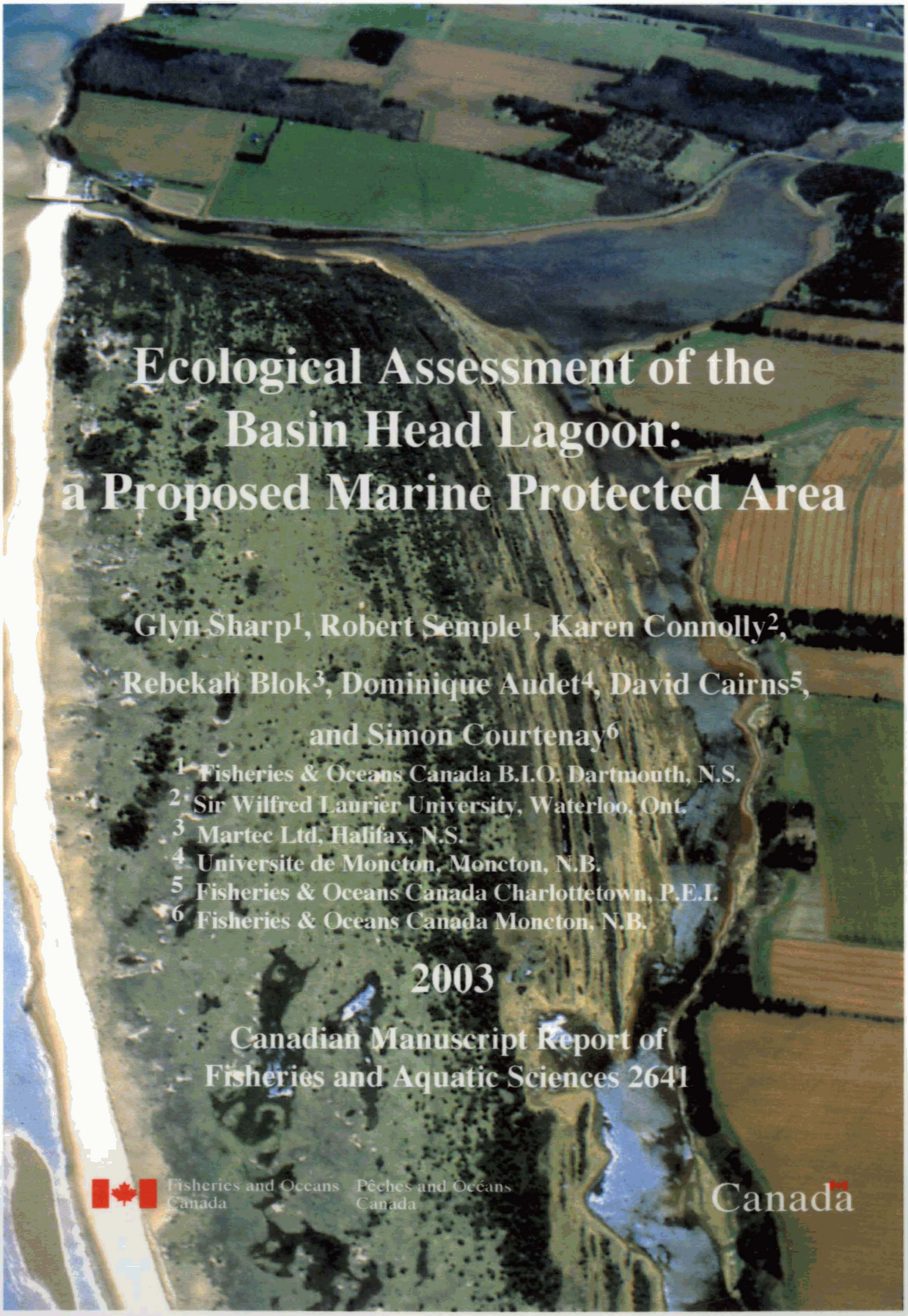

Ecological Assessment of the Basin Head Lagoon: a Proposed Marine Protected Area

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By

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ABSTRACT

Sharp, G., R. Semple, K. Connolly, R. Blok, D. Audet, D. Cairns, and S. Courtenay 2003. Ecological Assessment of the Basin Head Lagoon: a Proposed Marine Protected Area. Can. Manu.. Rep. Fish. Aquat. Sci. 2641: vi + 70 p.

Basin Head is a shallow marine lagoon located 12 km east of Souris, PEI. It has been nominated as an Area of Interest under the Marine Protected Areas program of the Oceans Act. The central region of the eastern arm supports a unique population of *Chondrus crispus* (Irish moss) whose biomass has been estimated at between 45.6 to 150 wet t over the past 30 years. This plant is ecologically, morphologically, and chemically distinct from the open water forms of *Chondrus crispus*. The information available on the ecological status of the lagoon was assembled from a wide range of published and unpublished sources. The lagoon is a system strongly affected by land based inputs but is still dominated by tidally influenced marine characteristics. Habitats range from a very saline, energetic ocean entrance to quiescent brackish backwaters. The lagoon habitat contains a minimum diversity of 93 plant and animal species excluding the planktonic community. The high input of nutrients from land sources creates optimal conditions for annual macrophyte blooms. This lagoon ecosystem faces potential threats from invasive species, storm surges, and commercial or recreational disturbances.

RÉSUMÉ

Basin Head est une lagune peu profonde située 12 km à l'est de Souris, IPE. Elle a été choisie comme site d'intérêt sous l'égide du programme des zones de protection marine de la *Loi sur les Océans*. La région centrale du chenal intérieur de la lagune supporte une population unique de *Chondrus crispus* (mousse d'Irlande) dont les estimés de biomasse se sont situés entre 45,6 et 150 tonnes humides au cours des 30 dernières années. Cette plante marine est écologiquement, morphologiquement et chimiquement distincte de la forme de *Chondrus cripsus* des eaux ouvertes. L'information disponible sur l'écologie de la lagune a été rassemblée depuis de nombreuses sources publiées et non publiées. La lagune est un système fortement affecté par des sources de pollution terrestres mais est tout de même dominée par des caractéristiques marines influencées par les marées. Les habitats varient d'une embouchure vers l'océan très saline à un bras quiescent saumâtre. L'habitat de la lagune contient une diversité d'au moins 93 espèces de plantes et d'animaux ce qui n'inclut pas la communauté planctonique. La valeur élevée de nutriments des sources terrestres crée des conditions optimales pour des proliférations annuelles de macrophytes et des conditions anoxiques localisées. Cet écosystème lagunaire fait face à des menaces potentielles de la part des espèces envahissantes, des ondes de tempête et des perturbations commerciales et récréatives.

INTRODUCTION

The Basin Head lagoon is located on the south side of the eastern tip of Prince Edward Island (PEI), 12 km east of Souris (Fig. 1). Basin Head is a marine lagoon which is almost completely surrounded by land, separated from the ocean by barrier sand dunes and connected to the ocean by a narrow 10 metre wide outlet.

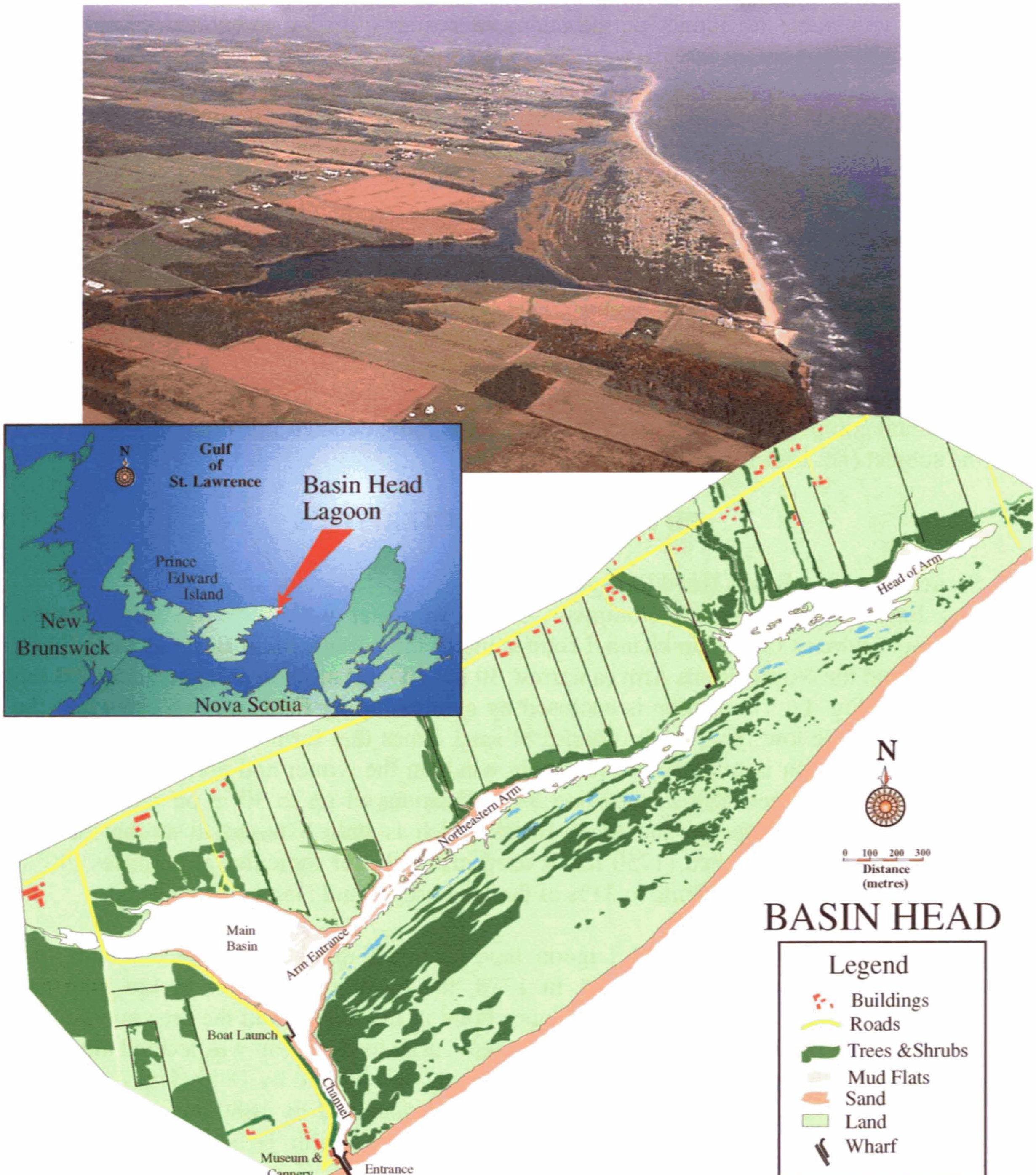


Figure 1. Oblique aerial view photo of Basin Head, Prince Edward Island, map of the southern Gulf of St. Lawrence showing location of Basin Head lagoon and a detailed map of the lagoon.

Under Section 35 of the Oceans Act, a Marine Protected Area (MPA) must have a special characteristic, habitat or species to qualify for designation. In the case of Basin Head, it is the protection of a unique strain of a perennial red seaweed *Chondrus crispus* Stackhouse (Irish moss, referred to in this paper as the Basin Head moss) that is one of the main justifications for inclusion of the basin in the MPA program. Since this lagoon ecosystem is very vulnerable to human perturbations, it requires special integrated management measures to maintain its integrity.

This assessment characterises the lagoon from existing physical, chemical, and biological databases. It will provide several baselines for ecosystem health that can be used for future management of this lagoon and similar basins. Potential or existing ecological problems in Basin Head lagoon and environmental factors with long-term ecosystem health implications will be identified along with knowledge gaps. This information is provided on a geographic database, if applicable. The photographic illustrations, although not always essential, are used to inform the reader and give subsistence to the data from this lagoon environment. A wide range of data sources have been utilised including historic grey literature, theses, primary publications, government reports, surveys and unpublished data sets. A separate section will be devoted to a species or habitat that is an important component of the lagoon where there is more detailed information available on the subject (i.e. Irish moss, American eel, etc.).

PHYSICAL CHARACTERISTICS

Structure of the Basin Head Ecosystem

The Basin Head ecosystem comprises 59 ha of water with three distinctive areas; Channel Entrance (a 0.5 km channel connecting to the ocean), Main Basin (a large 24 ha basin), and the Northeastern Arm (a narrow 30 ha, 20 – 50 m wide arm extending 2.9 km northeast (Fig. 1). The lagoon is enclosed by gently sloping fields on two sides and the third side is the low lying (< 8m) series of sand dunes that form the main barrier to the ocean. The lagoon is subjected to northerly winds in the winter and prevailing southerly winds in the summer. The surrounding land elevations of up to 30 m on the northwest and southwest side shelter the Main Basin which is only exposed to strong easterly winds. The total watershed (1750 ha) is used primarily for agricultural purposes (40%) while forested areas contribute to 31% of the land use (Island Nature Trust 2001).

The boundaries of Basin Head Lagoon have changed dramatically since it was first mapped in the late 1700's (Fig. 2). In 1778, the basin system was 11 km long and included Basin Head to the west, MacVanes Pond in the middle and the area now known as South Lake on the eastern side. The one main outlet to the ocean was located almost in the middle of these lagoons. A narrow barrier dune had formed by 1849 (Fig. 2) creating two entrances. This barrier had coalesced with the mainland by 1880 and three lagoons were created from one. In 1937, the entrance to the Basin Head lagoon was very

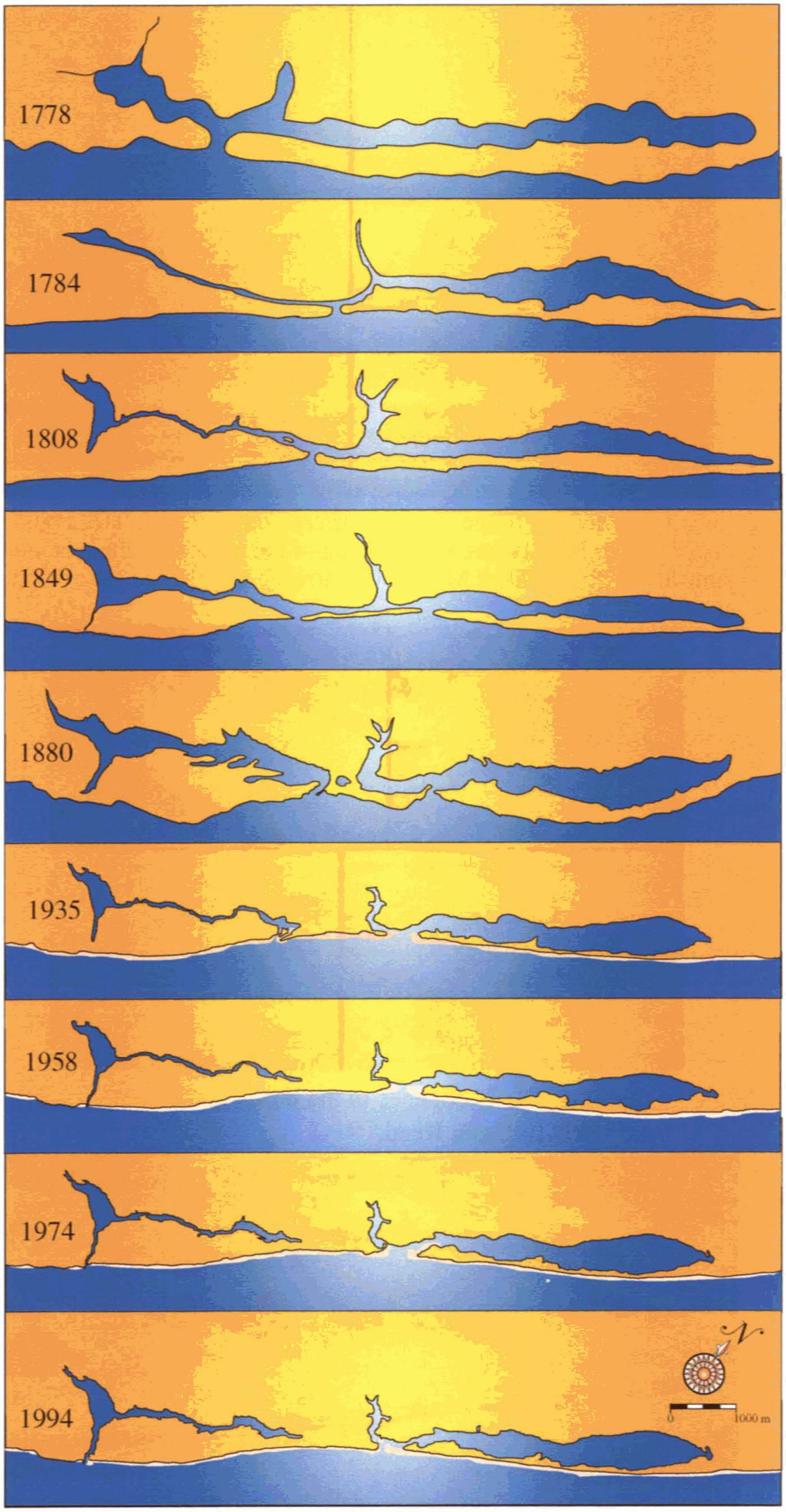


Figure 2. Changes in the area and shape of the Basin Head lagoon, McVanes Pond and South Lake region between 1778 and 1994, based on old maps, land-lot surveys and aerial photos from the National Air Photo Library.

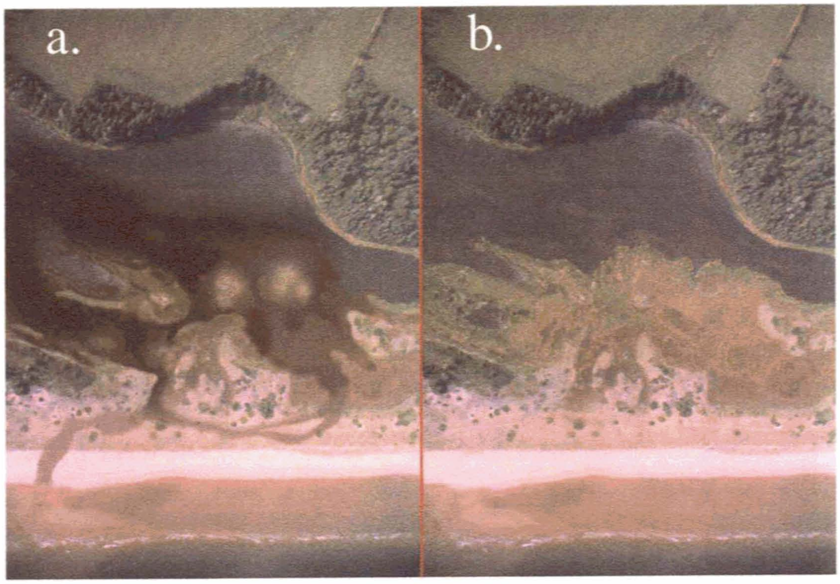


Figure 3. a.) A reconstructed version of the shallow eastern outlet at Basin Head on a recent photo showing what it looked like in 1935 before the dredging of the present channel at the western end occurred. b.) The same aerial photo taken May, 2002 showing the present state of the original entrance site which has since filled in.

Figure 4. Yearly and daily changes in the beach and channel sand at the entrance to Basin Head.

Figure 5. Aerial photo of Basin Head showing the basin, dunes and the off-shore sand and sediment patterns.

shallow and boat passage was difficult (Fig. 3a). An initiative was taken at this time to open up a new entrance at the opposite end of the lagoon adjacent to an existing lobster cannery where a small stream trickled across the dunes to the ocean. This new entrance was protected from erosion by wood pilings and sheathing and the former entrance filled in soon after the new one was completed (Fig. 3b). The new man-made channel resulted in dramatic change in the ecology of the system relative to the reverse in water flow exiting the lagoon and increased tidal flushing through the break in the dune structure.

The barrier dune system has grown over the past 67 years due to additional lines of dunes being stabilized by vegetation (Griffin 1973, Gilles 1999). The sand bars and sand beach associated with the entrance to the lagoon can constantly shift throughout the year. Sand is carried by storm waves over the channel liner during the winter, and in the summer this sand is carried out to the outlying sand bars (Fig. 4 & 5). The integrity and shape of the artificial entrance is critical to the tidal flushing of the lagoon. The outer coast sandbars are the most dynamic physical component of the coastline and can change from day to day (Fig. 5).

Bathymetry

Basin Head ecosystem is very shallow with an overall average depth of less than 1 metre above the chart datum (Fig. 6a). The Main Basin is shallow except for a deep narrow channel on the eastern side as a result of water flow from the Northeastern Arm and several holes in the northern section of the basin created by digging for "mussel mud" (Fig. 6b). Mussel mud was used by farmers to increase the pH of their agricultural soil. The Northeastern Arm is not navigable at low tide except by canoes or similar shallow draft vessels. On the higher high-tides, the low-lying inner portion of the sand dunes are flooded creating a salt marsh with frequent tide pools (Fig. 1, see INTRODUCTION)

Bottom Types

Extensive intertidal sand and mud flats surround the Main Basin and there are narrow sand flats on parts of the northern shore of the eastern arm (Fig. 1). There is a dynamic shifting of the sand bottom both in the high-energy entrance of the main channel to the basin and the oceanside inter-tidal area. There are large quantities of organic sediment deposition and soft sediments held by eel grass (*Zostera marina*) root systems in the Main Basin. The bottom type at the entrance to the Northeastern Arm, is a mixture of coarse sand and shells which stabilise the finer sediments. Rapid currents, which continue to a distance of a kilometer into the arm, reduce the deposition of fine sediments. Beyond this point of the arm, the sediments are highly organic and frequently anoxic.

Water Movement

Stream Input

Streams are the second major water source for the lagoon. There are 3 major streams that flow year round as well as many in-flows that are seasonal or related to rain events (Fig. 7). Measurements of stream flow identified Stream 3, near the highway bridge at the northwest end of the Main Basin, as the major source of fresh water (Connolly 2002). Stream discharge per day over the summer of 1999 was 10.01% of the total lagoon water volume and peaked at approximately 15% (opp. cit.). Stream 3 also receives the water discharge from a potato processing plant, which resulted in high discharge from this stream on days of zero rainfall (opp. cit.). [1]

Ocean Input

The mean water volume of the lagoon is 254,280 m^3, and at high tide, the volume is 1,103, 900 m^3 (Connolly 2002). The majority of water is tidal ocean water which enters from the narrow Channel Entrance. Depending on the amplitude of the tide, the lagoon may completely flush on one tide cycle but it can take over 6.82 days for turnover of the total water volume under other tide series. The mean residence time for Basin Head water was 2 days.

Circulation

A hydrodynamics model, based on tidal measures, bathymetry, stream flow and salinity gradients, was developed to simulate a 30-day period in the lagoon (Martec 2002). Water velocity reaches 1.5m/sec on peak tidal flows in narrow channels (Fig. 8a & b). There is moderate current flow in the area of the Basin Head moss bed (Fig. 8c). The analysis identified some regions that have very low or zero water movement. One of these regions is the very end of the Northeastern Arm (Fig. 8d).

The mean tidal amplitude in adjacent ocean waters is 1.05 m calculated from Souris, PEI, the secondary port of Pictou, Nova Scotia (DFO 2001). There is an average tidal lag time of one hour within the lagoon as compared to the open ocean because the water level in the interior can continue to drop as the ocean tide is flooding. The low tide amplitude can be dampened by as much as 0.5 m (Fig. 9).

Temperature

Water temperature in the lagoon is directly affected by tidal cycles during the spring to fall months. Hourly variations of bottom temperature in the Northeastern Arm can be correlated to the state of the tide (Fig. 10a). The temperature is depressed by the inflow of colder ocean waters to the high tide mark. Then temperature increases as the shallow waters are warmed during the slack and falling tide. The lagoon is shallow and well mixed vertically so that a thermocline is not formed. Seasonally, it warms quickly in the spring reaching maximum temperatures of 28^0C in the months of July and August. The water continually cools from September onward to a minimum of -1 degrees under ice cover (Fig. 10b). A geographical gradient is also present at the 11 stations monitored weekly (Fig. 10c). The maximum temperatures are reached at the head of the Northeastern Arm (Station A) and the coolest at the ocean entrances (Station H).

Salinity

The influence of ocean waters on salinity in the lagoon results in a gradient of salinity from the entrance to the further reaches of the lagoon (Fig. 11). The influence of stream input and land runoff at the head of the Main Basin and the end of the Northeastern Arm is reflected in brackish waters. Salinity is strongly influenced by tidal series but does not show a direct relationship to the specific tide level on one tide cycle (Fig. 12, see WATER MOVEMENT *Circulation*).

More recent 2002 information has been gathered on stream flow but has not been analysed

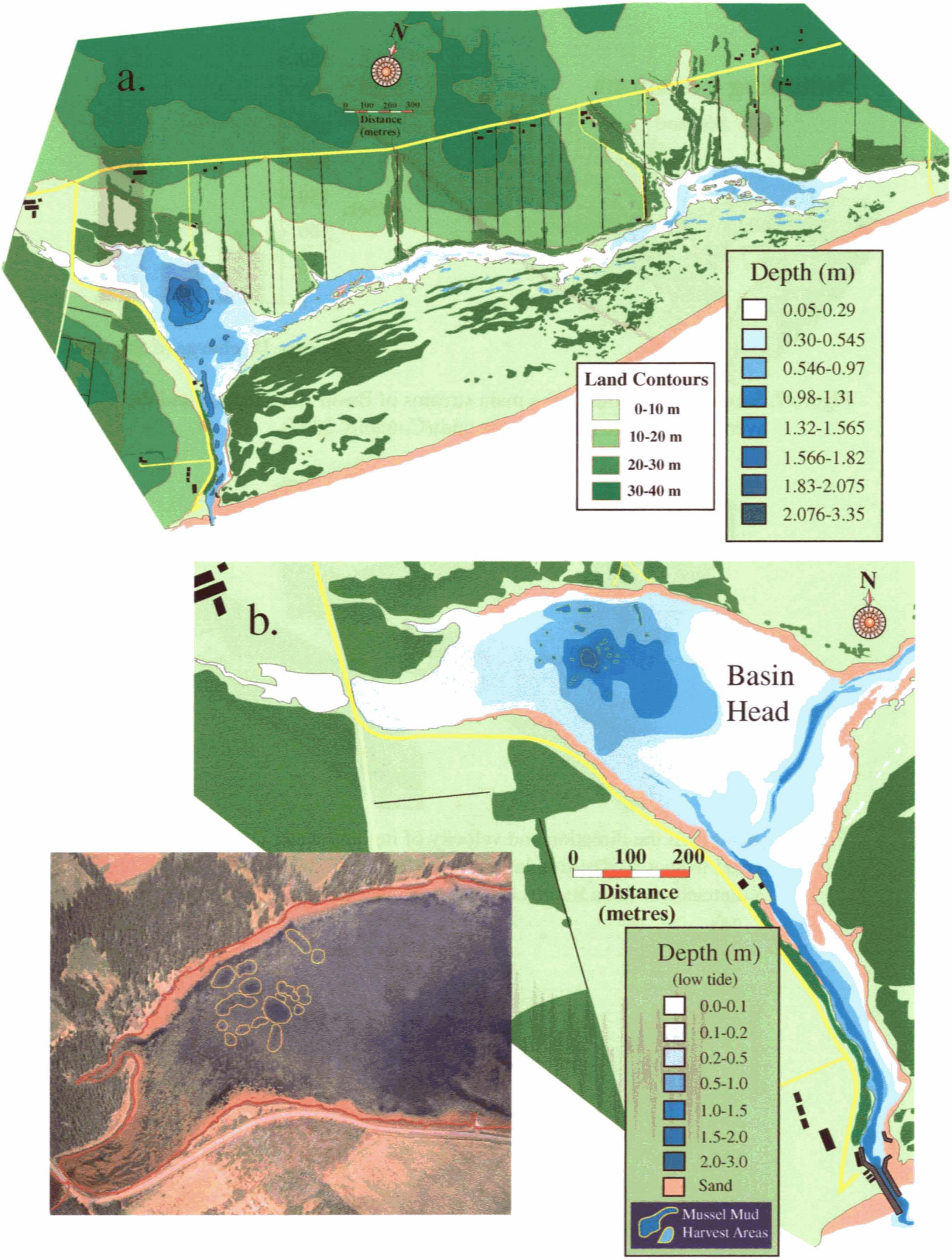


Figure 6. a.) Bathymetry of Basin Head lagoon (Connolly 2002).
b.) Detailed bathymetry of main basin from recent surveys and location of harvested mussel mud areas. Photo insert shows areas outlined in yellow.

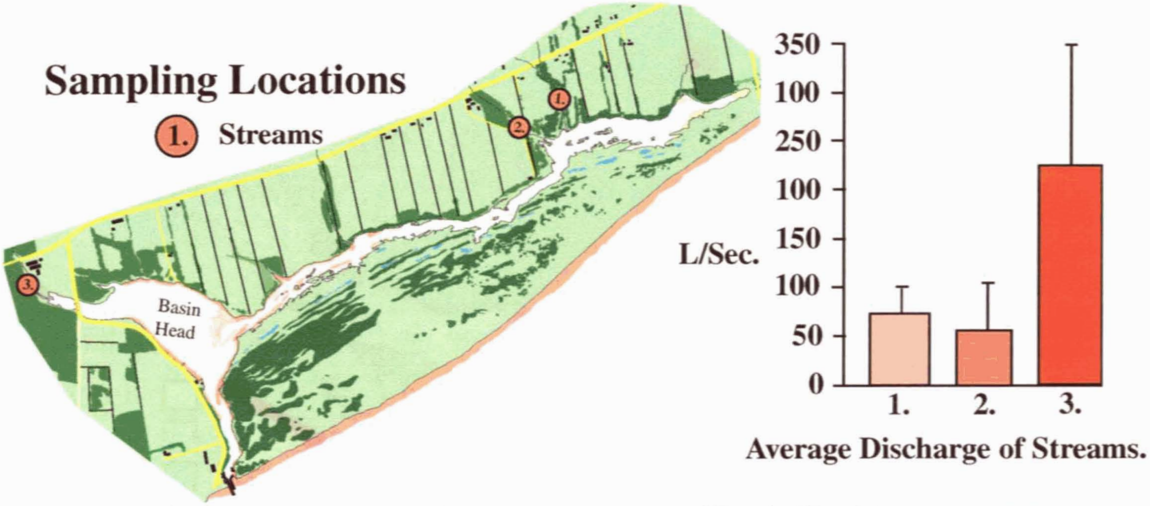


Figure 7. Sampling locations of the main streams of Basin Head lagoon and the average discharge [liters per second](Connolly 2002).

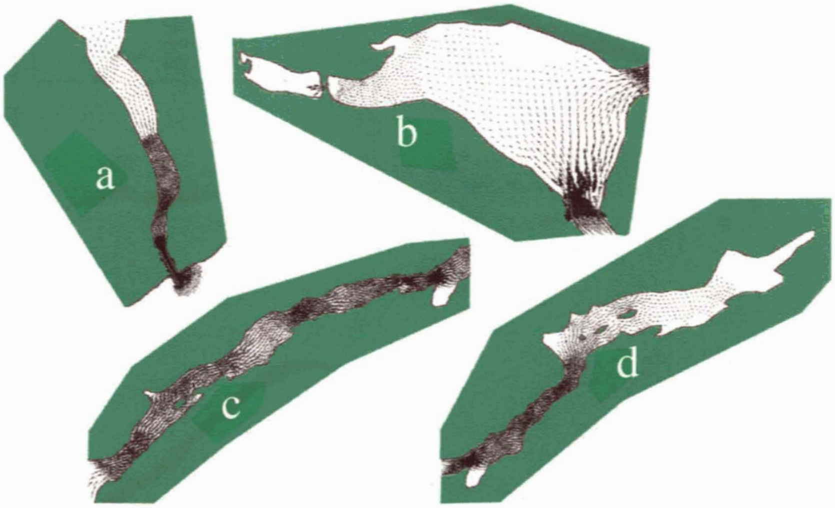


Figure 8. Sample of the direction and velocity of ingoing water currents in Basin Head from a 30 day simulation model, summer 2001(Martec 2002).
a=Entrance, b=Main Basin, c=Northeast arm from Basin, d=End of arm

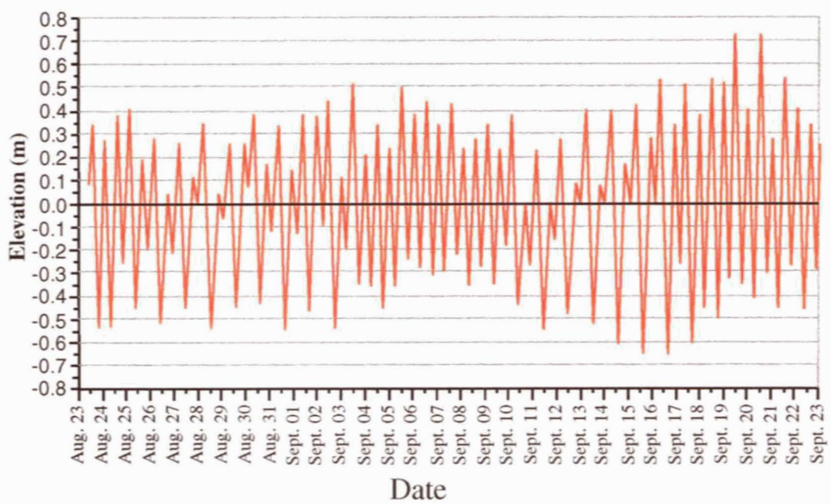


Figure 9. Tide guage measurement of water surface elevation at Basin Head wharf, summer 2001 (Martec 2002). The zero baseline is the average level of the amplitude.

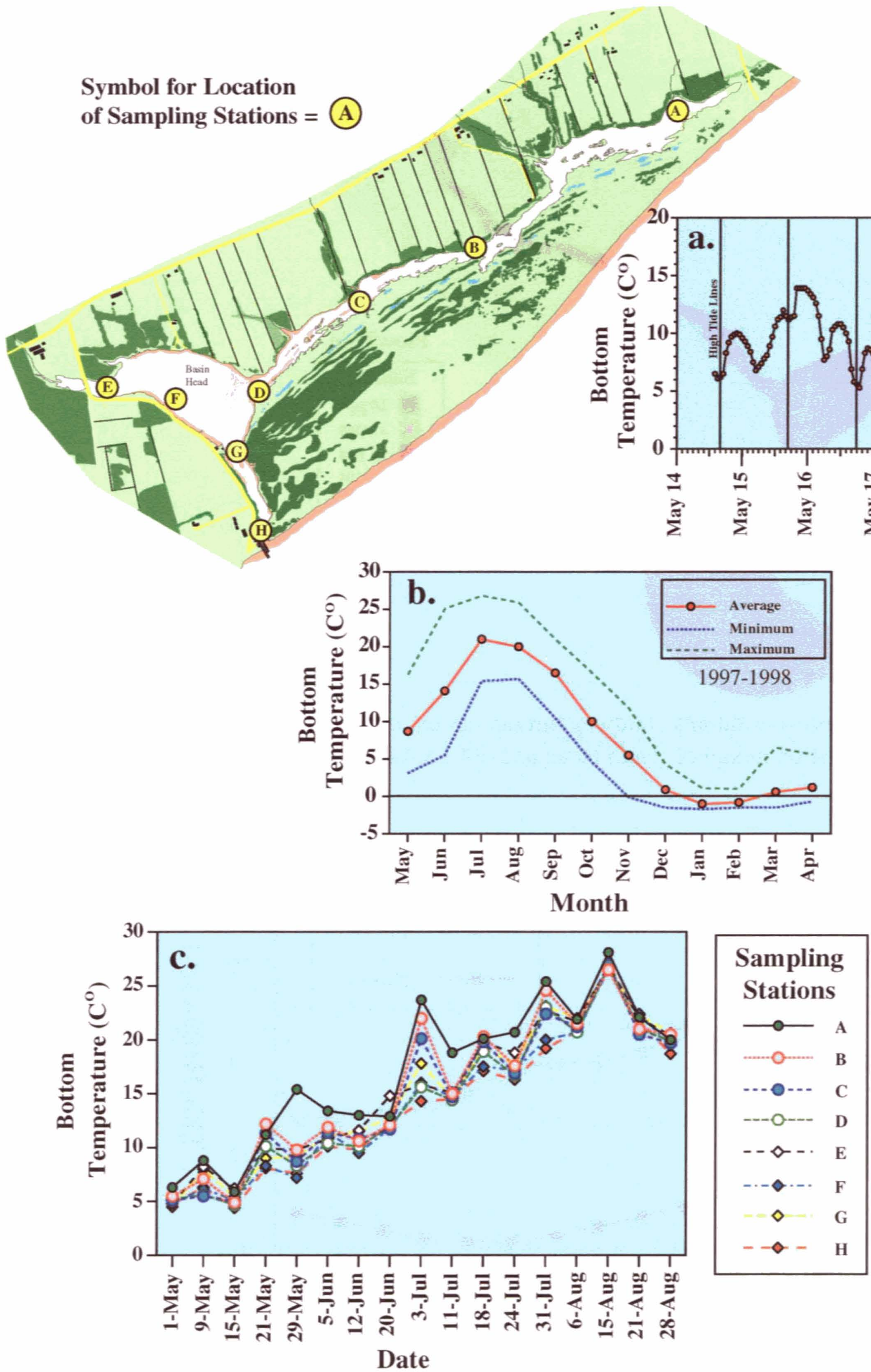


Figure 10. (a.) Tidal influence on the water temperatures at Station B, Basin Head during May 14-21, 1997.
(b.) Yearly variation in water temperatures at Station B, Basin Head for 1997-1998.
(c.) Geographical variation in water temperatures at 8 stations in Basin Head May to August, 2002

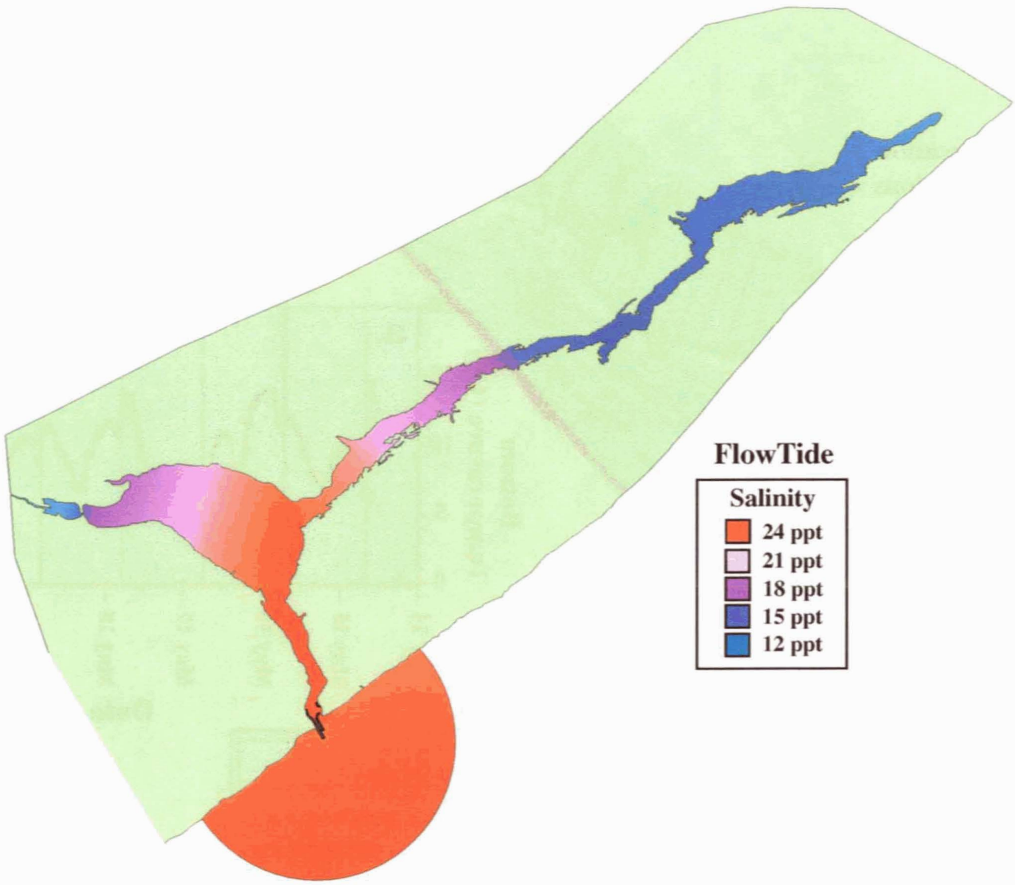


Figure 11. Variations of salinity, midway through an incoming tide, based on a circulation model of Basin Head and 2001 salinity data (Martec 2002).

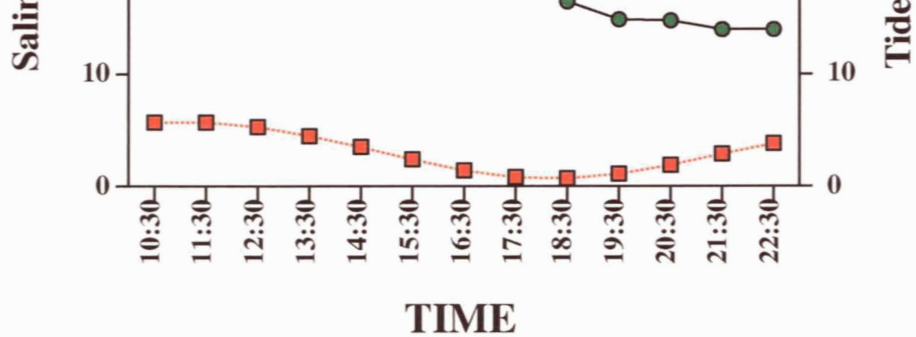


Figure 12. Salinity and tide height at Station B in the east arm of Basin Head, July 11, 1979 (McCurdy 1980).

WATER CHEMISTRY
Nutrients

Lagoon
Over the past four years the lagoon has been sampled at a series of 8 to 11 stations for nutrients (Connolly 2002, Sharp, unpublished data) (Fig.13). The pattern of concentrations was very similar between these studies with the exception of magnitude in the early McCurdy (1980) study. The overall pattern was of very high nitrate levels at Station E adjacent to the bridge and lowest levels were consistently recorded at the head of the Northeastern Arm, Station A (Fig. 13). Phosphate was low at Station F located on the Main Basin and highest at Station A at the head of the arm.

Nutrient samples taken on a weekly basis were collected on or near the high tide as was logistically possible ($^{\pm}$1 hr). However, tide level was still a strong factor influencing nitrate levels. Nitrate tended to increase over a tide cycle particularly if the tidal amplitudes resulted in longer retention of water in the lagoon. In contrast, the levels of nitrates in the ocean are very stable over the summer averaging 90 µg/l while there are large variations in stream inputs (see WATER MOVEMENT *Stream Input*). Nitrate levels at the stations closest to Stream 3 (Stations E and F) in the main basin were up to 10 times higher than ocean levels (Fig. 13). Open ocean values for phosphate (27 µg/l) derived from a series of samples in the Northumberland Strait were lower than those found at Stations A and B at the head of the Northeastern Arm (Connolly 2002).

There is one reference point for nutrients from the evaluation of the lagoon in 1979 that has a historic relation to the aquaculture potential of the Basin Head moss (McCurdy 1979). Connolly (2002) concluded that all nutrient values have become dramatically elevated over 20 years at comparable stations (T1 to T5) from McCurdy's data. The values were elevated by such orders of magnitude (50 to 100) that there were questions of comparable methodology. The values in the 2000 study have been confirmed by two subsequent years of sampling the same stations (Sharp, unpublished data).

Streams
Stream discharges, while not comprising the largest component of the water volume at any one time, can strongly influence mean nutrient concentrations in the lagoon. Their much higher ambient levels of nutrients than the ocean water increase the potential for pulses of nutrient input into the lagoon after rainfall. The importance of this input will be partly dependent on the volume of discharge and the flushing rate of the lagoon on a tide series. Phosphate levels in streams were between 19.9 and 85.5 µg/l in the summer of 1999 and these concentrations did not appear to be influenced by discharge rates. However, total phosphorous was related to stream discharge and reached a one day maximum of 387 µg/ sec (Connolly 2002). Nitrate levels were not correlated with stream discharge and averaged 11,077, 9,367, 8,773 µg/l in streams 1 through 3 respectively. Stream input over a period of time (discharge combined with concentration) could contribute an average over the season of 15,532 µg/sec of phosphate, 25,764 µg/sec of total phosphates, 11,544,860 µg/sec of nitrates and 2,730 µg/sec of nitrites (Connolly

2002). Stream nutrient averages compared with other sampled streams in PEI and in all cases were found to be above the provincial averages (Connolly 2002).

Oxygen

Station A located at the head of the Northeastern Arm had the largest weekly variation in the level of dissolved oxygen (Fig. 14a). This location exceeded oxygen level saturation in the early spring due to the photosynthetic evolution of oxygen during the day in the peak of the macrophyte bloom. Similar phenomena have been reported in other eutrophic lagoons (De Casabianca and Posada, 1998). This station had also reached the lowest level in the lagoon during the first week in August. There was a steady decline in oxygen levels in the lagoon from the spring to the end of summer. Generally, this seasonal trend could be related to the cycle of biomass accumulation and degradation of sea lettuce (*Ulva lactuca*) in the lagoon during this same time period (see SEA LETTUCE). The wide variation between weekly levels could not be explained directly by the tidal height at the time of sampling. As with many other chemical and environmental factors in the lagoon, the state of the tide is a major factor in variability (Fig.14b). The series of tides for a given week are more important than the individual tide for a sampling day.

Suspended Solids

Streams

Streams that drain the fields and forestland are important sources of suspended solids in the lagoon. Soil erosion is a problem in many areas of PEI and the elevated fields on the sides of the basin are a source of sediments. Although there appeared to be no relationship between discharge and suspended solids, this may have been due to the lack of high rainfall events during the 2000 summer. The combined contribution of the three streams in 2000 was an average of 75.6 g/hr (Connolly 2002).

BIOLOGY

General Biology and Diversity

The lagoon ecosystem supports a rich diversity, with a minimum of 52 animal and 41 marine plant species excluding planktonic species (McCurdy 1979) (Fig. 15a & b, Table 1). This level of diversity is due in part to the wide range of habitats in the lagoon. A portion of the habitat diversity can relate to the water chemistry, temperature, water movement, bottom types, tidal and salinity gradients discussed in previous sections. However, another layer of complexity in habitat is provided by a combination of bottom type and associated macroflora. Macrophytes provide higher structural complexity to any habitat, as well as altering environmental factors such as light and water movement. This complexity can also provide some competitive advantages by reducing vulnerability to predation, increasing food supply for herbivores and allowing territorial separation over very short distances.

Basin Head ecosystem can be divided into three major areas: 1.) Open Ocean, 2.) Main Basin, and 3.) Northeastern Arm. There are transitional areas at the entrances to the Main Basin and the entrance to the Northeastern Arm. The open ocean area is not addressed in this paper as it has been previously characterised in reviews of critical habitats and oceanographic conditions of the Gulf of St. Lawrence (Drinkwater et al. 2001, Whitford 2001).

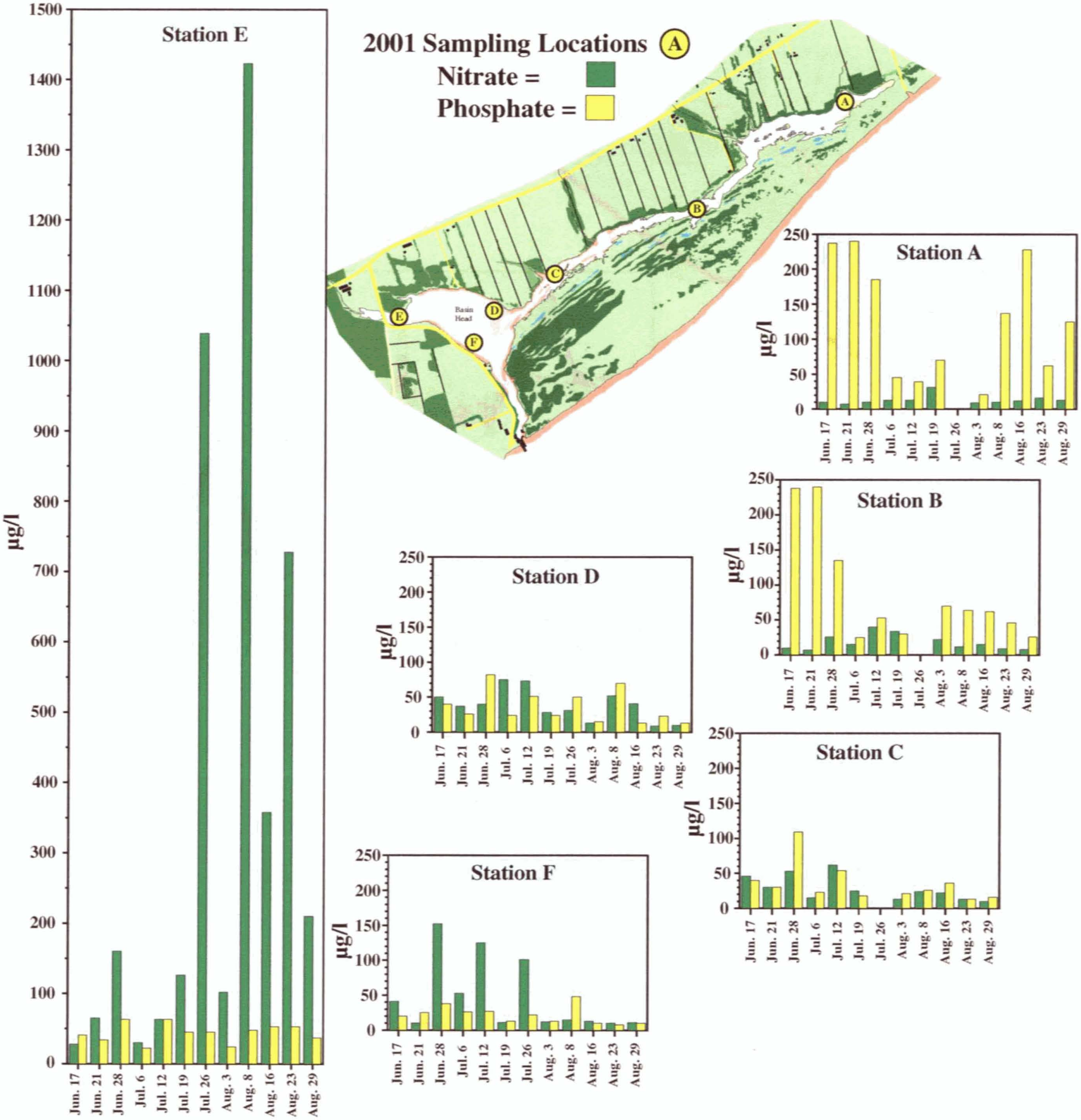


Figure 13. The relationship of the Nitrate and Phosphate levels at 6 sampling stations in Basin Head during the summer of 2000 (Connolly 2002).

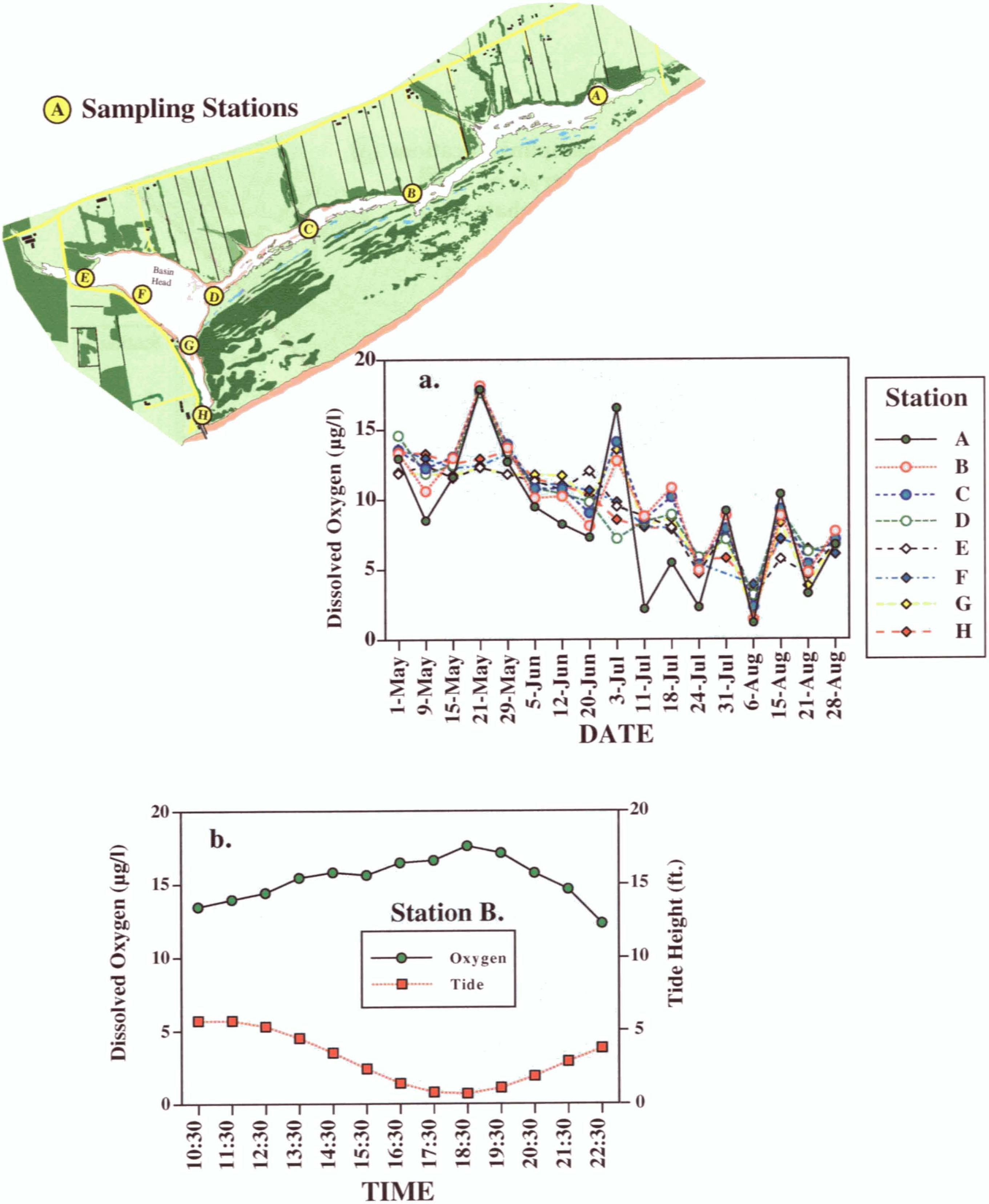
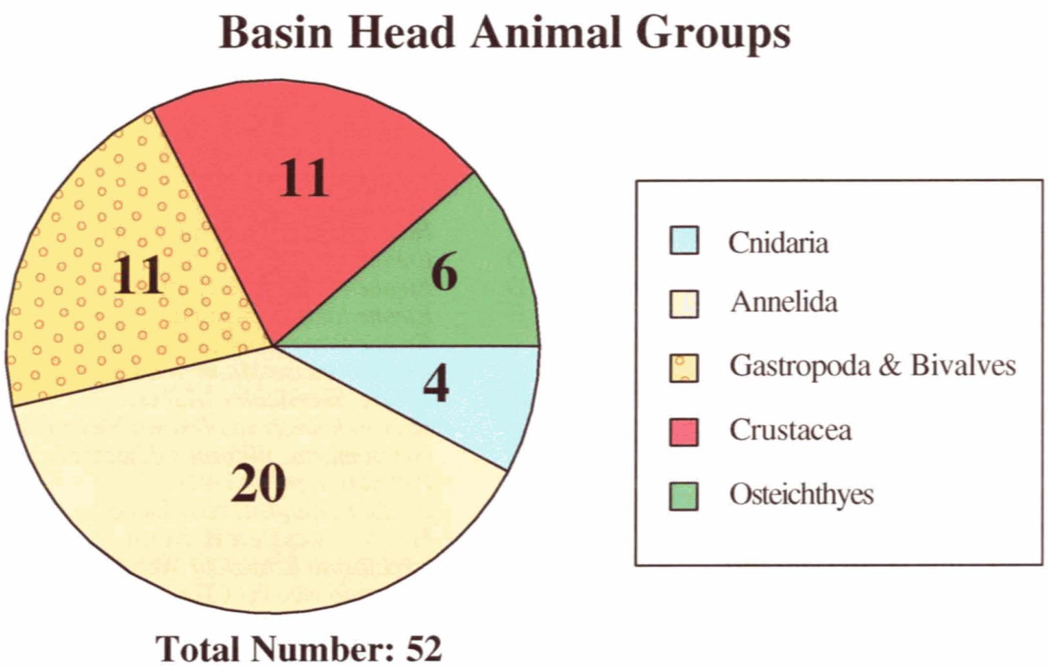


Figure 14. (a.) Dissolved oxygen between stations in Basin Head from May to August 2002.
(b.) Tidal variation and dissolved oxygen at Station B during a 12 hour period, July 11, 1979 (McCurdy 1980).



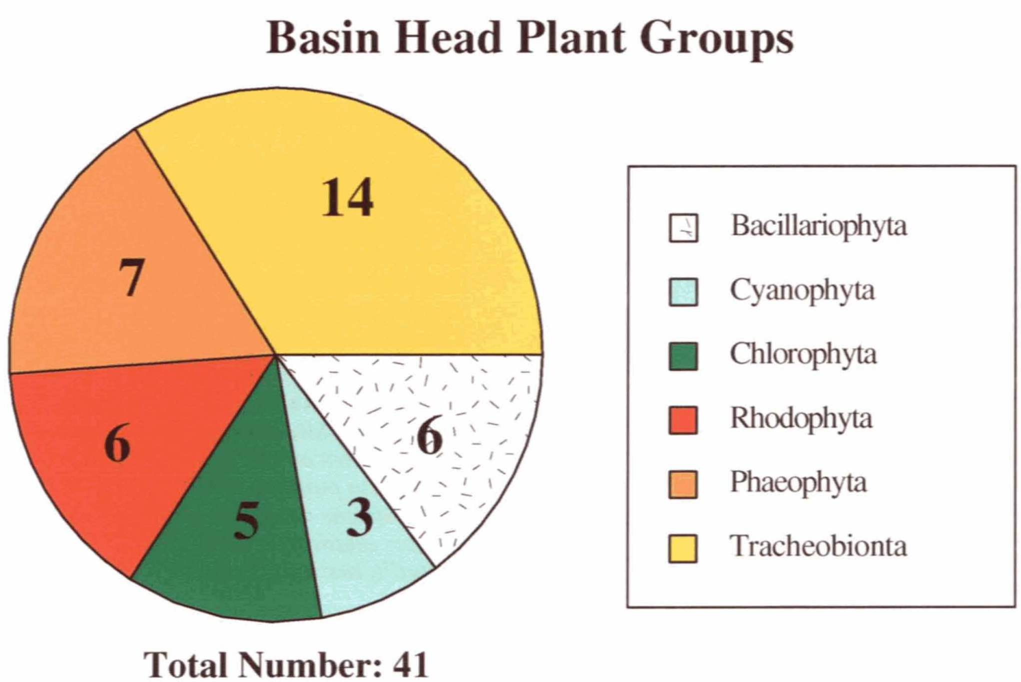


Figure 15. (a.) Major faunal groups in Basin Head (McCurdy 1980).
(b.) Major floral groups in Basin Head (McCurdy 1980).

Table 1. Species list and relative abundance Basin Head collections (McCurdy 1979).

Codes: Abundance: A=Abundant, C=Common, O=Occasional, R=Rare
Habitat: Be=Benthic, B=Attached to Bottom, D=Drift or Lying on Bottom, E=Epiphytic, F=Floating, P=Planktonic

Group/Species	Abundance	Habitat
Plants (Rhodophyta)		
Ceramium rubrum (Huds.) C. Ag.	O	F
Chondrus crispus Stack.	A	D
Polysiphonia urceolata (Lightf.) Grev.	R	D
Palmaria palmata	R	F
Plants (Phaeophyta)		
Agarum cribosum (Mert.) Bory	R	F
Ascophyllum nodosum (L.) Le Jol.	O	F,D
Chorda tormentosum C. Ag.	C	B
Ectocarpus sp.	A	E
Fucus serratus L.	O	D
Fucus evanescens C. Ag.	O	D
Plants (Chlorophyta)		
Chaetomorpha sp.	C	E
Enteromorpha clathrata (Roth) J.Ag.	A	E
Enteromorpha intestinalis (L.) Link	C	B
Ulothrix flacca (Dillw.) Thuret	C	E
Ulva lactuca L.	A	B.C,F
Invertebrates		
Platyhelminthes	R	Be
Nematoda	R	Be
Nemertina	R	Be
Cnideria		
Tima formosa L. Agassiz	O	F
Cyania capillata Eschscholtz	O	F
Obelia sp.	O	E
Ctenophora		
Pleurobranchia pileus Vanhoffen	C	F
Mollusca		
Littorina littorea (L)	A	Be
Littorina saxatilis (Olivi)	C	Be
Hydrobia minuta (Totten)	C	Be
Nassarius obsoletus (Say)	O	Be
Nassarius trivittatus (Say)	R	Be
Lacuna vincta Turton	R	Be
Mytilus edulis (Linn)	A	Be
Modiolus demissus (Dill.)	R	Be
Macoma balthica (Linn.)	O	Be
Macoma calcarea (Gmelin.)	R	Be
Mya arenia Linn.	O	Be
Gemma gemma (Totten)	O	Be
Annelida		
Harmothoe imbricata (Linne)	O	Be
Eteone longa (Fabricius)	C	Be
Eteone heteropoda Hartman	O	Be
Eteone lactea Claparede	R	Be
Eteone flava (Fabricius)	R	Be
Nephtys incisa Malmgren (Fabricus)	R	Be
Nereis diversicolor Muller	A	Be
Micropthalmus sczelkkowii Mecanikow	R	Be
Heteromastus filiformis (Calparede)	R	Be
Polydora ligni Webster	A	Be
Polydora quadrilobata Jacobi	R	Be
Polydora websteri Hartman	R	Be
Streblospio benediciti Webster	C	Be
Pygospio elegans Claparede	R	Be
Scolelepis squamata (Muller)	R	Be
Scolecolepides viridis (Verrill)	O	Be
Chaetozone setosa Malmgren	R	Be
Oligpchaeta	O	Be
Arthropoda		
Idothea balthica (Pallas)	O	Be
Jaera marina (Fabricius)	O	Be
Corophium acherusicum Costa	O	Be
Corophium insidiosum Crawford	R	Be
Corophium sp.	C	Be
Gammarus oceanicus (Segerstrale)	A	Be
Gammarus lawrencianus Bousfield	O	Be
Gammarus mucronatus Say	R	Be
Gammarus sp.	C	Be
Amphithoe longimana Smith	C	Be
Mysis stenolepis S.I.Smith	R	Be
Crangon septemspinosa Say	O	Be
Cancer irroratus Say	C	Be
Chordata		
Fundulus heteroclitus (Linn.)	A	
Pleuronectes americanus (Walbaum)	C	
Lioposetta putnami (Gill)	O	
Gasterosteus aculeatus Linn.	O	
Apeltes quadracus (Mitchill)	C	
Anguilla rostrata (LeSueur)	A	

Description of the Zones and Transitional Areas

Channel Entrance

The ocean entrance from the channel mouth to the inner wharf with boat launch (Fig. 1) has a strong representation of species from the exposed outer Gulf of St. Lawrence coast and is the only area with solid sandstone substratum intertidally (Fig. 16). These species include attached Irish moss (*Chondrus crispus),* bladder wrack (*Fucus vesiculosis*), Kelp *(Laminaria* spp.*)*, rock crabs (*Cancer irroratus)*, lobsters (*Homarus americanus)*, and barnacles (*Balanus balanoides).* It is also a region of high water velocity and a deep channel. Schools of fish including sticklebacks (*Gasterosteus* spp.*)* and silversides (*Menida menida)* form in this area. Adults and juvenile winter flounder (*Pleuronectes americanus)* are common in the summer months on the sand bottom. Drifting seaweeds are continuously in the water column moving in and out with the tide in the summer. The drift species vary seasonally, particularly as sea lettuce (*Ulva lactuca*) biomass increases rapidly in the lagoon over the summer (Fig. 16). Jellyfish (Cnidaria phyllum) and combjellies (Ctenophora phyllum) are commonly observed in the channel entrance. As this channel leads into the Main Basin, it has a sand bottom but the eel grass (*Zostera marina*) communities dominate the steeply sloping sides. Where the channel meets the shallow Main Basin, there is a large depositional area of drift algae dominated by toothed wrack (*Fucus serratus)*, dulse (*Palmaria palmata),* and kelp (*Laminaria* spp).

Main Basin

The Main Basin (Fig. 17) has a soft mud bottom is stabilized by extensive eel grass cover. The Main Basin also has a large population of the introduced green crabs (*Carcinus maenas*) and the indigenous rock crab. The Main Basin is almost completely covered by eel grass in the summer and inter-dispersed with fronds of drift algae including the occasional clump of Basin Head moss and dulse. Grazers are the dominant macrofauna in this area including periwinkles (*Littorina littorea, Littorina saxatilus, Lacuna vincta),* crustaceans, gamarid amphipods, and the isopod, *Idotea balthica*. During the summer, sea lettuce biomass and cover increases to the point where the mud bottom is not visible. Hidden under this cover are crabs and the detrivore mud snail (*Nassarius obsoletus*) plus a wide variety of worm species (Table 1). The most common finfish is the stickleback, but flounder, American eels (*Anguilla rostrata)*, and mummichogs (*Fundulus heteroclitus)* are also present. Both sea lettuce and *Enteromorpha* spp. are in higher abundance at the approaches to the entrance of Stream 3, near the highway bridge (Fig. 17) while eel grass is less abundant or absent. Near this end of the Main Basin are deep holes (> 2.5m) created by the removal of "mussel mud" used by early farmers as fertiliser. These deep holes usually are void of natural vegetation but can act as collectors for drift material. The majority of the perimeter of the Main Basin is an intertidal clam flat. While the most abundant shellfish species is the commercial soft shell clam (*Mya arenaria*), the smaller bivalve species *Macoma balthica, Macoma calcarea* and *Gemma gemma* are present in the benthos. Worm species such as the polychaete sandworm (*Nereis diversicolor*) are also found.

Note: In reference to Figures 16-20 on the following pages: The red outline on the inserted map represents the zone or transitional area discussed in the Basin Head lagoon. The numbers on the individual photos correspond to the numbers on the aerial photograph representing approximately where it was filmed.

Arm Entrance

The entrance to the Northeastern Arm is shallow (<1m) with a firm bottom (Fig. 18). Where the channel bottom is mud, eel grass is dominant. The American oyster (*Crassostrea virginica)* and the blue mussel (*Mytilus edulis*) are common. On the northern shore of the channel, sand and gravel substrate of intertidal flats provide more area of "clam flats". On the southern shore the marsh grass (*Spartina alterniflora)* and an unattached ecotype of knotted wrack or more commonly called rockweed (*Ascophyllum nodosum*), form the intertidal community. The low slope of the shoreline allows a large portion of this area to be salt marsh with a mix of salt marsh plant species. At the upper intertidal edges of the northern channel, fragments of drift rockweed become entangled with the marsh grass (Fig. 18).

Chondrus Bed

Patches of the Basin Head moss begin to occur in the middle of the channel approximately 900 m into the Northeastern Arm (Fig. 19). These patches become more frequent until the channel is over 50% cover of *Chondrus* in the centre. The association of blue mussels with the Irish moss creates large clumps (1-3 kg) that contain a high abundance of invertebrates. While there may be high species diversity in other parts of the lagoon, here the abundance is linked to the additional habitat complexity provided by the large clumps of *Chondrus*. Beyond the region of *Chondrus* abundance, towards the eastern end of the arm, the bottom consists of soft mud and the sand gravel bars cease to fringe the arm.

Eastern End of Arm

The macrophyte, sea lettuce (*Ulva lactuca*) is ubiquitous in the lagoon but dominates and structures the habitat in the far reaches of the Northeastern Arm (Fig. 20) and the head of the Main Basin. Eel grass is present in this part of the arm but low in density while sea lettuce is present year-round and becomes not only a layer on the bottom but floats in the water column and on the surface. Moving further into the head of the eastern arm the impact of the sea lettuce cover increases. Anoxic conditions are associated with the release of pungent hydrogen sulfide (H_2S) and *the* sea lettuce decaying as the summer progresses. Despite this situation, some species of fish have been collected in these locations, including American eel and sticklebacks (McCurdy 1979). However, crustacean grazers are low in abundance and only one species of gastropod, the common periwinkle, is present. Worms are the dominant invertebrate in this area, particularly *Polydora lingi*.

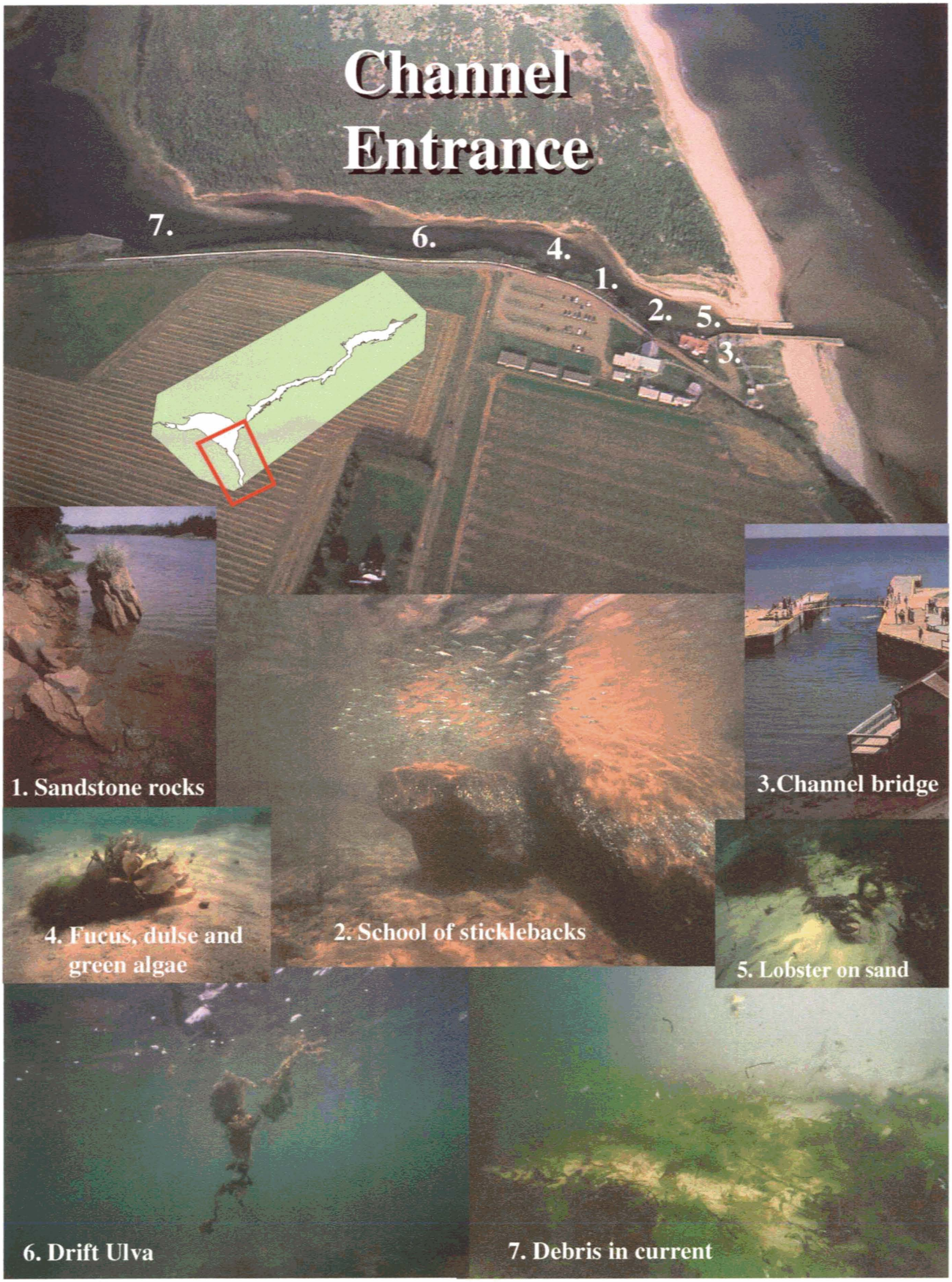


Figure 16. Characteristics of the current- dominated habitat and biota at the entrance of Basin Head.

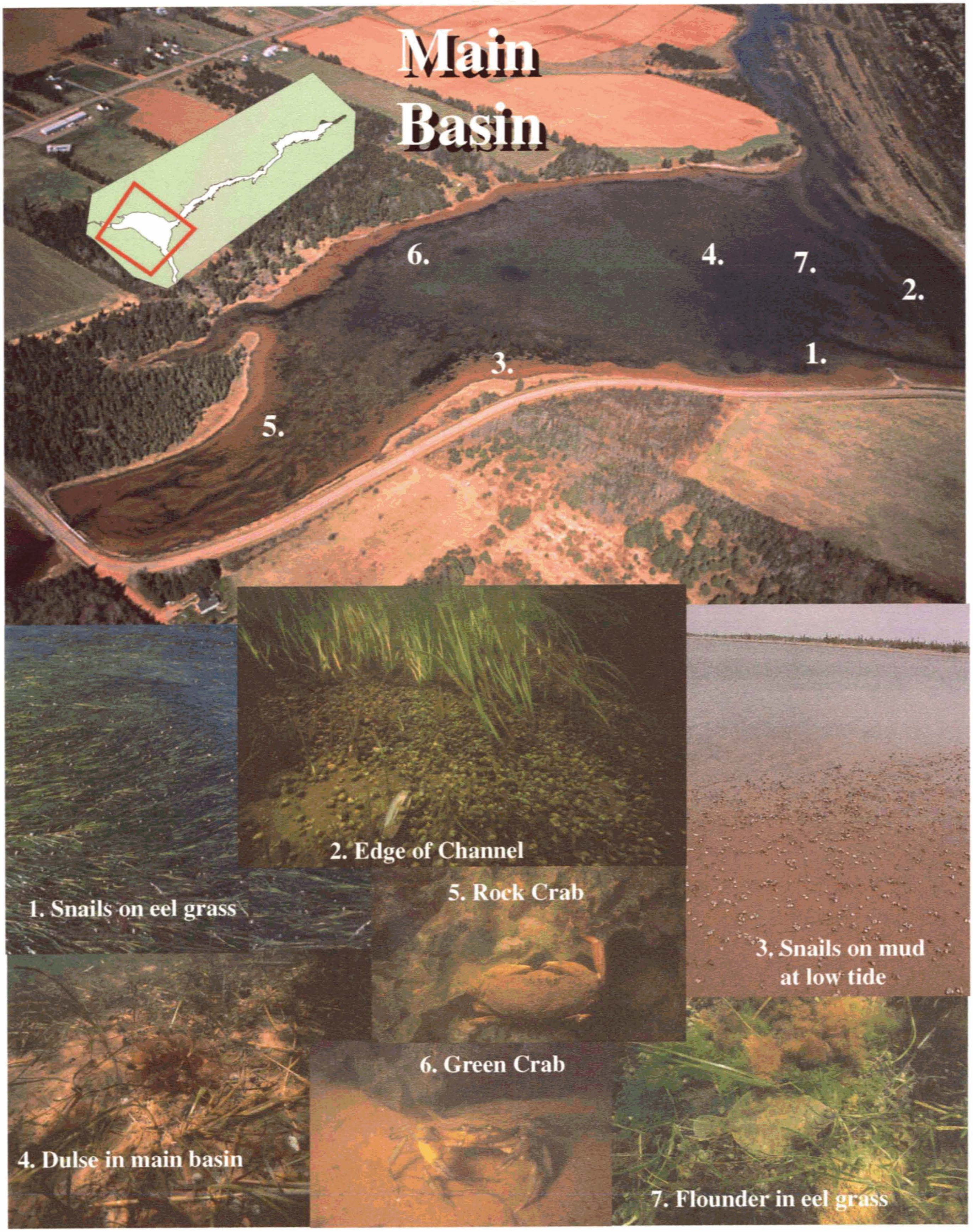


Figure 17. Characteristics of the habitat and biota in the main basin area of Basin Head.

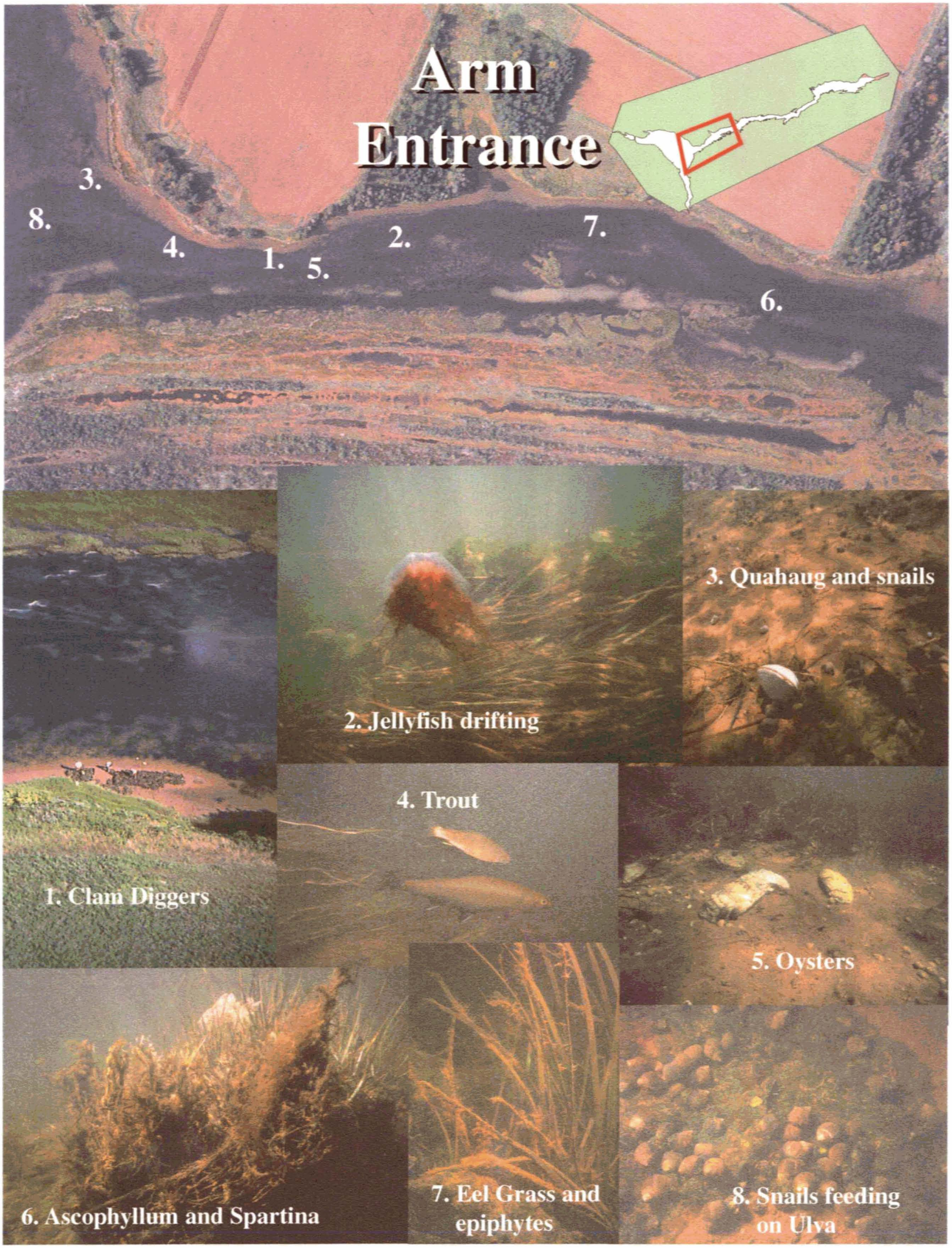


Figure 18. Characteristics of the habitat and biota in the entrance to the northeastern arm of Basin Head.

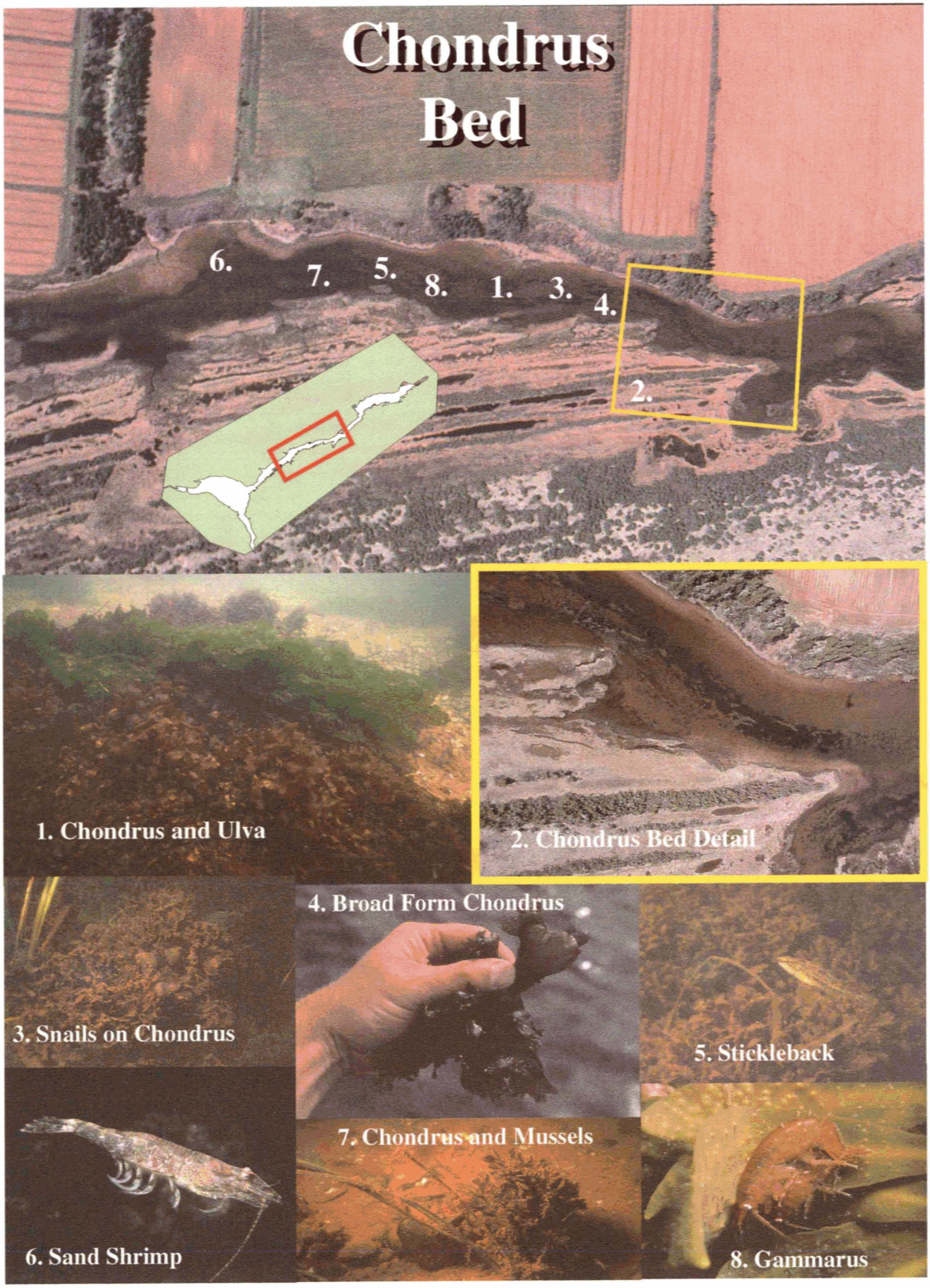


Figure 19. Characteristics of the habitat and biota related to the *Chondrus* bed area of Basin Head. The yellow-framed area is a detailed aerial view of the bed.

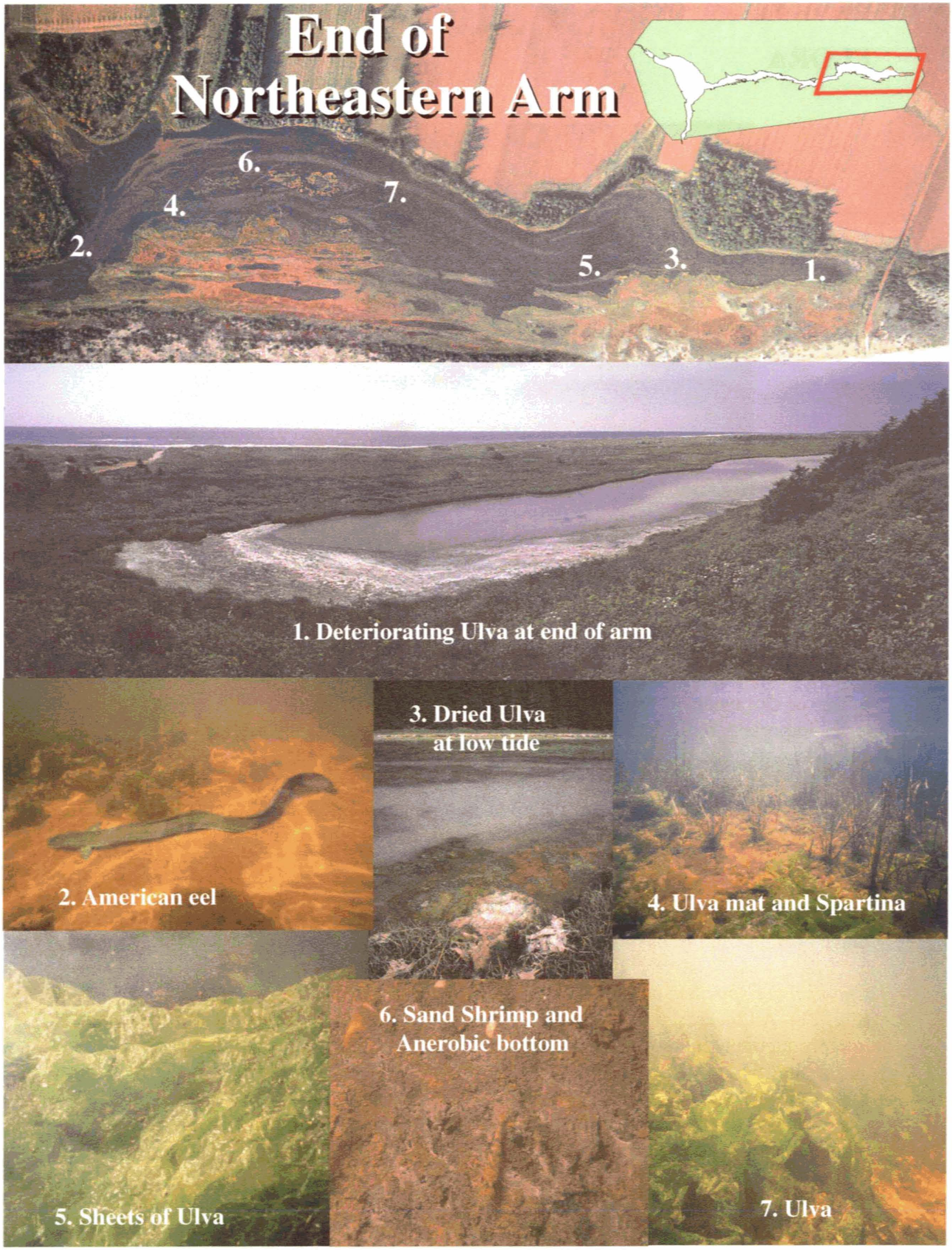


Figure 20. Characteristics of the habitat and biota at the east end of the northeastern arm of Basin Head.

FLORA

IRISH MOSS (*Chondrus crispus*)

Biology
Irish moss is a red alga of commercial value in the phycocolloid industry with up to 30,000 t being harvested in the Maritimes yearly (Pringle and Mathieson 1986). It is a source of carrageenan, which has the properties of emulsifying, gelling and stabilizing. It is an important food additive because carrageenan is natural, tasteless, odourless and colourless.

Irish moss is a perennial alga, distributed in a range of marine environments from semi-sheltered waters to wave exposed outer coasts. It grows in depths from 0 tide level to –15 m. It can tolerate a wide range of salinity from full seawater at 30 ppt to brackish waters about 15 ppt (Chopin 1986). While *Chondrus* has a temperature optimum of 15^0C to 20^0C, it can also survive in waters of -0.5^0C to 30^0C. It is adapted to growth in a wide range of light conditions but turbidity can affect the lower limit of distribution.

Chondrus crispus has a complex life cycle of three phases: two asexual and one sexual (Fig. 21). All macroscopic phases are similar in morphology except for some differences in reproductively mature male and female plants. Cystocarps develop on the female plant and a significant raised surface of thallus tissue is distinguishable from the tetrasporic asexual frond with very shallow swellings. The different life phases can be distinguished with a chemical test that identifies the type of carrageenan; lambda carrageenan indicates the tetrasporophyte phase and kappa the gametophytic plants (Chopin 1986).

Two types or strains of *Chondrus crispus* are found in Basin Head. The normal oceanic strain, which has each of the three life phases, is found attached to rocks at the Channel Entrance in the strong tidal flow. The unique Basin Head moss, also referred to as

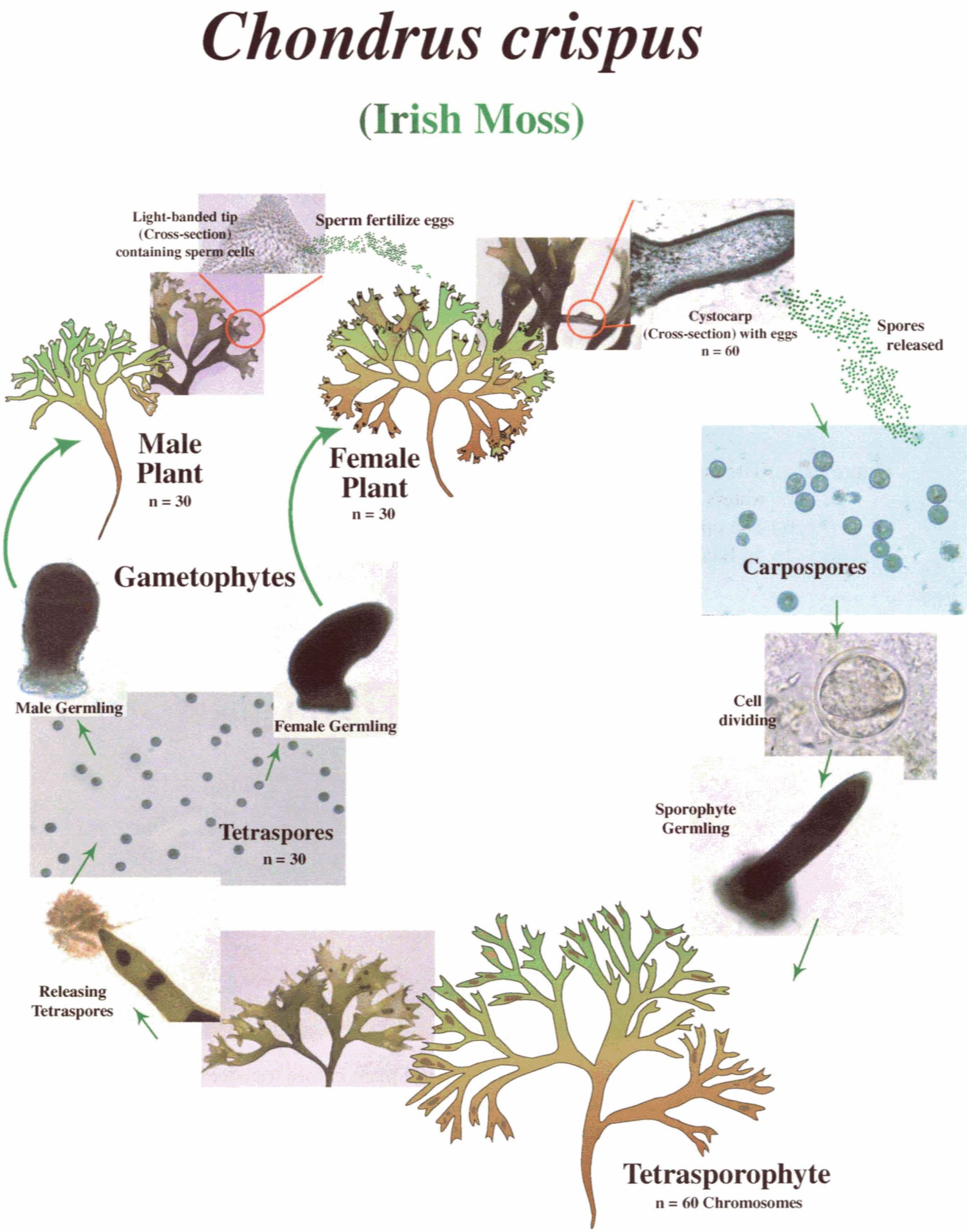


Figure 21. Life cycle of the red algae, *Chondrus crispus*.

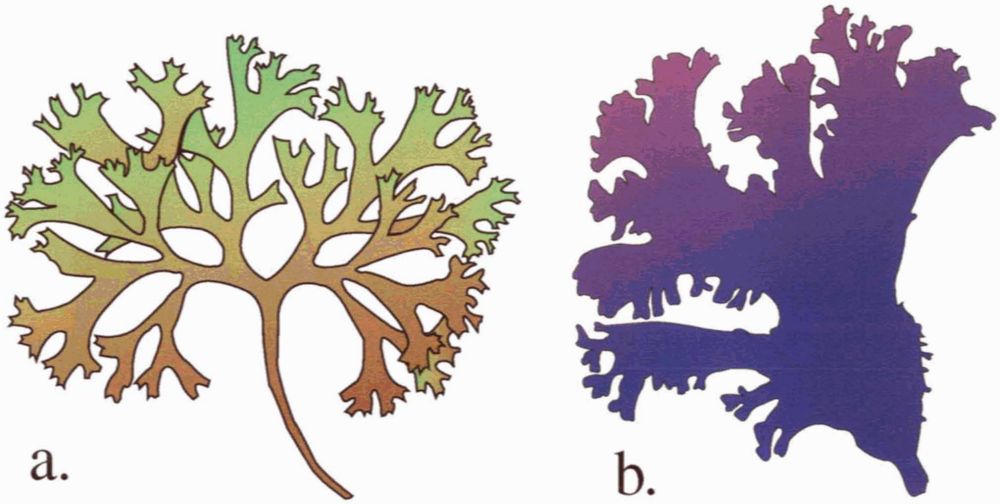


Figure 22. a.) The morphology of a "normal" *Chondrus crispus* plant from the shallow waters around Prince Edward Island.
b.) The unique broad morphology of the *Chondrus crispus* plant found only in Basin Head, eastern P.E.I.

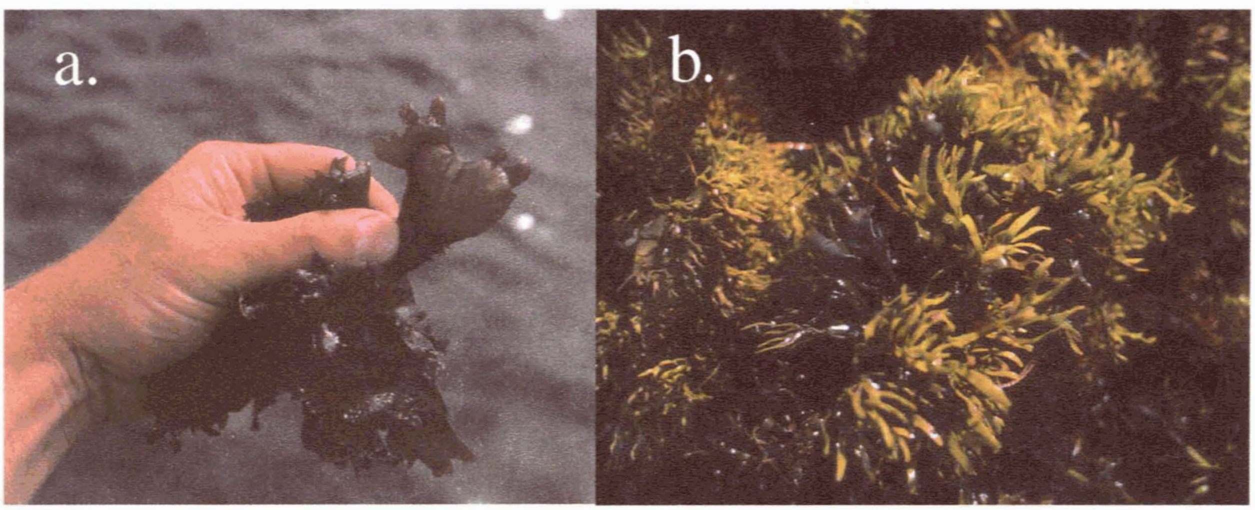


Figure 23. a.) The unique Basin Head *Chondrus crispus* plant before transfer from Basin Head.
b.) The Basin Head *Chondrus crispus* plant exhibiting change in color, shape and growth of tips after aquaculture in Freeland, P.E.I.

"Giant", (Gallant 1990) is occasionally found in the Main Basin but the population is concentrated in the Northeastern Arm in less than 1 m of water. The plant grows in large clumps of fronds often exceeding 500 g on a mud bottom. The fronds are held together by the byssal threads of blue mussels. This plant has very broad fronds with few dichotomies (Fig. 22a & b) in contrast to the oceanic type. It maintains a dark red to brown coloration throughout the year, while the oceanic types exhibit colour changes from red to yellow to green through the summer months. Aside from all these morphological and habitat differences, the most distinct biological feature of the Basin Head moss is the absence of sexually mature plants; thus reproduction is restricted to asexual fragmentation.

Chemical analysis of hundreds of fronds have identified a few tetrasporphytes producing lambda carrageenan but it is not known if these originate in the lagoon. The Basin Head moss is almost 100% kappa carrageenan compared to the 60/40 – 40/60% composition of open coast populations. It has much higher carrageenan yields of 55% to 75% versus 35% to 45% for open water plants (Cheney et al. 1981, Chopin et al. 1999).

McCurdy (1980) described 3 morphological types in the Northeastern Arm: 1. Ordinary (broad thalli, many apices and rubbery texture); 2. Foliose (very wide thick thalli with few apices with new fronds growing from the periphery); and 3. Spriggy (narrow thalli, numerous apices, brittle in texture, and spherical in form). Although recent studies have recognized this range of morphologies in the population at least two of the morphologies can be found on one frond. New growth from fronds that are cut in fragments typically appear as bladelets on the periphery of the frond. When the Basin Head moss is transferred, it does not maintain its morphology. The plant typically dichotomises more frequently leading to a much narrower thallus with a large number of apices (Fig. 23a & b).

Associated Fauna and Flora

Clumps of the Basin Head moss are held together by blue mussels and form patches that are resistant to removal by tidal currents or winds. The most abundant invertebrate is the gamarid amphipod (Table 2). The biomass of mussels is the greatest of the wide suite of invertebrates in these clumps. Gastropoda has the greatest number of species present with the small grazing snail, *Lacuna vincta* having the highest numbers of the group.

Epiphytes are remarkably absent on the patches of Basin Head moss, despite their concentration on adjacent eel grass. Irish moss, in the ocean, commonly has a large number of associated species both epiphytic on the plants and in the surrounding habitat. The intense grazing activity, while directed at associated and epiphytic plants does not seem to target the Basin Head moss as its net biomass increases during the summer peak period of grazing.

Biomass Distribution

The *Chondrus* bed is concentrated in a 500 to 600 m section of the Northeastern Arm (Fig. 24), although small clumps can be found in the Main Basin. The patches of clumps can change in shape and distribution but this bed has been a stable component in this part of the arm over the past 25 years (Murchinson 1977; McCurdy 1980; Judson et al. 1987). The earliest estimates of biomass of the *Chondrus* bed was the year 1977 (Murchinson 1977), followed by two biomass estimates in 1980, one in early summer and one in late summer (Table 3). The area of the bed in 1980 was obtained by measuring 680 transects over a 800 m portion of the arm (McCurdy 1980). Quarter meter square samples were taken at random locations on transects with the biased criteria of 100% *Chondrus* cover (McCurdy 1980). The Provincial Department of Fisheries measured the *Chondrus* bed in 1987 in preparation for an experimental harvest using the same survey methods (Judson et al.1987). Twenty-six transects were established along a base line on the northern shore of the arm. Three 0.25 m^2 samples were taken at random locations on each transect from stations with 100% *Chondrus* cover, a total of 78 samples. Thirty-three random samples were taken in 1988 in the area of the bed that had been harvested in 1987. Twenty-three of the 33 samples from the 0.25 m^2 quadrats had *Chondrus* (Table 3) (Judson et al.1987). The width of the arm and the presence or absence of *Chondrus* was measured at 1 meter intervals on transects across the arm in the known area of the bed in these early studies. The incidence of *Chondrus* on these transects indicate a high degree of patchiness. The variability of the mean biomass value was low in the earlier studies due to the procedure of sampling only the quadrats with 100% cover.

The area of the bed was calculated in 1999 from 24 parallel transects 25 m apart, where the % cover of major plant species were estimated within 1 m^2 on each transect. (Fig. 24) A 0.25 m^2 sample of *Chondrus* was taken in the centre of the transects through the main bed. Samples on the outside of the main bed were taken every 10 m. High resolution aerial photography (1:1000 or better scales) was used in 2000 and 2002 to create a detailed map of the bed (Fig. 25). Air photos were geo-referenced and compiled into one image of the *Chondrus* bed and analysed with an image analysis system (NIHimage) for area calculation and comparison (Table 3).

The dramatic difference in total biomass between our study and those completed earlier can in part be attributed to methodology. Our studies mapped the bed directly while earlier studies measured the water surface of the Northeastern Arm where the bed occurred and subsequently used a presence or absence index to calculate the area of 100% *Chondrus*. This method leads to a bias because the total arm area is considered potential habitat for the bed while the bed is not so widely distributed. Finally, the biomass values applied to this area are higher than those determined by our method. The difference in methods is in the selection of quadrats with 100% cover in the earlier studies compared to our use of quadrats with at least 10% cover. While the overall dimensions of the bed have been relatively constant for over 20 years, the patches of *Chondrus* are dynamic from year to year and perhaps season to season (Fig. 25).

In each study, *Chondrus* was reported to be associated with "foreign" weed meaning other species of seaweed. These foreign weeds were in most cases, sea lettuce reaching 223.5 g 0.25 m^{-2} in the 1988 survey (Gallant 1990). A study of the Basin Head moss bed in 1999 showed the biomass of the *Chondrus* was 488 g 0.25 m^{-2} where the sea lettuce was 100% cover. Eel grass, the other principal macrophyte was 495 g 0.25 m^{-2}. Cover of *Chondrus* along 24 transects surveyed in 1999 averaged 37%. Cover on individual transects in the area of the bed was dominated by sea lettuce or eel grass at the edges of the channel (Fig. 24). Eel grass was the only vegetation rooted to the bottom and was a ubiquitous component of all transects.

Harvesting
This population has recovered from several significant harvests in the past. In 1978, eight tons of Basin Head moss was removed for transfer experiments (PEI 1980). Oyster tongs and pumps were used to harvest 2.7 t in a commercial trial in1981. The provincial Department of Fisheries sponsored the removal of 23 t in 1987 for commercial sale from a 0.75 ha portion of the bed. This was 24% of the total estimate for the total standing crop. (Gallant 1990). The area harvested was not fully exploited as patches of *Chondrus* were documented in 1987 (Table 3) (Judson et al. 1987). A harvest of 21.5 t followed in 1988 (Gallant 1990). Although no licenses were issued under the Fisheries Act to harvest *Chondrus* in Marine Plants Harvesting Area 4, anecdotal reports that illegal harvesting in Basin Head by western PEI based harvesters occurred in the 1990's. The quantities were estimated to be less than 5 t annually. In 1992, a small sample of 30 kg was removed to examine its value as a direct food source (Novacek, pers. comm. 1992) Removals for aquaculture research since 1996 have been limited to less than 1 t and only reached this quota in 2001.

Transplanting Experiments
Experimental transfers of the Basin Head moss were begun in 1978 with limited success in South Lake and East River. A total of 8 t (including mussels and mud) of plants were spread at 1 kg m^{-2}. Screens were used in other sites and the transferred fronds were tied to wire mesh. Murchison (1977) obtained 1 to 2% growth per day in South Lake, Howe Bay, Eglington Bay, Brudenell River, and St. Mary's Bay over a 3 week period. McCurdy (1980) initiated an extensive series of transfer experiments. Basin Head plants were transferred to 15 estuaries, bays and lagoons in western PEI. The growth in these transplants was 0.8 to 4.0% per day in a first growth period of transfer, beginning July 2nd for 3 to 4 weeks (McCurdy 1980). However, during the second growth period in August, most transplants had necrotic tissue and positive growth averaged less than 1%. Experimental transfers of longer duration (May – October) and similar methodology were successful in 3 of 5 estuaries in western PEI (Chopin et al. 1999). Growth rates up to 6% per day and averages of 3% to 4% per day were recorded at Freeland and South Kildare (Fig. 26).

Aquaculture
A viable technique was developed to grow *Chondrus* with a potential for commercial success. This was based on loading plastic mussel socks with chopped fronds of the Basin Head moss (Zertuche-Gonzalez et al. 2001). Experiments to determine the optimal stocking densities, growing periods, harvest regimes and materials handling techniques have been conducted over the past 4 years. Growth rates of 2% to 4% per day were achieved with hanging and bottom culture methods in Malpeque Bay (Fig. 27). These techniques have been scaled to a pilot scale farm but further development awaits investment (Eric Wagner, pers. comm.).

Table 2. Abundance of principal invertebrates associated with *Chondrus crispus* in Basin Head, PEI, August 1999.

Group/species	Mean No. per wet kg *Chondrus*
Gastropoda	
Littorina littorea	0.050
Lacuna vincta	140.758
Hydrobia minuta	50.593
Onoba aculas	7.050
Mitrella lunata	2.532
Nassarius trivitatus	0.050
Bivalves	
Mytilus edulis <1mm	0.000
Mytilus edulis >1mm	123.678
Mya arenaria	2.284
Gemma gemma	8.341
Amphipoda	
Gammarus oceanicus	376.943
Isopoda	
Idothea balthica	0.248
Jarea marina	0.248
Idothea phosphora	0.149
polychaetes	5.015
mysids	0.055

Table 3. The area, biomass density and standing crop of the Basin Head strain *Chondrus crispus* bed over the last 22 years in Basin Head, PEI.

Study/Author/Year	Mean Biomass g 0.25 m^{-2}/sd	Total Area (h)/ Cover/# transects	Biomass in bed (t) (90% Confidence)	Comment
Murchison 1977	700 g		95 t (90% Confidence)	
McCurdy 1979	1764 g ±1616	No estimate	No estimate	
McCurdy 1980 (June)	2476 g ±1074 *N=76*	1.56 h ±.30/.26/440	154 t (114-199) (90% Confidence)	
McCurdy 1980 (Aug.)	2306 g ± 615 *N=76*	1.38 h ±.42/.23/240	127 t (82-178) (90% Confidence)	
Judson et al 1988	2668 g ± 924 *N=24*	0.96 h ±.31/26	101 t ± 14.9 (95% Confidence)	Harvested 23 t
Gallant 1990	792 g ±1080 *N=22*	No estimate		Harvested plot
This Study (1999)	1831 g ±1433 *N=20*	1.50 h ±.00/1.0/26	110 t	Area transect
This Study (2000)	1831 g ±1433 *N=20*	.69	49.7 t (90% Confidence)	Air Photo
This Study (2002)	1831 g ±1433 *N=20*	.62	45.6 t (90% Confidence)	Air Photo

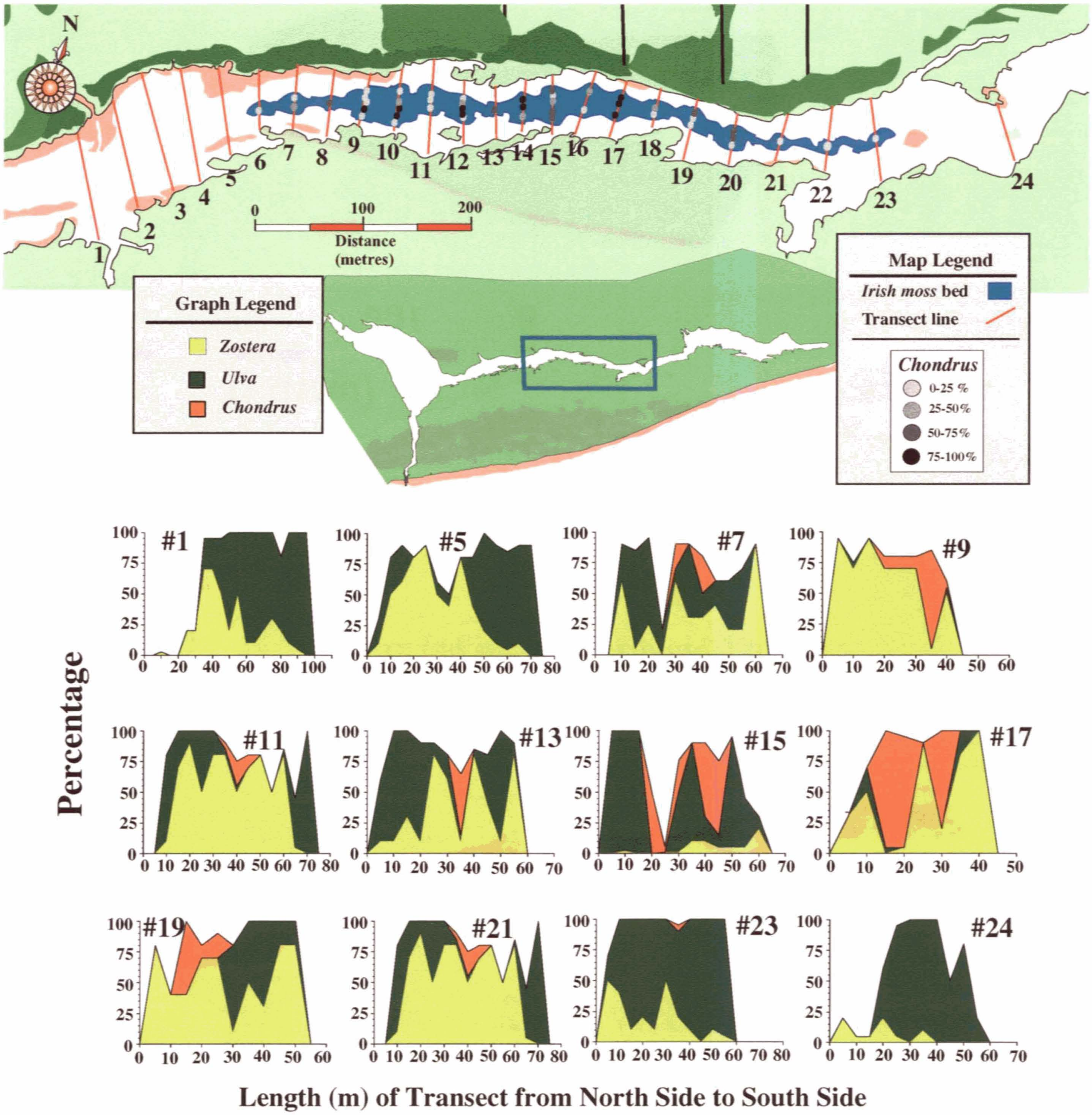


Figure 24. Percentage cover of *Zostera, Ulva* and *Chondrus* along 24 transects of the Basin Head Irish moss bed from July, 1999 survey.

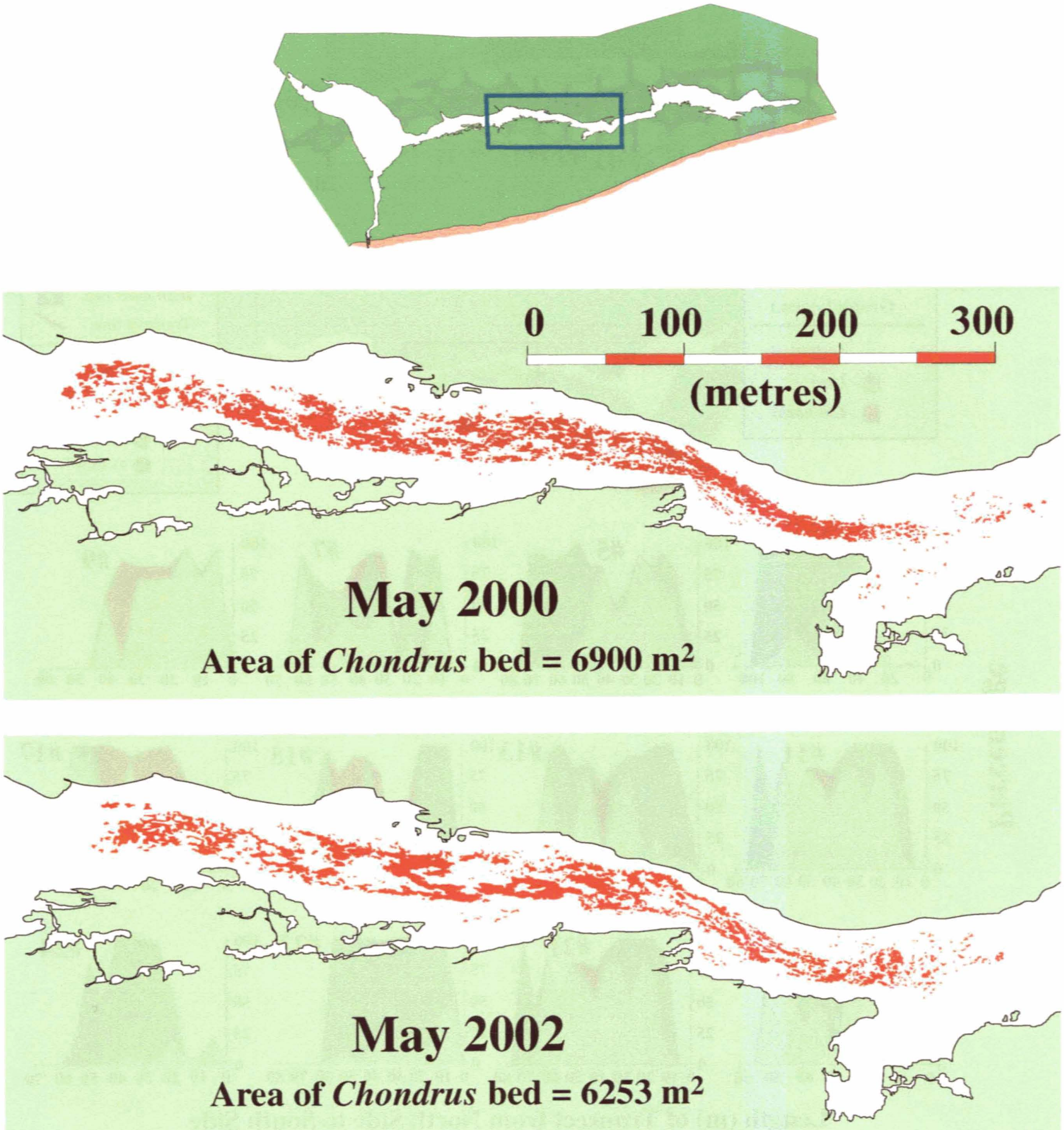


Figure 25. The dynamics of *Chondrus* patches in the Basin Head bed in 2000 and 2002.

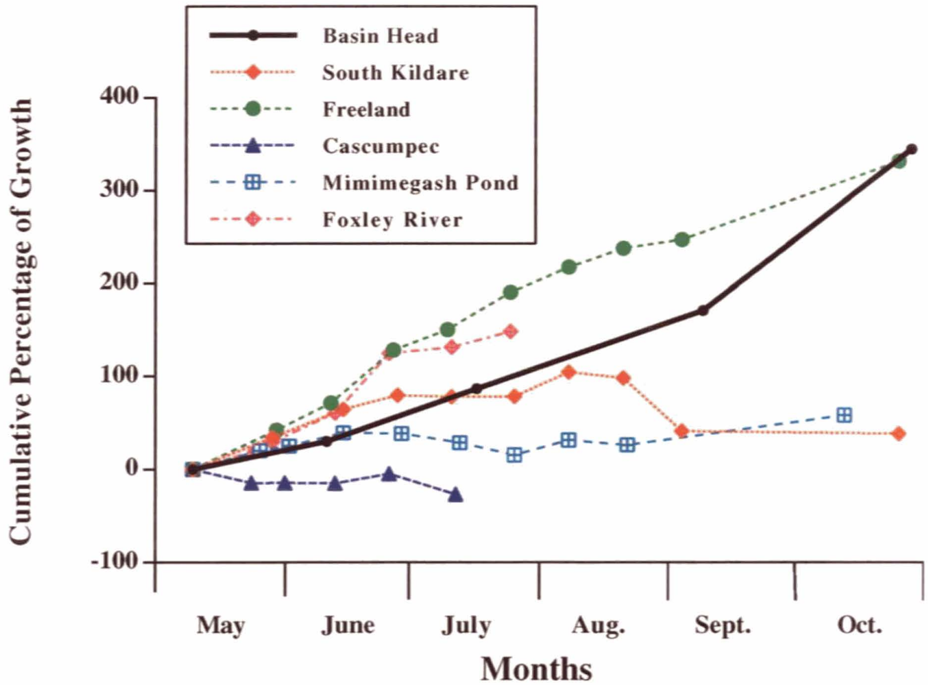


Figure 26. Cumulative percentage growth of *Chondrus* plants transplanted in five estuaries in Prince Edward Island from May to October, 1997.

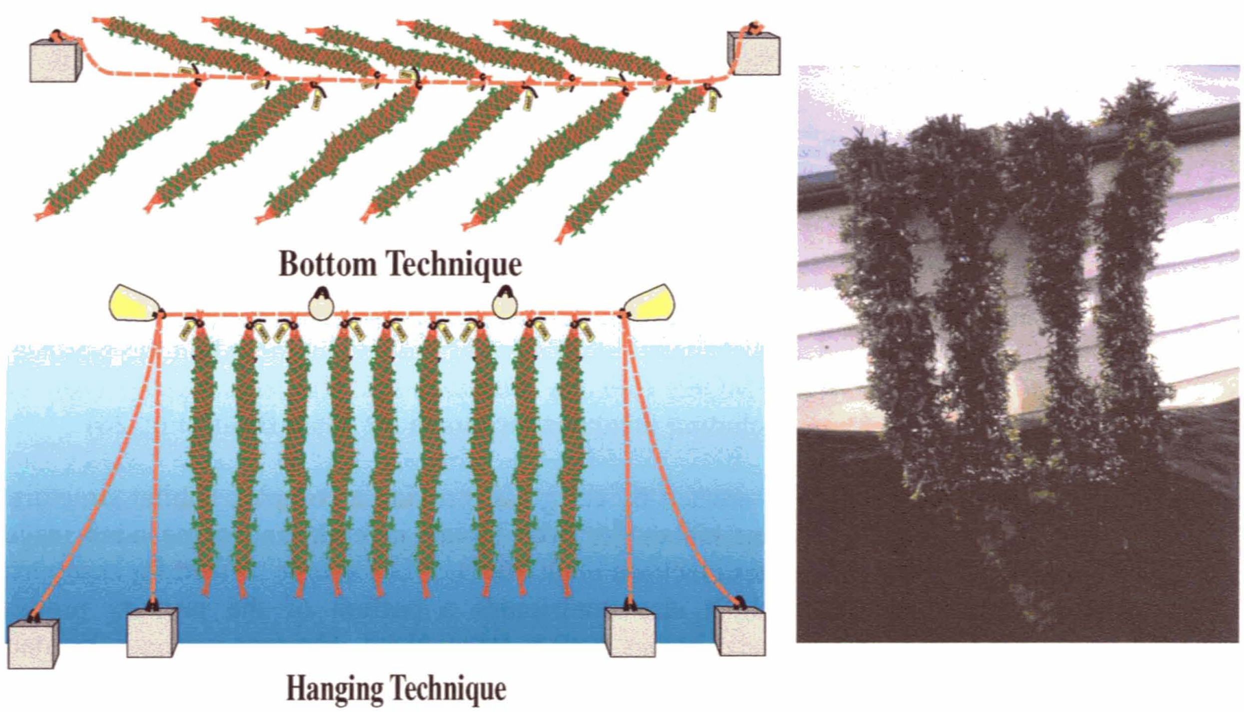


Figure 27. Two techniques of growing Irish moss in mussel socks on the ocean bottom and long-lines. Basin Head moss in mussel socks after after four months aquaculture.

EEL GRASS (*Zostera marina*)

Biology

Eel grass is a submerged angiosperm that grows both in sheltered shallow estuaries and the open ocean. Its shoots grow up to 2 m in length, rising from a rhizoid root system. In shallow waters these shoots are lost in the winter and replaced in the early spring. This is a perennial flowering plant but may act as an annual in stressful conditions. Although fertilisation can occur from May to September, it reproduces mainly vegetatively by rhizome growth except in areas of sediment disturbance. Seeds can be dispersed many kilometres by water currents and by waterfowl (Fishman and Orth 1996). The rhizome system of a bed can be 50 years old and the bed can grow in edge dimensions from 5 to 30 m per year (Short and Neckles 1999). The persistence of this species is considered critical to the maintenance of a healthy estuarine ecosystem (Short et al. 1995). In Basin Head, eel grass is widely distributed in all parts of the lagoon including the Northeastern Arm (Fig. 24, see IRISH MOSS *Biomass Distribution*). The largest cover (100%) and biomass (4.0 $^{\pm}$2.0 kg m^2 including rhizomes) occurs in the Main Basin (Fig. 28).

The underwater meadows created by eel grass, provide a complex habitat structure that has a number of important niches for both larval, juvenile and some adult stages of invertebrates and vertebrates (Jackson et al. 2001). It is a source of feed for many trophic levels including wildfowl. It also contributes a portion of the primary production particularly in restricted water bodies such as Basin Head. The root system helps stabilize sediments and the total plant is a water filtration system (Short and Burdick 1996).

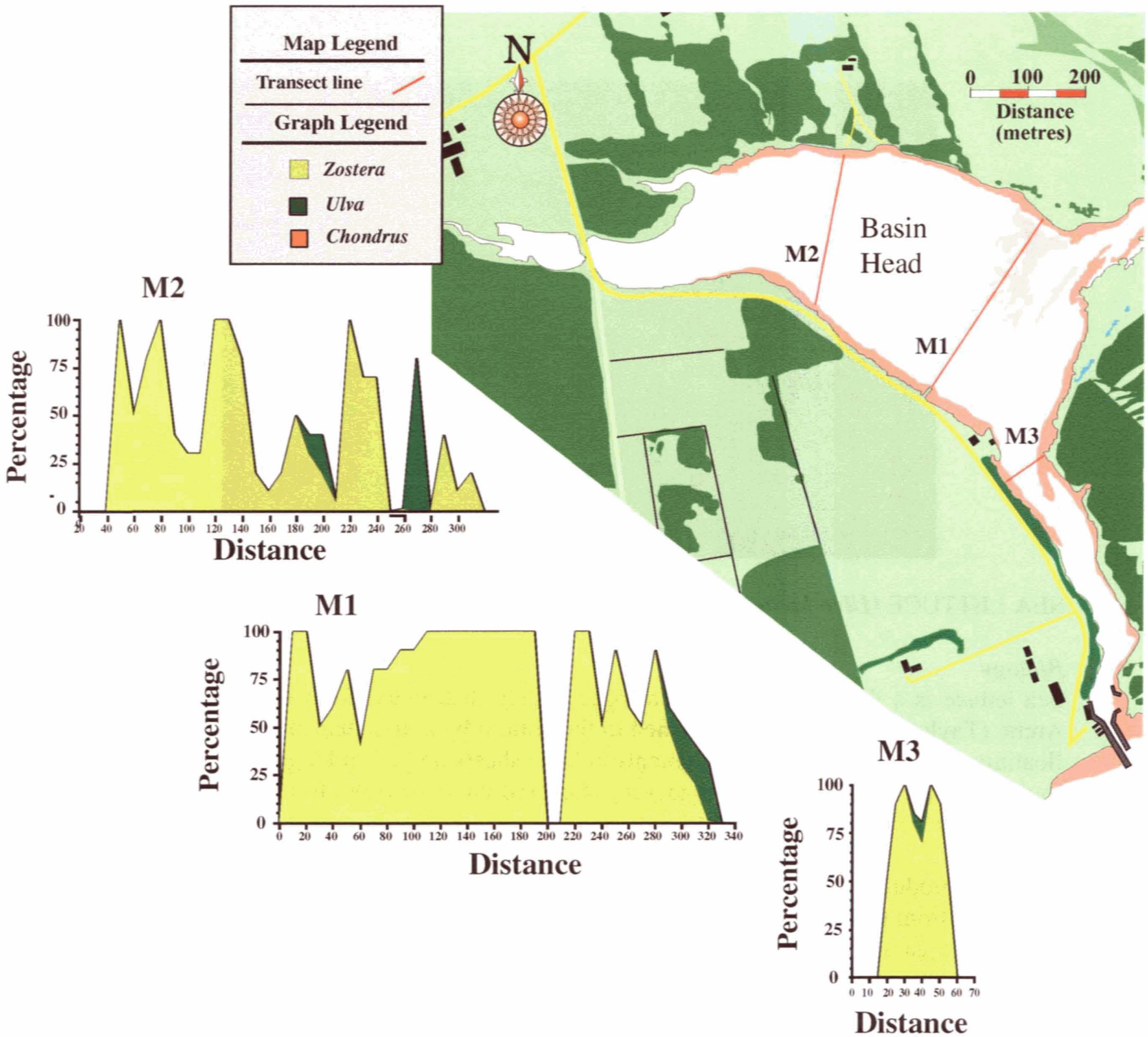
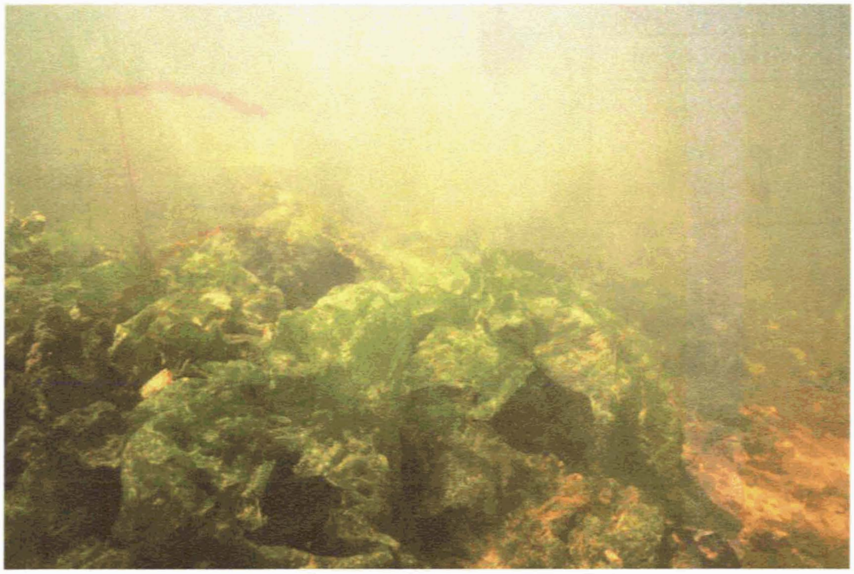


Figure 28. Percent coverage of the major seaweeds from 3 transects located in the main basin of Basin Head, PEI in July, 1999.



SEA LETTUCE (***Ulva lactuca***)

Biology

Sea lettuce is a thin, sheet-like green algae widely distributed from the Tropics to the Arctic (Taylor 1972). It can be attached to the bottom by a disc shaped holdfast or found floating unattached from small fragments to large sheets up to 2 m long. Locally it can be found in wave exposed locations to very sheltered environments, from the lower inter-tidal to over 10 meters sub-tidally.

It will reproduce asexually by fragmentation or by development of quadriflagellate zoospores from thallus cells (Fig. 29). Sexual reproduction is via motile biflagellate male and female gametes and subsequent external fertilization and zygote formation, which settle to form germlings.

Sea lettuce can tolerate a wide range of environmental factors, including temperatures from -1^0 C to 30^0 C, and salinity less than 10 ppt to over 30 ppt (Rivers and Peckol 1994). Ulva is one of the fastest growing algal species (>30% per day) but does not have nitrogen reserves to sustain growth for over 6 days (Pederson and Borum 1996). Its large surface area for absorption allows it to very rapidly take up nitrogen in the form of NO_3 or NH_4 at 4 to 6 times the rate of slower growing red algal species per unit biomass (Pederson and Borum 1996).

Distribution

Sea lettuce is only rarely attached to the bottom in Basin Head. It can be found on bivalve shells, primarily mussels and oysters or on sandstone at the Channel Entrance. However, the majority of the sea lettuce biomass is unattached laying on the bottom, among eelgrass, entwined in marsh grass, *Spartina,* floating in the water column, at the surface or in layers on the bottom in quiescent areas of the lagoon.

Ulva lactuca

Sea Lettuce

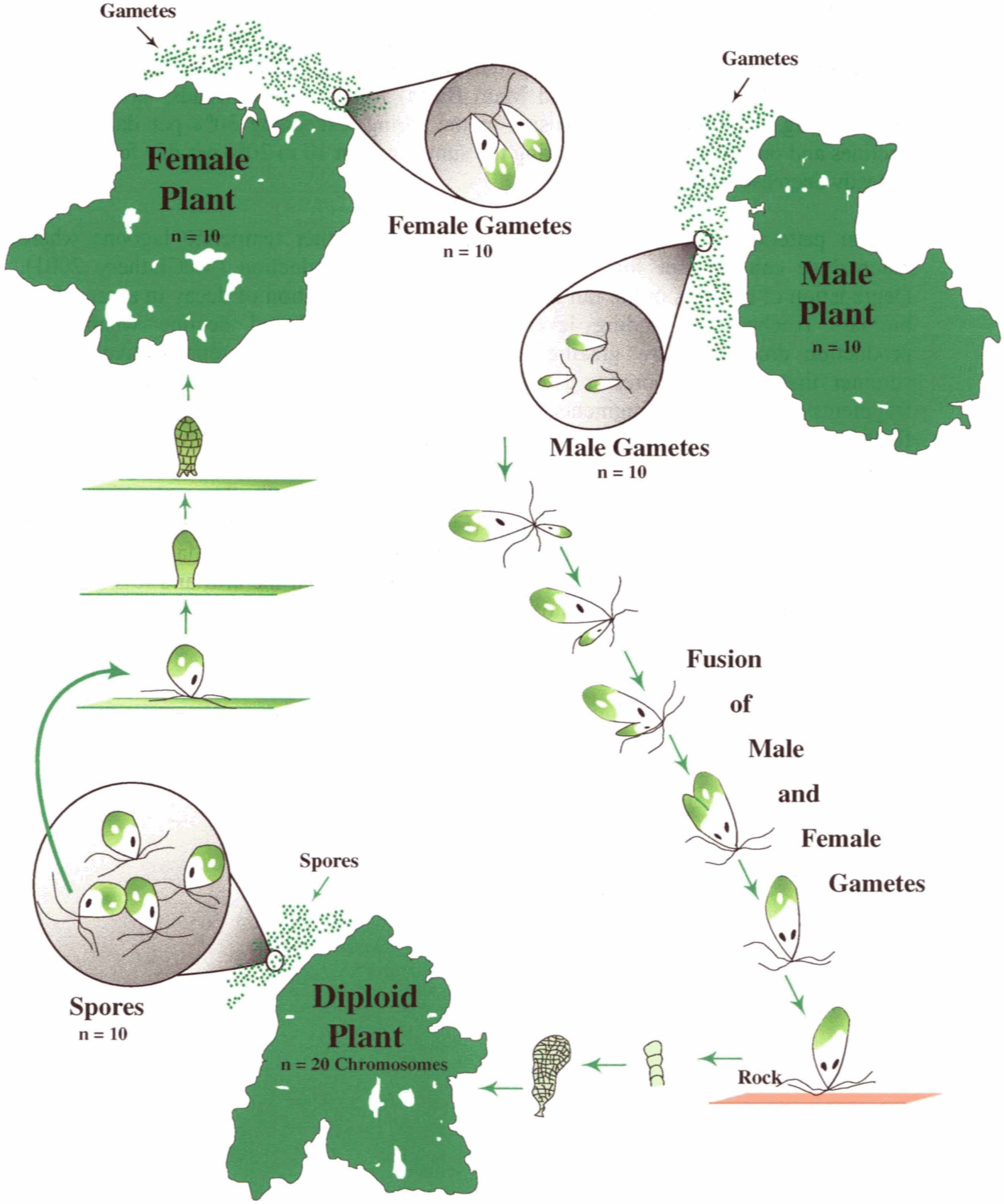


Figure 29. Life cycle of the green algae, *Ulva lactuca*.

The distribution and abundance of sea lettuce changes dramatically over the year due to growth and degradation processes. There is residual *Ulva* biomass at the head of the eastern arm and near the highway bridge in the winter but during the summer it is present throughout the lagoon (Fig. 30). The pattern of seasonal growth in area and biomass at two stations (Northeastern Arm and Main Basin) follow similar trends, as do annual patterns (Fig. 31). Growth is explosive in the spring, exceeding 30% per day, then it declines and pulses several times during the summer from 10 to 20% per day followed by a steady decrease in the fall (Fig. 31)[2].

Similar patterns of sea lettuce growth are found in other temperate lagoons where macroalgae can account for up to 96% of benthic production (McGlathery 2001). Degradation of biomass in the fall appeared to be a combination of decay in areas where biomass reached self-shading levels and herbivore-mediated decline when Ulva production dropped below grazing rates. When *Ulva* becomes reproductive in late summer, the release of spores or gametes weaken large parts of the thallus and the plant fragments easily. These fragments are carried by the tides out of the lagoon in the flushing cycle or become part of organic material on the bottom. Over a 15 minute period, up to 180 g dry wt of *Ulva* was captured in a 1.0 m^2 net on an outgoing tide at the junction of the Northeastern Arm and the Main Basin in 1999. The velocities of the incoming and outgoing tides were similar (Fig 32a) The outgoing tide carried more sea lettuce than the incoming tide, both at the Northeastern Arm and the Main Basin station (Fig. 32b & c). It appears there is export of sea lettuce from the arm and less from the basin. Movement of large amounts of drift material is a critical part of the *Ulva* biomass budget in sheltered waters.

[2] In 2002 an additional *Ulva* growth monitoring station was added near the inlet of stream 3

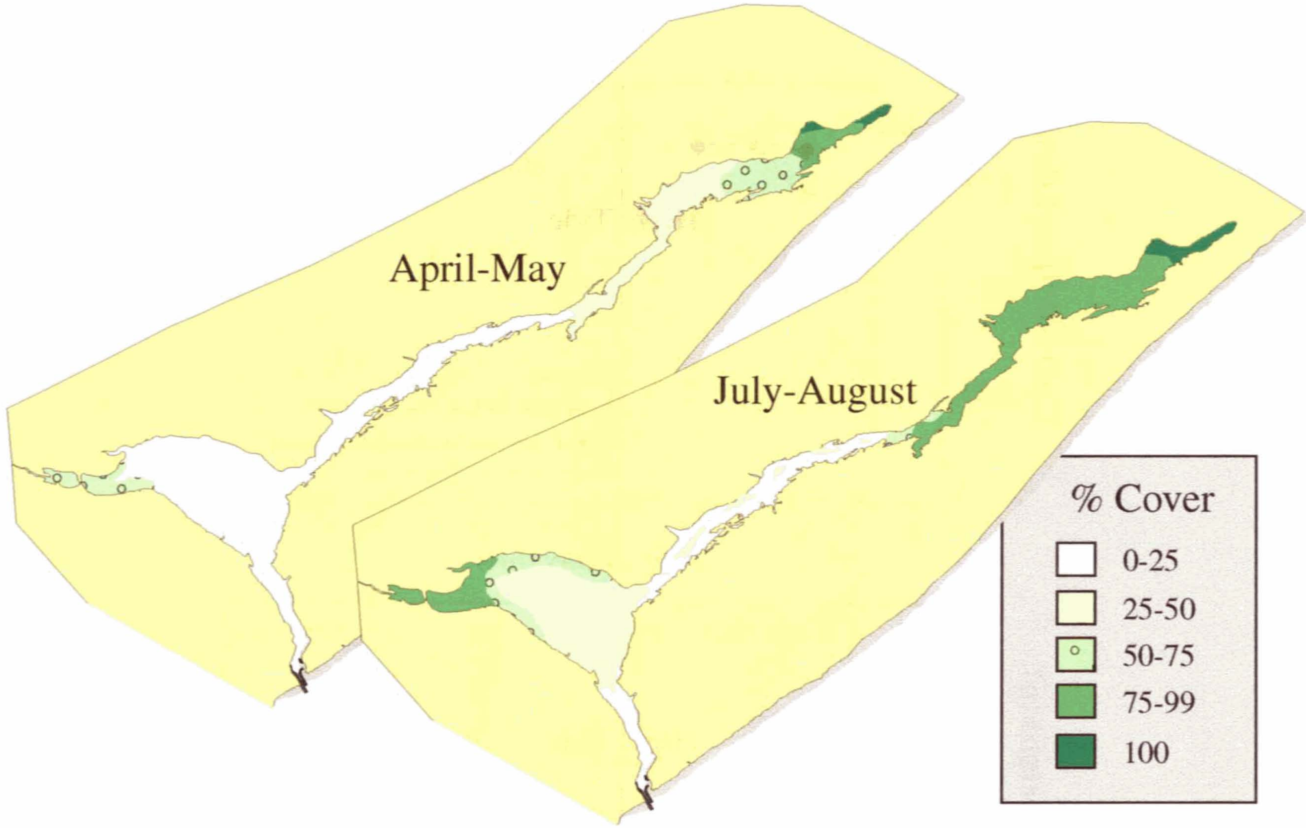


Figure 30. Percentage of *Ulva* cover in the Basin Head lagoon for the spring period of April-May and the summer period of July-August.

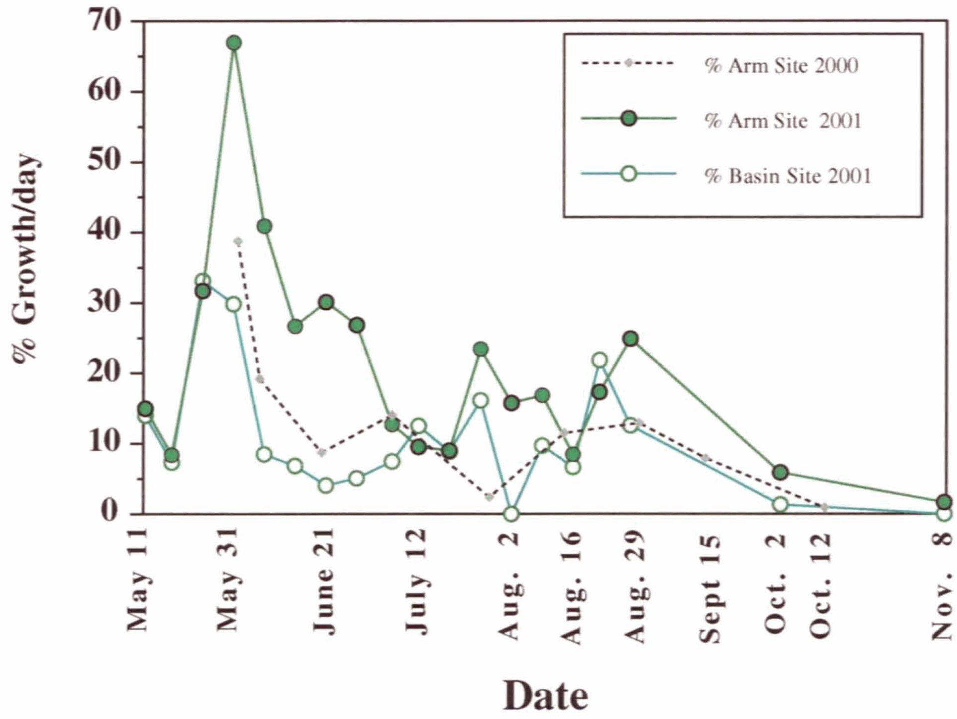


Figure 31. Percentage growth of *Ulva* per day at the Main Basin station D and middle arm station B for May to Oct.,2000 and May to Nov., 2001.

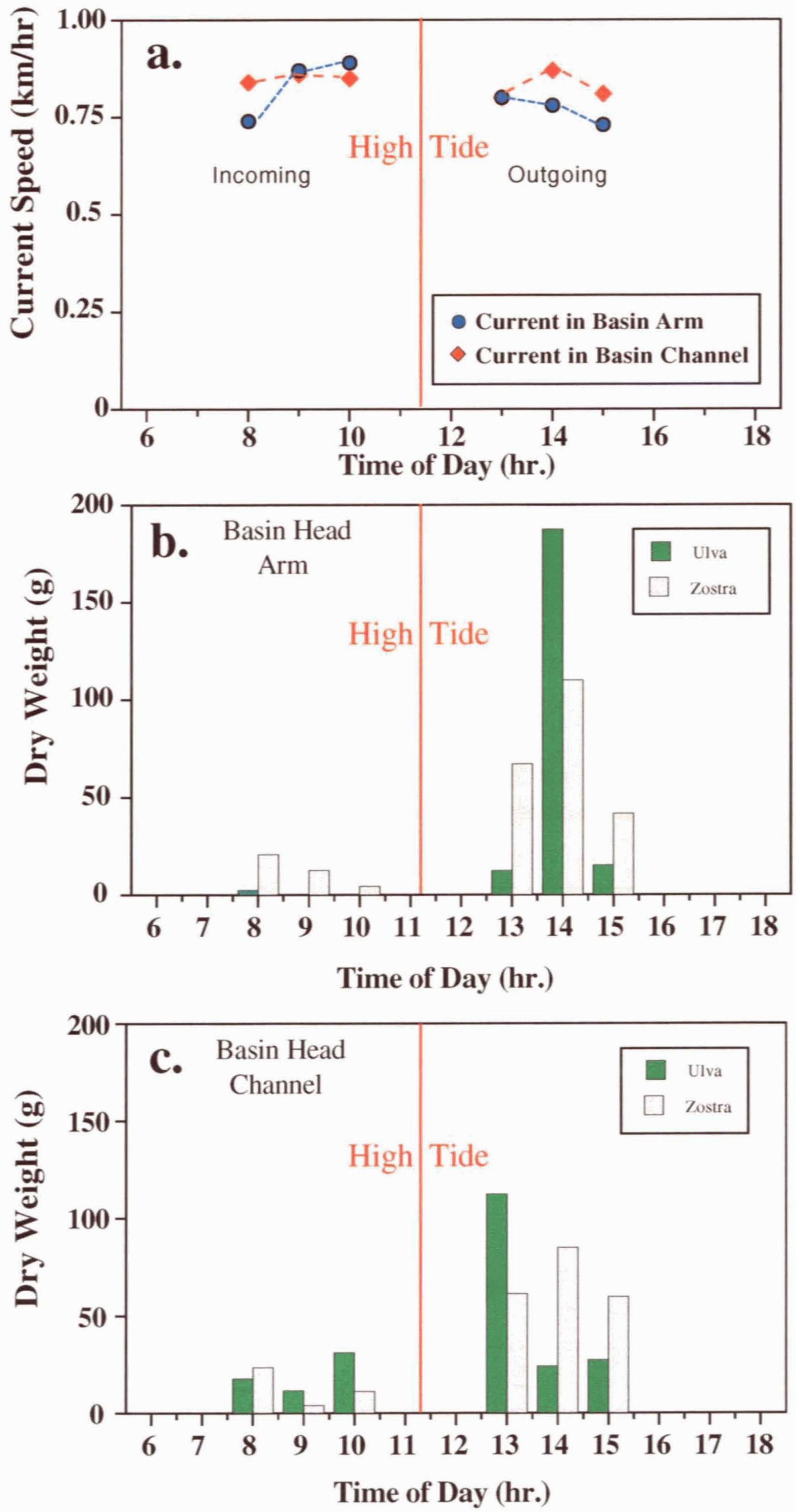


Figure 32. Current speed (km/hr) in the main basin and the eastern arm (a.) in relationship to the rise and fall of the tide. The amount of major drift seaweed moving with the current in both (b.) the arm and (c.) the main basin channel.

FAUNA

FISH SPECIES

Diversity
Basin Head contains a variety of finfish species, which is typical of sheltered bays and estuaries on PEI. Beach seining was the first method used to develop a fish species inventory in Basin Head and this technique identified 6 fish species (Table 1). The American eel and mummichog were abundant (see BIOLOGY *General Biology and Diversity*) (McCurdy 1980). Research fishing using fyke nets in September 2002 provided a rough indication of relative abundance of finfish in the lagoon (Fig. 33). Total catch per unit effort (CPUE) of all finfish was 14.1 fish per net-day (Table 4). *Fundulus* spp. (mummichogs and banded killifish) dominated catches by number, with a summed CPUE of 9.33 fish per net-day. American eels (see below) and winter flounder accounted for most of the rest of the catch. Other species (white perch, white hake, brook trout, unidentified sculpin) contributed 0.9% of total finfish CPUE. No smelts were found in research fishing. There is relatively little smelt fishing in eastern Kings County and smelt fishing effort in Basin Head has been sporadic (Cairns 1997; Island Nature Trust 2001; M. Rose, pers. comm.).

Fyke nets were placed in the entrance channel, roughly 100 m north of the wharf area, in September 2002 (Fig. 33). Results do not provide a valid CPUE because the nets filled with algae and were often distorted by the current. Finfish taken in these nets included mummichogs, winter flounder, Atlantic cod, and sculpins.

An index of biotic integrity (IBI) was developed for *Zostera marina* (see POTENTIAL ECOLOGICAL PROBLEMS Eel Grass Meadows) to be able to monitor habitat health. Beach seines and minnow traps were used in this study to sample fish at 11 locations in the lagoon (Fig. 33). The beach seine, conducted in September, 30 m long and 1 m deep was used along the accessible beaches at 7 sites. To compare catch rates, 2 to 10 minnow traps were baited with cat food and set near the beach seine stations. Ten species of fish were caught during beach seining with an average total abundance per haul of 205 fish and diversity of 5.6 species. Mummichogs and fourspine sticklebacks (Table 5) dominated the littoral fish community during this time of year (early September). Winter flounder (juveniles), threespine sticklebacks and Atlantic silversides were also common. Less common were ninespine sticklebacks, young-of-the-year gaspereau, cunners, blackspotted sticklebacks and a sculpin (grubby).

Nine fish species were caught in minnow traps with an average of 20 fish and 2.1 species per trap. The same two fish species that dominated beach seine catches dominated minnow trap catches: the mummichog and fourspine stickleback (Table 6).

A congeneric but different species of sculpin was caught by minnow trap (shorthorn sculpin) than beach seine (grubby) and unlike the beach seine catch, the minnow traps caught an American eel but did not capture any threespine sticklebacks or gaspereau. There is a concern that beach seining, at least without higher effort than 7 hauls per location, may not fully characterise a littoral fish community. This is justified as it caught only 10 of the 12 fish species known to be present at the time of sampling. Of the 3 types of gear, the fyke nets worked the best. The nets, fished at approximately the same time, caught another 5 species that the beach seine and minnow traps did not catch. These were white perch (*Morone americana*), banded killifish (*Fundulus diaphanus*), white hake (*Urophycis tenuis*), brook trout (*Salvelinus fontinalis*) and Atlantic cod (*Gadus morhua*). The total known count was 17 species present in the Basin Head ecosystem.

While none of the three types of gear caught all of the species known to be present, they all showed mummichogs are overwhelmingly the dominant. Fyke nets ranked eels second most abundant but the smaller meshed and more littoral beach seine and minnow traps both showed the small fourspine stickleback in second place. This degree of agreement among techniques on the most ubiquitous and abundant species suggests that low-effort beach seining provides an accurate assessment of dominant community-members at the time of sampling. Greater effort in beach seining, and night sampling, has been shown to increase number of fish species caught. If total species counts are important to IBI measurement in Basin Head, repeated beach seining could be done to provide advice on the requisite effort to catch all, or nearly all, species. It is also true that species counts will increase with longer duration sampling because some species will use this habitat at only certain times of year. An example of this would be rainbow smelts are known to inhabit Basin Head (Island Nature Trust 2001) but were absent from samples.

Table 4. Finfish and macro-invertebrates recorded in research fishing using fyke nets in Basin Head, June 4-Sept. 5, 2001 (Main Basin); Sept. 3-16, 2002 (Main Basin) and Sept.19-27, 2002 (Channel Entrance). Effort was 20 net-days in 2001 and 60 net-days in 2002.

Species	Individuals captured per net-day		
	2001	2002	
	Main Basin *	Main Basin *	Channel Entrance **
American eel	14.60	2.48	
White perch		0.05	
Mummichog		3.23	P
Banded killifish		1.68	
Mummichog/killifish (not identified to species)		4.42	
Winter flounder		1.78	P
Flatfish (not identified to species)		0.38	P
White hake		0.02	
Atlantic cod		0.00	P
Brook trout		0.02	
Sculpin (not identified to species)		0.05	P
Total finfish		14.12	
Rock crab		3.22	P
Green crab		53.60	P
American lobster		0.00	P

* From D. Audet (Unpublished data). Data available only for the American eel.

** Quantitative catch per unit effort not available. 'P' indicates species was present

Table 5. Fish caught in Basin Head by beach seine (N=7 hauls) September 2002.

Common Name	Species	Abundance - Mean CPUE (# per haul)	Ubiquity (# sites present of 7)
Mummichog	*Fundulus heteroclitus*	80.3	5
Fourspine Stickleback	*Apeltes quadracus*	64.3	7
Winter Flounder	*Pleuronectes americanus*	21.3	4
Threespine Stickleback	*Gasterosteus aculeatus*	13.7	7
Atlantic Silverside	*Menidia menidia*	13.0	4
Ninespine Stickleback	*Pungitius pungitius*	5.9	5
Gasperau	*Alosa* sp.	3.4	1
Cunner	*Tautogolabrus adspersus*	2.1	3
Blackspotted Stickleback	*Gasterosteus wheatlandi*	1.0	2
Grubby	*Myoxocephalus aenaeus*	0.1	1

Table 6. Fish caught in minnow traps (N=25 distributed among 7 sites) over 1 night-set at Basin Head, P.E.I., September 2002.

Common Name	Species	Abundance - Mean CPUE (# per trap-night)	Ubiquity (# sites present of 25)
Mummichog	*Fundulus heteroclitus*	15.6	21
Fourspine Stickleback	*Apeltes quadracus*	3.3	18
Winter Flounder	*Pleuronectes americanus*	0.2	4
Cunner	*Tautogolabrus adspersus*	0.2	3
Atlantic Silverside	*Menidia menidia*	0.1	2
Ninespine Stickleback	*Pungitius pungitius*	0.1	2
Shorthorn Sculpin	*Myoxocephalus scorpius*	0.04	1
Blackspotted Stickleback	*Gasterosteus wheatlandi*	0.04	1
American Eel	*Anguilla rostrata*	0.04	1

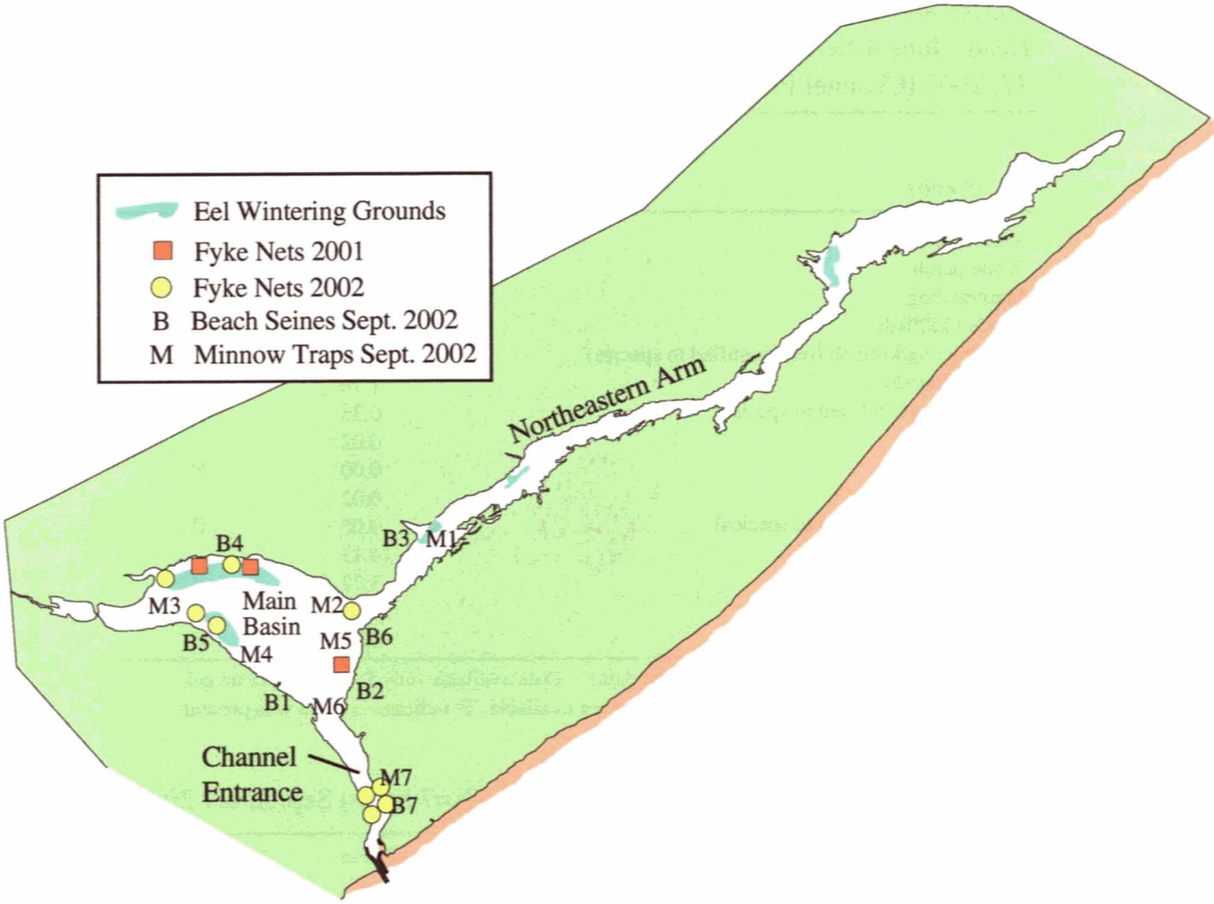


Figure 33. Location of the wintering grounds of the American eel and the locations of the fyke nets, beach seines and minnow traps in 2001 and 2002 at Basin Head, P.E.I.

AMERICAN EEL (*Anguilla rostata*)

Distribution

The American eel is one of the main finfish species occupying Prince Edward Island estuaries, where it is subject to a significant commercial and recreational fishery (Cairns 1997). The American eel forms a single stock in the west Atlantic. The species has been decreasing through most of its range in the last two decades (Haro et al. 2000). Landings data and subjective evaluations by fishermen suggest that eel numbers on Prince Edward Island are much lower than they were in the 1980's (Cairns 2002).

Basin Head is a traditional harvest site for recreational eeling (Island Nature Trust 2001). Eels are taken by spearing through the ice in winter, principally along the north side of the Main Basin, and in the Northeastern Arm (Mark Rose, Souris West, PEI, pers. comm.). A brief survey using a glass-bottomed boat on November 5, 2002 confirmed presence of wintering burrows in the lagoon (Fig. 33). Between 1977-1986, annual eel derbies were held on the ice, and attracted large numbers of participants as noted in the Charlottetown Guardian, February 16, 1981. The derbies ended because catch rates declined sharply. During the 1990's, relatively little eel fishing occurred in Basin Head.

Research and commercial fishing found substantial eel populations in Basin Head in 2001. Fyke nets deployed in a green crab study in June-September caught 14.6 eels per net-day (Table 4). This is equivalent to 3.3 kg of eels per net-day, which is the highest catch rate recorded in any research or commercial eel fishery in PEI (Cairns et al. in prep.). In fall 2001, one commercial fisherman fished eels in the Main Basin and the Northeastern Arm of Basin Head. A commercial fishery operated briefly in Basin Head in August 2002, but was shut down because the area had been closed to commercial fishing by variation order. From September 3 to 16, 2002, a research fishery using fyke nets captured 2.48 eels per net-day, equivalent to 0.59 kg of eels per net-day.

Basin Head is a relatively small, nearly enclosed body of water; therefore its eel populations may be particularly vulnerable to over-fishing. In many PEI estuaries, eel production from inflowing fresh waters bolsters the estuarine populations. This is unlikely to occur to any significant extent in Basin Head because the inflowing streams are very small. Local residents attribute the collapse of populations of the winter eel spearing grounds to over-fishing. Resident eel populations are influenced by fishing pressure and by elver recruitment rates. The relative importance of these two factors in determining Basin Head eel populations has not been measured.

GREEN CRABS (*Carcinus maenas*)

General Biology

The green crab was accidentally introduced on the American coast between the states of New Jersey and Massachusetts (Cape Cod) in the 19^{th} century. On the northeast American coast, the green crab was first documented in New York and New Jersey in 1817 and slowly moved northward towards New England where it was reported in Casco Bay (Maine, USA) in the early 1900's (Rathburn 1905). During the following 50 years, the species colonized various estuarine habitats along the coast of Maine up to the Bay of Fundy in Canada (Scattergood 1952, Glude 1955, MacPhail et al. 1955). By the 1960's, there has been a progressive expansion of its range to the southwestern coast of Nova Scotia (Glude 1955, Ropes 1968, Welch 1968). During the next 20 years it progressed up the Atlantic coast of NS (Berrick 1986). In the last decade the green crab pursued its northward expansion and recently (1997) invaded the southeastern part of PEI.

A two year field project was conducted from June to November 2000 and from May to December 2001 in Basin Head, to characterise the demographics and the biology of *C. maenas* at the northern end of its western range (Fig. 34). Baited modified eel traps were used as fishing gear. Fyke nets and megalopae collectors were also deployed to capture ovigerous females and juvenile crabs, respectively. The collectors are wiremesh boxes (0.61m x 0.61m x 0.15m) filled with *Crassostrea virginica* shells as described by Serfling and Ford (1974). A total of eight sampling sites were established in different regions of the Basin Head lagoon to obtain a pattern of distribution. Sites 2, 3 and 5, were situated in the main basin. Sites 1, 4 and 6 were established in the Northeastern Arm within the first kilometre of the 3.0 km arm to prevent any perturbation to Basin Head moss bed. Sites 7 and 8 were placed in the 500 m long sandy entrance channel, which is the only opening toward the Northumberland Strait. Water temperatures were recorded at each sampling site from June to December, 2001.

Green crabs were captured and brought to the laboratory for measurement and biological observations. Spawning was determined by observing the proportion of egg bearing females captured in the fyke nets. The gonadosomatic index (GSI) was calculated by-weekly as the ratio between the wet ovary weight and the carapace width, multiplied by 100. The mating period was estimated by measuring the proportion of females with a spermatheca filled with spermathophores, result of a recent copulation. The moulting period of females is synchronised with the mating period, since the female has to be soft and newly moulted to perform mating. The male moulting period was evaluated by computing the proportion of adult crabs in a post-moult state according to the colour of their abdomen and sternum. Green crabs exhibit a wide range of coloration from pale green for newly moulted crabs to dark red associated to a prolonged intermoult period (Kaiser et al. 1990). Size at maturity was determined by analysing the allometric growth of sexual characteristics of both males and females. The methods used were based on detecting the relative change in the growth of the dominant chela of males and the abdomen width of females after the puberty moult with stepwise regressions.

Population Structure

The maximum total number of green crab captured occurred from August to November when the mean temperature ranges from 21.59 $\pm$1.96°C to 3.99 $\pm$2.07°C, respectively (Fig. 34). The highest number of crabs captured in the baited traps occurred in November for both sexes, but more significantly for females. However, the proportion of females is significantly higher ($P < 0.05$) in the spring period and the males were more abundant in the traps from August to December. The abundance of green crabs in the baited traps fluctuates with season and the sex, but the geographical dynamics of the male and female populations can also be observed over time (Fig. 35). The catches from the Main Basin of the lagoon (Sites 2, 3 and 5), were dominated by males from July to December, but female abundance seems to follow the average abundance pattern over the same period. Male crabs dominate the catches at sites 4 and 6 in the Northeastern Arm from July to September-October (Fig. 33, see FISH). However, during the fall season, females seem to take advantage of the Northeastern Arm. The numbers of both male and female captured in traps increased in the Channel Entrance(Sites 7 and 8) during fall, suggesting that there might be a non-generalised migration to deeper waters when temperatures are decreasing.

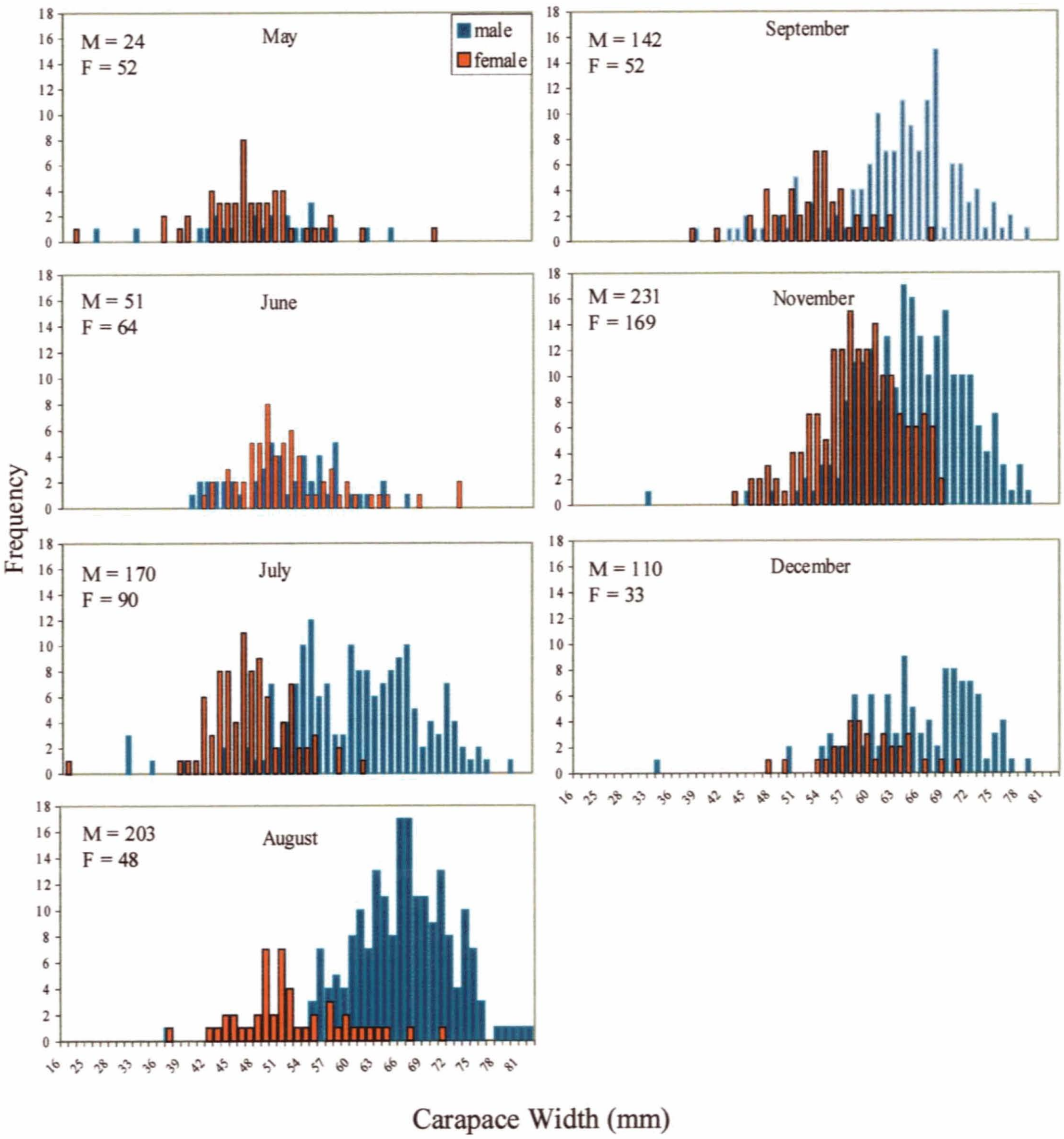


Figure 34. Size frequency distribution of male and female green crabs (*Carcinus maenas*) captured in Basin Head (PEI) with modified eel traps from May to December 2001.

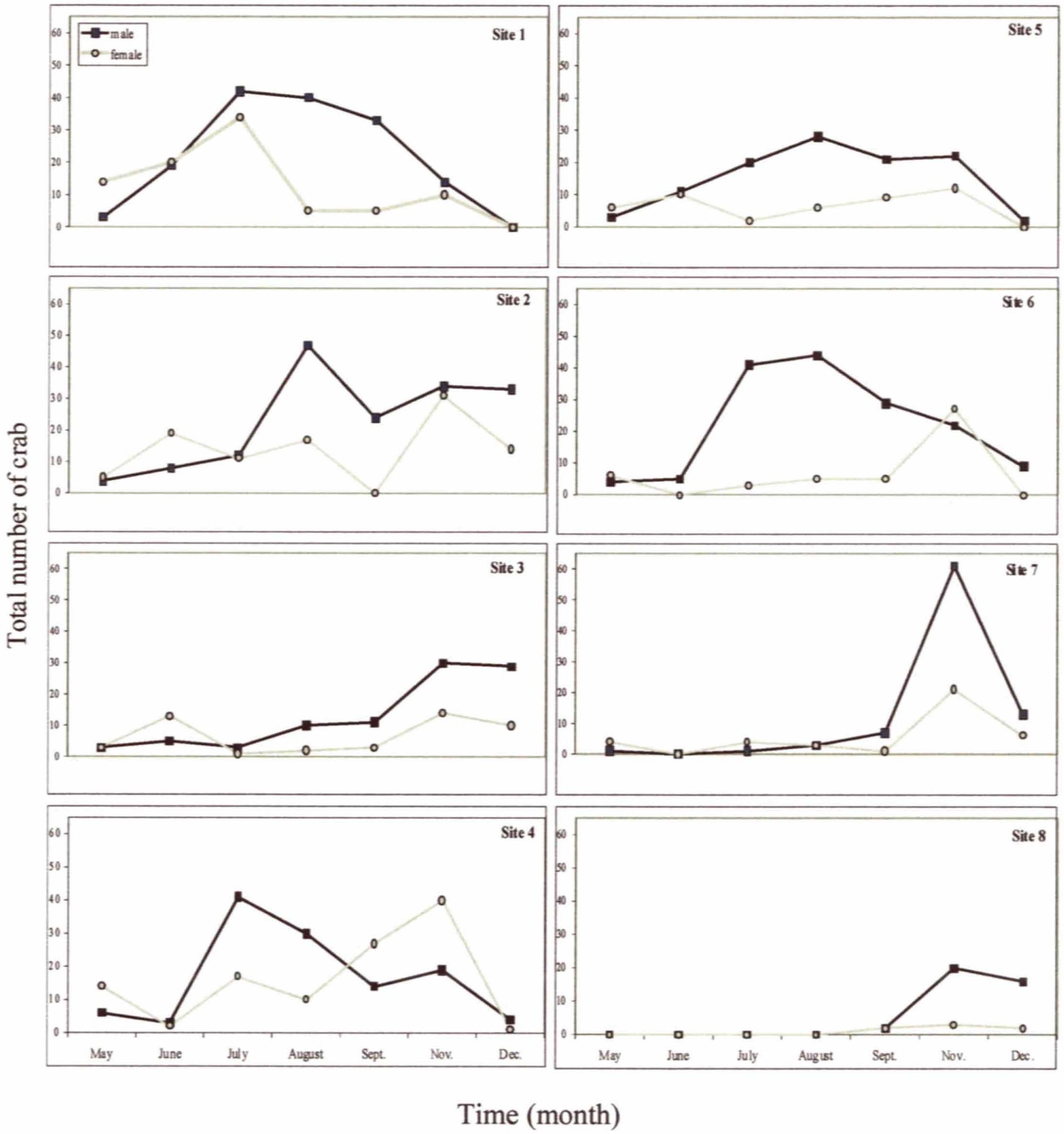


Figure 35. Abundance of male and female green crabs (*Carcinus maenas*) in Basin Head (PEI) with modified eel traps from May to December 2001, according to site of capture. Sites 1, 4 and 6: Northeastern Arm; Sites 2, 3 and 5: Main Basin; Sites 7 and 8: Channel Entrance.

These population dynamics are complex and influenced by many biotic and abiotic factors and the females are certainly less active and mobile during the summer period when they are bearing eggs and moulting. Females seems to be more active in the fall since they need to gain energy to regenerate the gonads which will be maturing in the spring prior to spawning (Audet, unpublished data).

Biology

Egg bearing female green crabs occurred from early July to mid-September in Basin Head. The peak seems to last two to three weeks from the beginning of July (Fig. 36). Water temperature varied between 16.5 and 20.0°C at that time of the year. Ovigerous females were captured with fyke nets situated on the north shore of the Main Basin and were rarely captured with the baited traps as they seemed less active during this period. Analyses of the GSI over time indicated a downward trend in the relative gonadal wet weight at the end of July up to mid-September 2001 (Fig. 37).

Mating occurs immediately after larvae are released from August to December with a distinct peak in September. In September, 32% of female captured were carrying a swollen spermatheca, which represent the highest proportion observed, since in November and December less than 5% of females were observed in an obvious post-mating state. For *C. maenas*, copulation can only happen when the female is freshly moulted and has a soft shell, so the period of reproduction corresponded to the period of moulting for adult females. Mature males are moulting from June to December, with the majority in July a few weeks before mating. Adult green crabs usually moult once a year, but juveniles expend more energy in growth and can moult two to three times a year (Naylor 1962). Size at maturity for males and females occur at a greater carapace length size of approximately 49.25 $^{\pm}$1.85 mm and 43.67 $^{\pm}$3.98 mm, respectively. Greater size at maturity is a characteristic of a northern population. In general, biological events of the green crab seems to occur about a month later in PEI (Basin Head) than what is observed in Maine (Berrill 1982). Moreover, the biology of the species in the Southern Gulf of St. Lawrence (Basin Head, PEI) is very different form what is described where the green crab distribution is endemic in the eastern Atlantic Ocean (Table 7). In European regions, where prolonged winters are less common, two spawning periods are noted (Broekhuysen 1936) and reproductive biology of the green crab happens more continuously over the year.

Warm summer waters of the Northumberland Strait and the Magdalen Shallows surround PEI. Estuaries and lagoons such as Basin Head can reach water temperature up to 26°C (see PHYSICIAL CHARACTERISTICS *Temperature*). However, the Basin Head system temperatures can drop to –2°C during the winter and can remain under 10°C for at least 8 months. Prolonged low water temperature conditions can certainly affect the development of *C. maenas*. Although the embryonic stages are highly vulnerable to fluctuating water temperatures and salinities (Nagaraj 1993, Anger et

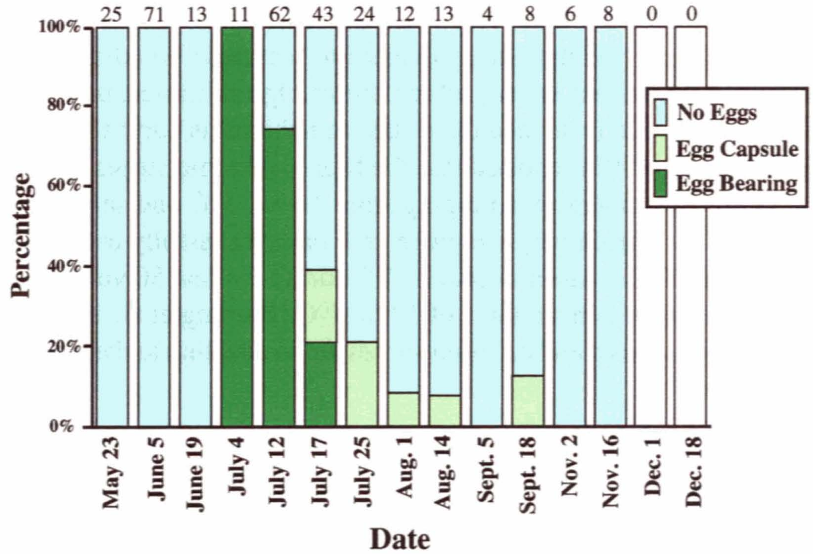


Figure 36. Proportion of ovigerous green crab (*Carcinus maenas*), and females carrying empty eggs capsules captured in fyke nets in Basin Head, PEI from May to December, 2001. Proportion were calculated weekly only from July 4 to August 1.

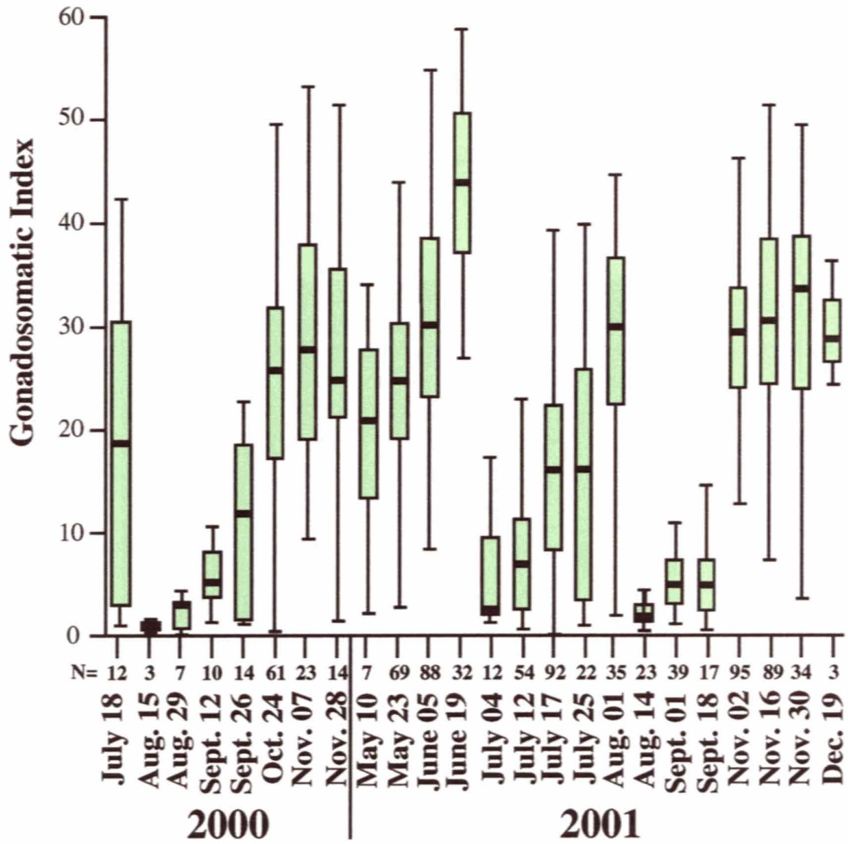


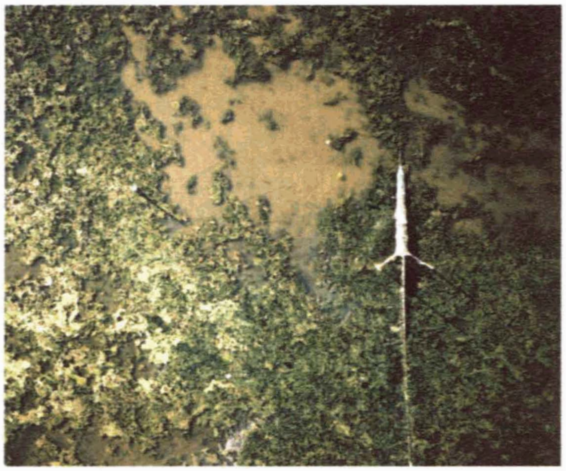
Figure 37. Values of gonadosomatic index (wet gonadal weight / carapace width x 1000) over the 2000 and 2001 sampling seasons for female green crab (*Carcinus maenas*) from Basin Head, PEI. Bars, boxes, and vertical lines are averages, standard deviations, and range values, respectively.

al. 1998), this species may have adapted to a narrow breeding time frame during the warmer months. Zoeal larvae, which prefer high salinities, probably migrate offshore during ebb tides and re-invade the estuarine habitats as euryhaline megalopae (Queiroga 1998). Nagaraj (1993) reported that the four planktonic stages of C. maenas developed successfully in temperatures ranging from 10 to 25°C and salinities from 20 to 35‰. This may be the reason why the green crab has successfully established itself in the Bay of Fundy and off the eastern coast of NS during the last 50 years despite relatively low mean surface water temperatures of 12 to14°C (Harding et al. 1983). Carcinus maenas is a very versatile species and has been successful in adapting to the environmental conditions in Basin Head.

Table 7. Synthesis of different green crab (*Carcinus maenas*) biological events occurring at different geographical regions.

Event	East Atlantic	Central Maine [1]	Basin Head (PEI)
Mating	Peak: August[1] & June - Oct.[4]	Peak: August	Peak: mid-August - Sept.
Egg Bearing	Peak: Mar.-April[1] & Nov. - Dec.[2-3]	Peak: May - June	Peak:July
Moulting (Male)	May - June [2]	June - Oct.	Peak:July
Larva Released	Peak: July-Aug.[2]	Peak: September	Not Observed
Maturity (Female)	36.0 -42.0 mm [2] 23.0 -45.0 mm [4]	34.0 - 45.0 mm	43.67 ±3.98
Maturity (Male)	>42.0 mm[4]		49.25 ±1.85

1. Berrill, 1982 2. Broekhuysen, 1936 3. Wheatly, 1981 4. d`Udekem d`Acoz, 1993



OTHER INVERTEBRATES

Fyke Net By-catch

Fyke nets in the 2002 study also caught other crustaceans. Rock crabs (3.22 crabs per net-day) were much less numerous than green crabs (53.6). Rock crabs, green crabs, and American lobsters were caught in fyke nets in the Channel Entrance.

Surveys that were directed at fish (See FISH) caught macroinvertebrates as a by-catch. Beach seining in the IBI study captured 13 species of invertebrates with an average of 4.7 species per haul (Table 8). Four decapod species (sand shrimp, grass shrimp, green crab, and in much lower abundance, the rock crab were counted in the catch. On average, total abundance for these four species was 124 per haul. Other species captured but not counted or identified were: periwinkle (Littorina sp.), razor clam, isopod, amphipod, hermit crab, horse mussel, whelk, starfish and polychaete.

Eight species of invertebrates were observed during the IBI study in minnow traps, with an average of 3 individuals and 1.3 species per trap (Table 9). These species were also observed during the beach seining.

Table 8. Decapods caught in Basin Head by beach seine (N=7 hauls) September 2002.

Common Name	Species	Abundance - Mean CPUE (# per haul)	Ubiquity (# sites present of 7)
Sand Shrimp	*Crangon septemspinosa*	90.7	7
Grass Shrimp	*Paleomonetes vulgaris*	20.9	3
Green Crab	*Carcinus maenus*	10.1	7
Rock Crab	*Cancer irroratus*	1.9	2

Table 9. Invertebrates caught in minnow traps (N=25) distributed among 7 sites over 1 night-set at Basin Head, September 2002.

Common Name	Species	Abundance - Mean CPUE (# per haul)	Ubiquity (# sites present of 7)
Sand Shrimp	*Crangon septemspinosa*	0.5	8
Grass Shrimp	*Paleomonetes vulgaris*	0.4	8
Green Crab	*Carcinus maenus*	1.4	6
Rock Crab	*Cancer irroratus*	0.1	2
Hermit Crab		0.4	2
Starfish		0.3	5
Isopod		0.04	1
Amphipod		0.04	1

SOFT SHELL CLAMS (*Mya arenaria*)

Biology
The soft-shell clam (*Mya arenaria*) is a commercially important bivalve found in bays and estuaries from Cape Hatterus to Labrador (Fig. 38). It occurs burrowed in sediments 15 to 20 cm deep intertidally to a water depth of 9 meters. *Mya arenaria* can tolerate salinity as low as 5 ppt but optimal salinity should be between 25 to 35 ppt. While it can survive in temperatures of 0 to 28°C, optimal spawning and larval development temperatures are 10 to 15°C. There is a wide variation in these optimums over its range of distribution.

Animals reach maturity at 1-4 years and 20-50 mm depending on growing conditions. Growth is most rapid in the late spring and early summer and is affected by temperature, food and water circulation. Mature animals spawn one or two times in a year between May and October (Strasser 1999). Females have a very high fecundity releasing millions of eggs for external fertilisation. Larvae are in the water column for 2 –3 weeks. An initial settlement is made with byssus threads that are released for a short-term exploration of the bottom by the foot prior to burrowing when they reach 6 mm size. Less than 1% of settled spat reach maturity.

Distribution
In Basin Head, densities of adults range from 10 to 500 m^{-2}. Samples (N=45) from the lagoon were collected from 15 stations using $0.25m^2$ quadrat to a depth of 20 cm at mid-tide level at 100 m intervals. The size frequency of these soft-shell clams (Fig. 38) had an average of 41 mm and a range of 8 to 80 mm. There are 4.4 hectares of soft shell clam beds in the Main Basin but some parts of the Northeastern Arm are also traditionally utilised (see PHYSICAL CHARACTERISTICS)
The population of *Mya* in Basin Head has been commercially exploited for over 100 years. Recent catches reported for the lagoon since 1991 reached a maximum of 963 kg in 1996. The landings for the other years were less than 50 kg or not reported (Fisheries and Oceans Statistics). Catches in the lagoon have been very sporadic due to bacterial contamination closures in 3 of the last 5 years (see SANITARY POLLUTION). There is

still an opportunity to harvest clams under the restrictions of transport to depuration facilities but this appears to be uneconomical.

In Basin Head, this bivalve is vulnerable to eutrophication (smothering from excess algal growth) and indirectly by low oxygen levels (caused by algal degradation). The introduced green crab population in Basin Head is a threat to this clam as the crab is a predator throughout its life cycle (see POTENTIAL ECOLOGICAL PROBLEMS: GREEN CRABS).

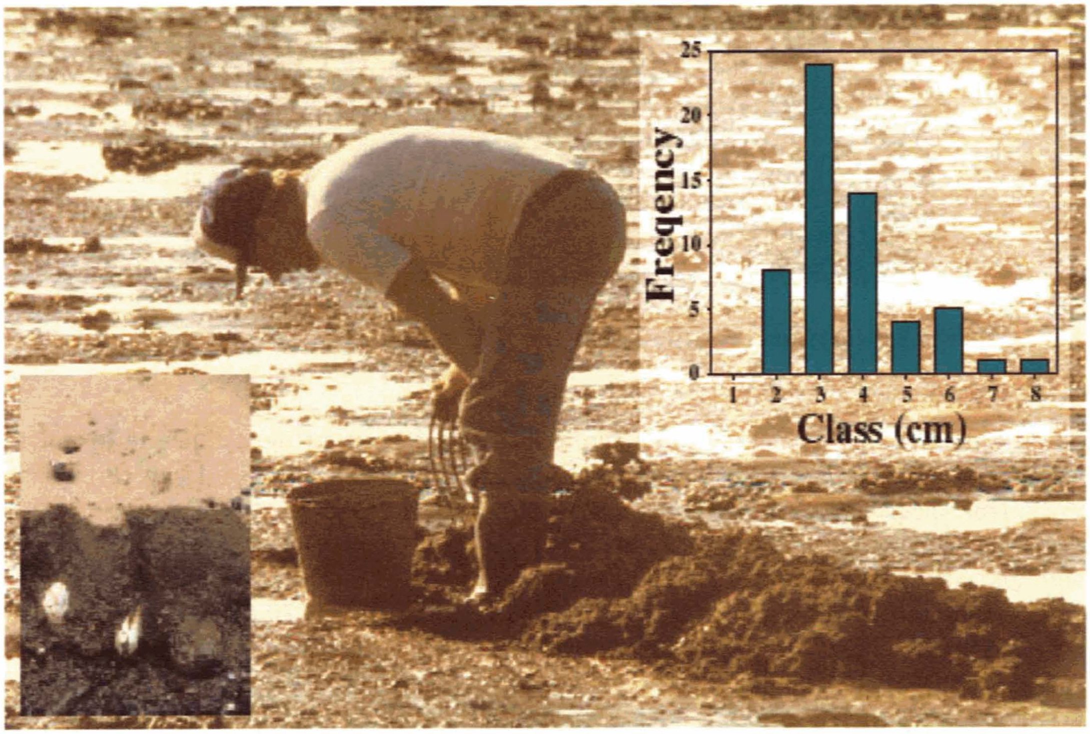
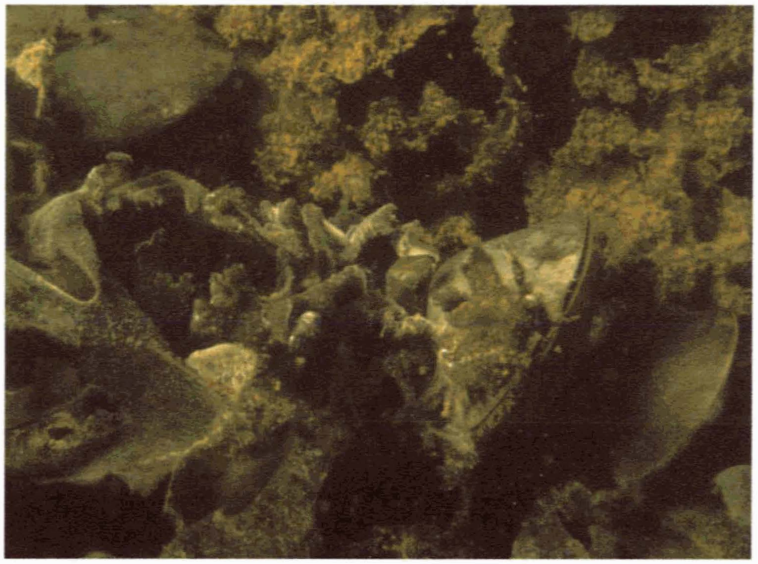


Figure 38. Size-frequency of soft shelled clams in Basin Head, PEI
Inset: cross section of clams under the sand.
Background: clam digger.



BLUE MUSSELS (*Mytilus edulis*)

Biology

The blue mussel (*Mytilus edulis)* is a mollusc, distributed from the temperate to polar seas of the world. It is primarily intertidal but can occur to depths of 15 m (Freeman 1998). This species can tolerate a wide range of environmental factors from freezing in ice to water temperatures of 29°C, short-term periods of freshwater or low oxygen levels (Seed and Suchanek 1992). Blue mussels have fertilisation externally, spawning occurs twice, spring and late summer or early fall. Larvae develop over 20 to 30 days, initially settling as pediveligers on filamentous substrates. Final settlement occurs after a period of bottom exploration but post larvae can over winter on the primary substrate. Recruitment can be episodic but once established recruitment pulses do not have to be large or regular to maintain the bed (McGrorty et al. 1990). In many areas, blue mussels form extensive beds of 100% cover, sometimes up to several layers thick of living animals (Freeman 1998).

Distribution

In Basin Head, the mussel beds are not found in extensive, thick layers. In the Main Basin, *Mytilus* tends to be in clumps of 20 or less animals and in the Northeastern Arm, they are found as more frequent clumps or attached to other shells. The most important concentration is attached *to Chondrus crispus* clumps, helping to maintain the bed (see IRISH MOSS biomass *distribution*). The biomass of mussels associated with *Chondrus* was 150 $^{\pm}$66 g/kg of plant material. Aside from the mechanical importance to *Chondrus* as a means of attachment, mussels contribute to the turnover of nutrients and organic carbon as filter feeders building secondary production in the system. Mussel production can be 2.5 to 3 times the maximum standing crop per year.

PERIWINKLES (*Littorina littorea*)

Biology

The common periwinkle (*Littorina littorea*) is widely distributed in the North Atlantic from Labrador to New Jersey. The first live specimens were collected in 1840 but shells have been found at Pre-Columbian Mi'k Maq campsites. Despite this evidence of its early presence, it was not found in great quantities until after European settlement. Since then, it rapidly increased in abundance and distribution and gradually displaced the indigenous *Littorina palliata* (DFO 1997).

This small snail can have a maximum shell height of 37 mm but is usually less than 25 mm. This snail lives from the high water mark to depths of 40 m on diverse substrata ranging from rock to sand. It can tolerate the low salinity (13 ppt) that is found at the head of estuaries and the Northeastern Arm of Basin Head. Aggregations can be found on subtidal drift algae, in tide pools and along rock crevices. During the winter months, the periwinkle population migrates down the intertidal zone near or below the mean low tide mark.

Females are mature at 14 mm shell height, releasing eggs up into the plankton from April to July. Periwinkle larvae remain in the water column for up to 4 weeks. Recruitment occurs in July-August or August-September depending on water temperatures. After settlement, periwinkles are at risk of predation by humans, fish, waterfowl, crabs and lobsters. They have two peak periods of growth during the year early spring and early fall. Periwinkles usually live to 3 years and to an average 20 mm shell height.

Distribution

Periwinkles are widely distributed in the lagoon and are the largest gastropod in association with *Chondrus* but less abundant than smaller gastropods (Table 2). In the Main Basin, they are notable as the dominant herbivore both intertidally and subtidally at 55 m^{-2} $\pm$42.

Littorina littorea plays an important role in the cycling of algal biomass in the lagoon. Direct consumption and conversion into secondary production may be secondary to the importance in degrading and fragmenting plants. The smaller fragments of algae are then more likely to be flushed from the lagoon.

POTENTIAL ECOLOGICAL PROBLEMS

EUTROPHICATION

Eutrophication is a water quality problem that has been recorded since the early history of human civilisation (Vollenweider 1992). It has recently been well identified as a problem in the estuaries of PEI (DFO 2000, Cairns 2002). Excessive nutrient inputs from domestic, agricultural and industrial sources build nitrogen (N) and phosphate (P) levels to a point that primary production is stimulated, creating phytoplankton and macrophyte blooms. The bloom in itself can reduce water clarity or directly shade other species and may contain toxic species. During the production of high biomass of sea lettuce, water channels can become clogged, reducing water flow causing accelerated degradation, increased water temperatures, lowered salinity and lowered dissolved oxygen. More commonly, the bloom species go through a normal ageing process or create very dense populations resulting in negative conditions for survival. The degradation of tissues depletes the soluble oxygen reserve of surrounding waters. Under these conditions concentrations of deleterious substances such as hydrogen sulfide, ammonium, methane and carbon dioxide build up in the water column and the sediments. The rapid release of nutrients with degradation can also trigger a bacterial bloom either in conjunction with or after the algal bloom (Vollenweider 1992). In Basin Head, the nutrient inputs from streams are above the average of other estuaries and lagoons of PEI (Connolly 2002). The average estuary in PEI has high levels of N and P and in some cases, rivers entering these estuaries have increased their contribution of nitrates to the receiving estuaries over the past 30 years by factors of 100 to 300% (Raymond et al. 2002).

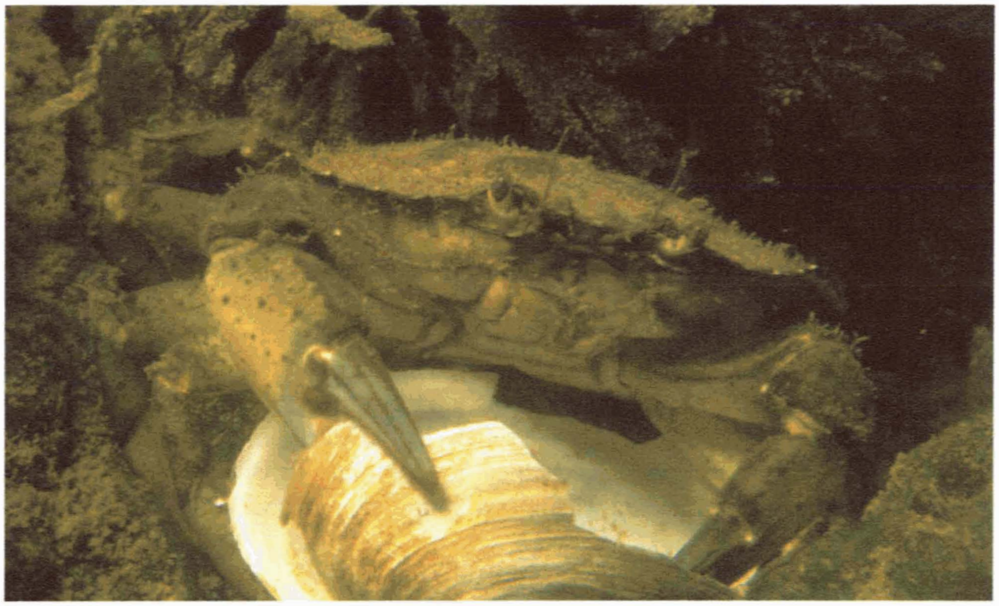
Inputs from the principal streams of Basin Head are the primary source of N and P. The input levels of Basin Head is higher than most of PEI streams, which are also above the average temperate estuaries (Raymond et al. 2002). In general 0.63 to 3.0 mg/l total N can cause eutrophication and all of the PEI estuaries are reported to have mean levels above these values (Raymond et al. 2002). In a survey of 21 bays and estuaries around PEI, 6 sites were reported to have had anoxia (opp. cit.). Basin Head has an annual anoxia, or low level oxygen events in the upper reaches of the eastern arm at the end of summer (see OXYGEN). Basin Head is especially vulnerable to anoxic events due to the periodically low flushing rates, high water temperatures, very high nutrient levels, and restricted channels to ocean waters.

Anoxic events reduce species diversity and can cause large fluctuation in species that are not mobile or whose mobility is related to tidal currents. The lack of *Mya arenaria* in the upper reaches of the eastern arm may relate to some extent to the type of sediments. Mortalities of soft-shell clams can result from smothering or low oxygen levels (Mackenzie 1995). The area of anoxia has, over the past 3 summers, reached the edge of Basin Head moss distribution. While the *Chondrus* bed is relatively free of *Ulva* in the early spring, large *Ulva* fronds form a significant portion of the algal cover in the summer (Fig. 24, see IRISH MOSS *biomass distribution*). The high abundance of crustacean and gastropod grazers in the *Chondrus* bed consume a part of this primary production helping to prevent over-shading of the fronds. In the region of the Northeastern Arm to the east of the *Chondrus* bed, anoxic conditions reduce invertebrate density or eliminate these animals. *Chondrus* found in this area was in low abundance in isolated clumps.

Ulva blooms existed 20 years ago in the lagoon and the *Chondrus* bed was to a large degree similar to its present day distribution (McCurdy 1980, see IRISH MOSS *Biomass Distribution*). The portion of the *Chondrus* bed closest to the *Ulva* concentration in the upper reaches of the arm had dense *Ulva* cover and patches of deteriorated or rotted plants (McCurdy 1980). This was due to a combination of shading and anoxic conditions. Observations would suggest that these conditions have not deteriorated since this time. The amount of nutrient inputs has dramatically increased over the past 20 years, therefore the duration, extent and frequency of blooms could in theory, have increased. A critical factor in limiting the build-up of *Ulva* is the degree of flushing in the lagoon, which dilutes nutrients, oxygenates waters and removes excess production.

There are several options to change or to prevent further eutrophication effects in Basin Head. The first is to reduce nutrient inputs in the drainage basin. The excess biomass of sea lettuce could be removed. And perhaps the water circulation in the lagoon could be enhanced.

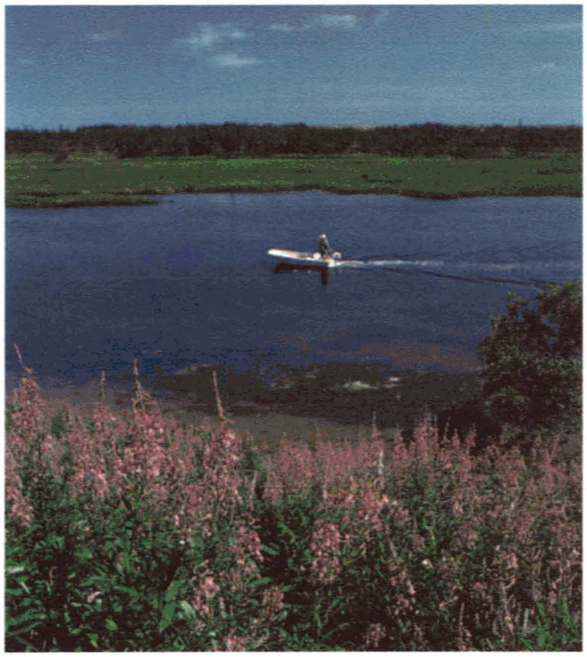
Effective remediation depends on knowledge of the total nutrient load, and knowledge of the tolerance level (assimilative capacity of the waters). The answers will come from an understanding of the functioning of the Basin Head lagoon. Modelling of the relationship between nutrient inputs, water quality, water circulation, and primary production has been well established for some lagoon systems (Coffaro et al. 1997). The initial stages of this type of modelling have been completed for circulation for Basin Head (Martec 2002). The physical, chemical and productivity data bases built over the past 3 years are ready to be incorporated into the RMA 10 and 11 water quality models (Martec 2002). Model simulations will provide a forecasting ability to answer key questions for the MPA managers regarding the impacts of nutrients on the general ecological health status of the lagoon in the short and long-term.



GREEN CRABS

The green crab is a voracious predator of a wide range of invertebrates (Elner 1981) and has been blamed for the collapse of the soft-shell clam industry in New England and NS in the 1950's. In fact, green crabs demonstrate a prey preference for bivalves (Ropes 1968) such as American oysters (*Crassostrea virginica*) soft-shell clams, blue mussels (*Mytilus edulis*) and northern quahogs (*Mercenaria mercenaria*) which can be found in great density in PEI. Aquaculture stakeholders expressed their serious concerns about the threat of green crabs to the cultured and wild shellfish populations in PEI waters.

Green crabs could also be a threat to the ecological equilibrium of the Basin Head ecosystem. Long-term effects are still difficult to identify at the moment, but may have great consequences. Green crabs with their high fecundity, high capability to tolerate a wide range of environmental conditions, omnivorous feeding behaviour and the limited number of predators and parasites, are an excellent invader and can certainly displace native species. Lagoons and estuaries that green crabs have been colonizing are also considered to be major nurseries for different crustacean species such as the American lobster (Wahle and Steneck 1991). Conflicts for habitat and food amongst them may be foreseen (Moody and Steneck 1993). The American lobsters, rock crabs (*Cancer irroratus*), and mud crabs (*Rithropanopeus harrisii* and *Dyspanopeus sayi*) are the potential species having a direct conflict with the green crab in the Southern Gulf of St. Lawrence, as they share similar habitats and prey.



DISTURBANCE OF THE IRISH MOSS BED

While the origins of the Basin Head moss are left to theoretical concepts, the reasons for the persistence of this strain in lagoon are clear. The 500 to 800 m section of the eastern arm has the critical conditions for the growth and survival of the population of Irish moss.

Disturbance that loosens clumps or individual fronds, can release this biomass to be carried away by water currents out of the lagoon or into sub-optimal areas of the lagoon. Neither of these environments, the Main Basin or the inside Northeastern Arm, have developed *Chondrus* beds and only scattered individual plants survive. Low salinity, poor water circulation and low oxygen levels prevent growth in the head of the Northeastern Arm. A large and diverse herbivore population heavily grazes fronds in the Main Basin.

At low tide, the area of the Basin Head moss is reduced to a 50 cm or less depth, and on extreme low tides, the *Chondrus* patches are partially exposed in some parts of the arm. Motor driven vessels have a high probability of disturbing the clumps by propeller action and the wash of the wake. Fishing activities such as eel trapping that require deployment of anchors, ropes and nets also promote disturbance of the Irish moss bed. The degree of disturbance that would reduce the bed to some critical minimum of biomass is unknown, but it is clear human activities are in addition to normal disruptive forces of wind driven waves, tidal currents and drifting debris. Patches of fronds are not totally stable and can increase or decrease in area and biomass year to year (see IRISH MOSS *Biomass Distribution*).

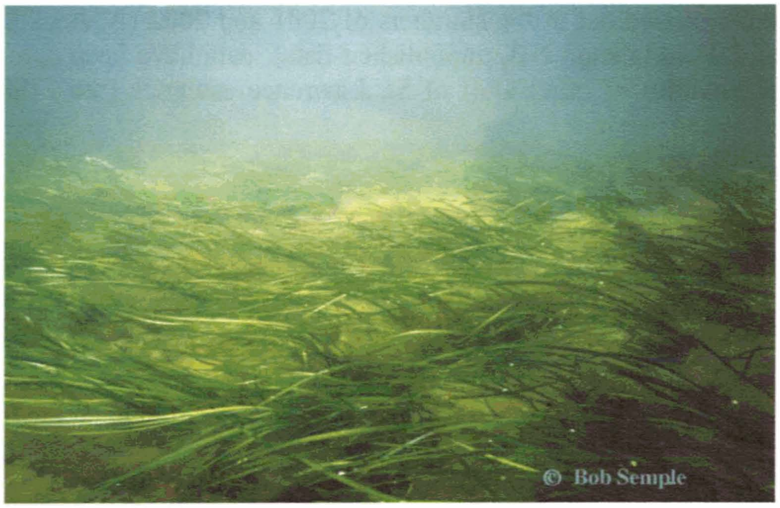
The banning of motorised vessels from the majority of the lagoon, except in cases of emergency and health, as part of the proposed management plan has effectively removed this activity as a threat.

SANITARY POLLUTION

There have been statistically valid bacteriological surveys at 5 stations in the Basin Head lagoon since 1995 (Curtis et al. In press). Of the 5 stations, station 1 on the north shore of the Main Basin was above acceptable levels of fecal coliforms (maximum count 1600 MPN/100ml). This station had levels above 43 MPN/100ml 13% of the time. The second station in the Main Basin (2) was marginal at a max level of 350 MPN/100ml, and 10% of the samples were above 43 MPN/100ml. To further investigate the reasons for high counts, a shoreline sanitary survey identified 9 potential sources of contamination on the Basin Head watershed. These sources range from agricultural drainoff, cattle access to streams, cottages and tourist development. No single source has been identified as the most significant problem.

This contamination has led to closure of the lagoon to clam harvesting in three of the last 5 years (Canadian Food Inspection Agency, pers. comm.). Fecal coliform contamination to some extent, goes along with eutrophication, poor water circulation, high water temperatures and large amounts of particulate organic matter. Sanitary wastes frequently accompany inputs of nutrients from many sources.

Remediation is possible for this contamination beginning at sources, reducing the fecal coliform loading on the watershed. Secondly reduction of eutrophication in the lagoon as a whole would create conditions less favourable to growth of fecal coliform bacteria.



EEL GRASS MEADOWS

There has been a large-scale loss of *Zostera marina* populations in Nova Scotia. Although the wasting disease was the cause of a large decline in the 1930's and was still present in the 1980s, there is as yet no evidence this is the cause of the more recent decline (Short et al. 1987).

Zostera marina is sensitive to local perturbations such as eutrophication from human sources of nutrients including residential development, agricultural runoff or industrial sources (Short et al.1995). There has been a link proven between housing development and subsequent increases in ground water nutrients and loss of eel grass populations in New England (Short and Burdick 1996). Basin Head is a eutrophic lagoon and *Zostera* may be at similar risk.

The introduction of the green crab as a potential predator also could threaten the eel grass beds of Basin Head. The densities of green crab populations in the lagoon are among the highest recorded for this species (see GREEN CRABS *general biology*). Mortality of transplanted *Zostera* plants has been attributed to the green crab cutting off shoots but no large-scale eelgrass loss has been attributed to this animal (Davis et al. 1998). Environmental change is another hypothesised cause for *Zostera* population decline. The intertidal eelgrass population is most subject to environmental extremes of temperature and air exposure therefore global climate change has the potential to reduce local eel grass populations. The first impact would be an alteration in growth rates and changes in the pattern of sexual reproduction (Short and Neckles 1999).

Since 1997, researchers at DFO, the University of New Brunswick and Kouchibouguac National Park (KNP), have been adapting a method for measuring aquatic health, called the IBI, for coastal eelgrass (*Zostera marina*) beds of the southern Gulf of St. Lawrence. This IBI compares the structure of the fish community in the onshore, or littoral zone of a site with an un-impacted reference site such as KNP. A healthy eelgrass bed will have the same fish species, and in the same relative proportions, as the reference site. A less healthy site impacted by an anthropogenic effluent or physical disturbance, for example, may have fewer fish and be missing some species. In conjunction with a survey for non-indigenous species carried out in the summers of 2001 and 2002 (A. Locke, M. Hanson and G. Klassen, DFO-Moncton NB, unpublished data), data have been compiled on the littoral fish communities of other Gulf of St. Lawrence estuaries (see FISH SPECIES *Diversity*).

STABILITY OF THE ENTRANCE CHANNEL

Wholesale changes in size and structure of the Basin Head lagoon have occurred over past decades. The width, depth and seasonal stability of the single entrance to the ocean are critical to an entire suite of environmental factors that determine the character of the lagoon. The depth of the entrance channel is also related to the dynamics of the adjacent sand bar that is reformed by storm events. Wooden cladding protects the integrity of the present entrance but the adjacent sand dune is unstable. This is due to the heavy human use of this small area of the beach. The western shore of the channel has stable sand stone slopes but the eastern side is vulnerable to inundation by storm surges.

Any change in channel dimensions and shape will directly impact the flushing rate or cycle of flushing patterns. It is clear from the history and structure of the original channel outlet on the Northeastern Arm that the lagoon may have been less frequently flushed than at present (see Structure of the Lagoon).

Improving circulation of the lagoon may be the most efficient and direct way of dealing with sub optimal environmental conditions in the lagoon. The bare minimum criteria for the ecosystem is to maintain the existing access to the ocean waters.

GENERAL RISKS TO ECOSYSTEM HEALTH

Although this document has identified a number of potential risks to the health of this ecosystem, it is not a comprehensive list. We are lacking information on such factors as toxic chemicals inputs, although we have observed one fish kill in the past 5 years. Similarly while information is available on specific input points for, there is no data on the rates of accumulation in the lagoon. Land-use practices adjacent to Basin Head are typical of PEI estuaries and the risks to ecosystem health are similar. Due to the limited flushing of the Basin Head lagoon, the risks from toxic or nutrient inputs to this system may be higher than in other semi-enclosed marine waters (DFO 2000, Cairns 2002). The research recommendations that were the result of a habitat status review of the effects of land use practices on fish, shellfish, and their habitats on PEI should be applied to support the maintenance of the Basin Head ecosystem. These recommendations included:

- "monitoring the inputs of sediment, toxic chemicals, animal wastes including bacteria, and nutrients into PEI watercourses,
- quantifying and modelling effects of these inputs on fish, shellfish and their habitats,
- establishing benchmarks to support enforcement of legislation, and
- evaluating existing and designing new measures to mitigate problems" (DFO 2000).

The Basin Head MPA can become a model for coastal zone management, optimal land use practices, and protection of unique species and habitat.

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