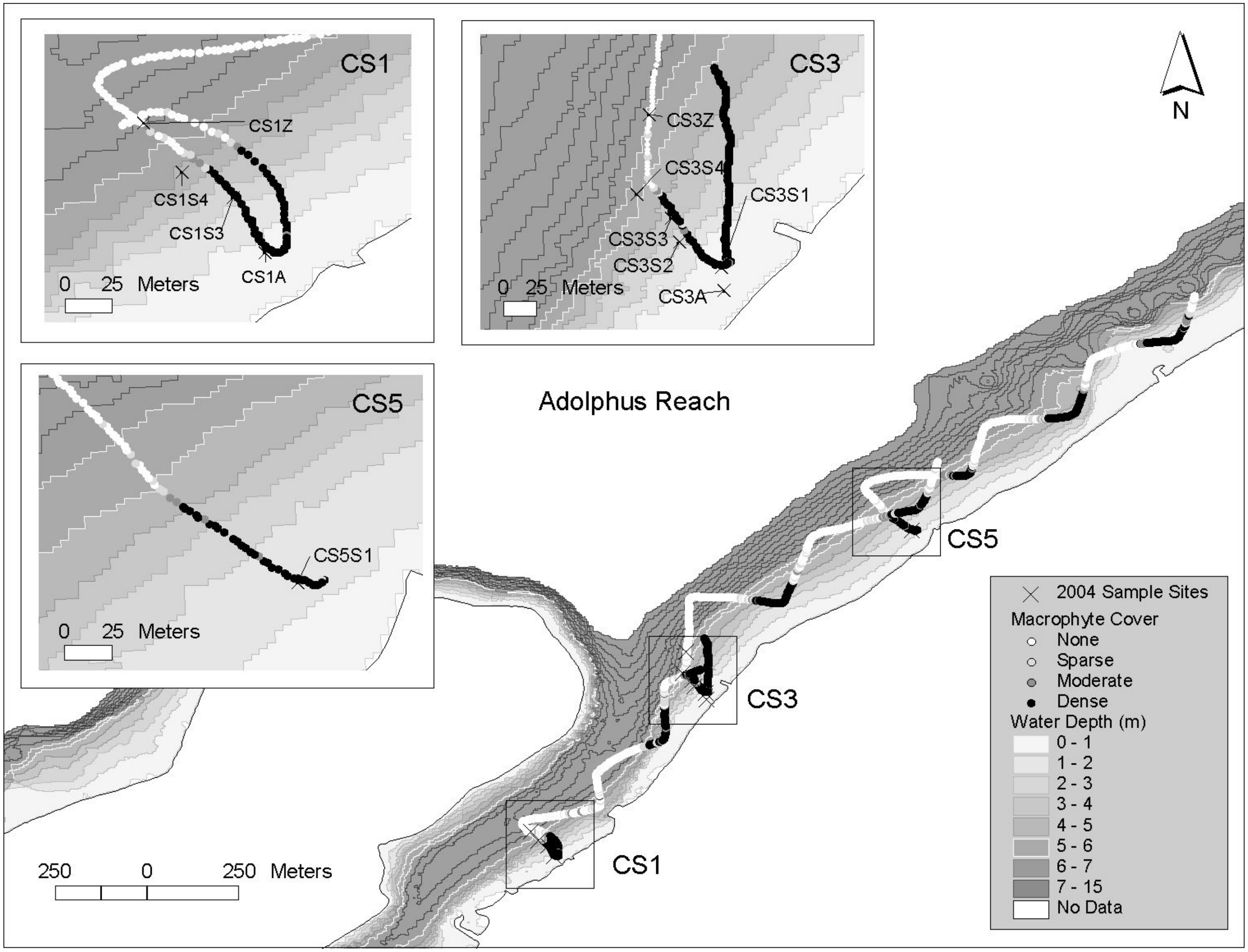


Figure 16. 2004 submerged macrophyte cover for Conway South transects based on analysis of the BioSonics acoustical data. Water depth is to IGLD 85.

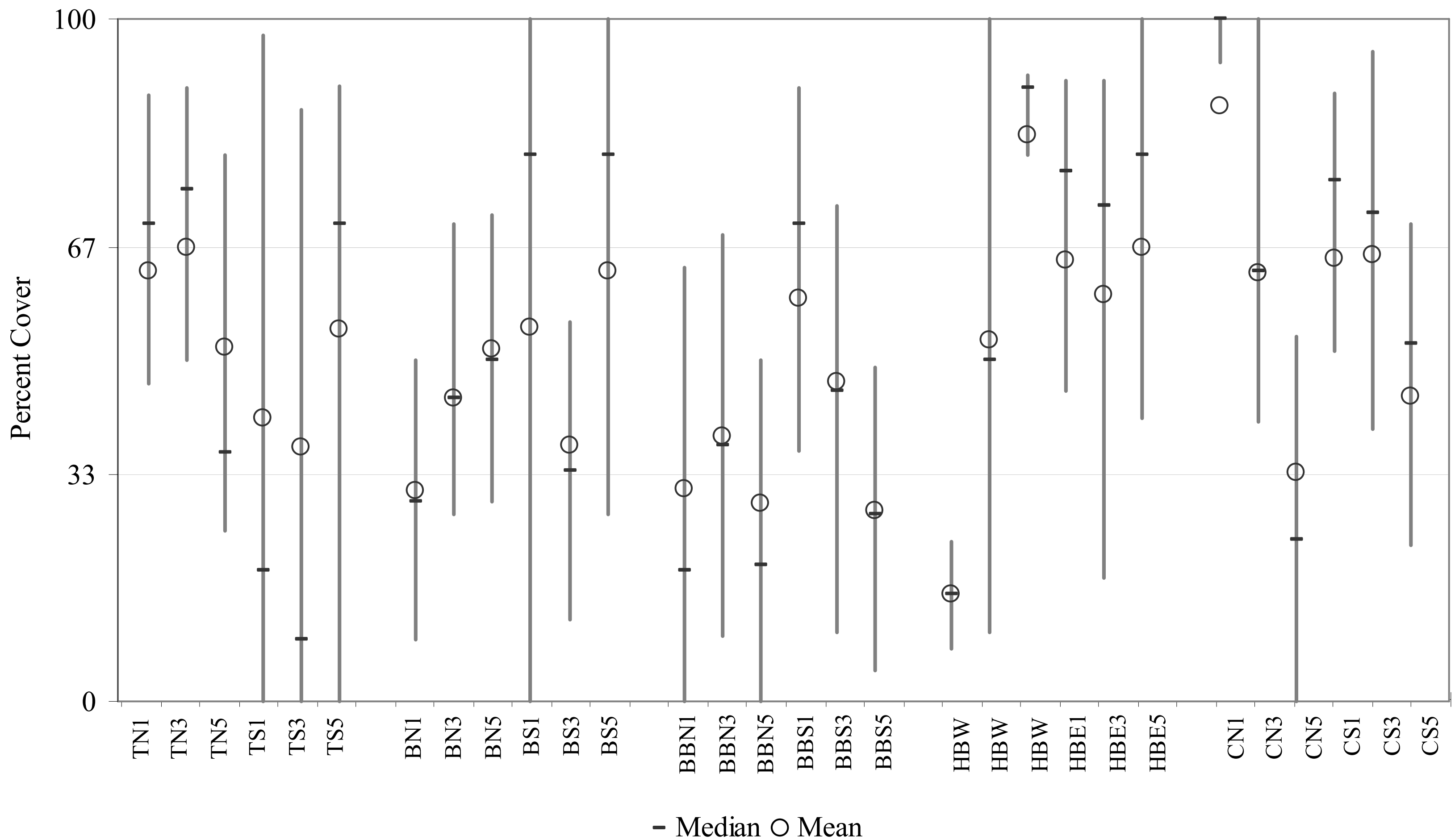


Figure 17. Summary statistics of SAV percent cover for all 2004 transects. Shown are the 1st quartile, median, mean and 3rd quartile values.

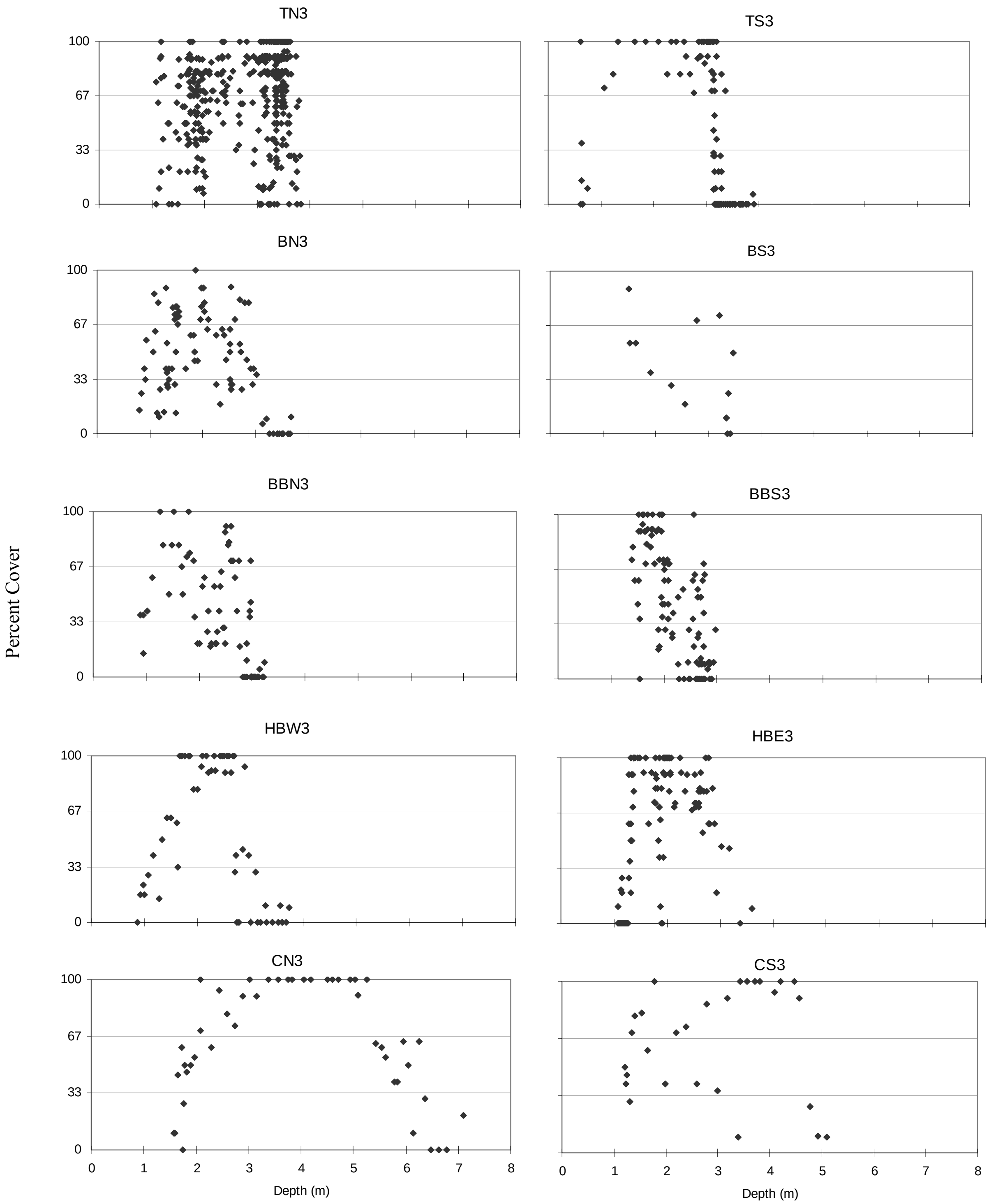


Figure 18. Scatter plots of percent SAV cover and water depth for all transect number 3 in the 2004 survey.

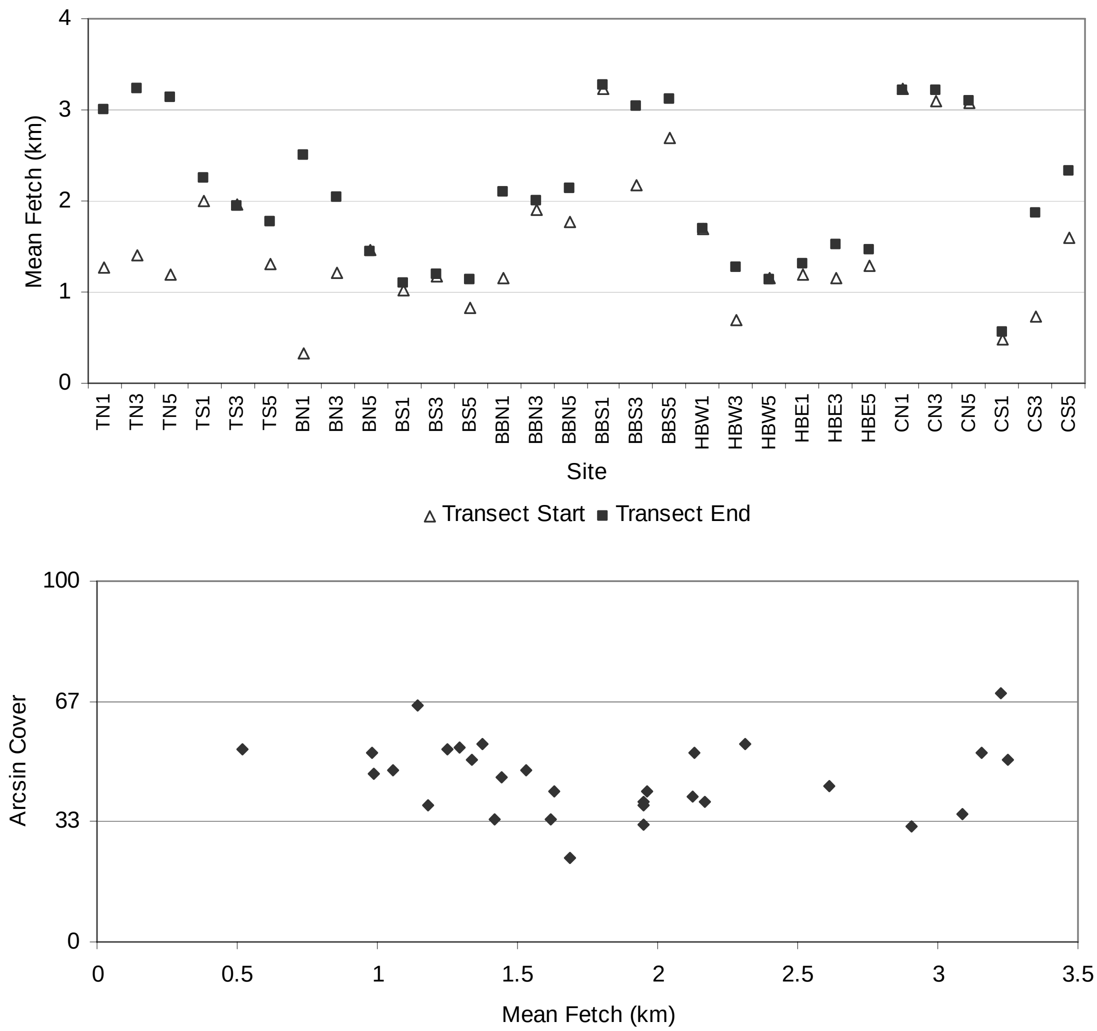


Figure 19. The effect of fetch on percent cover. a) Mean fetch at the start and end of the 2004 transects and b) scatter plot between the mean fetch at a site (average of start and end fetch) and the mean cover from transect start to the last plant.

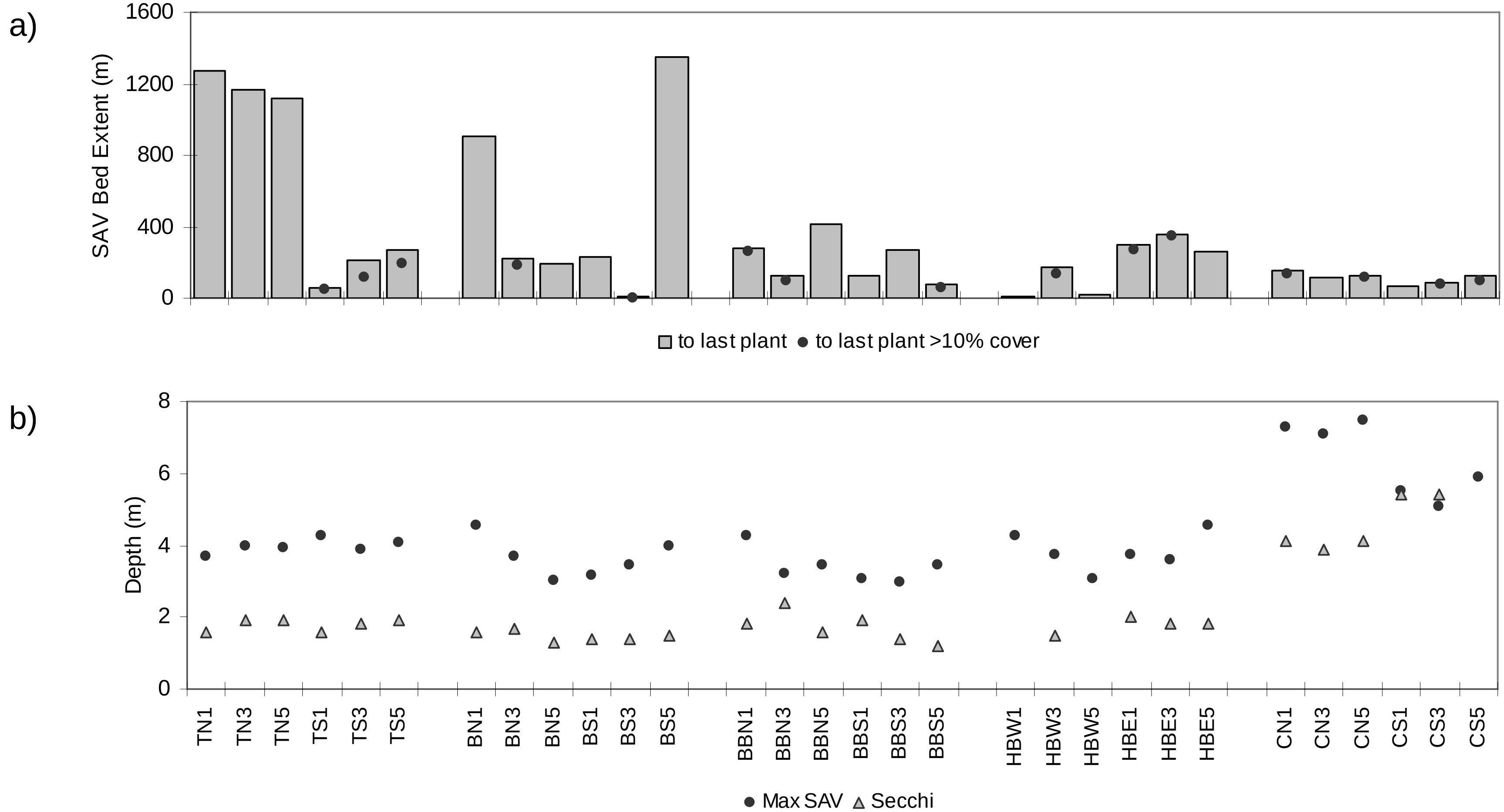


Figure 20. a) SAV bed extent for all the 2004 transects. Extent measured from start of 2000 transects to the last plant as determined by the BioSonics data. Also shown is SAV bed extent to the last plant which had a cover value greater than 10**%.** b) Maximum depth of SAV colonization and Secchi depth.

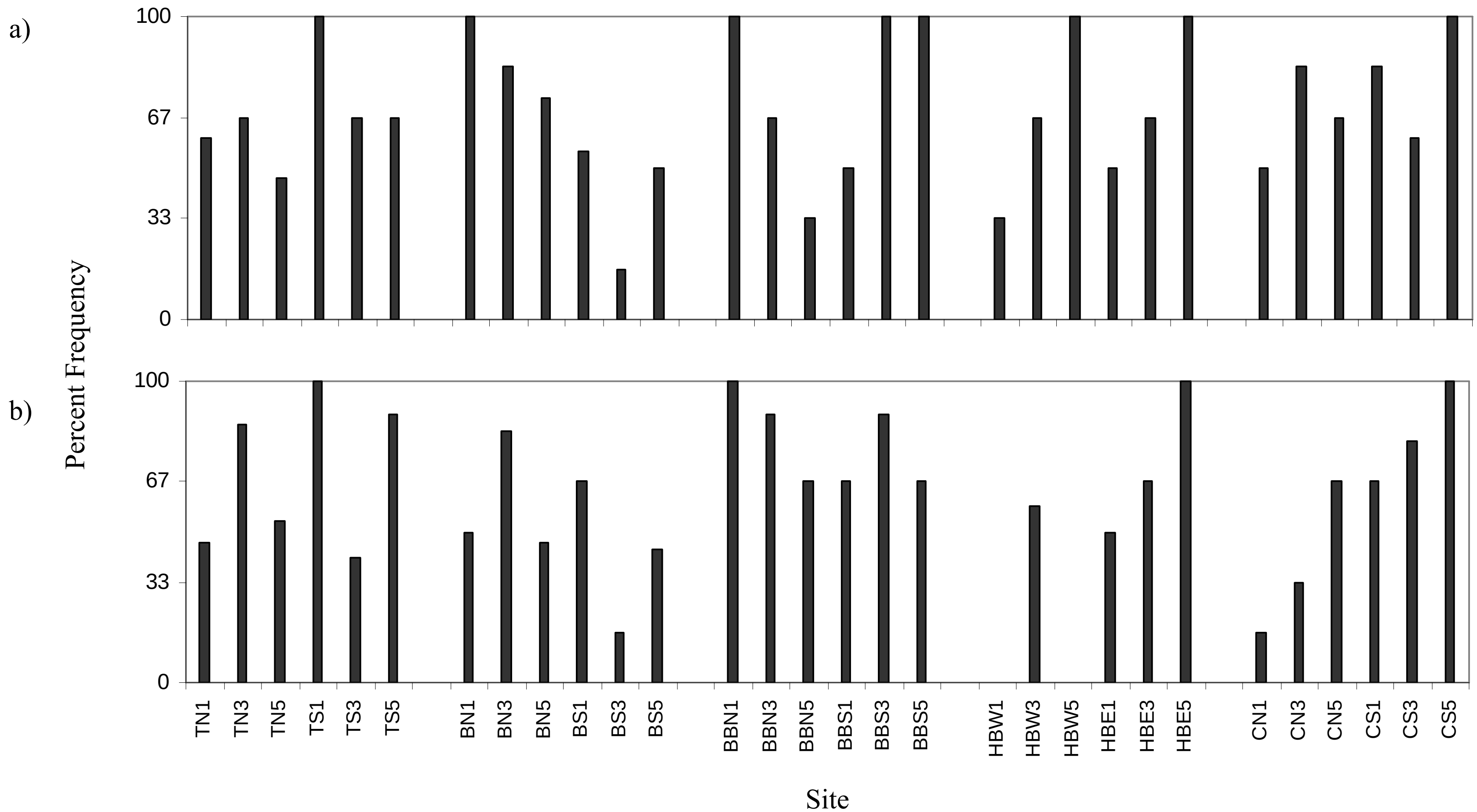


Figure 21. Percent frequency of occurrence of a) *Vallisneria americana* and b) *Heteranthera dubia* on all 2004 transects

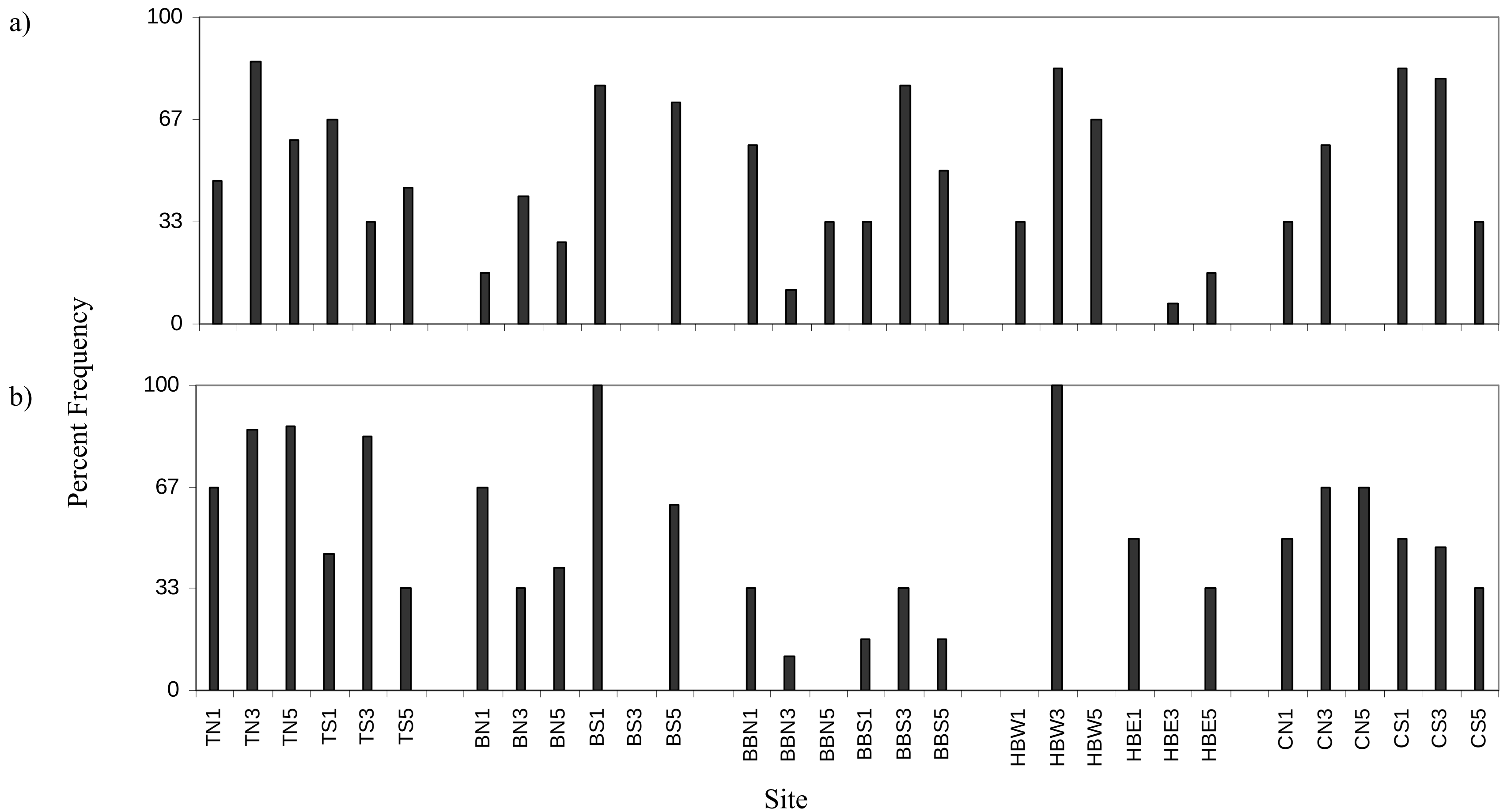


Figure 22. Percent frequency of occurrence for a) *Myriophyllum spp.* and b) *Ceratophyllum demersum* on all 2004 transects.

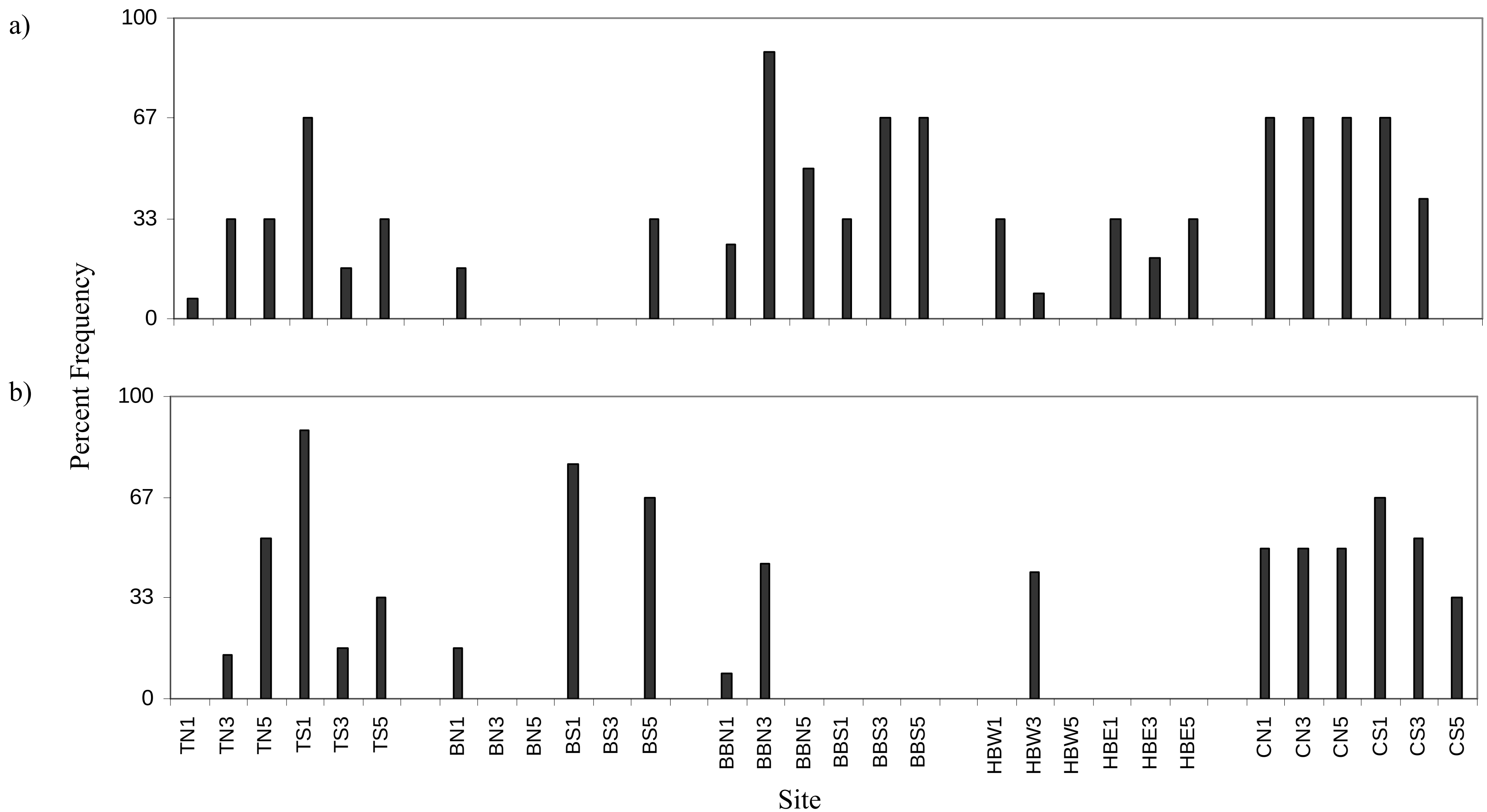
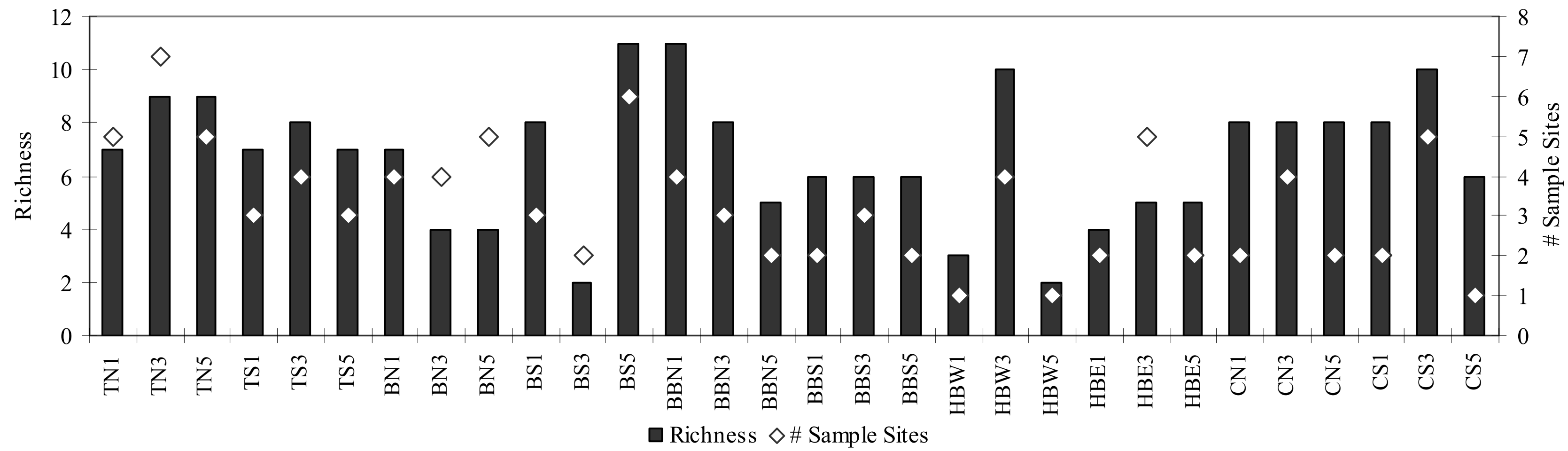


Figure 23. Percent frequency of occurrence for a) *Najas spp*. and b) *Elodea canadensis* for all 2004 transects.

a)



b)

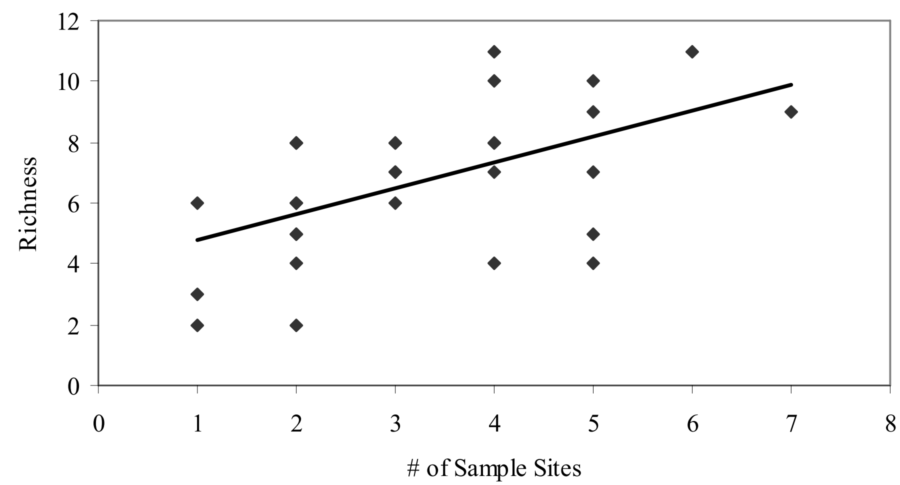


Figure 24. a) Species richness for all 2004 transects surveyed. Also shown are the number of sampling sites per transect since sampling effort varied depending on the length of the transect. b) scatter plot of number of sample sites versus richness.

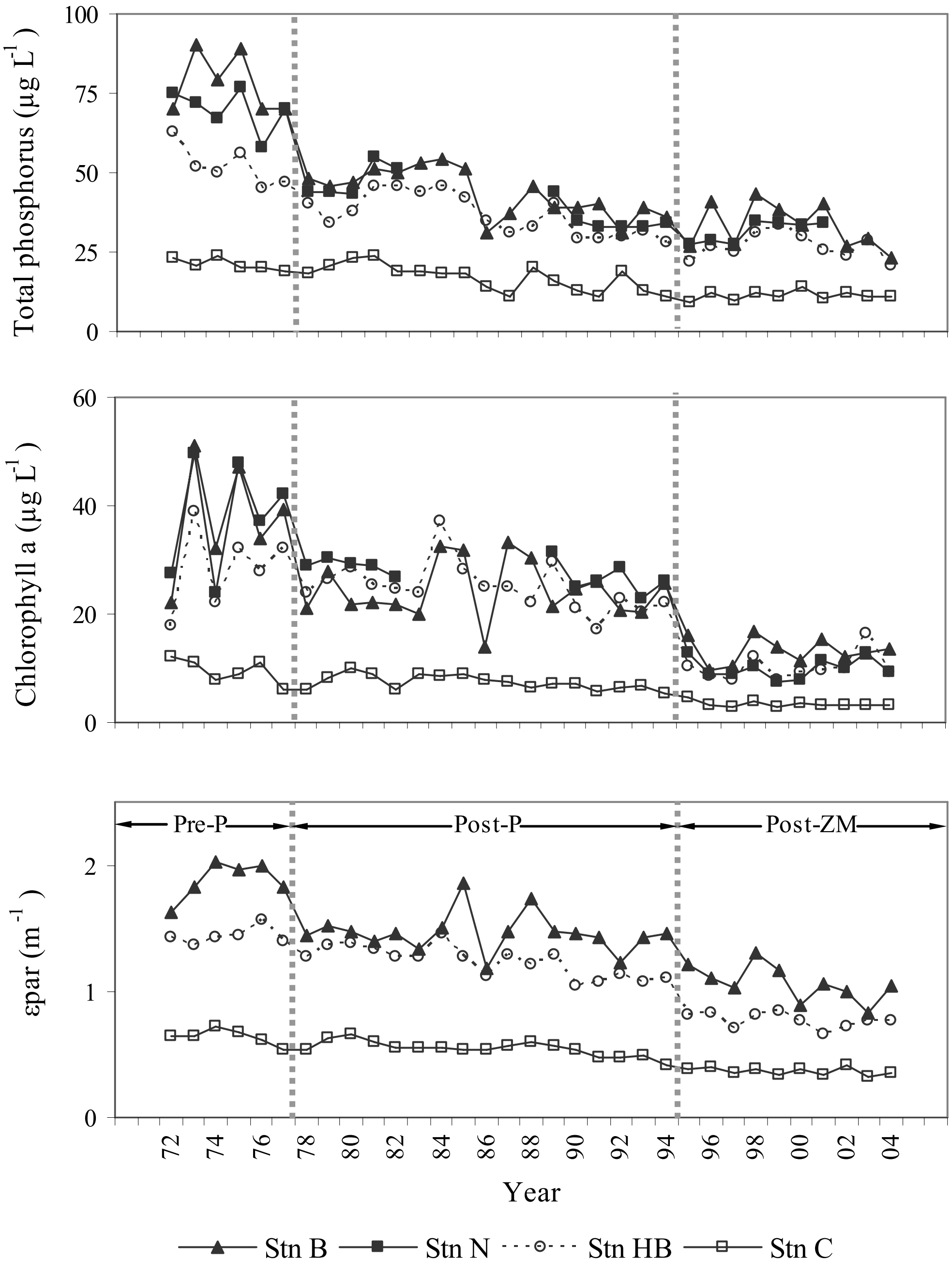


Figure 25. May to October mean concentrations of a) total phosphorus, b) total chlorophyll a, and c) the light extinction coefficient (εpar) at the Project Quinte Belleville, Napanee, Hay Bay and Conway stations from 1972 to 2004. TP data from 1972 to 1999 and Chl a data from 1972 to 1976 obtained from OME . All chlorophyll data are uncorrected for phaeopigments. The 1972 – 1976 OME Chl a data was adjusted by +35% to allow comparison with later values since a change in method resulted in approximately 35% higher recovery.

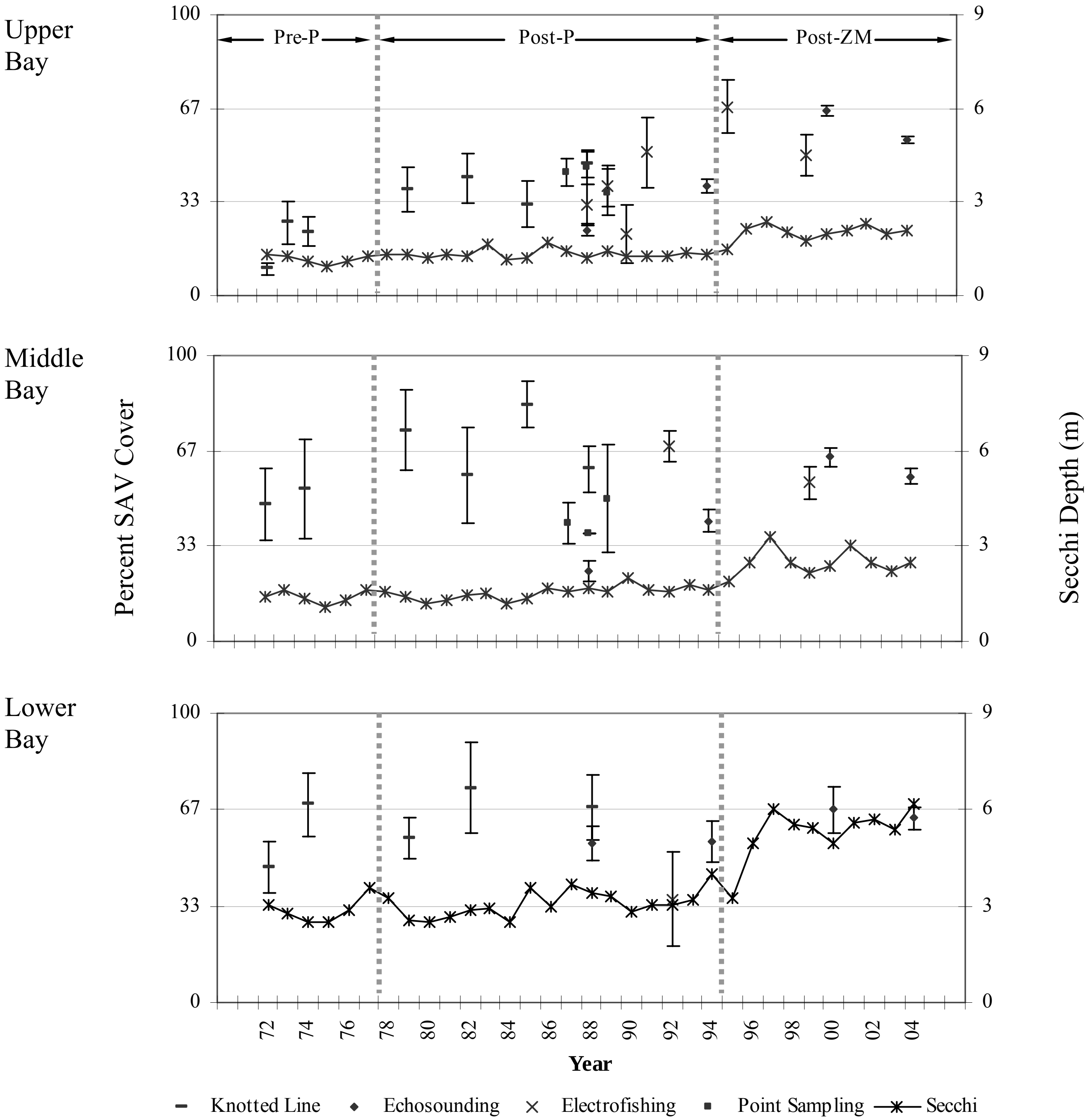


Figure 26. Submerged macrophyte percent cover by bay for the years 1972 to 2004. The knotted line and echosounding protocols were conducted on the same reference transects with knotted line determining SAV presence/absence at every 1 m while echosounding used echogram interpretation. For the knotted line, only TN3, BN3 and BBN3 were surveyed in the upper bay in 1973 and only BS3 in 1974. BBS3 was not surveyed in 1982 or 1985. Mean percent cover was calculated to the last plant on reference transect 3 with these two methods. Electrofishing and point sampling protocols used visual assessment of SAV cover. Secchi depth is the May to September mean taken offshore at Project Quinte stations. Error bars indicate ± 1 SE. .

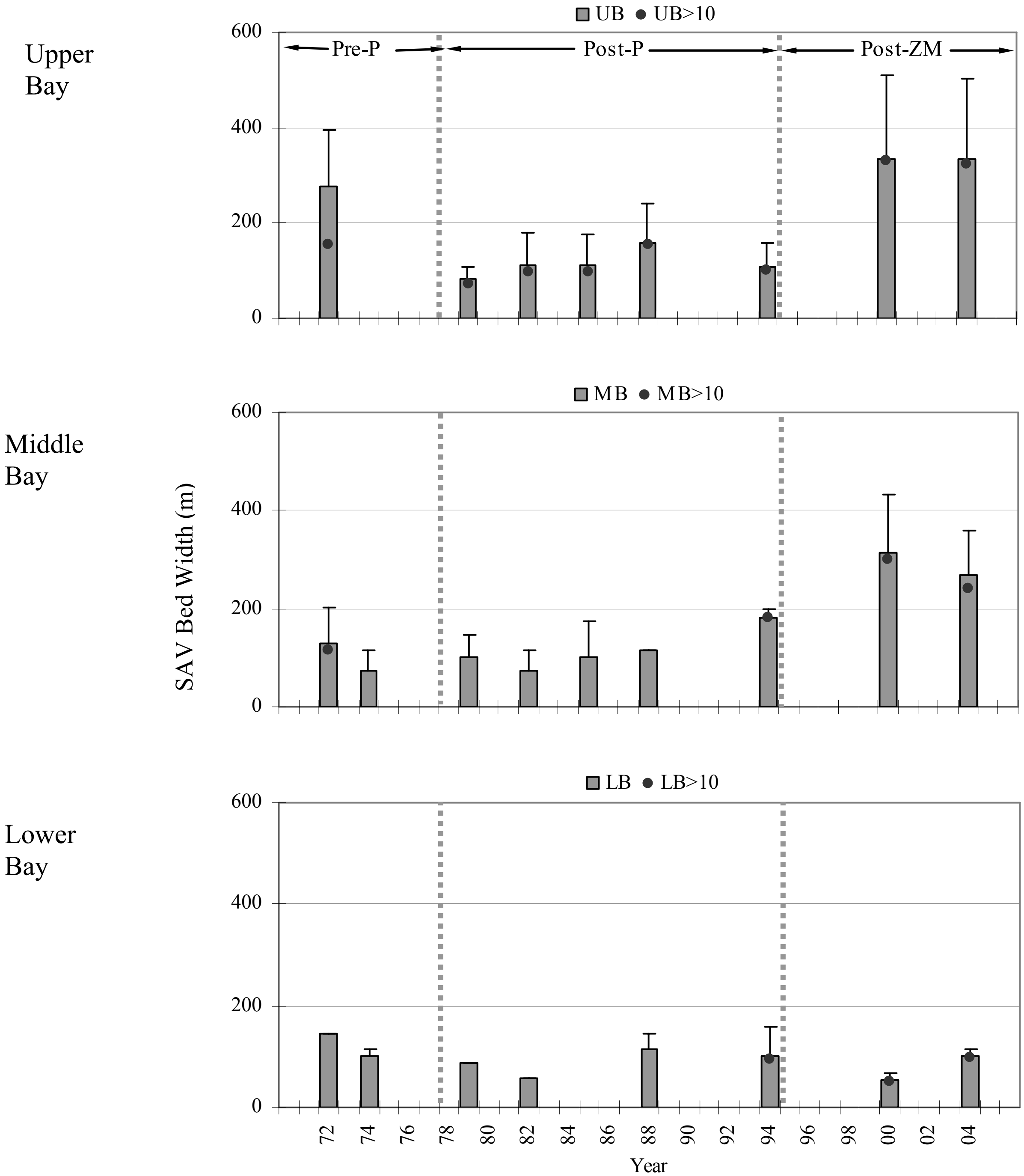


Figure 27. SAV bed extent to the last plant by bay for reference transect #3 for the years 1972 to 2004. Data calculated by the number of 29 m sub-transects for the Crowder dataset (1972 to 1988) and measurement in ArcView from the start of the transect to the last plant as determined by echogram interpretation for 1994 to 2004. Also shown is the transect length to the last plant which has a cover value greater than 10%. Error bars represent a SE.

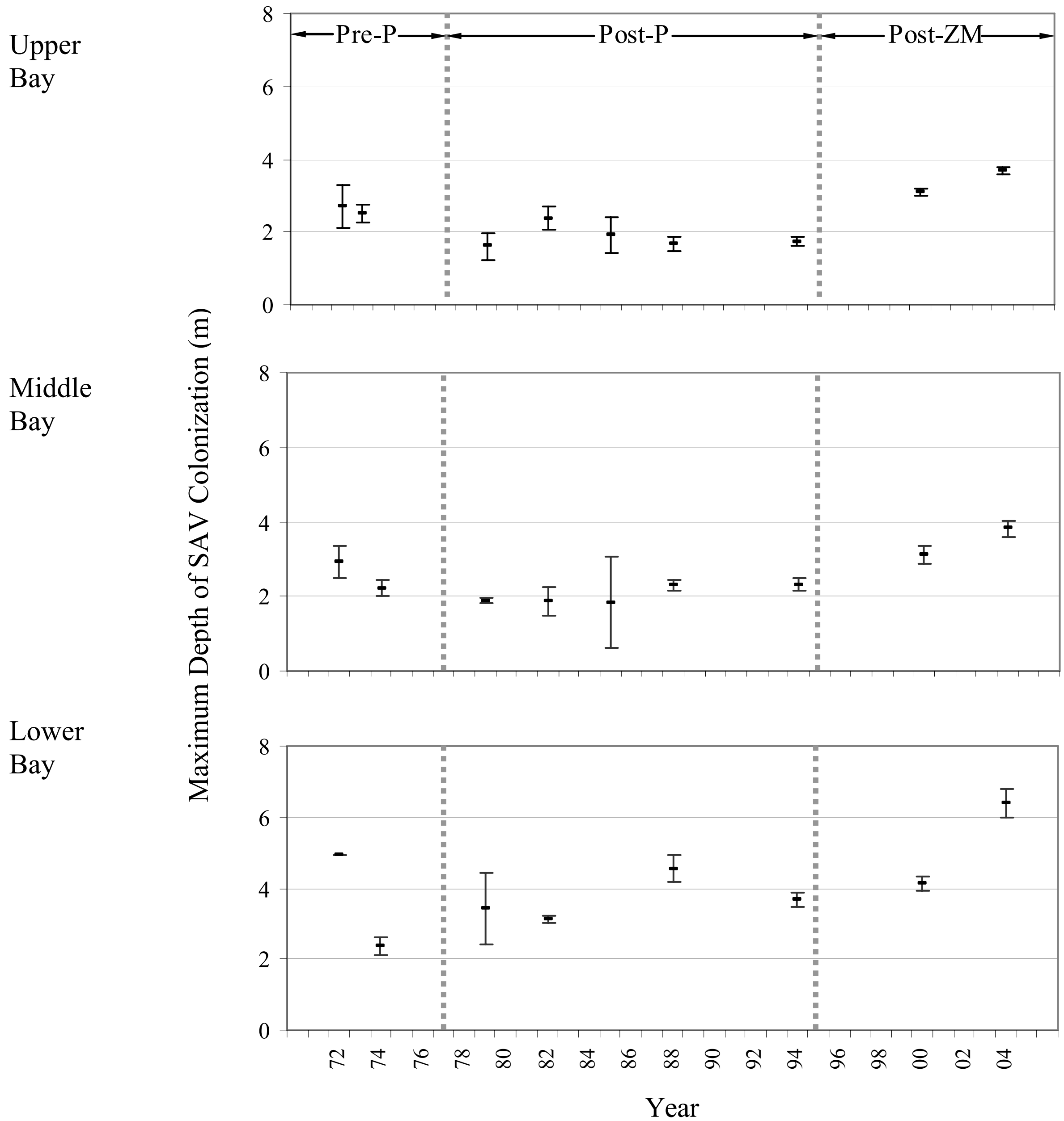


Figure 28. Mean maximum depth of SAV colonization by bay for the years 1972 to 2004. Data obtained from reference transect 3 from the knotted line dataset (1972 to 1988) and echosounding (1994 to 2004). Error bars indicate ± SE.

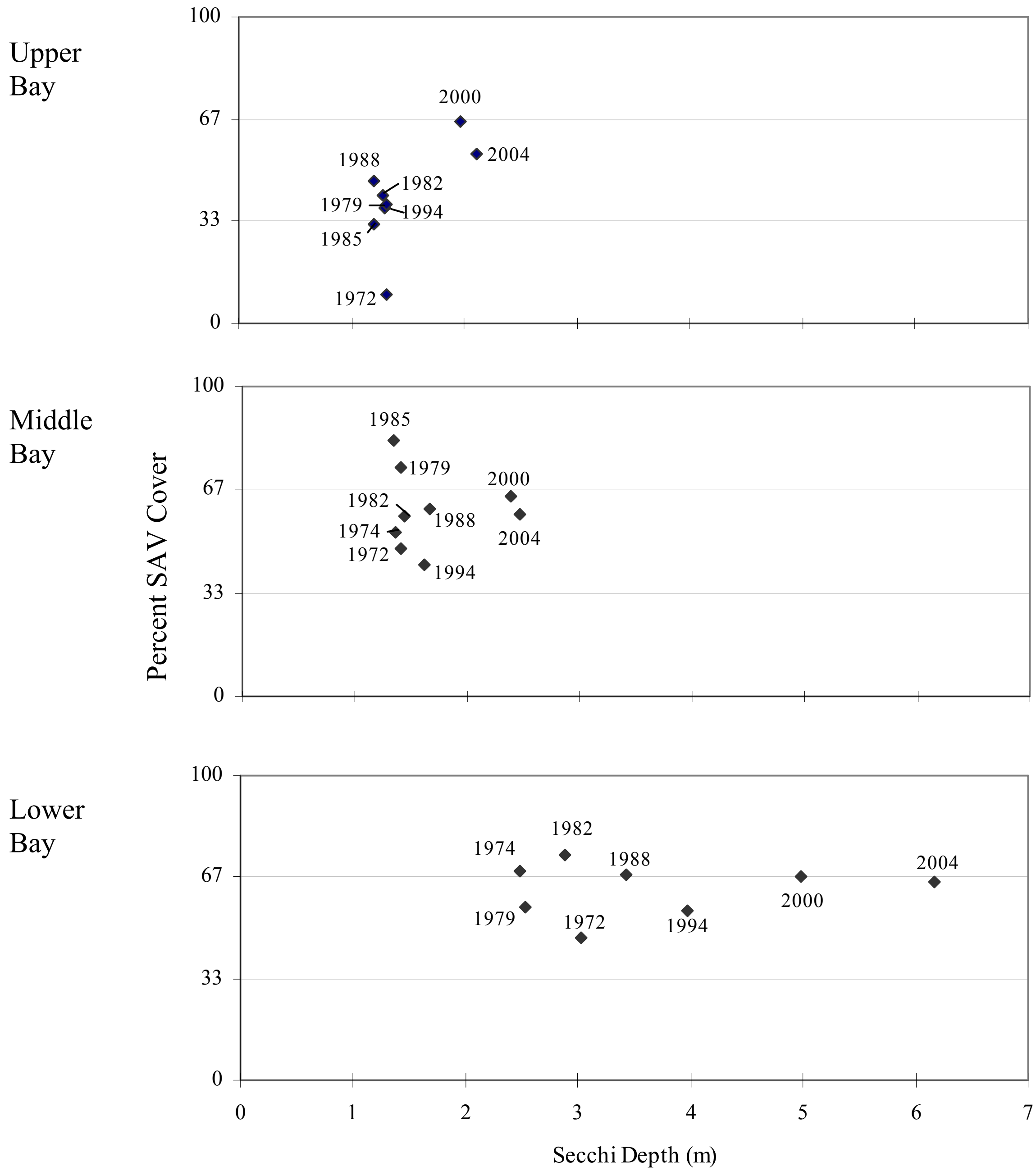


Figure 29. Scatter plots of percent cover and Secchi depth by bay for the years 1972 to 2004. Mean percent cover from the knotted line and echosounding reference transects to the last plant. Secchi depth is the May to September mean taken offshore at Project Quinte stations.

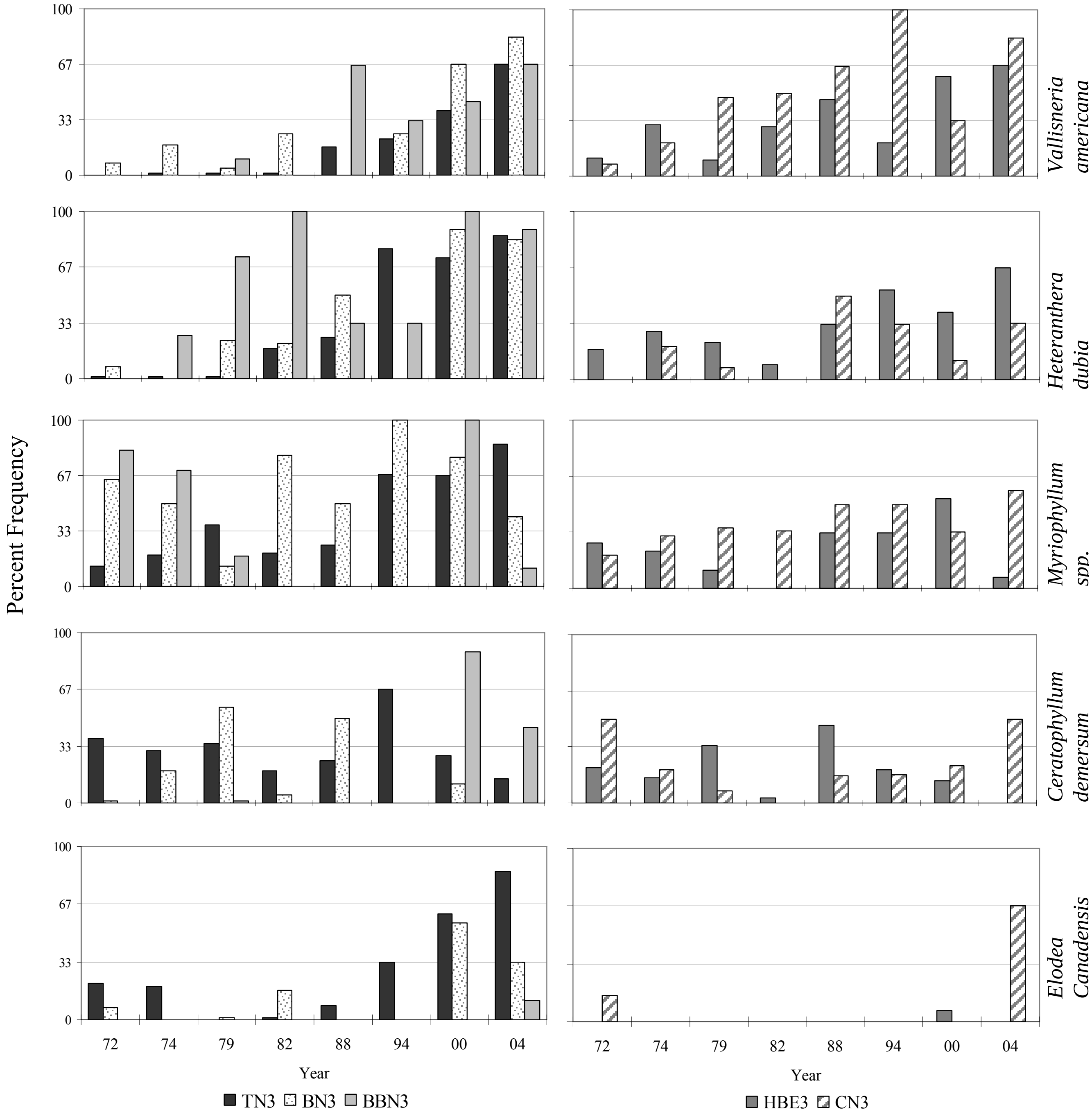


Figure 30. Percent frequency by transect N3 of the 5 most frequent SAV species for the years 1972 to 2004. Data from 1972 to 1982 obtained from (Crowder and Bristow 1986).

Appendix 1. Description of Field Methodologies

This appendix details how percent cover was measured in the field by each of the four different methods: the knotted line, point sampling, echosounding and electrofishing. It also describes any calculations necessary to convert field measurements into values of percent cover. Additionally, it describes how the SAV bed extent and the maximum depth of colonization was determined for the reference transects.

1) Knotted Line Technique (1972 – 1988)

From 1972 to 1988, a total of 9 surveys were conducted by Adele Crowder using a modified form of point transect (Crowder and Bristow 1985), (Crowder and Bristow 1986), (Crowder, Bristow et al. 1988). Starting in water that was approximately 0.5 m deep, a 29 m rope with knots at every 1 meter interval was pegged perpendicular to the shoreline along a set compass bearing. The number of knots along this sub-transect that were touched by macrophytes were counted by divers. The offshore end of the rope remained in a fixed position while the near shore end was swung into deeper water to continue the count. This process was repeated until three consecutive sub-transects had no macrophytes

Percent cover was calculated for each sub-transect as follows (Loftus, Sayer et al. 1992):

$$\% \, Cover = 100\left(\frac{number\ of\ knots\ touched\ by\ plants}{total\ number\ of\ knots}\right)$$

A maximum of 10 transects were sampled with sub-sampling occurring in some years. No other data other than those given in the reports cited above were located from these surveys.

2) Point Sampling (1987 – 1989)

Dushenko examined the near shore distribution of macrophytes in conjunction with selected environmental parameters to detect any relationships (Dushenko 1990). He conducted point sampling at scattered locations throughout the upper and middle bays, selecting areas with either exposed shorelines or protected shores which were buffered by cattail marshes.

Percent cover was determined by visual survey from a boat. In 1987, macrophyte cover was classified into four codes, while in 1988 and 1989; the classification was simplified to a 3 code system that also used half values. These codes were converted to percent cover as follows:

1987 Code Category	% Cover	1988 and 1989 Code Category	% Cover
0 = no vegetation	0	0 = no vegetation	0
		0.5	6.25
1 = scarce (occasional plants)	12.5	1 = scarce	12.5
		1.5	25
2 = moderate (beds in regular patches)	37.5	2 = moderate (regular beds, not reaching water surface)	37.5
		2.5	62.5
3 = dense (extensive beds, well below water surface)	62.5	3 = dense (heavy vegetation, reaching water surface)	87.5
4 = very dense (extensive beds reaching water surface)	87.5		

In 1987, a total of 47 sites were surveyed with a sub-sample of these sites sampled in 1988 and 1989 (27 and 10 sites respectively).

3) Echosounding (1988, 1994 and 2000)

Echosounding, in conjunction with quadrat sampling for macrophyte biomass, was conducted along the same transects as the knotted line method. The principal investigator for the 1988 and 1994 surveys was Jeff Warren (Marshal, Macklin, Monaghan Ltd.) while GLLFAS, DFO conducted the 2000 survey. The echosounding protocol added four new transects that were parallel and at a 100 and 500 m distance on either side of the original knotted line transects (Limnos Ltd. 1989; Marshall, Macklin, Monaghan Ltd. 1995). The 1988 survey used a Raytheon DE-719C Recording Fathometer that had a 1 degree cone angle transducer (Jeff Warren, personal communication) while the 1994 and 2000 surveys used a Lowrance X-16 echosounder with a 20 degree cone angle transducer. Paper traces of each transect were produced for all 3 surveys. The transects ran perpendicular to the shoreline and were continued at least 30 m beyond the end of the macrophyte beds. A minimum length of 50 m was sampled on those transects where macrophyte growth did not occur.

In 1988 and 1994, start and end Loran C coordinates for each transect were recorded using a Raytheon Raynav 550 navigation unit. The 2000 survey used a GPS unit. Coordinates were also recorded for the biomass sampling sites that occurred along the transects. Typically, a minimum of 3 sampling sites were located along each transect and these sites were marked on the echograms. In the 1988 and 1994 surveys, transects that did not record macrophytes on the echosounder were not sampled for biomass (Jeff Warren, personal communication).

Difficulty was encountered when attempting to relocate the 1988 and 1994 transects within a GIS using the Loran C coordinates. The transect start and end coordinates were shifted either into deeper waters on onto land, but this shift was not in a consistent direction for all sampling locations. Therefore, relocating these transects for the 2000 survey involved using maps and site descriptions provided in the 1994 report (Marshall, Macklin, Monaghan Ltd. 1995).

Percent cover values were obtained by interpretation of the 1988, 1994 and 2000 echograms. Interpretation was conducted through visual examination of the echogram and ground truthed via the biomass values obtained at the biomass sample locations. Biomass sample sites were marked directly on the echogram in the field with a vertical line. Transparent sheets which had a series of vertical lines drawn every 3 mm were overlaid on top of each echogram. The percent of the bottom that was occupied by SAV in each of these 3 mm sections was recorded. Difficulty was encountered in sections where the image saturated (usually less than 1.2 m water depth) or where dense canopy growth shadowed the bottom and any biomass sampling sites in these locations were used to assist with the interpretation.

There were a total of 50 transects at 10 different general locations for the echosounding survey. In 1988, a total of 46 echograms were produced; in 1994, 50. In 2000, replicates of some transects were taken resulting in a total of 57 echograms.

4) Electrofishing (1988 to 1999)

Macrophyte surveys were conducted by various Fisheries and Oceans personnel in conjunction with electrofishing. These surveys occurred along 100 m transects located parallel to the shoreline in approximately 1.5 m depth of water (Crowder 1988), (Minns, Cairns et al.

1993). Percent cover was estimated visually, either at 10 m intervals (1991, 1995) with a single mean value calculated, or a single visual estimate made after observing the entire transect (1988, 1989, 1990, 1999) (Mike Stoneman, DFO Calgary, personal communication). Data from the 1992 survey was obtained by echogram interpretation of macrophyte presence/absence by Fisheries and Oceans personnel (Mike Stoneman, Brent Valere, CCIW Burlington, personal communications).

In 1999, a four category code was employed in the field to describe macrophyte abundance. The codes were converted to percent cover values as follows:

Classification Code	Percent Cover
0 = None	0
1 = Sparse	17
2 = Moderate	50
3 = Dense	83

There were a total of 33 upper bay, 18 middle bay and 6 lower bay electrofishing transects that surveyed macrophytes. Most upper bay sites were surveyed in 1988 and 1989 with sub-sampling of these transects occurring in the 1990's. The only year that the middle bay sites were surveyed was in 1992.

Determination Of SAV Bed Extent For Reference Transects

As detailed above, the knotted line technique used a series of sub-transects that were 29 m in length. The only surviving records from these surveys is the number of knots per sub-transect where SAV was present. SAV bed extent was calculated by multiplying the number of sub-transects that recorded SAV by 29. This technique assumes that the last plant occurred on the last knot of the transect.

In the 1994 echosounding survey, Loran C coordinates were recorded for the start and end of the transect, but when plotted in ArcView, these points were not located correctly, sometimes further on land and other times, too far offshore. The Loran C coordinates were converted into latitude and longitude and the great circle distance between the start and end points was calculated. The transect length to the last plant was determined by measuring the echogram to the last plant and scaling it to the length of the transect. This method assumes that the boat speed was constant along the transect. In the 2000 survey, latitudes and longitudes for the start and end of the transect were plotted and the length of the transect measured in ArcView.

The echogram length to the last plant was determined and the distance calculated with a scaling factor as in 1994. In 2004, the coordinates for the last plant on the transect were recorded by the BioSonics equipment. The transect length was measured in ArcView from the start points of the 2000 survey since lower water levels moved the 2004 start points further offshore, to the last plant as determined by the BioPlant software.

Determination of the Maximum Depth of Colonization for the Reference Transects

Water depths in the knotted line methodology were measured at the beginning and end of each of 29 m sub-transects and the only surviving data is the mean of these two values. Therefore, the maximum depth of colonization from 1972 to 1988 are the mean water depths determined for the last transect that recorded a plant. This method thus assumes that the last plant occurred at the middle of the transect and that the slope of the bottom from the start to the end of the transect was constant.

For the 1994 and 2000 echosounding surveys, the maximum depth of colonization was determined by interpreting the location of the bottom on the echogram where the last plant occurred. In the 2004 survey, the BioPlant software provided the water depth at the last plant on the transect.

Appendix 2. Field Observations for the Trenton North transects. Refer to the PDF version of this document for data on the remaining transects.

Date (2004)	Lake Condition	Site	Depth (m)	Secchi (m)	Bottom Visible?	% Cover	Avg SAV Height	Alisma	C. demersum	Chara sp.	E. canadensis	H. dubia	Myriophyllum sp.	Najas sp.	Thread pot.	Ribbon pot.	Broad pot.	V. americana	Epiphyte Coat	Algae coating	Calcareous coat	Notes
Aug 18	W	TN1S1	0.9	B	Y	30	S						40					60		VH		S1 - S2: sparse to mod, very patchy. VA dom., M subdom. just below surface, heavy algae
		TN1S2	1.1	B	N	NV	S													H		S2 - S3: bottom nv, heavy algae, sparse w/ dense patches, VA & M dominant just below surface
		TN1S3	1.8	1.3	N	NV	U													H		S3 - S4: start with sparse and mod patches VA & M, end dense beds of HD in upper water column
		TN1S4	2.7	O	N	100	U					90	10							H		S4 - S5: start dense beds HD just under surface, mod patches P, M, HD in upper water column
		TN1S5	3.4	1.5	N	NV	NV															S5-END: mid-upper wc, except 1 patch of HD just below surface, most of time no SAV visible
		TN1Z	4.0	2.0	N	NV	NV															
		TN1B	3.8	1.7	N	NV	NV															
Aug 17	L	TN3A	0.8	B	Y	20	M					100										
		TN3S1	1.3	B	Y	100	M											100		H		
		TN3S2	1.9	B	N	NV	NV															
		TN3S3	2.3	1.6	N	100	U					100										
		TN3S4	2.5	1.6	N	40	M					100										S4 - S5: dense beds CD in upper wc
		TN3S5	3.5	o	N	100	S		90			10										
		TN3S6	3.6	2.2	N	NV	NV													H		
		TN3Z	4.0	2.3	N	NV	NV															
Aug 18	W	TN5S1	1.4	B	N	NV	NV													H		Start not accessible due to shallow water, heavy surface algae
		TN5S2	2.2	1.7	N	40	U					80						20				S2 - S3: heavy algae, HD dom., M subdom in upper wc
		TN5S3	3.0	2.0	N	NV	NV															S3 - S4: moderate, M dom in upper wc
		TN5S4	3.6	2.0	N	NV	NV															S4 - S5: heavy algae, M dom. at beginning, HD dom at end, mid wc
		TN5S5	3.7	O	N	NV	NV															
		TN5Z	3.9	1.8	N	NV	NV															

Appendix 3. Coordinates and Site Codes for the 2004 Rake Sampling Points

Site Code	Site	Latitude	Longitude
Transect: Trenton North 1 (TN1)			
TN1S1	1	44.10181	77.55683
TN1S2	2	44.10136	77.55649
TN1S3	3	44.10087	77.55572
TN1S4	4	44.09804	77.55281
TN1S5	5	44.09692	77.551
TN1SZ	end	44.09308	77.54697
Transect: Trenton North 3 (TN3)			
TN3A	start	44.10246	77.55033
TN3S1	1	44.1023	77.55026
TN3S2	2	44.10193	77.54991
TN3S3	3	44.10017	77.54903
TN3S4	4	44.09988	77.54775
TN3S5	5	44.09894	77.54646
TN3S6	6	44.09817	77.54555
TN3Z	end	44.0952	77.53989
Transect: Trenton North 5 (TN5)			
TN5S1	1	44.10386	77.544114
TN5S2	2	44.10297	77.5433
TN5S3	3	44.10057	77.5408
TN5S4	4	44.10007	77.54022
TN5S5	5	44.09907	77.53849
TN5SZ	end	44.09673	77.5306
Transect: Trenton South 1 (TS1)			
TS1A	start	44.07952	77.53697
TS1S1	1	44.07959	77.53701
TS1S2	2	44.07975	77.5371
TS1Z	end	44.07994	77.53715
Transect: Trenton South 3 (TS3)			
TS3A	start	44.07992	77.53123
TS3S1	1	44.07991	77.53126
TS3S2	2	44.07999	77.53131
TS3S3	3	44.08018	77.53127
TS3Z	end	44.08066	77.53131
Transect: Trenton South 5 (TS5)			
TS5A	start	44.08205	77.52532
TS5S1	1	44.08253	77.52589
TS5S2	2	44.0828	77.52618
TS5Z	end	44.08351	77.52678

Site Code	Site	Latitude	Longitude
Transect: Belleville North 1 (BN1)			
BN1A	start	44.15685	77.38002
BN1S1	1	44.15551	77.37973
BN1S3	2	44.15309	77.37918
BN1S4	3	44.15143	77.37938
BN1S5	4	44.15092	77.37907
BN1Z	end	44.14936	77.37871
Transect: Belleville North 3 (BN3)			
BN3A	start	44.15605	77.37187
BN3S1	1	44.15588	77.37157
BN3S2	2	44.15537	77.37133
BN3S3	3	44.1546	77.37094
BN3Z	end	44.1539	77.37058
Transect: Belleville North 5 (BN5)			
BN5A	start	44.15845	77.36754
BN5S1	1	44.15818	77.36736
BN5S2	2	44.15785	77.36711
BN5S3	3	44.15751	77.36695
BN5S4	4	44.15692	77.36661
BN5Z	end	44.15649	77.36631
Transect: Belleville South 1 (BS1)			
BS1A	start	44.14148	77.37937
BS1S1	1	44.14174	77.37935
BS1S3	3	44.14228	77.37932
BS1Z	end	44.14333	77.37874
Transect: Belleville South 3 (BS3)			
BS3A	start	44.1427	77.3734
BS3Z	end	44.14291	77.3733
Transect: Belleville South 5 (BS5)			
BS5A	start	44.13401	77.36672
BS5S1	1	44.13445	77.3671
BS5S2	2	44.1351	77.36749
BS5S3	3	44.13535	77.36759
BS5S4	4	44.13602	77.36772
BS5S5	5	44.13708	77.36789
BS5Z	end	44.14479	77.36951

Appendix 3 (continued). Coordinates and Site Codes for the 2004 Rake Sampling Points

Site Code	Site	Latitude	Longitude
Transect: Big Bay North 1 (BBN1)			
BBN1A	start	44.17617	77.24377
BBN1S2	2	44.17591	77.24334
BBN1S3	3	44.17581	77.24308
BBN1S4	4	44.17529	77.24242
BBN1Z	end	44.17435	77.24058
Transect: Big Bay North 3 (BBN3)			
BBN3A	start	44.17757	77.23776
BBN3S2	2	44.17724	77.23741
BBN3S3	3	44.17708	77.23708
BBN3Z	end	44.17542	77.23722
Transect: Big Bay North 5 (BBN5)			
BBN5A	start	44.17913	77.23078
BBN5S3	3	44.17772	77.22871
BBN5Z	end	44.17529	77.22926
Transect: Big Bay South 1 (BBS1)			
BBS1S1	1	44.13187	77.24832
BBS1S3	3	44.13271	77.24886
BBS1Z	end	44.13311	77.24914
Transect: Big Bay South 3 (BBS3)			
BBS3A	start	44.13237	77.24489
BBS3S2	2	44.13273	77.24503
BBS3S3	3		0
BBS3Z	end	44.13476	77.24608
Transect: Big Bay South 5 (BBS5)			
BBS5A	start	44.13483	77.23777
BBS5S1	1	44.13509	77.23783
BBS5S2	2	44.13545	77.23791
BBS5Z	end	44.13586	77.23779

Site Code	Site	Latitude	Longitude
Transect: Hay Bay West 1 (HBW1)			
HBW1S1	1	44.09505	77.08025
Transect: Hay Bay West 3 (HBW3)			
HBW3A	start	44.10092	77.08181
HBW3S2	2	44.10086	77.08145
HBW3S3	3	44.10084	77.08118
HBW3S4	4	44.10072	77.08067
HBW3Z	end	44.10056	77.07981
Transect: Hay Bay West 5 (HBW5)			
HBW5S1	1	44.1049	77.07778
Transect: Hay Bay East 1 (HBE1)			
HBE1S1	1	44.08826	77.06263
HBE1S5	5	44.08878	77.06534
HBE1Z	end	44.08909	77.06644
Transect: Hay Bay East 3 (HBE3)			
HBE3A	start	44.09096	77.05828
HBE3S1	1	44.09108	77.0583
HBE3S2	2	44.09111	77.05849
HBE3S3	3	44.09122	77.0596
HBE3S5	5	44.09142	77.06041
HBE3Z	end	44.09216	77.06314
Transect: Hay Bay East 5 (HBE5)			
HBE5S1	1	44.09388	77.05338
HBE5S3	3	44.09453	77.05612
HBE5Z	end	44.09449	77.05654

Appendix 3 (continued). Coordinates and Site Codes for the 2004 Rake Sampling Points

Site Code	Site	Latitude	Longitude
Transect: Conway North 1 (CN1)			
CN1A	start	44.11632	76.89623
CN1S3	3	44.11609	76.8951
CN1Z	end	44.11601	76.89458
Transect: Conway North 3 (CN3)			
CN3A	start	44.11864	76.89061
CN3S1	1	44.11857	76.89034
CN3S2	2	44.11849	76.89002
CN3S3	3	44.11841	76.88968
CN3S4	4	44.1183	76.88956
CN3S5	5	44.11831	76.8892
CN3Z	end	44.11815	76.88926
Transect: Conway North 5 (CN5)			
CN5A	start	44.12079	76.88685
CN5S3	3	44.12049	76.88564
CN5Z	end	44.12036	76.88534

Site Code	Site	Latitude	Longitude
Transect: Conway South 1 (CS1)			
CS1A	start	44.09391	76.87724
CS1S3	3	44.09417	76.87739
CS1S4	4	44.09429	76.87763
CS1Z	end	44.09452	76.87781
Transect: Conway South 3 (CS3)			
CS3A	start	44.09775	76.87351
CS3S1	1	44.0979	76.87353
CS3S2	2	44.09807	76.87381
CS3S3	3	44.09823	76.87386
CS3S4	4	44.09839	76.87409
CS3Z	end	44.09892	76.87401
Transect: Conway South 5 (CS5)			
CS5S1	1	44.10187	76.8685

Site codes and locations are the same that were used for the biomass sampling sites from the 2000 macrophyte survey. Due to shallow water at the start of the transect, or time restrictions, some sampling sites were not revisited in 2004 and therefore were left out of this Appendix.

Appendix 4. Rake toss results for the Trenton North 1 transect. Refer to the PDF version of this document for data on the other transects.

	Start			**TN1S1**			**TN1S2**			**TN1S3**			**TN1S4**			**TN1S5**			**TN1Z**		
	R1	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**	**R1**	**R2**	**R3**
Veg Abundance	-	-	-	S	S	S-M	S	M	M	M	M	S	D	M-D	D	D	D	D	N	N	N
A. gramineum																					
B. beckii																					
C. demersum							30			5	5	60	3	4	30	95	100	30			
Chara sp.																					
E. canadensis																					
H. dubia						5	40					40	90	90	40	4					
L. trisulca																	T				
Myriophyllum sp.					40	25					20		**7**	**1**	T			T			
Najas sp.															10						
P. crispus																					
P. friesii																					
P. pectinatus																					
P. perfoliatus																					
P. pusillius																					
P. richardsonii																		T			
P. zosteriformis																					
R. longirostris																					
U. vulgaris																					
V. americana						70	30	100	100	95	75			5	20	1					
Algae				100	60													70			
Algae coating				H	H	H	H	H	H	H	H	H	H	H	H	H	S	H			
Calcareous coat																					
Zebra Mussels																S					

Appendix 5. Comparison between BioSonics and Lowrance Data

All transects were surveyed in 2004 with a BioSonics DT4000 system using a 430 KHz single 6.8 degree beam (serial number DT494012) transducer. The newer technology BioSonics has not been previously used in the Bay of Quinte, but possesses advantages over the old systems in terms of data acquisition and analysis. The BioSonics records digital data at a rate of 5 pings per second and inserts a GPS coordinate into the data stream every 8 to 10 pings (a cycle). EcoSav software contains algorithms that determine bottom depth, macrophyte cover and height over each cycle. This data is geo-referenced and can be exported into a GIS for mapping.

BioSonics data was acquired with Visual Acquisition software version 4.0.2. BioSonics instrument settings in the 2004 macrophyte survey include: pulse length = 0.1 ms, threshold = -130 dB squared, pulse rate = 5 pps monotone, start range = 0 m and stop range varied depending on water depth. The equipment was tested for instrument drift every day of the survey using a 120 kHz calibration sphere.

A Lowrance X-16 with a 20 degree cone angle transducer was used in the 1994 and 2000 survey and on a subset of transects in 2004. It produces a paper trace that must be manually interpreted to extract SAV cover. It does not produce any form of digital data or any type of geo-referencing. Geo-referencing was accomplished with the Lowrance X-16 by marking the paper trace when passing a sample site, but this only occurred between 3 and 6 times along an entire transect. Settings for the Lowrance unit included: sensitivity = minimum, grayline = 4, print intensity = 1, suppression = 0, paper speed = 5. The discrimination and surface clutter settings varied depending on site conditions and pulse width varied from 30 µs for dense SAV and 110 µs for sparse SAV.

In 2004, both the BioSonics and the Lowrance X-16 were run concurrently on one transect per location, with the exception of Hay Bay West, for a total of 9 transects. The BioSonics was pole-mounted near the middle of a 5 m McKee boat on the port side while the Lowrance transducer was mounted on the transom near the starboard side, approximately 2.5 m away from the BioSonics transducer. The transducer face of the BioSonics was positioned between 0.25 and 0.35 m in the water, depending on conditions while the Lowrance transducer was approximately 0.15 m under the water.

The data BioSonics data was analyzed using BioPlant software version 1.0 while the Lowrance paper echograms were manually interpreted (

Appendix 1). Both methods used data from field observations along the transect (Appendix 2) and at the rake sampling sites (Appendix 4) for ground truthing. The start and end points of the echograms were used to ensure the same portion of transect was analyzed regardless of equipment used. If a segment of the Lowrance echogram image was saturated (usually occurring in shallow water), this portion of the transect was disregarded and the start point for both echosounders was moved to the closest rake sampling site.

As seen in Figure A 3.1, the means between the 2 echosounders are within 12 percent with the BioSonics slightly higher in the majority of cases. Median values are further apart and again the BioSonics are higher in the majority of cases. The Lowrance data usually had the largest interquartile range which in some cases was substantially larger.

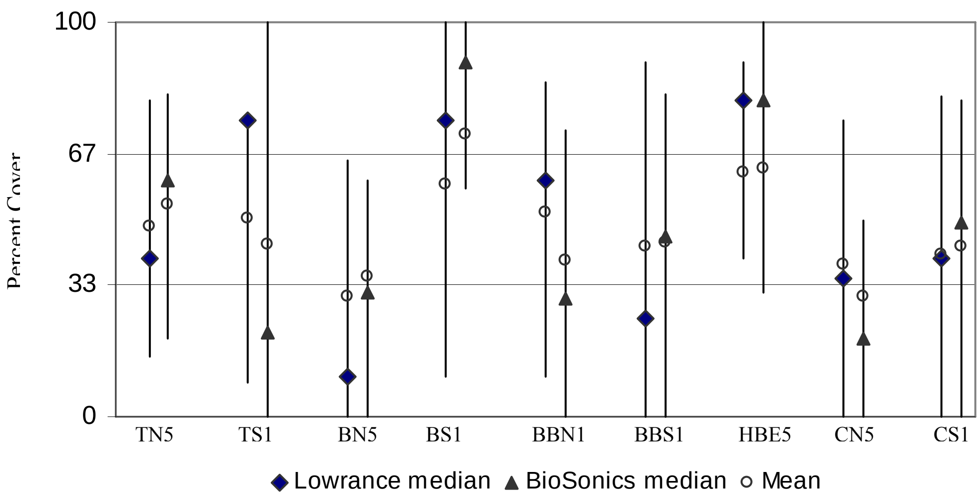


Figure A 3.1. Percent cover 1st quartile, median, mean and 3rd quartile values for each of the concurrent transects summarizing both the Lowrance and BioSonics data. Transect codes are listed on the x axis.

A regression was performed using the Lowrance and BioSonics mean percent cover, Figure A3.2 to determine an appropriate correction factor.

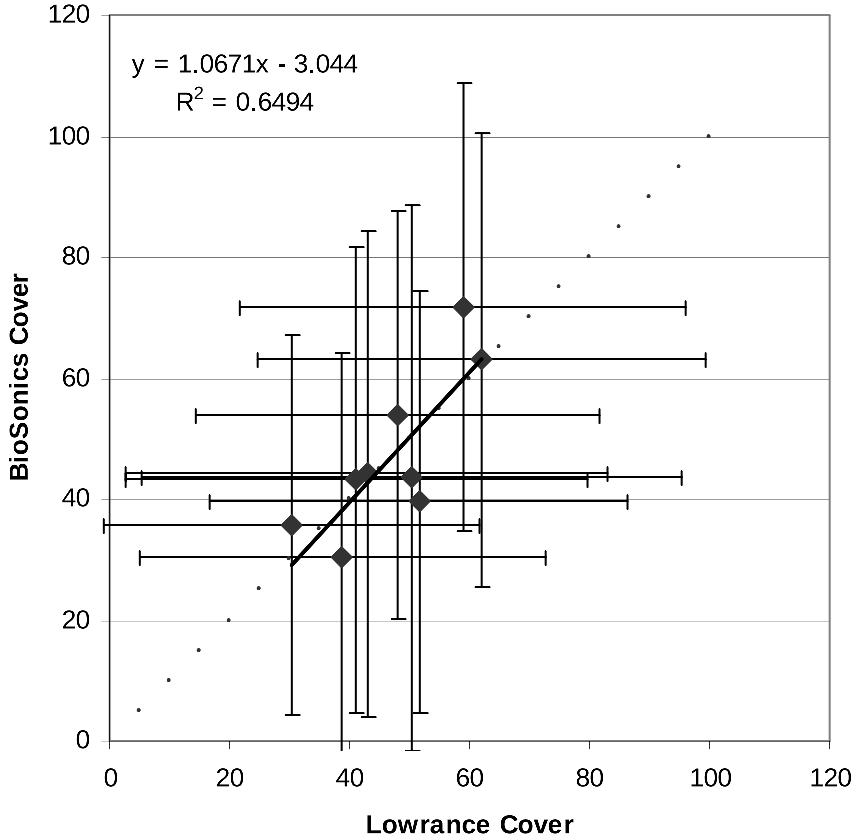


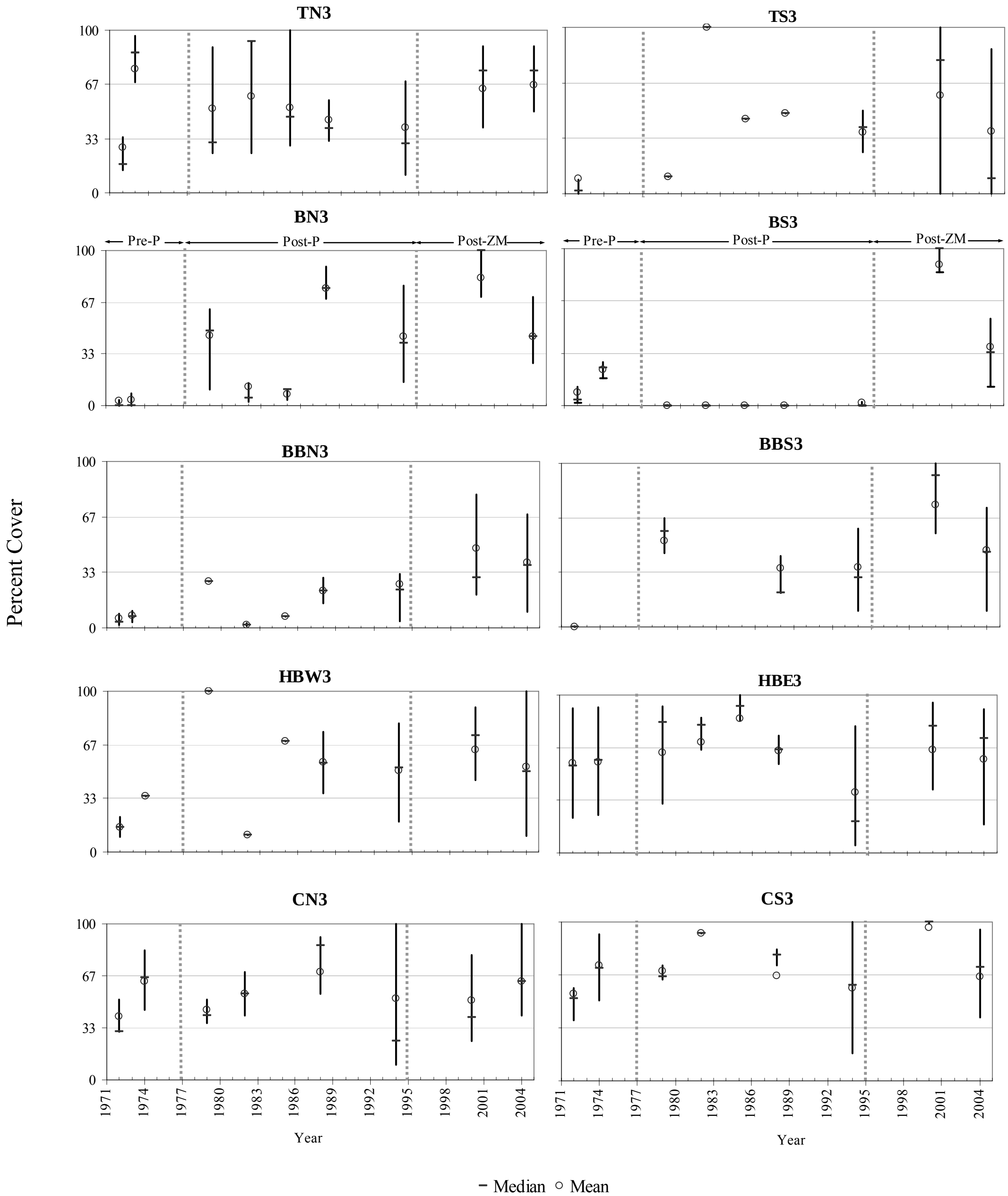
Figure A 3.2. Regression of Lowrance and BioSonics mean percent cover values with ± SD error bars

Appendix 6. Analysis of BioSonics Acoustical Data

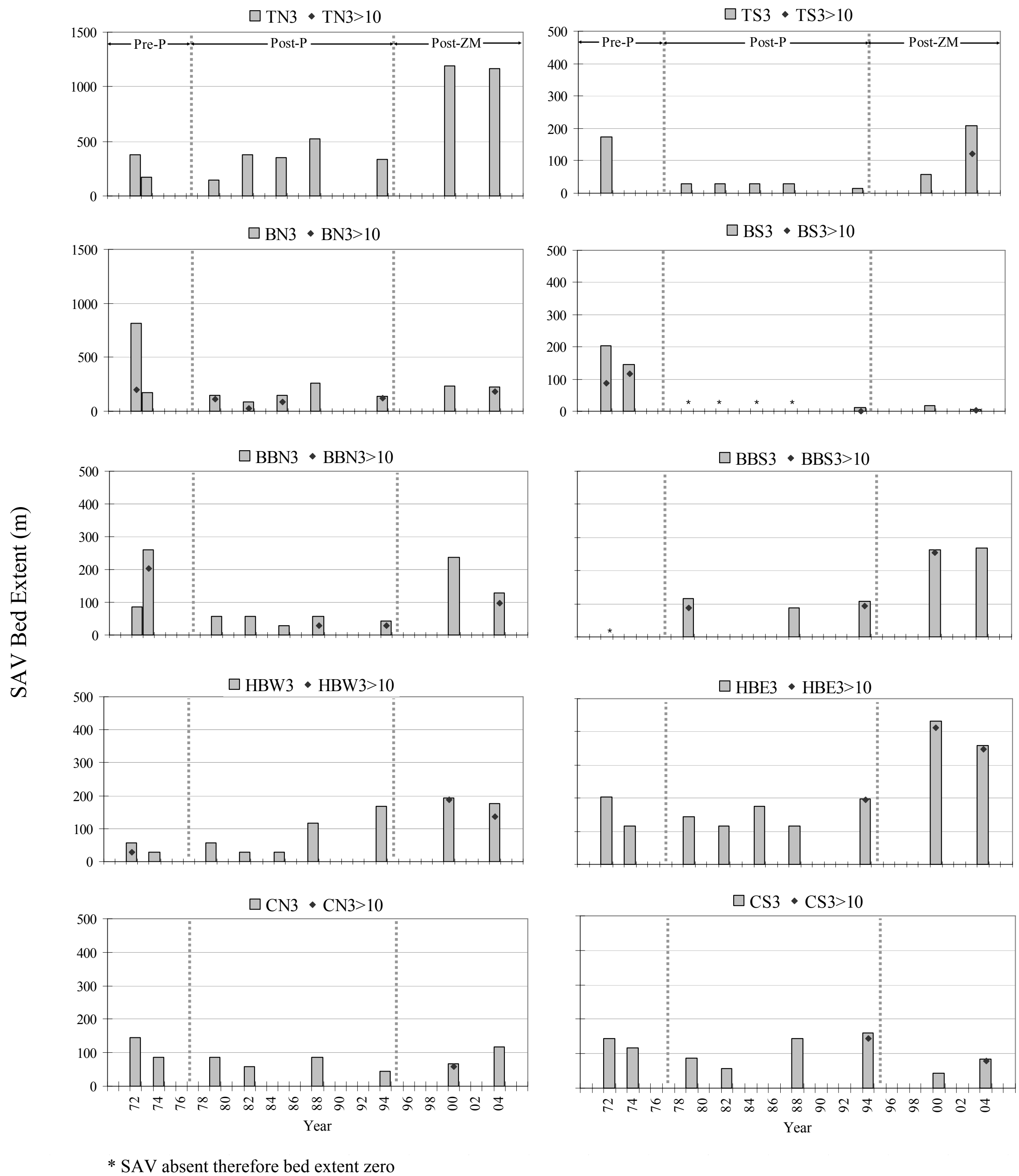
The BioSonics data was analyzed with the software BioPlant version 1.0. A 6 dB bias correction was made to all the files to account for the software bug that reads the incorrect receiver sensitivity (BioSonics, personal communications, 2005). The INI file settings were as follows: A1 = .03516, B = 6, LH = 0.01744 or 0.01771 depending on water temperature at the time of sampling, MBC = 0.11, NF = 0.24, N1 = -65, T2 = 12, # ping out = 8 and # noisy pings = 8. Maximum plant depth and the plant height threshold were determined for each file as detailed in the BioSonics manual (BioSonics, 2001). The output was then graphed in Excel and checked against the echogram and the visual inspection conducted in the field. Manual adjustments were made to bottom depth when the algorithm incorrectly located the bottom in the middle of dense macrophytes, plant height and cover was adjusted according to field descriptions as necessary. The data was imported into ArcView 3.2a and maps of percent cover overlaying water depth were created.

Appendix 7. List of submerged macrophytes identified during the 2004 survey.

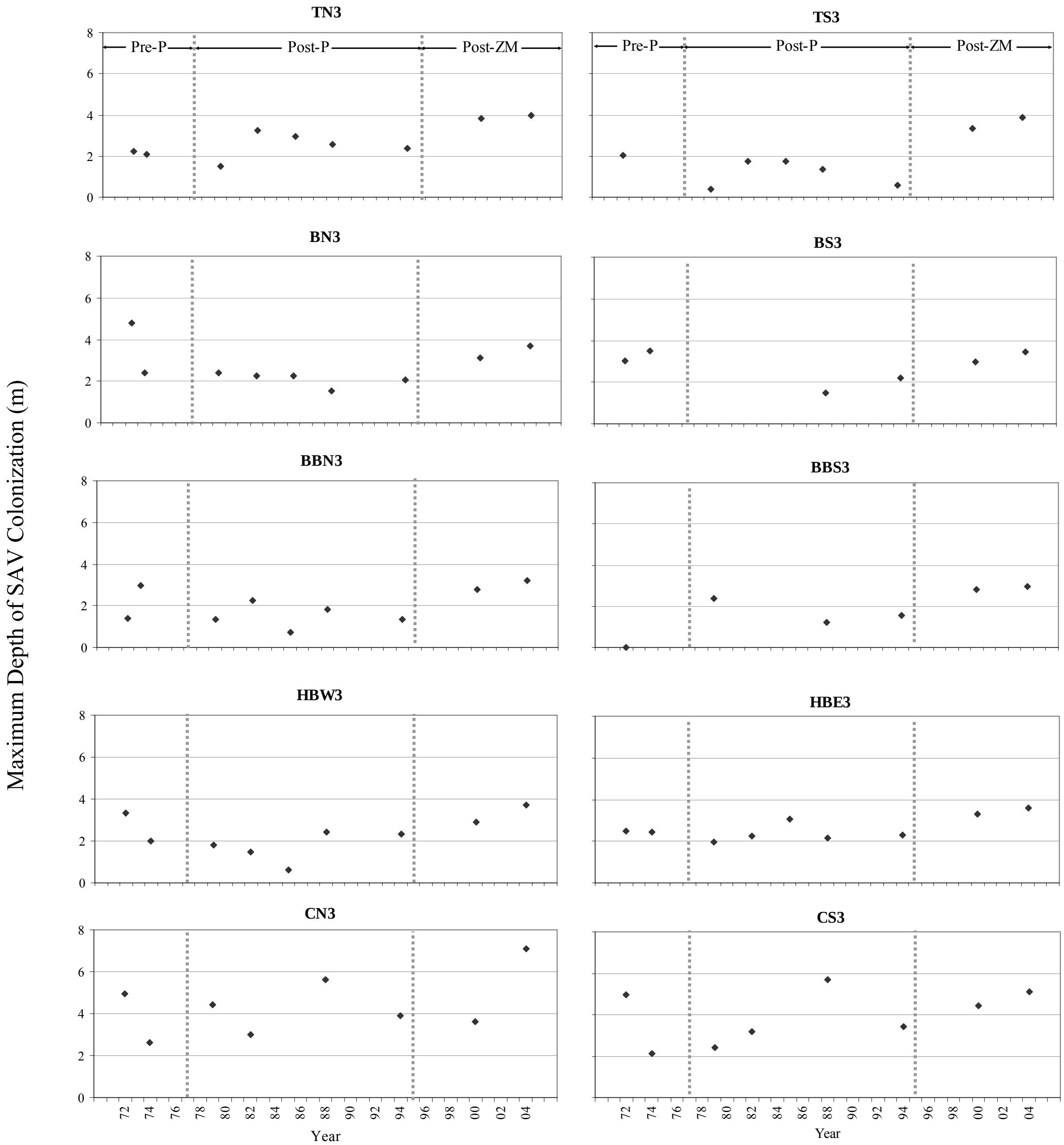
Scientific Name	Common Name
Alisma gramineum	Water plantain
Bidens beckii	Beggar-ticks
Ceratophyllum demersum	Coontail
Chara sp.	Muskgrass
Elodea canadensis	Canada waterweed
Heteranthera dubia	Water star grass
Lemna trisulca	Star duckweed
Myriophyllum excalbescens	Milfoil
Myriophyllum spicatum	Eurasian watermilfoil
Najas flexilis	Bushy pondweed
Najas guadalupensis	Busy pondweed
Potamogeton crispus	Curly-leaved pondweed
Potamogeton pectinatus	Sago pondweed
Potamogeton richardsonii	Clasping leaf pondweed
Potamogeton zosteriformis	Flat stemmed pondweed
Ranunculus longirostris	White water-crowfoot
Vallisneria americana	Tapegrass



Appendix 8. Percent SAV cover by reference transects for the years 1972 to 2004. Data derived from the knotted line (1972 to 1988) and echosounding surveys to the last plant on the transect. Shown are 1st quartile, median, mean and 3rd quartile values.



Appendix 9. SAV bed extent by reference transect for the years 1972 to 2004**.** Data derived from the knotted line (1972 to 1988) and echosounding surveys to the last plant on the transect. Also shown are transect lengths to the last plant whose cover value is greater than 10%. Note changed in scale of the Y axis for TN3 and BN3.



Appendix 10. Maximum depth of colonization for reference transects for the years 1972 to 2004. Data derived from mean depth taken mid point along the last sub-transect that contained a plant for the knotted line (1972 to 1988) and echogram interpretation of cover and depth for echosounding surveys.