


OYSTERS IN NEW BRUNSWICK:

More than a harvestable resource

By
Inka Milewski and Annelise S. Chapman

Conservation Council of New Brunswick

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Table of Contents

Acknowledgments	**2**
Preface	**3**
1.0 Introduction	**5**
2.0 The ecological role of oysters in estuaries	**9**
2.1 Oysters as habitat	9
2.2 Oysters as filters	11
2.3 Oyster as recycling centre	12
3.0 The decline of oysters	**14**
4.0 Oyster beds as habitat: A field survey of four major bays	**18**
4.1 Survey sampling methods	18
4.2 Sample analysis	19
4.3 Results	21
4.3.1 Caraquet Bay	21
4.3.2 Miramichi Bay	27
4.3.3 Bouctouche Bay	30
4.3.4 Cocagne Bay	38
4.4 Summary and discussion	43
5.0 Conclusions	**47**
References	**48**
Appendices	
1. Summary of statistical data for all Bays	53
2. Species summary for Caraquet Bay	54
3. Species summary for Miramichi Bay	55
4. Species summary for Cocagne Bay	56
5. Species summary for Bouctouche Bay	57

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As mentioned earlier, the inspiration for this project came from talking to oyster fishermen and coastal residents concerned about the state of their oyster beds and their bays. They told us their stories and gave us permission to use their stories in this report. We greatly appreciate their contribution.

Caraquet Bay
Gérard Cormier
Guitan Dugas
Alain Landry
Gilles Thériault
Guy Thériault

Bouctouche Bay
André Jaillet
Norbert Jaillet
Reno Jaillet
Lionel LeBlanc
Jacques Nowlan

Miramichi Bay
Terry Manuel
André Martin

Cocagne Bay
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Inka Milewski Annelise Chapman

Preface

In 1998, the Conservation Council began a review of the environmental concerns facing the coastal ecosystems of New Brunswick's northern and eastern coast. The result of that review was the publication of a report, *Shifting Sands: State of the coast in northern and eastern New Brunswick*, in 2001. One of the key findings of the report was that, despite the historic importance of oysters to the economy, there was virtually no information or research on their ecological function in the coastal ecosystems of northern and eastern New Brunswick.

As part of the Conservation Council's commitment to act on priority issues identified in Shifting Sands, we initiated a research project to begin addressing the gaps in knowledge about the role of oysters in the estuaries of northern and eastern New Brunswick. Although oysters are found in many bays along the northern and eastern coast of the province, insufficient project funding made it impossible to survey all the estuaries. This project, therefore, focused on four estuaries: Caraquet, Miramichi, Bouctouche and Cocagne. Given the large size of Miramichi estuary, only the southeastern portion – Baie-Ste-Anne – was surveyed.

Prior to conducting our field investigations, we met with retired and active oyster fishermen and coastal community residents. We also examined historic records, consultants' reports, publications by federal and provincial government departments and the scientific literature. The picture that presented itself during the field investigations concurred with the observations made by oyster fishermen and coastal residents. The by-products of human development - sediment, waste and nutrient loading - were having a negative effect on their bays and oyster beds. What perhaps was not as obvious was the impact of oyster bed destruction on other components in the ecosystem.

Oysters are more than a harvestable resource. They form extensive and distinctive habitats which contribute to an estuary's biological diversity including its species, seascapes and functions. The loss of oyster beds has an effect that trickles or cascades throughout the ecosystem to include even commercial fish species. These are well-known facts that have been ignored or forgotten by the managers of our marine resources.

This report is not the last word on oyster beds but rather a beginning. We hope it will increase public awareness of the importance of oyster beds in coastal ecosystems, lead to community-based oyster bed restoration projects, stimulate new research initiatives, and trigger the enforcement of existing legislation or the creation of new legislation to protect critical marine habitats. The restoration of oyster beds will not only result in ecological benefits, it will lead to economic benefits for current and future generations.

Conservation Council of New Brunswick 2002


QUEBEC
Restigouche River
Dalhousie
Campbellton
Atholville
Eel River Crossing
Charlo
Jacquet River
Belledune
Chaleur Bay
Miscou Island
Grande-Anse
Pointe-Verte
Petit-Rocher
Nigadoo
Beresford
Nepisiguit Bay
Caraquet
Lamèque
Lamèque Island
Bas-Caraquet
Shippagan
Bathurst
Tracadie-Sheila
Val-Comeau
Nepisiguit River
GULF OF ST. LAWRENCE
Northwest Miramichi River
Tabusintac
Neguac
Burnt Church
Miramichi Bay
Bartibog Bridge
Miramichi
Eel Ground
Baie-Sainte-Anne
Bay du Vin
Miramichi River
Red Bank
KOUCHIBOUGUAC NATIONAL PARK
PRINCE EDWARD ISLAND
Southwest Miramichi River
Richibucto
Big Cove
Cap-Lumière
Northumberland Strait
Buctouche
Cocagne
Shediac
Cap-Pelé
CONFEDERATION BRIDGE
Cape Tormentine
Port Elgin
Baie Verte
Baie Verte
N.S.

1.0 Introduction

Ryette LeBlanc

Cocagne Island protects Cocagne Bay

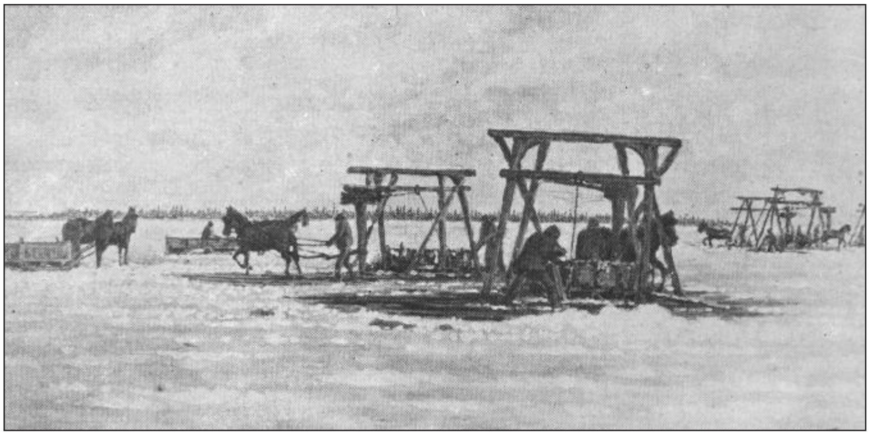
The shallow, warm water, protected bays and estuaries of northeastern and eastern New Brunswick are ideal for oysters – specifically, the American (sometimes called the eastern) oyster, *Crassostrea virginica* (Gmelin). Typically, oyster-producing bays are guarded by a chain of barrier islands, sand reefs or dunes that act as natural breakwaters to protect against strong waves and cold water. These same bays and estuaries are also ideal for human settlement. It is, therefore, not surprising that oysters have been an important part of the social and economic development of native and non-native communities along New Brunswick's northern and eastern coasts for hundreds of years.

Nicolas Denys (1672), Moses Perley (1849) and Joseph Stafford (1913) wrote of the tremendous abundance, distribution and economic value of oysters. Oysters were harvested for human consumption and their shells were used in the building of roads and burned for their lime content. Nicolas Denys (1672), in his natural history account of the coast of New Brunswick, tells of oysters being piled "like rocks one over the other" along the coast of Northumberland Strait to the Bay of Chaleur. Denys (1672) also wrote about the large size of the oysters where the shell of an oyster would serve as a pot to cook the meat of two or three oysters over a camp fire.

"I have spoken of the oysters [Huistres] in the first book, but I have not told you that they are a great manna for the winter when the weather does not permit going on the hunt. They are in coves or on the shore near the land. To obtain them the ice is broken, and a large opening is made. Then one has little poles long enough to reach to the bottom of the water. Two of them are tied together about half-way up; then this [arrangement] is opened and closed like pincers. The oysters are drawn from the water and thrown upon the ice." Nicolas Denys (1672)

Historical oyster landing data for New Brunswick is scarce. Stafford (1913) provides some of the earliest catch statistics (Table 1). According to Stafford (1913) New Brunswick had shipped 554,594 barrels (50,417 metric tonnes - mt) of oysters between 1876 and 1910, an average of almost 1,500 mt per year. New Brunswick first surpassed Prince Edward Island (P.E.I.) in shipments in 1900 but fell behind until 1907 when the province once again took the lead in oyster shipments.

By the early 1900's and despite legislation in place since 1867 which imposed restrictions on how, where and when oysters could be fished, oyster production in the Maritimes began to decline due to overharvesting, first in Prince Edward Island and later in New Brunswick and Nova Scotia (Stafford 1913). According to Stafford (1913), the legislation at the time simply slowed the rate of decline by reducing waste and injury to the oyster but it did little to ensure that the number of oysters fished would not out-pace the productive capacity of the oyster beds.



Centre d'Études Acadiennes (U de M)

Digging oysters and mussel mud in Shediac Bay- a painting by Hind c.1870

Table 1. Oyster Production in New Brunswick 1910

Shipping Stations	Barrels	Metric tonnes (mt)
Bathurst	100	9.0
Caraquet	300	27.0
Shippegan	45	4.0
Tracadie	30	2.7
Neguac	2,800	252.0
Bay du Vin	3,800	342.0
Chatham	420	37.8
Richibucto	300	270.0
Bouctouche	3,240	291.6
Cocagne	2,200	198.0
Shediac	400	36.0
Botsford	350	31.5
Sackville	60	5.4
Total	**14,045**	**1,264.0**

Source: Stafford 1913

[1] One barrel held 500-600 oysters weighing about 200 lbs (Medcof 1961)

With the market demand for oysters exceeding natural production, government scientists in the late 1920s were directed to explore oyster farming as a way to increase the number of marketable oysters. In its simplest form, oyster farming involves collecting young oysters (spat) by providing an artificial surface for their settlement and then transferring the spat to natural grow-out sites. Methods of culturing oysters date back to early Roman times when spat were caught on bundles of branches (Stafford 1913). Today, advances in science and technology have made oyster farming or aquaculture more sophisticated.

By 1950, New Brunswick's production of oysters, dependent on naturally-produced stocks, was 6.5 million pounds (2,950 mt), twice the production of P.E.I. (Medcof 1961). Just a couple of years later, oyster stocks in New Brunswick and Nova Scotia were struck with a disease epidemic that hit Cocagne Bay first and spread in both directions along the mainland shore of Northumberland Strait (Medcof 1961). By 1954, Malpeque disease had reached Shippegan and by 1958 oyster production in New Brunswick had dropped to 75 mt. Thirty-five years earlier (1915), the disease had struck Prince Edward Island (P.E.I.) starting in Malpeque Bay and spreading throughout the Island's oyster producing bays. The disease struck P.E.I. again in 1937.

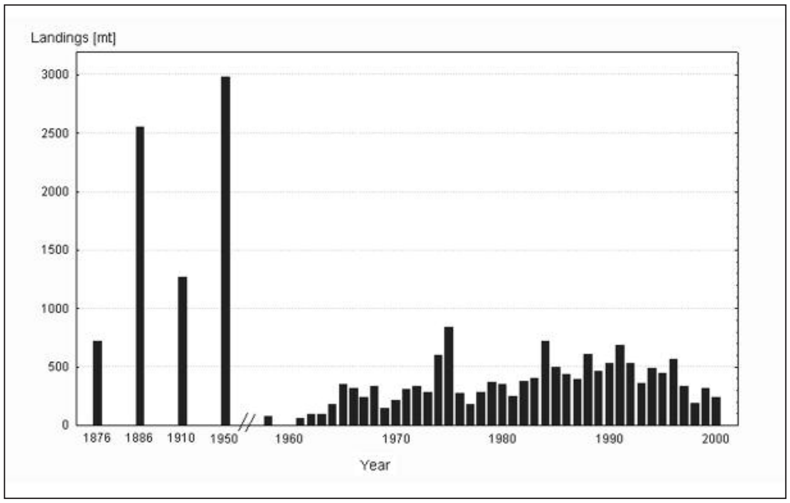


Fig. 1: Oyster landings in New Brunswick between 1876 and 2000 (in metric tonnes - mt).

Source: Stafford 1913; DAFA 2001, DFO 2001.

During the P.E.I. epidemic of 1915, it was discovered that about 10 percent of the oysters survived because they were resistant to the disease and that the survivors produced large numbers of resistant young (Found and Logie 1957). Through an extensive rehabilitation program that saw the transplantation of disease-resistant oysters from P.E.I. to bays in New Brunswick, oyster production was restored in New Brunswick. After the outbreak of what is now called Malpeque disease, oyster production in New Brunswick has never come close to matching the level reached in 1950 (Fig.1). Oyster landings, farmed and wild, in 2000 were 240.9 mt (DFO 2001).

The gradual shift from harvesting oysters on natural beds to farming oysters precipitated the transfer of public lands to private control as oyster farmers were given exclusive access to and control over areas where their oysters were "seeded" and tended. In the late 1930's, public oyster grounds began to be leased to individuals. By the 1970's, only a little more than 10 per cent of the estimated 6,200 hectares (ha) of good oyster grounds in the Maritime provinces (New Brunswick, Nova Scotia and P.E.I.) remained public oyster grounds (Lavoie 1995). The rest were under lease to private interests. In 1992, New Brunswick had 808 shellfish culture leases covering approximately 2,200 ha (Lavoie 1995).

According to Lavoie (1995), many of the current oyster leases in New Brunswick are not used or are too small to sustain a viable culture operation. As oyster aquaculture continues to be promoted by government agencies, the need for large leases on suitable bottom will also grow. The possibility that the shellfish aquaculture industry will put pressure on the provincial government to raise the annual fee for leases, institute a mandatory surrender of unused leases, or establish a buy-back program as a means of making more area available for shellfish farming, will also grow.

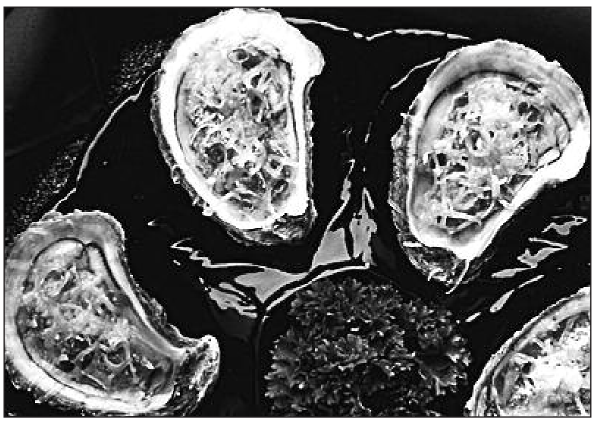
The focus on oyster aquaculture has also shifted research attention: from research on the restoration, recovery and ecological importance of natural oyster beds or reefs, to aquaculture-oriented topics such as oyster seed supply, new seed production technology, grow-out techniques, predator and disease control, and genetic engineering. Virtually no research has been done on the impact of oyster bed destruction on local marine productivity and species diversity, nor on the potential for oyster bed restoration. In fact, the ecological role of oysters in coastal ecosystems of northern and eastern New Brunswick has been ignored.

"In the early years of the fishery there was a protracted period of indifference, during which the oyster was used by few people and then more as a novelty than as a staple article of food. This was followed by a period of strife between fishermen and farmers as to whether it should be regarded as a food or as a fertilizer. In the meantime improvements in the means and rapidity of transportation had carried oysters inland to a widening market and occasioned a demand which left no room for doubt as to their uses. The at first locally abundant, easily procured, cheap oyster rose in price and became sought after in such an extent that more and more beds were discovered until all our areas had been explored. The demand continued and the natural supply became so far reduced that many people feared all the beds might be depleted and the oyster become a thing of the past. Places that formerly yielded many barrels per year can now furnish none. Beds which were at one time prolific are now not worth fishing. In some districts the greater part of the season's catch is taken on the first day. It is no uncommon spectacle to see fleets of boats assembled over promising areas awaiting the hour of open fishing. I have myself had hauled in succession four dredgefuls of dead shells among which could not be found a single living oyster; and this was on the Shediac reserve, which for seventeen years had been under the care of an oyster expert, but had been thrown open immediately before the election of the previous autumn and almost destroyed by the crowds of fishermen who flocked from every direction and unreasonable distance."

From: ***The Canadian Oyster: Its Development, Environment and Culture,*** *Stafford (1913), p.100*

2.0 The ecological role of oysters in estuaries

For most people, the oyster is not much more than an edible shellfish. Their first and only encounter with an oyster is likely in the supermarket where individual oysters are laid out on a bed of crushed ice. It may surprise many people that oysters grow attached to one another or on some other hard surface such as a rock,


NB Image Bank

A more common view of oysters.

empty shells or any other submerged object. Oysters cannot swim, crawl, or dig into the mud like clams. Over time, as older oysters die off and younger oysters build upon the older shells, dense and extensive oyster beds or reefs are formed. These beds can rise several centimetres to several metres off the sea floor and cover large areas of sea bottom. One of the distinctions between an oyster reef versus a bed is height, with reefs extending higher up into the water column. Oyster reefs have been compared to coral reefs, which are also complex three-dimensional structures on which many other species depend for food and shelter (Mann 2000; Peterson et al. 2000).

Oysters have been referred to as a 'keystone' species (Ray et al. 1997), which means that their functional role is more important than their simple abundance or biomass suggests (Wilson 1992). Changes in keystone species' populations can have significant impacts upon the composition, structure and function of the entire community in which they live. Ray et al. (1997) summarize the ecological value of oysters and oyster reefs as follows:

> *Structurally and functionally the oyster (individually and the reef it builds) strongly influences species diversity and productivity at the local scale. As a structure, reefs provide habitats that sustain an abundance and diverse range of species. As metabolic "hot spots", oyster reefs form centres of production and absorption of nutrients. Oyster reefs also contribute to estuarine resilience and robustness, and serve as metacommunity habitats for species re-establishment after major physical disturbances. Alteration of these functional roles might have widespread consequences for migrating and estuarine-dependent species, as well as the ecology of the coastal zone.* Ray et al., 1997, p.364.

Thus the health of coastal and estuarine ecosystems in northern and eastern New Brunswick may well depend on the health of wild oyster populations.

2.1 Oysters as habitat

Oysters are often characterized as 'ecosystem engineers' or biogenic (living) habitat (Jones et al. 1994; Ray et al. 1997). They provide a hard surface for the attachment of a wide variety of marine organisms. Architecturally complex, oyster beds provide nooks and crannies for other species that act as refuges from predators and, at the same time, allow for the coexistence of competitors (Lenihan and Peterson 1998).

Studies done elsewhere have found that the number of benthic invertebrate species (i.e. crustaceans, polychaetes, gastropods, bivalves) associated with oyster beds were significantly higher than on adjacent soft sediment bottoms. The number of invertebrate taxa reported on subtidal oyster beds along the eastern coast of the United States ranged from 90 to 138 (Kennedy 1996a). These invertebrates, either as adults or their planktonic larvae, can become food for other trophic levels of the coastal food web such as zooplankton, predatory invertebrate crustaceans (i.e. lobsters, crabs, shrimp) and fishes.

Lawrence Taylor- Biodiverse Canada

A wide range of fishes depend on the habitat created by oysters.

Oyster beds are also known to support a complex and diverse assemblage of fishes that use the beds as nursery and/or feeding grounds. Harding and Mann (1999) documented 32 species of finfishes representing 26 families on or in proximity to a small (1 ha) restored oyster reef in the Piankatank River (Virginia). The reef, composed of oyster shells (0.63 ha) and crushed clam shells (0.27 ha), was constructed in 1993 as part of an oyster restoration project.

Harding and Mann (1999) focused on pelagic fishes and used a variety of sampling gear (i.e. gill nets, trawls and crab pots). Sampling effort was extensive. It spanned two seasons and involved sampling during daylight hours only and covered at least two parts of the tidal cycle. A total of 42 gillnet sets, 132 trawls and 120 crab pot sets were deployed in 1996 and 270 gill nets sets and 172 crab pot sets were completed. Species captured during sampling included resident benthic fishes such as striped blennies and naked gobies, and transient fishes such as striped bass, bluefish and Atlantic menhaden and eel. According to Harding and Mann (1999) other studies on natural or restored oys-

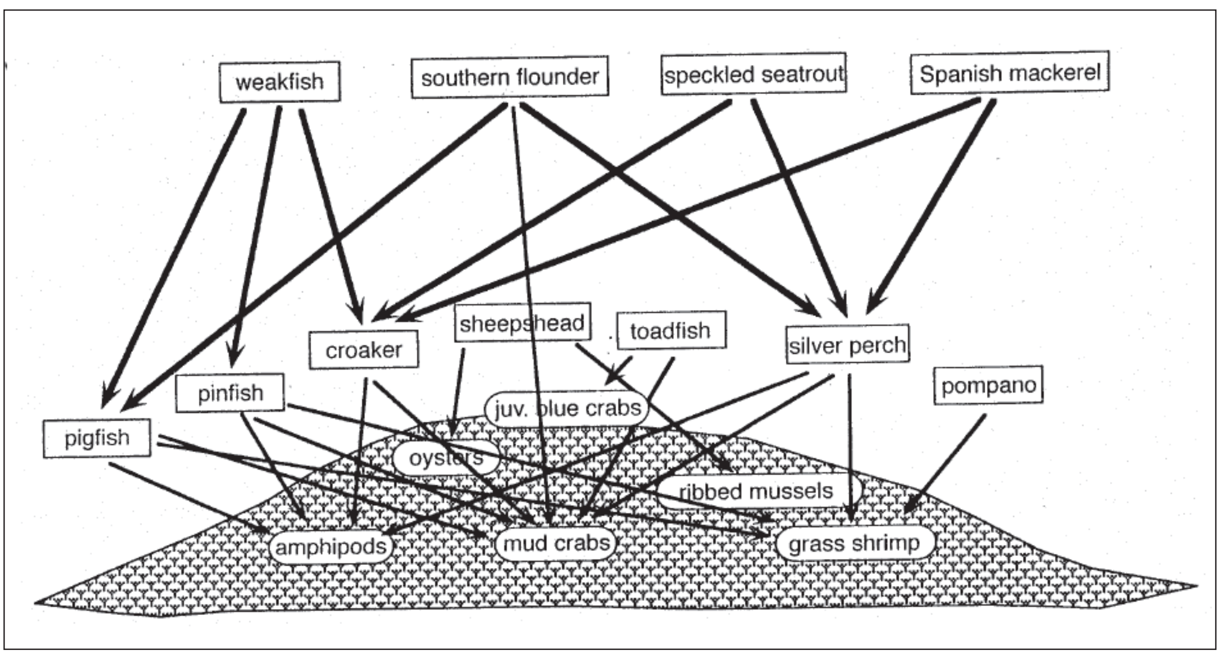


Fig. 2. A partial food web describing predator-prey interactions among large mobile fishes, benthic crustaceans, and other large invertebrates inhabiting experimental oyster reefs in the Neuse River estuary (North Carolina). Trophic interactions depicted are based solely on stomach contents of fishes sampled on reefs.

Source: Lenihan et al. 2001, Ecological Applications 11(3): p. 772.

ter reefs within Chesapeake Bay have observed similarly high numbers of finfish species.

More recently, Lenihan et al. (2001) reported the results of a study to compare how fishes and invertebrates on natural and restored reefs and on sand bottom utilize these different habitats and to characterize the trophic relations among large reef-associated fishes and benthic invertebrates. The study sites were within the Neuse River estuary in Pamlico Sound (North Carolina) where production and harvest of oysters had been historically high but had declined by two orders of magnitude over the last 50 years because of reef habitat degradation, degraded water quality, and oyster disease (Lenihan 1999, Lenihan and Peterson 1998). They found that both natural and restored oyster reefs are utilized by more fish, and a greater number of fish species, than unstructured sand-bottom habitat. The gut contents of the fishes captured revealed that they were feeding on crustaceans associated with the oyster reefs. Based on this information, Lenihan et al. (2001) proposed a partial food web describing the predator-prey interactions among the large mobile fishes, benthic crustaceans, and other large invertebrates inhabiting the oyster reefs in the Neuse River estuary (Fig.2).

In another recent study on a restored oyster reef in Virginia, it was determined that bottom-dwelling invertebrates associated with oyster beds have the capacity to directly influence the composition and abundance of overlying zooplankton and directly influence the community dynamics on oyster reefs (Harding 2001). The implication of this finding, according to Harding (2001), is that restoration of oyster beds can translate into increased abundance of fishes that forage on oyster beds.

In addition to providing hard substrate, the physical structure of oyster beds can alter the speed of water flow over the beds and can influence the delivery rate and retention of planktonic oyster larvae, suspended food material and sediments (Wildish and Kristmanson 1997). These effects in turn can affect the recruitment, growth and survival of oysters and the quality of oyster reef habitat (Lenihan 1999). An equivalent effect in the terrestrial environment would be caused by trees modifying the local wind currents and thereby altering patterns of seed dispersal and deposition (Lenihan 1999).

Historically, it is likely the oyster beds in the estuaries of northern and eastern New Brunswick rose off the bottom much higher than they do today. Decades of fishing, in particular oyster dredging, probably reduced the elevation of oysters reef significantly. A study by Lenihan and Peterson (1998) demonstrated that one of the functions of an oyster reef is to elevate the oysters and associated organisms into the upper water column thereby providing a refuge against exposure to bottom water that may become low in oxygen (hypoxic) or completely devoid of oxygen (anoxic). These hypoxic/anoxic events can occur during the summer and fall when warm temperatures increase rates of microbial activity, surface waters stratify (separate into discrete temperature or salinity layers) and earlier plankton blooms and/or land runoff have loaded the system with organic matter (Peterson et al., 2000).

Given the results of these studies, it is not surprising that in the United States oyster reefs are considered critical or essential fish habitat (Breitburg and Miller 1998; Coen et al. 1999; Peterson et al. 2000).

2.2 Oysters as filters

Another important ecological function of oysters is their filtering activity. Oysters are suspension-feeders, filtering microscopic plants from the water using their gills. Thousands of hair-like structures called cilia located on the gills create a water current into and out of the shell. An adult oyster can circulate up to 34 litres of water per hour (Lavoie 1995). In addition to maintaining a steady water flow and filtering the water to collect food particles, the gills sort and separate food from detritus and other suspended solids.

The oyster's ability to remove suspended sediments, phytoplankton and other organic material from the water column helps to decrease the turbidity or murkiness of the waters, and mitigates the effects of eutrophication (see page 18). Prior to 1870, it has been estimated for Chesapeake Bay, which covers an area of approximately 11,000 km^2, that the oyster population had the potential to filter the equivalent of the entire water column of the bay in three days (Newell 1988). By the early 20th century, oyster catches had been reduced to a few percent of peak values and have not recovered to their 1914 historic high levels. Today, filtration of the bay is estimated to take over 46 weeks (Newell 1988). As a result, more sediment remains in suspension and much of the phytoplankton goes ungrazed, sinking to the bottom and creating low oxygen conditions near the bottom.

2.3 Oysters as recycling centres

Considerable research has been done to examine the role oysters play in processing, retaining and recycling estuarine material such as sediments, organic material and nutrients (N, P, and C) (Officer et al. 1982; Dame et al. 1984; Dame et al. 1989; and Dame and Libes 1993). Dame et al. (1984) developed an innovative method of measuring the uptake and release of nutrients over the oyster beds using a 10-metre long plastic tunnel which they called the Benthic Ecosystem Tunnel or BEST. The tunnel was placed over an oyster bed with the edges carefully sealed to the bottom. The concentrations of phytoplankton, oxygen, and dissolved nutrients could be measured at the upstream and downstream ends of the tunnel. These measurements combined with measurement of the volume of tidal water flowing through the tunnel were used to calculate a range of ecosystem properties such as rate of grazing on the planktonic algae, total system metabolism, and the uptake and release of nutrients.

This experimental method was applied to a number of estuaries in South Carolina where oysters are a prominent coastal feature. The results demonstrated that the oyster reefs significantly reduced the particulate organic carbon and phytoplankton concentrations in the water while increasing the ammonia concentration. In areas where oysters are found in association with submerged aquatic vegetation such as saltmarshes or eelgrass beds, Dame et al. (1984) concluded that oyster reefs play a significant role in material cycles. The influence of oysters in an estuary will depend on their abundance and the turnover time of the water in the estuary.

This description of the various roles oysters play in estuaries is simply a brief overview. Ray et al. (1997) prepared a summary of the function roles of oysters in the east coast estuaries of the United States which would also apply to oysters on the northeast and east coasts of New Brunswick (Table 2). Clearly, the oyster is more than a harvestable resource.

Table 2. Functional roles of oysters in USA East Coast Estuaries

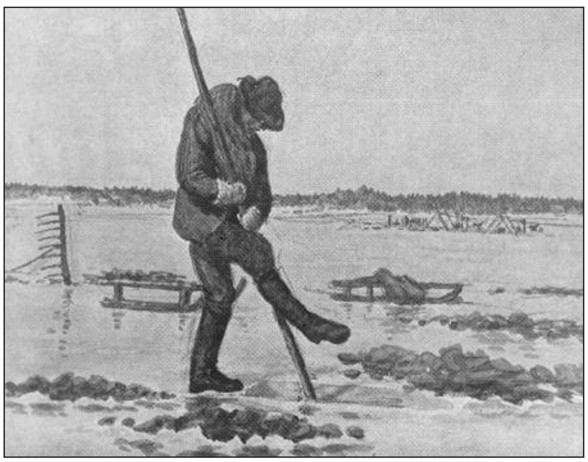
Oysters	Estuaries
Filtration capacity	High turnover rate potential of estuarine water
Nutrient links to other habitats	Release POC and NH4+ and takes up N from marshes
Increases bodiversity	Provides increased niche space for ecological complexity that radiates upward through the system; supports stenohaline species along a salinity gradient; sustains epizoan diversity
Affects water flow patterns	Benthic boundary layer and water column hydrodynamics; particle movements (enhances feeding opportunities, sedimentation, estuarine flushing and particle dispersions)
Influences shoreline processes	Builds and erodes marshland in a continuum of change; buffers against moderate storms and wave action
Increases benthic productivity	Adds nutrients/sediment to benthos to feed demersal feeders
Contributes to estuarine land/seascape	Affects marshland development and benthic infauna community
Seasonal pumping of carbon in form of eggs and larvae	Feeds filter-feeding organisms
Converts plants to useful organic and inorganic forms	Feeds on phytoplankton to build somatic tissue, reproductive tissues, shell, and faeces
A metabolic hot spot	High community metabolism
Dynamic interaction with physical environment	Builds and degenerates in a continuum of change
Contributes to estuarine resiliency	Forms meta-populations and communities as sources to restock disturbed areas; responds to storm events; contributes sediment to build benthic and shoreline habitat; dead shell stabilizes benthos
Active shutting of valves at sustained high rate removes particles in water around oyster	Keeps the benthic water clear around oysters
Provides feeding stations	Seasonal migrators can find food, rest, or shelter in and out of estuary; visitors by day or by night to feed

Source: Ray et al. 1997, p. 363. In: Marine Biodiversity: Patterns and Processes, Edited by R.F.G. Ormond, J.D. Gage and M.V. Angel. Cambridge University Press.

3.0 The decline of oysters

Before the advent of man, and at the present time where man does not interfere, the oyster was and is capable of holding its own in the struggle for existence. But where man interferes, with his reasoned methods of fishing and his selfish disregard for the future of the fishery, he disturbs the balance which has been obtained between the natural and opposed powers of production and destruction, and in a comparatively few years reduces the productivity of the natural beds to the verge of depletion.

Stafford 1913, p. 103



Centre d'Études Acadiennes (U de M)

Oyster fishing in Shediac is captured in a drawing by Hind c.1871.

By the early 1900's, oyster populations throughout eastern North America were being heavily exploited. In fact, oysters had been virtually eliminated from many areas including Bedeque Bay (P.E.I.), southern shore of Nova Scotia, and the southwest coast of the Gulf of Maine (i.e. Maine and New Hampshire) (Stafford 1913, Churchill 1920, Needler 1931). Oysters were initially harvested by hand in shallow water, then by a long-handled rake for deeper waters. This method was improved upon with the development of oyster tongs, a pair of long-handled rakes fastened together like scissors. Machine harvesting using oyster dredges or drags was introduced in the late 1800's. This method of harvesting was very efficient (Table 3), but destructive to the beds and reefs. Dredges broke down the structure of the beds, buried living oysters under dead shells or tumbled them into the mud (Stafford 1913). In New Brunswick, oyster dredges are still used on some private leases in some bays (i.e. Caraquet and Tabusintac Bays).

Table 3. Oyster yields using different kinds of oyster harvesting gear

Harvesting method	Rate of yield (boxes[1] of marketable oysters per 8 hour day)
Rakes (1 person)	2
Tongs (1 person)	2 - 4
Standard dredge (2 people)	30 - 60
Escalator harvester (3 people)	180 - 200

[1] 1 box = 1.25 bushels = 5 pecks = 0.044 cubic metres *Source: Medcof (1961)*

The onset of Malpeque disease, which hit New Brunswick oysters in 1950, has often been cited as the key reason for the decline in oyster production. Diseases, however, often take hold in populations that are physiologically stressed or genetically weakened. Kennedy (1996a) pointed out that the biological activity of oysters on beds, such as shell and spat production, particle filtration and deposition, and nutrient flux are reduced as oyster abundances decline. In the laboratory, oysters exposed to a variety of pollutants showed an increase in infection by the parasite, *Perkinsus marinus,* (Chu and Hale 1994).

As early as the 1940's, Gross and Smyth (1946) in their evaluation of the history of declining oyster populations on the Atlantic coast of Europe proposed that overfishing leads to loss of genetic variability and reduced adaptability to long-term environmental changes. They argued that "when an animal population has been reduced below a certain minimum the trend towards extinction continues although the original main cause of the decline - overfishing in the case of the oyster - has ceased to operate" (Gross and Smyth 1946). This occurred because "under adverse conditions approaching the limit of adaptation, the community will die out unless there are sufficient genetic variants present which can survive these conditions and establish the breeding stock of a population increasingly better adapted to the prevailing set of conditions" (Gross and Smyth 1946).

Since Gross and Smyth (1946) published their theory on the consequences of overfishing on the genetic health of oyster populations, there has been a considerably amount of research done to evaluate effects of fishing mortality on fish population genetics (see reviews by Allendorf et al 1987; Policansky 1991). Policansky (1991) summed up the state of knowledge this way:

Fishing mortality is often very high and nonrandom with respect to several life-history traits that are at least partly heritable [i.e., growth rate, fecundity, age and size at sexual maturation, etc.]. Therefore, it seems likely that fishing causes evolution in fishes....However, the action of many other factors makes the detection and measurement of evolution difficult, so many observations that show changes in life-history traits of exploited fish populations are not sufficient by themselves to establish the occurrence of evolution. The difficulty of detecting and measuring evolution by observation alone should not be interpreted as evidence that evolution is not occurring; instead, it provides an opportunity for experimental research that has theoretical and practical importance.

While less attention has been paid to the genetic impacts of fishing on oyster populations, the theory put forward by Gross and Smyth (1946) more than five decades ago still has some merit today, although more research needs to be done. Similarly, it is quite possible that the devastation caused by Malpeque disease was a symptom, rather than the cause, in the decline of oysters populations.

The oyster fishery in New Brunswick never recovered to its 1950 peak despite large sums of federal and provincial government money expended to purchase oyster seed, collectors and equipment, and provide free leases, surveys and advice (Lavoie 1995). This funding was directed at increasing oyster production through farming.

Despite this outpouring of funding and effort, René Lavoie, a federal fisheries scientist and administrator asked "why is the industry not producing closer to its projected potential?" (Lavoie 1995). In answering this question, Lavoie (1995) cited a combination of historical, administrative, social and political factors, but suggested the ultimate explanation for the problems rested with the unsuitability of the targeted people. Lavoie (1995) argued that oyster farming is a sophisticated operation which is not suitable for unsupervised, unskilled labourers recruited through job-creation projects.

The same experience can be found in other oyster-producing coastal areas such as Maryland, Virginia, South and North Carolina, Florida, Texas and Delaware where current oyster populations are still a fraction of their historic landings, and for other species (i.e. whales, manatees, dugongs, monk seals, cod, swordfish, sharks and rays) and ecosystems. In what can only be called a landmark paper, Jackson et al. (2001) examine the paleoecological, archaeological, historical and ecological records for several key marine ecosystems including estuaries dominated by oysters and eelgrass beds. The authors conclude that in each case historical overfishing precedes all other human impacts including pollution, degradation of water quality, and climate change, as the principal cause of recent collapses in coastal ecosystems.

According to Jackson et al. (2001), the collapse of the oyster industry in Chesapeake Bay in 1930 was followed - not preceded - by a decline in water quality and disease outbreak. The full symptoms of eutrophication in Chesapeake Bay - increased microbial activity, reduced oxygen and decreased biological diversity - did not appear until after the collapse of the fishery. Jackson et al. (2001) demonstrate that the ratio of planktonic to benthic diatoms, a proxy for eutrophication, remained relatively constant (1:1) for 1200 years until the late 1700's. The ratio increased threefold with the increased runoff of sediments and nutrients that accompanied increased agricultural and other human development activities. The ratio remained at 3:1 until 1930 after which time it increased to 8:1. This ratio implies that, until the collapse of the oyster fishery, the existing oyster population was able to limit the potential for eutrophication induced by increased inputs of nutrients (nitrogen and phosphorus) and organic material. In other words, prior to the collapse of the oyster fishery, the dense populations of oysters and other suspension-feeding bivalves grazed plankton so efficiently that they limited blooms of phytoplankton and prevented symptoms of eutrophication.

With oyster beds destroyed, the effects of eutrophication, disease, hypoxia and fishing interact to prevent the recovery of oysters and associated communities. The ecological consequences of reducing the populations of a key species such as the oyster for other components of the coastal ecosystem are unknown (Jackson et al. 2001).

What is known is that the coastal food web of Chesapeake Bay has changed (Fig. 3). Long before oyster populations collapsed, gray whales, dolphins, manatees, river otters, sea turtles and alligators in Chesapeake Bay had been overfished to near and, in the case of gray whales in the Atlantic, complete extinction (Jackson et al. 2001). Declines in these species were followed by the virtual elimination of giant sturgeon, sheepshead, sharks and rays. Today, the abundance of commercially important predatory fish (i.e. striped bass, bluefish) and predatory invertebrates (i.e. blue crab), benthic algae, seagrasses and oysters are currently at low levels compared to one hundred years ago (Jackson et al., 2001). Fishing down the food web, combined with the destruction of essential fish habitat - saltmarshes, eelgrass and oyster beds, has resulted in a shift in species composition and dominance in the entire food web. Today, species such as worms and amphipods which feed on detritus (organic debris), pelagic bacteria, and jellyfish which feed on phytoplankton have increased in dominance (Newell 1988; Jonas and Tuttle 1990; Ulanowicz and Tuttle 1992).

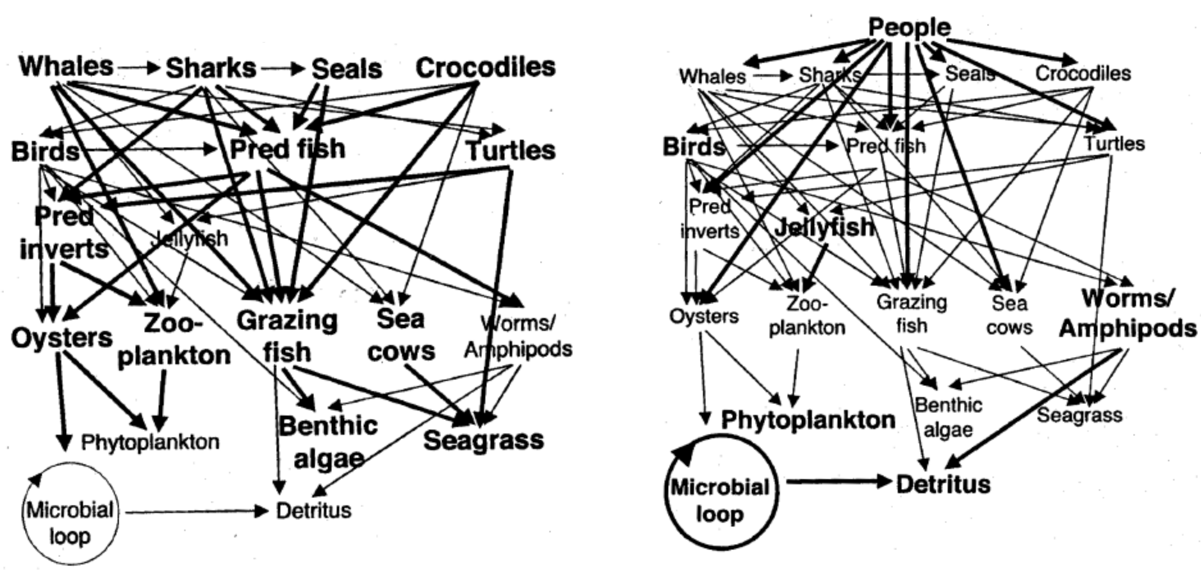


Fig. 3. Simplified temperate estuarine food web showing changes in some of the important top-down interactions due to overfishing before (left side) and after fishing (right side). Bold font represents abundant; normal font represents rare. Thick arrows represent strong interactions; thin arrows represent weak interactions.

Source: Jackson et al.2001. Science 293: p. 630.

The events leading to the collapse of temperate estuaries described by Jackson et al. (2001) are strikingly familiar to events in northeastern and eastern New Brunswick - massive overfishing of higher trophic level species, habitat destruction, decline in water quality and symptoms of eutrophication (Milewski and Harvey 2000). Despite considerable effort by federal and provincial governments, oyster production is still less than 10 percent of historic levels. Once abundant commercial fish species such as striped bass, cod, tomcod, rainbow smelt, gaspereau, salmon, shad and smelt have also declined since the collapse of the oyster fishery a half century ago (LeBlanc and Chaput 1991; Chaput et al. 1998). In the case of striped bass, the species has been all but eliminated from the estuaries, and Atlantic sturgeon is gone entirely. Meanwhile, according to anecdotal information provided by coastal residents on the east coast of New Brunswick, jellyfish, seaweeds and detritus appear to have increased.

Very few people would dispute the fact that the coastal ecosystems we see in New Brunswick today are unlikely to resemble the ecosystems of 100 or 300 years ago. It is likely that, as with Chesapeake Bay, nutrient, organic and pathogen loading (i.e. manure spreading, fish processing and sewage plants), increased sedimentation (i.e. dredging, pulp mills, and clearcutting) and further wetland destruction (i.e. shoreline development) are preventing oyster populations from recovering in New Brunswick, and therefore are contributing to estuarine decline.

Eutrophication

Nutrient (nitrogen) loading in marine waters initiates a process called eutrophication. Depending on the volume and duration of the nutrient loading and the assimilative capacity of the receiving waters, this process can culminate in a fundamental shift in the ecology of an area. Increased nutrient input tends to shorten the number of trophic levels in food webs and result in "ecological simplification" (Taylor 1997). The Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP 1990) outlined the following biological and ecological changes that take place as eutrophication progresses:

1) increased primary production;

2) changes in plant species composition;

3) very dense, often toxic, algal bloom;

4) condition of hypoxia (low oxygen concentration) or anoxia (no oxygen);

5) adverse effects on fishes and invertebrates; and

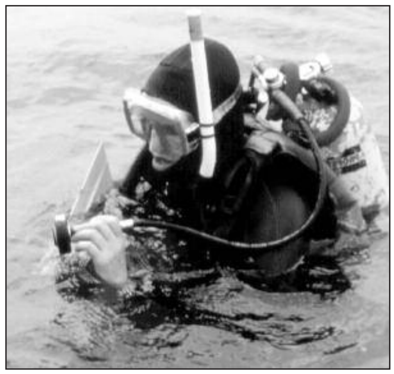
6) changes in structure of benthic communities.

In a series of workshops sponsored by the US Environmental Protection Agency and the US National Oceans and Atmospheric Association, experts from around the US identified characteristic features of coastal environments that had been over-enriched with nutrients. These included:

- *reduced diversity*
- *a shift from large to small phytoplankton*
- *a shift in the species composition of the phytoplankton from diatoms to flagellates*
- *increased incidence of toxic phytoplankton blooms*
- *increased incidence of undesirable phytoplankton blooms*
- *increased seaweed biomass*
- *loss of seagrasses*
- *a shift from filter-feeding to scavenger-type animals*
- *a shift from larger, long-lived animals to smaller rapidly growing but shorter-lived species, and*
- *increased disease in fish, crabs, and/or lobsters.*

4.0 Oyster beds as habitat: A field survey of four major bays

Historically, oysters were harvested from almost every bay and estuary along the north and eastern coasts of New Brunswick. Yet no biological surveys, other than studies on the distribution, abundance and population structure of oysters on the beds, have been carried out on any oyster beds in New Brunswick.



CCNB

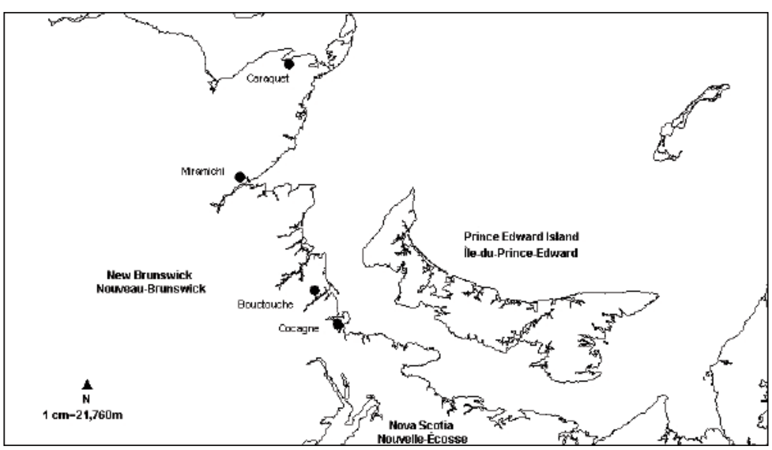
Annelise (Lise) Chapman prepares to gather data.

In the summer of 2001, the Conservation Council of New Brunswick (CCNB) initiated a study to begin to address some of the gaps in knowledge regarding the ecological status of oyster beds, specifically their function as habitat for a variety of associated species. For this ecological study, a subset of oyster beds were selected from four estuaries between Caraquet and Cocagne. The objective of the survey was not to provide a random assessment of an entire estuary, but rather to identify different types of oyster habitat, different conditions of oyster beds in relation to potential external factors such as fishing, sedimentation, nutrient loading, and to investigate the associated species communities.

4.1 Survey sampling methods

Field work took place over a six-day period from July 23 - 28, 2001. As time and other associated resources were limited, a sampling approach was chosen in which the level of quantitative data collection was flexible for each site (see Table 4). Hence, a sampling location was initially determined to be a historical or recent oyster bed based on information provided by local fishermen. In a first step, the site was assessed using a 'viewing box' from the boat. Since many sites were in very shallow water, it was usually possible to get some impression of the bottom habitat by this method. Unless visibility was extremely poor, we could distinguish between an eelgrass bed, an oyster reef, or simply a mud bottom without epibiota (surface-dwelling organisms).

Once a site was selected for further explo-



Location of field survey sites

ration, the boat was anchored and divers entered the water to assess the overall habitat characteristics of the area. These events were identified as 'site' visits. Twenty-three (23) site visits took place in the four bays: 7 in Caraquet; 6 in Miramichi; 4 in Cocagne and 6 in Bouctouche. If the habitat appeared in any way relevant for the study or unique for the area, sampling proceeded further at the site.

In the next step, photographs were taken with a fixed-area frame that covered 0.25 m^2. Any surface living biota (eelgrass, mud whelks, bivalves etc.) were quantified from the image. In a more detailed quantitative sampling, all living organisms were removed from a defined area of bottom. This was achieved with a suction airlift, a sampling device which essentially functions as an underwater vacuum cleaner. With this device, all organisms, sediment, shells and debris down to at least 20 cm depth (and always to the anoxic sediment layer) were transferred into a 1 mm mesh bag, which was then taken to the boat, sieved (1 mm mesh size) and fixed in 5% formalin. If oysters covered the surface of the sample site, they were removed by hand into sample bags before using the suction lift. If at all possible, quantitative samples were taken in replicates of three. Sampling in Caraquet Bay was only semi-quantitative because of a mechanical problem with the airlift. Hence, oyster population data are comparable to other bays, but associated macrofauna and –flora are clearly under-represented.

Generally, any information on associated species is reliable only for attached or slow moving organisms. This survey did not include sampling techniques to quantify abundances of pelagic or highly mobile benthic species, such as fish or shrimps. However, whenever such species were observed under water, their presence was documented non-quantitatively.

In conjunction with quantitative benthic sampling, physical parameters were assessed through sediment samples (cores of 2.5 cm diameter, 5 cm depth) and water samples (20 ml tubes, generally surface and bottom) and analyzed in the laboratory for grain size composition and salinity respectively. In some cases (i.e. in the presence of a dense oyster matrix) it was impossible to core into the sediment; under these conditions, no sediment samples were taken.

4.2 Sample analysis

Sediment samples were analyzed for grain size using a Coulter LS200. The Coulter LS200 is a particle size analysis system that uses laser diffraction technology to measure the particle size distribution of a sample from 0.4 to 2000 micrometres (µm) diameter. Twenty-one samples from 9 sampling sites were analyzed. Water samples were analyzed for salinity by means of a refractometer.

All benthic organisms were identified to species level wherever possible. Individuals of all invertebrate species were counted. Seaweed species were noted as present or absent. Oysters were included in the analysis if they had both valves present, and were identified as live or dead at the time of sampling. Dead oysters are likely to contribute significantly to the structural component of oyster beds and hence probably affect associated species diversity. The distinction between live and dead oysters allowed us to disentangle structural effects from other potential effects of oysters as habitat. Oysters were counted and measured (length and width at widest point to nearest mm) and any presence of attached barnacles and boring sponges was noted for each individual oyster.

Table 4. Summary of sampling effort in four bays in northern and eastern New Brunswick. Water samples for salinity analysis were taken at the surface (S) and bottom (B).

Bay	Site no.	Location/Assessment			Benthic Sampling				Sediment/Water	
			Orient. Dive	Photos	Semi-quant.	Quant.	Area m^2	No. of Samples	Grain Size No. of samples	Salinity
Caraquet	1	47° 46.958' N 65° 02.976' W	X	X	X		0.25	3	3	S
Caraquet	2	47° 47.226' N 65° 01.431' W	X	X						
Caraquet	3	47° 47.022' N 65° 01.403' W	X	X	X		0.25	3	3	S/B
Caraquet	4	47° 46.899' N 65° 01.156' W	X							S
Caraquet	5	47° 46.821' N 65° 00.767' W	X							
Caraquet	6	47° 47.033' N 65° 01.266' W	X							
Caraquet	7	47° 47.267' N 65° 03.291' W	X	X	X		0.25	3	3	S/B
Miramichi	8	47° 05.255' N 65° 00.853' W	X	X	X		0.25			
Miramichi	9	47° 06.151' N 65° 01.017' W	X	X		X		3	2	S/B
Miramichi	10	47° 06.746' N 65° 01.285' W	X	X			0.25			S/B
Miramichi	11	47° 06.315' N 65° 02.415' W	X	X		X		3	2	
Miramichi	12	47° 06.116' N 65° 02.900' W	X	X			0.25			S/B
Miramichi	13	47° 05.116' N 65° 03.494' W	X	X		X		3		
Cocagne	14	46° 22.465' N 64° 36.032' W	X				0.125			
Cocagne	15	44° 22.723' N 64° 36.046' W	X	X		X	0.125	3	2	S/B
Cocagne	16	46° 20.163' N 64° 36.348' W	X	X		X	0.125	3	2	S/B
Cocagne	17	46° 19.815' N 64° 37.200' W	X	X						
Bouctouche	18	46° 28.400' N 64° 40.886' W	X							
Bouctouche	19	46° 28.777' N 64° 40.801' W	X							
Bouctouche	20	46° 29.036' N 64° 40.588' W	X			X	0.125	2	2	S/B
Bouctouche	21	46° 28.412' N 64° 41.511' W	X			X	0.125	3		S/B
Bouctouche	22	46° 28.166' N 64° 41.948' W	X	X		X	0.125	3	2	S/B
Bouctouche	23	46° 30.065' N 64° 40.497' W	X	X						

4.3 Results

The following sections present environmental backgrounds and fishing histories, as well as survey results, for each of the four bays individually. These sections are followed by a summary of the findings across all four bays. Unfortunately, fixed-frame photographs turned out to be of limited use for quantitative analysis – at least in Cocagne and Bouctouche, where turbidity in the water was so high that too much back scatter largely obscured the images.

4.3.1 Caraquet Bay

Caraquet Bay, eight km long and three km wide, is a small semi-enclosed tidal bay. A sandbar (Maisonnette dune) at its mouth separates it from Chaleur Bay. At high tide the dune is submerged. Outside the main channel, the average water depth at low tide is about 2 m and the mean tidal range is 1.4 m (Booth and Sephton 1993). The bay is weakly stratified which means the water in the bay divides or separates into discrete layers based on temperature or salinity (i.e. fresher, less salty water can sit on top of cooler, more salty water). Fresh water enters Caraquet Bay through the Northwest Caraquet and Southwest Caraquet Rivers and MacIntosh Brook. The bay freezes over in the winter.

Caraquet Bay is the northern limit for the American oyster, *Crassostrea virginica*. The largest natural oyster bed, a public bed, is situated in the inner part of the bay just outside the area where the two rivers empty into the bay. Privately leased areas are located near the south and north shore of the bay. A recent study has demonstrated that the size (surface area) of the public bed and density of oysters on it have decreased by 20 percent since 1974 (Landry et al. 2001).

According to local fishermen, there has been an increase in sediment on the beds and the waters in the bay are more turbid. Some fishermen attribute the increased turbidity to oyster dredging on private leases, and the increased sediment loads in the bay due to clearcutting in the watersheds and to nearby peat harvesting operations, and to a recent breach (1991) in the Maisonnette dune.

There have been several deliberate and natural breaches in the Maissonnette dune over the past five decades. Regardless of the forces that alter a dune, the removal of sand in one area could mean excess erosion or deposition of sand in another area. The sands of tidal gullies, dunes, spits, barrier islands and beaches which characterize the north and eastern coast of New Brunswick are in dynamic equilibrium which

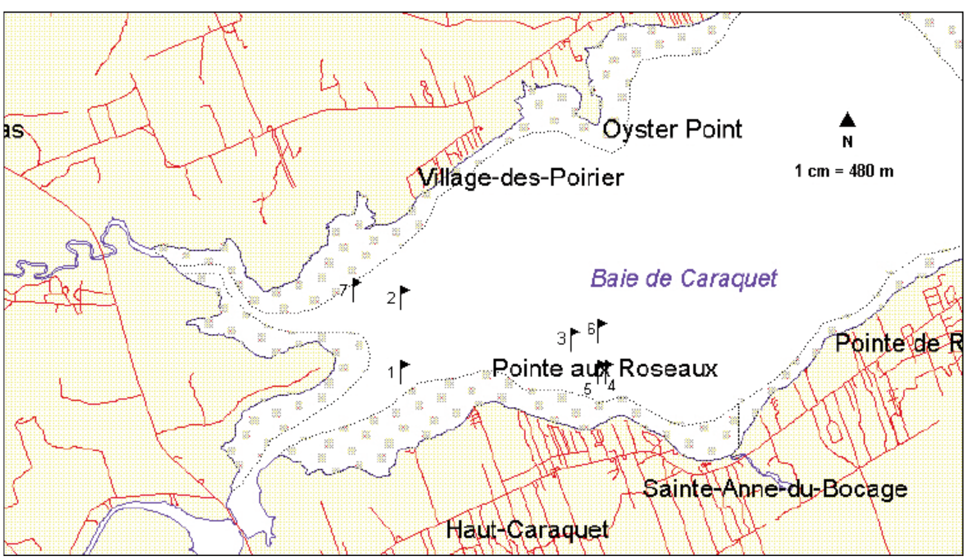


Fig 4. Caraquet Bay (flags indicate sampling sites).

Service Nova Scotia: Geomatics Centre

1996 aerial photo of the Maisonnette dune showing a breach in the dune.

means they are continually changing depending on the strength or weakness of the forces that shape them. As a result, these coastal features are very sensitive to disturbances. Some fishermen suggest a sand bar or bank has been forming inside the bay since the most recent breach in the dune. No studies have been published on the effect these breaches have had on the circulation or sediment distribution in Caraquet Bay.

Most of New Brunswick's peat harvesting is concentrated in the Acadian Peninsula including the area around Caraquet Bay and in the Tabusintac and Baie-Ste-Anne regions of Miramichi Bay (DNRE 1999). Peat is harvested by machines which clean and loosen the surface layer of large sections of a moss deposit. This loosened moss is left to air-dry in the field. When dry, it is harvested by a large vacuum and bagged. Winds can lift and deposit large volumes of fine peat particles into drainage ditches which eventually discharge into water bodies. Peat particulars are also deposited directly into streams, rivers and estuaries. There they are moved around by currents and tides.

While current regulations require harvesting companies to install settling basins to reduce excessive run-off, the effectiveness of this remains to be demonstrated. A study into the effects of a large release of peat moss into Mill Creek which flows into the Richibucto River revealed a decrease in the number of fish, shrimp and clams, and habitat for bottom-dwellers was "modified" where peat depths are greatest (Ouellette et al. 1997). Oyster fishermen believe that peat moss particles in estuaries may be slowing the growth of their oysters and even killing them. Strychar and MacDonald (1999) found that suspended peat is ingested by oysters and, depending on the concentration of peat particles in the water, can fill their gut with material that is not readily digested. The implication is that oyster are eating largely "empty calories" which could have a negative impact on their growth and survival. The fine particles of peat suspended in the water column can also interfere with the free circulation of phytoplankton, the oyster's primary food source. Hence,

NB Image Bank

Particles from peat harvesting can be carried to rivers and estuaries where they may impact oyster growth.

normal feeding and respiratory processes of oysters and other bivalves (i.e. clams, quahogs) may be impaired. Large amounts of peat settling out in the lower layer of the water column for long periods may result in oxygen depletion which can have deadly results for bottom-dwelling species of all kinds (Lavoie 1995).

Sediments sampled during this study in Caraquet Bay consisted largely of medium sands (0.25 – 0.5 mm grain size). However, at site 3 (Table 5), sediments were very fine and were classified as 'medium silt' (0.016 to 0.033 mm grain size). Unfortunately, the scope of this project limited the range of sediment analyses that could be done. No analyses were done to measure organic content of the sediment or to distinguish peat particles from other components of the sediment.

Prior to the decimation of the oyster population in Caraquet Bay by Malpeque disease in 1950, oyster landings were 325 mt per year (Biorex 1991). In 1959 and 1960, a total of 133 mt of oysters from P.E.I. were transplanted to Caraquet Bay. In 1968, the oyster fishery resumed. In 2000, oyster landings for Caraquet Bay were 34 mt. Since the early 1970's, portions of the Bay have been closed to harvesting due to bacterial contamination. At the time, a pollution study identified a number of sources of bacterial contamination including the piggery at Burnsville, discharge of untreated sewage from the Caraquet municipal sewage plant, fish processing plants and land runoff (VanOtterloo et al. 1974). Today, discharges from both treated and untreated municipal sewage, poorly operating septic systems, and direct discharges from boats and shorefront residences keep half of the public oyster beds under "conditional approval" by Environment Canada (GTA 1993). Conditional approval means that the area must be sampled regularly and that median fecal coliform levels or most probable number (MPN) must be 14 or less with no more than 10% of the samples in excess of 43 MPN/100 ml.

The conditional approval classification of the public beds also means that the beds are not always harvested or "worked" because they are often closed due to unacceptable levels of fecal coliforms. Fishermen believe that, as a result, sediment builds up on the beds, eelgrass begins to encroach onto the beds, and the quality of the oysters declines. According to fishermen, reduced harvesting activity on the beds reduces spat settlement, and oysters appear to grow less and live less long. Fishermen believe that the public beds as a source of oyster stock are decreasing, and that there is a need to protect and restore the beds. They have also noticed that since fewer fishermen are able to fish the beds, there is less government interest in the fishery and fewer services to oyster fishermen. In 1993, there were an estimated 140 commercial oyster fishermen who used the public beds in Caraquet (GTA 1993). Today, between 35-40

Table 5. Average grain size classifications for median particle sizes at sampling sites in northeastern and eastern New Brunswick. (For location of sampling sites see Figs. 4,7, 9 and 15.)

Bay	Site	Classification	Grain Size Range [mm]
Caraquet	1	very fine sand	0.065 - 0.125
Caraquet	3	medium silt	0.016 - 0.033
Caraquet	7	very fine sand	0.065 - 0.125
Miramichi	19	fine sand	0.125 - 0.250
Miramichi	11	coarse silt	0.033 - 0.065
Cocagne	15	medium sand	0.250 - 0.500
Cocagne	16	fine sand	0.125 - 0.250
Bouctouche	20	very fine sand	0.065 - 0.125
Bouctouche	22	medium silt	0.016 - 0.033

fishermen work the public beds for a five-week period.

There have been no biological surveys done on the beds other than studies on the distribution, abundance and population structure of oysters on the beds (Lavoie 1978; Lavoie and Robert 1981; Sephton and Bryan 1988; Senpaq 1991 and Landry et al. 2001). Over the years, however, fishermen have noted changes in presence and absence of various species such as seastars, lobsters, crabs, sea squirts, eels, and eelgrass. Historically, the most important commercial estuarine species for this region (statistical district 65) were rainbow smelt, gaspereau and tomcod. No commercial landing of gaspereau or tomcod have been reported since the late 1980's and rainbow smelt landings in 1994 were 25 mt, down from a historic high of 436 mt in 1938 (Chaput and LeBlanc 1996). Rainbow smelt fry feed on zooplankton and as they grow they prey on invertebrates such as amphipods, shrimp and marine worms. As adults they feed on small fishes such as silversides, mummichogs and herring (Scott and Scott 1988). Rainbow smelt are in turn food for larger fishes such as cod and Atlantic salmon, as well as seals and birds such as cormorants and gulls.

Of the three sites sampled in Caraquet, site 1 and 7 contained oysters at densities of 84 ± (plus or minus) 26 and 67 ± 27 individuals per square metre (ind. m^{-2}) respectively. Both sites are located within the public bed in areas that are characterized as being medium density (10-100 ind. m^{-2}) oyster areas (Lavoie 1977; Sephton and Bryan 1989; Landry et al. 2001). In 1972, 14.4% of the oysters on the medium-density portions of the public bed were determined to be of 'legal' size (i.e. individuals longer than 75mm) (Lavoie 1977). At this size the oysters become marketable. Our survey found that the percentage of legal sized oysters on the medium-density portions of the public bed had declined to less than 2% (Fig.18, page 43).

All oysters were measured and their length to width ratio (LWR) determined (Fig. 5). This measure gives an indication of the average oyster shape, i.e. distinguishes long and narrow individuals from more stout and rounded ones. According to observations and samples from this study, young oysters are often uniformly rounded until they reach approximately 50 mm length, and their shape is characterized by an LWR of 1.5 which indicates they are approximately 1.5 times as long as wide. Differences in shape of individuals among oyster populations become apparent once oysters outgrow 50 mm length. For this reason, we calculated the average LWR for oysters larger than 50 mm (LWR_{50}) for each site, and added this value to the plot of size ratios for all oysters at any one site.

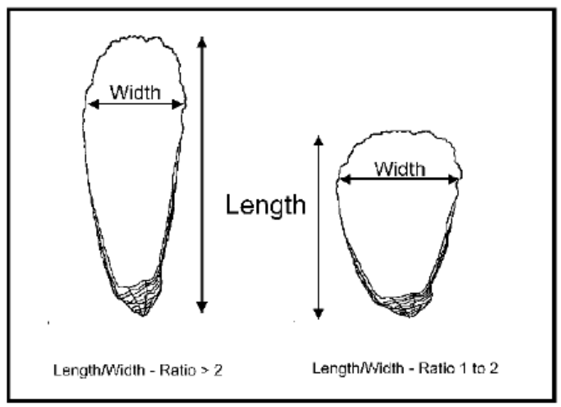


Fig. 5. Different growth forms of oysters on reefs (left) and on beds (right). A high density of individuals leads to more elongated growth of adults. Growth forms are described quantitatively as Length/Width Ratio (LWR).

In Caraquet, oysters from the public bed (sites 1 and 7), had LWR_{50}s of 1.61 and 1.67 respectively, i.e. they did not appear particularly elongated (Fig. 6). In conversation with local fishermen, it was mentioned that oysters in areas of the public beds, which were not regularly harvested, and especially those near the river channel, were growing to a very long and narrow shape, which is undesirable from a market point of view. We could not confirm this information for Caraquet in our study.

Site 3, which was also sampled semi-quantitatively, was in a private lease area that is regularly dragged for oysters. The difference between site 3 and sites 1 and 7 regarding oyster presence, sediment type and benthic life was striking and immediately apparent despite the

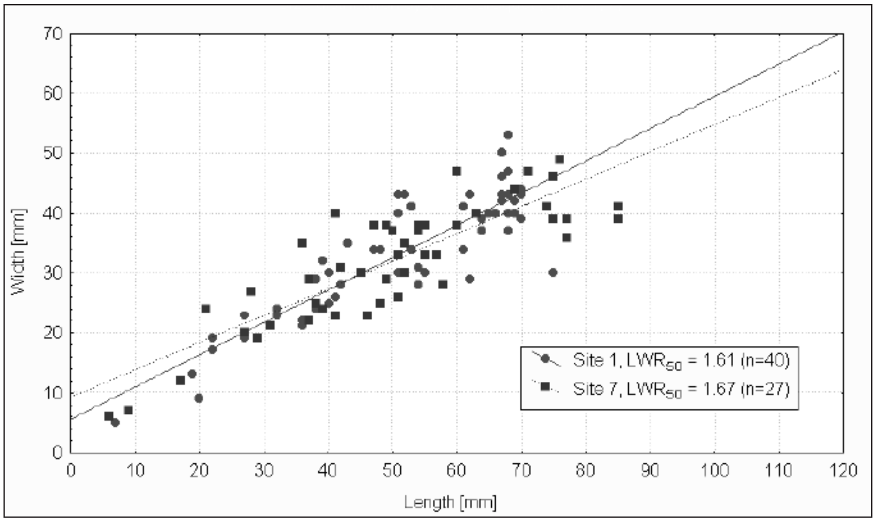


Fig 6: Size distribution of oysters (length to width) in Caraquet Bay for sites 1 and 7. Length to width ratio for oysters >50 mm (LWR_{50}).

fact that no full quantitative sampling took place in Caraquet. At site 3, we found no oysters and only a few epi-benthic animal species that are characterized as having a scavenging or detritus feeding life style in very muddy habitats. The most conspicuous, and sometimes the only abundant species at site 3, was the mud snail, *Ilyanassa obsoleta* (Appendix 2). In contrast, the two sites with oysters had various species which were either directly associated with the shells, or indirectly linked to the presence of oysters (i.e. through the food web) (Appendix 1). Sites 1 and 7 yielded a number of species of mobile predatory polychaete worms (e.g., *Neanthes caeca, Phyllodoce mucosa, Lepidonotus squamatus*) which were not found at site 3 (Appendix 2).

Six species of seaweeds which utilize shells as attachment substratum were found at sites 1 and 7. All of these but one were red algae, not the green algal species indicative of eutrophicated estuarine conditions. In fact, some of the red seaweed species found at sites 1 and 7 occur only in the lower Gulf of St Lawrence within Atlantic Canada, as they require high water temperatures during summer. Various seaweeds of distinct texture - some like finely branched trees (*Antithamnion cruciatum* or *Ceramium sp.*) and others rather firm (*Daysa baillouviana*) or sheet-like (*Ulva sp.*) - occur on the oysters. They attract small herbivorous crustaceans which feed on and hide among them. This is reflected in the presence of gammarid amphipods and the isopod, *Idothea balthica,* in our samples from sites 1 and 7 (Appendix 2).

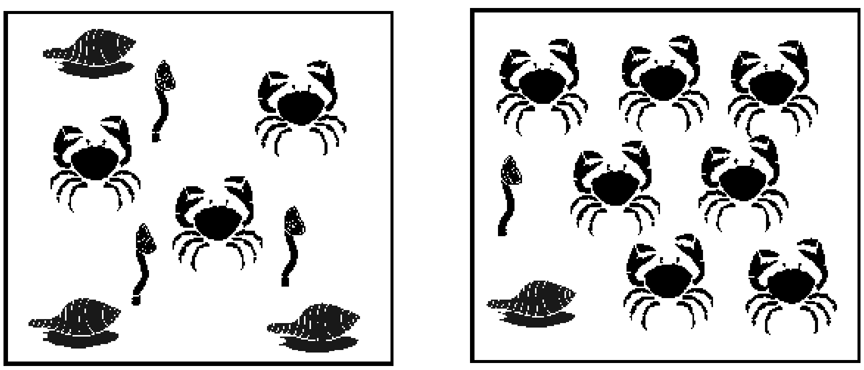
Also in sites 1 and 7, in the presence of oysters and attached seaweeds, we found seven species of polychaetes including mobile and sessile, detritus-feeding and predatory species, several species of other bivalves such as soft-shell clams (*Mya arenaria*), blue mussels (*Mytilus edulis*), and angel wings (*Petricola pholadiformis*), and among the gastropods primarily two species of slipper limpets, which are filter feeders like bivalves and attach themselves to a hard surface.

The number of epi-benthic species found at sites 1 and 7 is indicative of a complex surface structure (provided by the oyster matrix and associated seaweeds) as well as a species community with several trophic levels and intricate species interactions. Although we did not test the hypothesis and it is only speculative at this point, it is possible that community and food web complexity in the benthos are reflected in species presence and interactions in the water column.

At both public bed sites, oysters were interspersed with eelgrass (*Zostera marina*) at varying densities (an average of 19 and 137 shoots m^{-2} at sites 1 and 7 respectively). Eelgrass increases the surface complexity of the habitat and is utilized as substratum, food and shelter by a variety of epi-benthic species similar to a matrix of live oysters and shell debris. However, as a result of our sampling method in Caraquet, species recorded at our sites were generally directly associated with oysters rather than eelgrass.

We noted the abundance of mud shrimp, *Crangon septemspinosa*, at all the sites in Caraquet (Appendix 2). However, sites with oysters were characterized by higher abundances of mud shrimp than sites without oysters. Overall species richness and diversity (measured as Shannon-Wiener diversity index, *H'*), were at their minimum at site 3 in Caraquet (see box for explanation of diversity indices). Whereas comparison with other bays for these parameters is difficult as Caraquet was only semi-quantitatively sampled, the assessment among the three sites within Caraquet is valid. Also, our visual assessment of sites 4 and 6 revealed very similar conditions as at site 3. Benthic life was severely impoverished at site 3 where heavy oyster drags frequently removed oysters and was likely to have created repeated disturbances to the sea floor.

Species Diversity Indices



Species richness = 3
No. Individuals = 9
Shannon Diversity H = 1.09

Species richness = 3
No. Individuals = 9
Shannon Diversity H = 0.68

In an attempt to quantify the biological diversity (biodiversity) of species at a local or community level, various measures or indices have been developed such as the Simpson's Index and Shannon- Wiener diversity index (H'). Most of these measures take into account both the number of species (species richness) and the distribution of individuals among species (eveness). The use of diversity indices is one way of quantitatively acknowledging the intuitive understanding that two areas which may have the same number of species and the same number of total individuals, may still be considered more or less diverse depending on whether one or few species are represented much more strongly than most others. The more evenly individuals are distributed among all species present, the higher the diversity, if the overall species richness and abundance of total individuals is constant. In the illustration above, both areas have 3 species and 9 individuals, but diversity is much higher on the left, as individuals are more evenly distributed among species.

4.3.2 Miramichi Bay

Shaped like a triangle, Miramichi Bay extends approximately 45 km along its north and south shores and 32 km across its mouth. Its surface area covers more than 300 square kilometers (km^2) making it the largest estuary on New Brunswick's eastern shore. It is a shallow bay averaging 4-5 metres in depth with a navigation channel averaging 6 metres running through the centre (Chiasson 1995). The Northeast Miramichi and Southwest Miramichi rivers which cover a combined drainage area of 11,600 km^2 flow into Miramichi Bay. Numerous smaller rivers such as Burnt Church, Oyster, Little Bartibog, Napan, Black, and Eel rivers and countless brooks and creeks such as the Lyons, Black, Nadeau and Sturgeon Creek also empty into the bay. The entrance to the inner bay is guarded by a number of barrier islands (Portage, Fox, Huckleberry, Bay du Vin and Egg Islands), the dune at Neguac and Horse Shoe Shoal.

At present, there are two regions of Miramichi Bay with commercial oyster beds: the Neguac area on the northern shore and the Baie Sainte-Anne/Baie du Vin areas on the south shore. The public bed in the area around Egg Island, located between Bay du Vin Island and Fox Island, has been considered to be among the most productive oyster producing areas in Atlantic Canada (Figure 7) (Biorex 1991; GTA 1993).

Historic landings of oysters in Miramichi Bay are poorly documented (Biorex 1991). Stafford (1913) reported landings of 2,800 barrels (252 mt) in Neguac, 3,800 (342 mt) in Bay du Vin and 420 barrels (37.4 mt) in Chatham. At the time, these landings represented 50 percent of the total landings for New Brunswick. In 2000, oyster landings in Miramichi Bay still represent 50 percent (122 mt) of the total (241 mt) oyster landings in New Brunswick: 50 mt in statistical district 73 (Baie-Ste-Anne, Baie du Vin) and 82 mt in statistical district 70 (Neguac). These values are less than 10 percent of historic levels for Miramichi Bay. Historical records and anecdotal information from fishermen and coastal residents suggests that the size and distribution of oyster beds were more extensive than current data indicates (Stafford 1913; Senpaq 1990; Milewski and Harvey 2000).

Although oyster harvesting in Miramichi Bay is currently restricted to two areas, historically oyster fishing took place throughout Miramichi Bay and estuary. For example, the areas around Sheldrake Island and in Napan Bay were once productive oyster fishing grounds (Senpaq 1990). These areas are now permanently closed to harvesting due to widespread bacterial pollution and the presence of chemical pollution (Senpaq 1990). In addition, the bottom characteristics of these areas have changed to a more soft-mud type bottom. This change has been

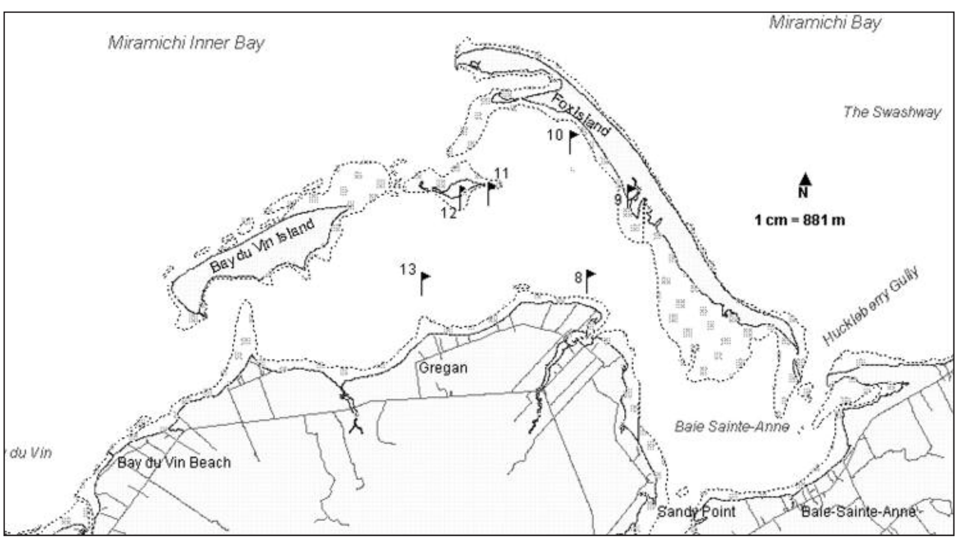


Fig. 7 Southeastern portion of Miramichi Bay (flags indicate sampling sites).

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Sewage lagoons like this one in Chatham Head remove only 50% of the suspended solids and fecal coliforms.

attributed to sedimentation caused by natural erosion and dredging operations in the Miramichi channel (Senpaq 1990). It is likely that the oysters once harvested from these areas, as well as further upriver, were the source of oyster landings reported for Chatham in 1910.

In 1949, bacteriological surveys identified a long list of contamination sources entering the river from privies, agricultural land, sewer outlets from the towns of Doaktown, Blackville, Quarryville, Millerton, Chatham, and Newcastle, pulp mill, cargo vessels, cottages and trailer parks (Waller et al., 1976). Despite recent efforts to upgrade and improve the quality of sewage discharges from municipal and private outfalls, oyster fishing in the main channel of the Miramichi River as well as areas in/near Bay du Vin River, Black River, Eel River and Portage River, lower Hardwicke River Bridge, Escuminac wharf, Burnt Church River, Neguac wharf and McKnight Brook in Lower Neguac, remain closed (MREAC 1992).

Siltation caused by clearcutting, suspended solids discharged from pulp mills, and channel dredging have also been identified to affect oyster beds. Dredging of the Miramichi River has been implicated in changes to the shape of barrier islands in the eastern end of inner Miramichi Bay (Buckley 1995). The size and orientation of Portage Island has changed noticeably and the Portage Gully on the north end of the island has moved three km south. Fox Gully separating Fox and Huckleberry Islands closed completely around 1972. Fox and Huckleberry Islands are now essentially one island. In 1837, five gullies served as entry points to the inner bay. Today, there are only three gullies.

The largest dredging operation on the eastern coast took place between 1981 and 1982 in the Miramichi River. A total of 7,716,000 cubic metres (m^3) of sediments were dredged from the river and re-distributed to three locations in the estuary. At the time, it was thought the sediments would remain at the dump site and not disperse. In reality, one study suggested that 4,000,000 m^3 of dredge spoils were dispersed from the dump sites (in particular the site in the central part of the inner Bay) over a five year period (Krank 1989). At the time of the 1981–82 dredging, long-term impacts to the Miramichi River and Bay were not expected. The impacts of the 1980's dredging in Miramichi River on biological communities and natural sediment transport are still being evaluated.

Between 1977 and 1980, areas in Bay du Vin/Baie-Ste-Anne, as well as Richibucto Village Bay, Petite Aldouane River, Bouchtouche Bay, Cocagne Harbour and Shediac Bay, were the sites of an experimental program to grow oysters using bottom-culture (trays) techniques and to reclaim abandoned oyster beds (Bacon 1981). Seed oysters collected in Bouctouche Bay were transferred to Bay du Vin/Baie-Sainte-Anne areas where they were grown in trays on the bottom. In addition, an abandoned oyster bed at Hardwicke was harrowed to remove the eel grass, stir up the sediment and expose any old residual shell material (as cultch), and was then seeded with oysters from Bouctouche.

The study found numerous small crabs on the trays and it was presumed they were feeding on slipper limpets (*Crepidula fornicata*) and other small epizoic fouling organisms. No sea stars, major predators of oysters and other bivalves, were found on the trays, and fouling algae were moderate and not as dense as in Bouctouche and Shediac. The trays were transferred and overwintered in the Hardwicke area. In both the bottom culture and reclamation experiments at the Hardwicke site, oyster growth was slow and sediment loading and oyster mortality were high. The slow growth was attributed to less favourable hydrographic conditions (low temperature and/or salinities). Poor recruitment was attributed to high flushing rates of the Bay and to the presence of relatively few creeks and other estuarine habitats which support brood stock (Bacon 1981). It is also possible that "upstream" oyster populations such as those around Chatham and Newcastle served as recruitment sources for 'downstream' beds, although Bacon (1981) did not examine this possibility. Since the upstream oyster beds were the first beds to be eliminated, it is possible that their destruction had a impact on populations in the outer Bay. Bacon (1981) did caution that, because of the slow growth of oysters in this area, the practice of fishing the beds heavily until the market size oysters were severely depleted, was not advisable.

While the history of the decline in the oyster fishery has been poorly documented for Miramichi Bay, the declines in fish populations are relatively well known. Species that spend a lot of time in the Miramichi estuary at various life stages (i.e. rainbow smelt, Atlantic tomcod, American eel, striped bass, alewife, blueback herring) have been declining in abundance for decades. In some cases (but not always as landings are also a function of fishing effort), this decline is reflected in commercial landings. The fisheries for shad, salmon and striped bass are all classified as "precarious" and smelt and tomcod are "declining" (Chaput 1995).

Smelt catches have declined steadily to about one third the level of the 1920s, leveling off at about 400 mt annually, a drop in the Miramichi contribution to total Southern Gulf landings from 40% to 30%. Tomcod landings (a by-catch of the smelt fishery) have declined in lockstep with smelt, from about 500 mt annually in the early 1900s to less than 50 mt. This is less than 50% of total southern Gulf landings, compared to an historic level of 75%. Gaspereau landings in 1995 were under 2,000 mt which represents between 20 and 45% of total southern Gulf landings compared to the historic level of 60% (Chaput and Atkinson 1997). Eel catches peaked between 1970 and 1972, and have since declined to about 40 mt, a drop from 30% to between 10 and 20% of the Gulf total catch (Chaput 1995).

Shad landings peaked in 1955 at 450 mt; by 1970 they had collapsed to 25 mt, an amount taken annually as a by-catch of the gaspereau trapnets. While the striped bass fishery was never large, the Miramichi landings at one time constituted as much as 75% of total landings in the Southern Gulf of St. Lawrence. In 1996, the commercial fishery was permanently closed and, in 1998, a stock status assessment for this species forecasted poor prospects for its recovery in the short term (Bradford and Chaput 1998).

The loss of spawning, nursery, refuge and recruitment habitats for estuarine species and the decline in food availability associated with those habitats are likely to have played a significant role in the decline of inshore coastal fish populations (Harding and Mann 1999; Peterson et al. 2000; Lenihan et al. 2001). It has been widely acknowledged that very little research has been done on habitat requirements of, and habitat changes on, fish species. The focus of scientific research has been largely on fish distribution, migration patterns and trends in fish population sizes. Unfortunately, this information only indicates the location and (imperfectly) quantities of fish, and not the ecological requirements of fish populations (i.e. food, shelter, and reproduction) necessary to sustain a healthy population.

Our biological survey in Miramichi Bay was restricted to the southern part, i.e. the Baie-Ste-Anne area, particularly inside Fox Island, Egg Island and Bay du Vin Island (see Fig 7). Out of six sites visited, three were sampled quantitatively. All of the three sampled sites had oysters, and all had eelgrass present, although only site 9 could be characterized as an eelgrass mead-

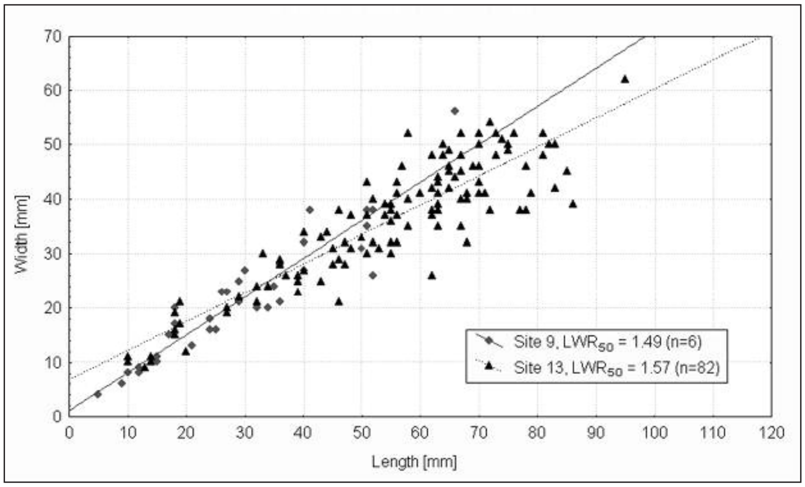

Fig 8: Size distribution of oysters (length to width) in Miramichi Bay for sites 9 and 13 (site 11 was omitted because of few individuals). Length to width ratio for oysters >50mm (LWR_{50}).

ow (shoot densities 97 m^{-2}). Sediment analysis revealed fine sands and coarse silts (Table 5). Site 13 was slightly unusual in its relative depth of 4-4.5 m, as opposed to most other sites which were only 1-2 m deep. In conversation with local fishermen, we were given the impression that site 13 was largely unknown as an oyster bed, that it had probably been rarely fished (if at all), and that this was possibly related to its relative depth and the associated difficulties to access it.

Total abundance of oysters for the three sites was 44 ± 32 ind. m^{-2} (site 9), 16 ± 21 ind. m^{-2} (site 11) and 164 ± 139 ind. m^{-2} (site 13). Figure 18 (page 43) shows overall abundances of oysters at all sites and compares the percentages of market size (>75mm length) oysters. As in Caraquet, legal size oysters were few or absent (0% at site 9 and 3.24% at site 13; at site 11, the percentage of legal sized individuals was 9.17%, however this was based on a single individual found at that site). The length to width ratio (LWR_{50}) was similar to populations in Caraquet (1.49 at site 9, 1.64 at site 11 and 1.57 at site 13); certainly individuals did not appear particularly elongated (Fig. 8).

Sites 9 and 13 were characterized by a high diversity of associated species, both in terms of species richness (25 each) and in terms of Shannon-Wiener diversity index (*H'*). The latter was even higher for site 9, which is explained by the more even distribution of individuals among species (Appendix 1). Diversity was significantly lower at site 11, which might be related to the low oyster densities and simultaneous low eel grass abundance at this site. At sites 9 and 13, the species richness is comprised mainly of: 1) crustaceans (including sessile species like barnacles growing directly on the oysters, and mobile ones such as mud crabs (*Rithropanopeus harrisii*), mud shrimps (*Crangon septemspinosa*), and small herbivorous amphipods and isopods); 2) various species of polychaetes (mobile predators and tube building suspension feeders); and 3) an array of small mud dwelling gastropods (e.g. *Acteocina canaliculata, Bittiolum alternatum* and *Sayella fusca* to name just a few). Both species of slipper limpets (*Crepidula fornicata* and *C. plana*) were particularly abundant in samples with high oyster densities, and across all samples and all sites. There appears to be a correlation between the abundance of slipper limpets and the abundance of oysters (Appendix 2 - 5) which could be explained by the fact that oysters provide slipper limpets with a hard surface on which to settle and develop.

4.3.3 Bouctouche Bay

A key feature of Bouctouche Bay is the prominent 11 km long sandy barrier spit or dune guarding the entrance to the Bay (Fig. 9). The long arm of the dune is, literally, a barrier between the sea and the mainland. It effectively slows down the eroding action of waves on land-based structures and offers protection for harbours. The surface area of Bouctouche Bay is 33 km^2 and three rivers drain into the bay: the Buctouche, the Little Buctouche and the Black rivers. The most important river is the Buctouche River which drains a basin basin of 125 km^2 (Thibault 1978).

Historically, Bouctouche Bay was the second largest producer of oysters next to Miramichi Bay. In 1910, oyster landings were 291 mt and the distribution of oyster beds was extensive. All three rivers had beds that yielded oysters in commercial quantities as did the central and westerly sections of the Bay (England and Daigle 1973). Today, many beds are extinct and the main natural oyster beds are located in closed or conditionally closed zones (under the Canadian Shellfish Sanitation Program). Although Bouctouche Bay is still widely recognized as a principal oyster producing area and a principal source of spat for oyster culturing or farming, the total amount of oysters landed (farmed and wild) from Bouctouche Bay (DFO statistical area 77) in 2000 was 56 mt (DFO 2001, GTA 1993, Biorex 1991).

Like all oyster-producing bays on the eastern and north coasts of New Brunswick, Bouctouche Bay was hit by Malpeque disease which wiped out the natural oyster population in the early 1950s. Despite an intensive program to re-seed all natural beds, oyster production failed to recover to historic levels in all bays (Found and Logie 1957). The late 1960s and early 1970s saw the federal government commission a number of studies to examine the potential of the oyster industry to provide employment and economic benefits to the Maritimes (Morse 1968a; Morse 1968b; Bissell 1972). These studies indicate that a viable oyster industry could provide a significant economic base for many communities in the Maritime provinces if the industry were restructured to become more economically efficient. Improved efficiency could come from increasing the number or size of leased oyster beds, ensuring a steady supply of seed oysters, shifting harvesting techniques from hand (tonging) methods to oyster farming, and the development of industry associations.

The oyster fishery in Bouctouche Bay served as a testing ground for many of the recommendations made in these studies. Numerous studies and projects were carried out here in the

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Oyster fishing in Bouctouche c.1920.

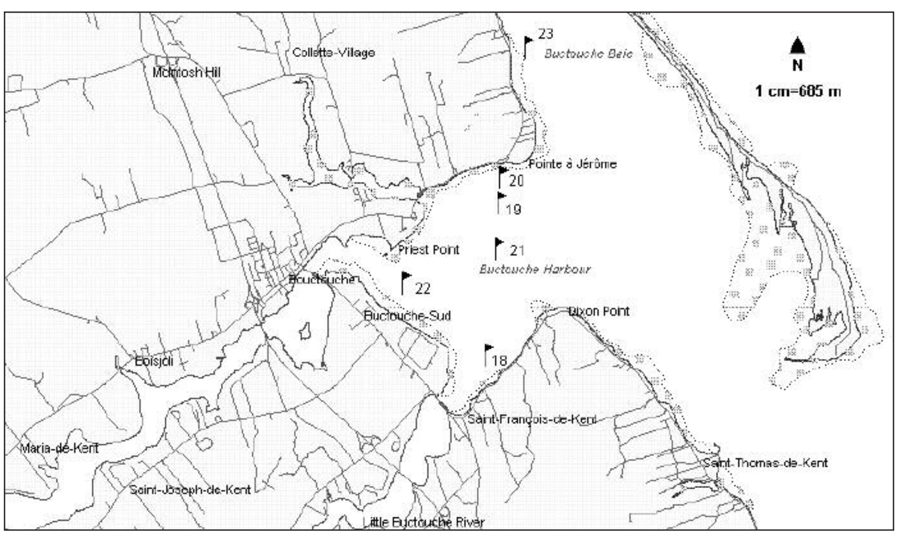


Fig. 9 Bouctouche Bay (flags indicate sampling sites).

1970s (Andrews 1971; Andrews and Gallant 1972; Billard 1974; LEAP 1975; McIver and Woo 1975; McNamara 1976; Robichaud and Robichaud 1976; Woo and Robichaud 1976; Bacon 1977). Leases were issued, oyster seed, collectors and equipment for aquaculture were purchased, and associations such as the Buctouche Bay Oyster Cooperative were formed.

Efforts to bring economic efficiency to oyster production, however, were being undermined by a growing problem - fecal coliform contamination of shellfish. Shellfish surveys dating back to 1936 reported that drainage from manure piles, direct sewage discharges from various municipal lagoons, institutional operations (i.e. convent, regional school, etc), private homes and commercial businesses were point sources of contamination to Bouctouche Bay (Waller et al. 1976). As community development expanded, larger areas were being closed to oyster (and other shellfish) harvesting for longer periods of time.

By the mid-1970's, growing awareness of the human health and economic costs associated with the disposal of raw sewage in fresh and coastal waters prompted many municipalities, including Bouctouche, to install some form of wastewater treatment. Despite improvements to

Serge LeBlanc

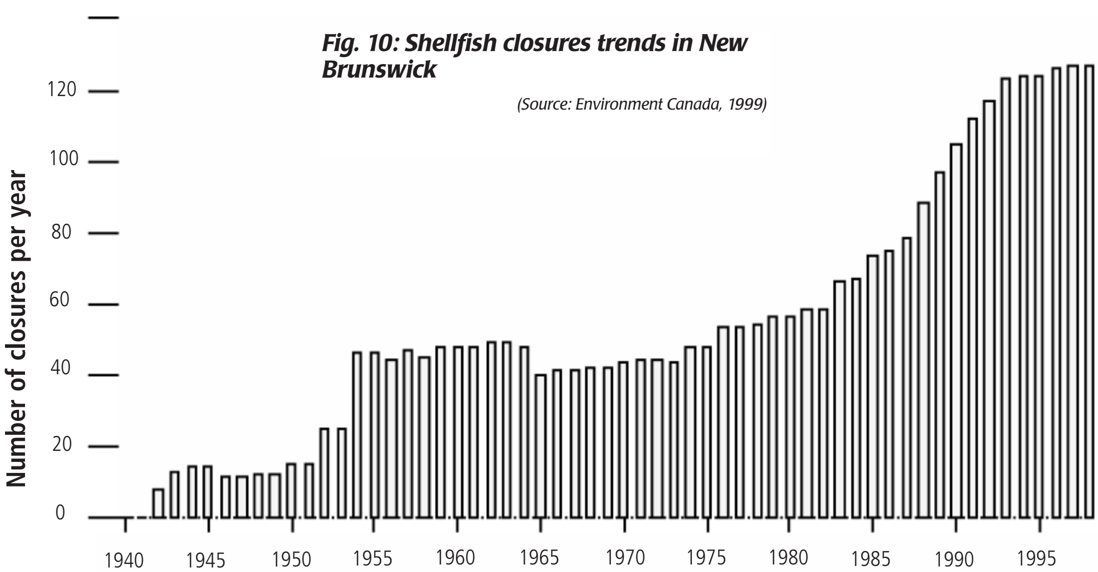
Without buffers along watercourses, runoff from farm operations can contribute nutrients, sediments and pathogens.

some municipal sewage facilities and upgrades and replacements to many domestic septic systems, the number of shellfish closures in New Brunswick increased in the early 1980s (Fig. 10). While some people would suggest that the rise in shellfish closures are the result of improved surveillance rather than an actual increase in contaminated areas, there are still many villages and public and private sewage outfalls (i.e. fish plants, pulp mills, industrial parks, campgrounds, home owners, motels, restaurants, stores, malls, schools, hospitals, etc) that have no or only minimum sewage treatment.

In addition, agricultural run-off from livestock farms contributes to over 40% of shellfish har-

Fig. 10: Shellfish closures trends in New Brunswick

(Source: Environment Canada, 1999)



vesting area closures in the Atlantic region (Eaton et al. 1994). Livestock agriculture is an important economic activity along the Northumberland Strait, particularly in the Richibucto, Bouctouche, and Cocagne river watersheds. Most of the farmers in these areas have a few hundred head of cattle or hogs. The run-off from these operations is sufficient to cause shellfish closures, particularly after heavy rainfalls and, in the spring, snow melt. Farmers have been working to reduce these problems by developing better manure management systems, limiting animal access to streams, and through the creation of larger "green belt" buffer zones between the farms and watercourses.

In August 1999, the New Brunswick Department of Agriculture and Rural Development issued a license to Metz Farms 2 Ltd to produce 35,000 hogs annually, the largest hog operation in Atlantic Canada. The "intensive livestock operation' or ILO, as such large-scale operations are called, is located in Sainte-Marie-de-Kent, about 10 km west of Bouctouche, 1.5 km from Mill Creek, a tributary of the Bouctouche River, and about 5 km from the Bouctouche River itself. The operation generates approximately 5.5 million gallons of liquid manure each year which is stored in an open lagoon the size of a football field and spread on local fields.

Table 6. Summary of the Surface Water Monitoring (April - October 2000) Results in the vicinity of Sainte-Marie-de-Kent, New Brunswick

Monitoring Station(s) *(Farm fields designated by initials)*	Livestock Numbers	Amount of Hog Manure Applied (Imperial gallons)	Fecal Coliforms CFU/100 ml		Notes on Sampling
			Range	After October Manure Application	
DFI and FCI	none	none	50-80	N/A*	- not sampled after heavy rainfall in October
MG	none	none	10-130	N/A	- not sampled after heavy rainfall in October
EC, KL, and PW	- 50 cows on EC	none	100-2,000	N/A	- sampled after heavy rainfall in October
OM and RR	- 40 cows on OM	none	10-1,560	N/A	- not sampled after heavy rainfall in October - no fecal coliform results for some stations in June, August or mid-September
BM 7,8,9	none	472,500	10-400	No manure spread in October	- sampling was a "considerable distance from treated areas" - manure applied three months prior to October sampling; - no fecal coliform results for a station in mid-September
CP and BM	- 350 cows on CP - 80 cows, 20 heifers and 20 horses on BM	1,027,500	100 - >300	200 - 2000	- sampled after heavy rainfall in October - no fecal coliform result for two stations in mid-September and for one station in August
VM	- 40 cows	165,000	40 - 1000	10 - 390	- not all stations sampled before and after heavy rainfall in October; - no fecal coliform results for two stations at the end of July
AN and LC	- 100 cows and 75 calves on AN	405,000	100 - 400	>3000	- sampled after heavy rainfall in October - no fecal coliform results for one station in September
AR and MA	- 30 cows and 80 sheep (neither pastured in treated area)	367,500	0 - >300	10 - >3000	- no fecal coliform results for one station in June and September
FW2	- 45 cows and 50 sheep	311,250	<100 - >300	No manure spread in October	- no fecal coliform results for two stations in August and for one site in September

***N/A - Not Applicable** *Data source: NB DELG. 2001. Metz Farm 2 Ltd: Surface water and groundwater monitoring results (April to October 2000). 40 pp.*

In 2000, the Department of Environment and Local Government (DELG) conducted a monitoring program to "assess the effects of land application of liquid manure generated on Metz Farm on local surface and well water quality". Despite the report's conclusion that the monitoring results "provide no conclusive evidence that manure application affected the bacterial quality of drainage waters and well water in the study area", the results appear to indicate otherwise (NB DELG 2001). The monitoring results do show a cause-and-effect relationship between manure spreading and increased fecal coliform counts in surface waters for several of the areas monitored (Table 6). In fact, the results confirm what is common knowledge - runoff from livestock operations and manure spreading contributes to higher fecal coliforms in surface waters. According to the monitoring results, fecal coliforms were consistently higher in areas with livestock and/or manure spreading than in areas with no livestock and no liquid manure application.

Today, key oyster producing areas in Bouctouche Bay - the Bouctouche River and harbour area - are still closed to oyster harvesting and there has been an increase in the frequency of closures on conditionally approved areas (GTA 1993). In 1999, an Environment Canada bacteriological water quality survey of the Bouctouche River and harbour recommended that a seasonal winter shellfish harvest be permitted during the month of February. Bouctouche harbour was designated a conditionally approved area (Richard et al. 1999). Due to high coliform levels, the conditionally approved area was open to oyster harvesting for only 4 or 5 days in February 2000 and it was completely closed in February 2001 (LeBlanc 2001, pers. comm.).

Contamination of shellfish is only one of the problems associated with sewage discharges, agricultural runoff, and fish plants. These discharges add nitrogen and phosphorous (nutrients) to the environment and can initiate eutrophication (see box page 17).

Although to date no studies have been done to assess the eutrophication status of estuaries on the eastern and northeastern coasts of New Brunswick, a 1981 report identifies symptoms of nutrient pollution (i.e. dense growth of annual green algae) in Bouctouche Bay. This Bay was one of six estuaries/bays participating in an experimental program to grow oysters using bottom-culture (trays) techniques and to reclaim inactive abandoned oyster beds (Bacon 1981). Oysters placed in suspended trays in Bouctouche Bay experience heavy algal fouling in July, August and early September. Large, thick mats of seaweeds restricted flow over the trays and considerable silting of the trays was observed (Bacon 1981). Of the six experimental sites, Bouctouche and Shediac Bay exhibited the greatest amount of algal fouling.

The oyster fishermen in Bouctouche Bay understand the need to close oyster beds because of high fecal coliform levels in the water. However, their inability to fish or "work" the natural oyster beds means that silt and sediment builds up on the beds and smothers the oysters - a situation also observed by oyster fishermen in other bays in northeastern and eastern New Brunswick. Inability to work the beds also reduces the amount of 'cleaned' (manipulated) shell debris which serves as attachment substratum (cultch) for newly settling oysters. Medcof (1961) suggested that an

Serge LeBlanc

Harvesting oysters in Bouctouche Bay.

oyster bed was like a garden that needed to be 'cultivated' or worked in order to thrive. The benefits of working or cultivating the bed, according to Medcof (1961), were more than 'weeding' out predators, thinning or preventing oysters from crowding but it improved the shape, growth and fatness of the oysters. Working the bed helped to clear away silt or lift the oysters above the silt, thereby enabling the oyster to grow relatively unrestricted.

Along with increased sedimentation of the oyster beds, oyster fishermen in Bouctouche have noted the arrival of a new species of seaweed in Bouctouche Bay over the past three years. *Codium fragile spp. tomentosoides* is a green alga and non-native to North Atlantic shores (Fig. 11). The species is native to Japan but was introduced accidentally to Europe around 1900 (Chapman 1999). It eventually spread to North America. The first record of *Codium* for eastern North America was in Long Island Sound (US) in 1957 and, in 1989, *Codium* was reported in eastern Nova Scotia (Bird et al.1993). It is now also found in P. E. I. (Garbary et al. 1997), as well as some parts of the east coast of New Brunswick.


Lise Chapman

Fig. 11. Codium fragile spp. is a sponge-like green alga commonly referred to as the oyster thief.

As with many seaweeds, *Codium* needs a hard surface to attach itself and oysters, as well as scallops, can provide that hard surface (Chapman et al. 2002). Often after a storm event, *Codium,* attached to a clump of oysters, can be found tossed up on shore or in waters where oysters are not normally found. These observations have earned *Codium* the nickname of 'oyster thief'. The ecological impact of *Codium's* presence on other plant and animal species (i.e. alteration of habitat and replacement of native species) is not clear at present.

As with other bays and estuaries along the east and northern coast of New Brunswick, Bouctouche Bay has seen declines in commercial estuarine fish species such as smelt. Species which were once considered commercial species, such as salmon, are now part of a recreational fishery only. On the Bouctouche River, returns of large salmon ranged from 95 to 244 fish between 1993 and 1999 (DFO 2000). According to a DFO stock status report, 1999 was the first in seven years of assessing the river that there were sufficient eggs deposited by large and small salmon to meet conservation targets (DFO 2000).

Our biological survey included six site visits to Bouctouche Bay; three sites were sampled quantitatively (sites 20-22). Our visual assessment revealed a high degree of similarity of sites 18, 19 and 23 with site 20. Sites 21 and 22 stood out among all other sites in this study because of the very dense oyster aggregations which formed a three-dimensional oyster reef. Site 21 is known locally as 'Barnes Bed' and is located immediately near the main channel of the Bouctouche River where currents reach very high velocities, especially at mid tides. According to local fishermen, Barnes Bed is very old and has not been harvested much in recent years, mostly as a consequence of frequent coliform contamination.

These factors appear to have contributed to creating what is now a fascinating dense matrix of live oysters at the surface, and layers of dead shell material within the sediment. Limited harvesting activity on the bed has allowed the build-up of an oyster population which is very firmly cemented together. Recruitment and growth of new oysters has happened on the existing firm structure, so that dying individuals are not removed but simply covered in sediment over time and replaced by live oysters on the top. In several areas, it appeared that the oyster matrix in the sediment was at least 50 cm deep.

Oyster densities on Barnes Bed (site 21) were 1603 ± 340 ind. m^{-2}. Site 22 had fewer oysters (848 ± 327 ind. m^{-2}), but population densities were still high enough to create a reef structure at this site. In contrast, site 20 was much more similar to sites visited in other bays (Fig. 18, page 43) in that overall oyster densities were 60 ± 74 ind. m^{-2} (levels still classified as ´medium densities´ by Sephton and Bryan 1989). However, in this case, there were no live oysters among the shells found at this site.

The relative contribution of larger (>50 mm) oysters to the reef populations at sites 21 and 22 was much lower than at most other sites (Fig. 18, page 43) and many recently recruited oysters contributed to the high overall abundances (Fig. 12). Nevertheless, absolute numbers of oysters >50 mm still exceeded those at most other sites with 443 and 213 ind. m^{-2} for sites 21 and 22 respectively (Appendix 1).

The relative abundance of legal (market size) oysters (individuals >75 mm) was only 1.38% and 1.27 % for sites 21 and 22, but, expressed as absolute densities, abundances of legal oysters were significantly higher than at any other site (22 and 10 ind. m^{-2} on average for sites 21 and 22) (Fig.18, page 43). At site 20, there were no legal sized individuals in the population.

The striking features of the oyster reefs found at sites 21 and 22 were also reflected in individual oyster growth shape, i.e. many oysters were very elongated. This feature is best expressed as a high LWR_{50} for populations at sites 21 and 22 (2.18 and 2.35 respectively), and can also be seen as a much lower slope of the length-width relationship for oyster populations at sites 21 and 22 compared to site 20 (LWR_{50} of 1.54) (Fig. 12).

Sediment grain size distribution in Bouctouche Bay was variable, but generally characterized by fine sediments (very fine sand at site 20 and medium silt at site 22). No sediment samples could be taken at site 21 as the dense oyster matrix allowed no coring for sediments. In contrast, at site 22, the oyster reef structure was less complete, and small spaces remained open from which samples could be taken.

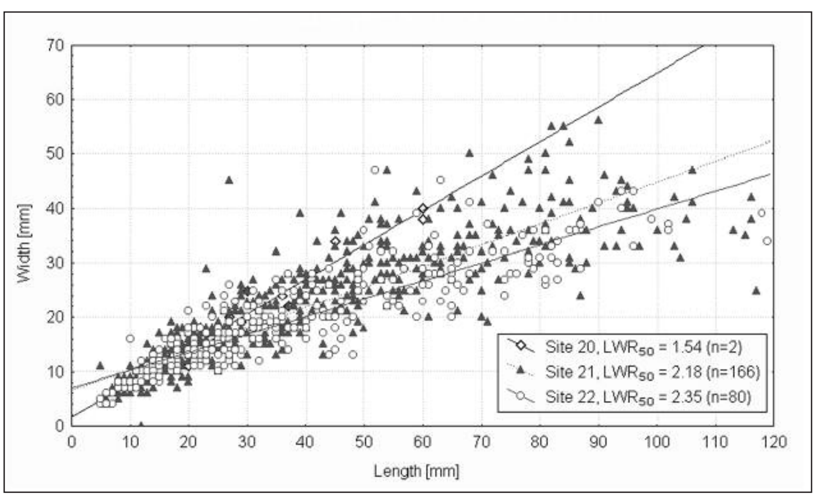


Fig. 12: Size distribution of oysters (length to width) in Bouctouche Bay for sites 20, 21 and 22. Length to width ratio for oysters >50 mm (LWR_{50}).

Our general observations included extremely high turbidity in Bouctouche Bay. In fact, our 0.25 m^2 frame underwater photography at this site was unsuccessful as there was too much back scatter from particulate matter in the water column. Sampling at site 20 was terminated early because visibility dropped to zero.

Associated species richness was highest on Barnes Bed (site 21), where we found the most complete reef structure. Twenty-nine (29) benthic species were associated with the reef. In contrast, site 22 had 21 benthic species, and site 20 had 19 species associated. The most immediately visible difference between sites 21 and 22 was a green slime-like cover on many oysters at site 22 (Fig. 13). This green film was later identified as a blue-green algal species which is often indicative of low flow conditions and likely high nutrient loading. At site 22 the blue-green algal film appeared to trap sediments, and often covered a blackened surface underneath. As with other green algal mats in eutrophicated soft-sediment systems, bacterial mat disintegration removes oxygen from the water creating oxygen deficits for other species (see review of Rafaelli et al. 1998). Anoxic sediments and surfaces usually appear black and give off a foul stench of hydrogen sulfide.

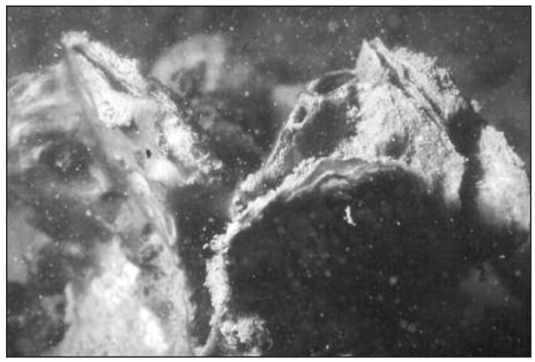


Fig. 13: Blue-green algal mat covering oysters at site 22 in Bouctouche Bay; frame is approximately 10 x 7 cm

We did not directly investigate the effects of the blue-green algal cover. However, the low associated species diversity at site 22 compared to site 21 indicates that lack of oxygen and suffocation of organisms through additional sediment accumulation may have interfered with attachment and persistence of various epibenthic species. Particularly, various species of red seaweeds (*Antithamnion cruciatum, Chondria baileyana, Dasya baillouviana, Lomentaria baileyana* and *Polysiphonia sp.*) are present at site 21 but missing at site 22. At site 20 we found the non-native seaweed *Codium fragile ssp. tomentosoides*.

Apart from apparent differences in species richness, sites 21 and 22 are clearly distinct from each other with regard to the number of individuals of associated faunal species in the benthos (Fig. 14). The average total number of individuals (excluding oysters) at site 21 was 4456 ind. m^2. At site 22 there were 1541 ind. m^2 (which is still higher than at any other site). Mean numbers of total individuals at site 20 are 315.

Species which contributed significantly to these high abundances at site 21 included barnacles (*Balanus crenatus*) among the crustaceans, three species of polychaetes (*Heteromastus filiformis, Lepidonotus squamatus* and *Neanthes succinea*), the eastern white slipper limpet *(Crepidula plana)*, among the gastropods and the blue mussel, (*Mytilus edulis)* among the bivalves (Appendix 5). The abundance of blue mussels is much higher than at any other site in the study, and individuals are distributed across all size groups. Compared to many sites where oysters form small spatially separated clumps on the mud surface, the near absence of infaunal bivalves (e.g. soft shelled clams, *Mya arenaria*) is obvious and intuitive: the dense oyster matrix prevents burrowing and siphon activity of suspension feeders within the sediment.

Generally, benthic fauna which is able to benefit from the increased hard substratum and shell matrix availability is more abundant at site 21 than at all other sites. Hence, species which grow attached or semi-attached to the oysters – seaweeds, barnacles, slipper limpets and blue mussels - are supported, whereas species burrowing in the sediment are much reduced in abundance as their surface access is limited by the rigid oyster matrix.

Another characteristic of site 21 was the high abundance of two sponge species: the bright orange red beard sponge, *Microciona prolifera*, and the sulfur sponge, *Cliona sp.*, which bores into oyster shells. When oysters are submersed, *Cliona sp. oscules* (surface openings) protrude as small mushroom-like structures out of little holes in the oyster shells. Once removed from the water, the sulfur sponge makes oysters appear to be covered in a seeping greenish slime. We found *Cliona* in no other bay but Bouctouche, where it was overly abundant at site 21, possibly a reflection of the high flow conditions and little harvesting on the reef. At site 22, *Cliona* was absent; sediment accumulation under the green-algal film and apparently reduced flow conditions are likely to have excluded this sponge from this site. Similarly, the red beard sponge was much less abundant at site 22 than at site 21 and was only found in two other samples from Cocagne and Caraquet Bay respectively.

Sites 21 and 22 also had the highest abundance of the polychaete worm, *Heteromastus filiformis*, of any of the sample sites in the survey (Appendix 5). This long and thin (100 mm x 1.6 mm) worm is one of a number of species of polychaetes referred to as capitellid thread worms. These worms feed in the same way earthworms do, literally eating their way through the substratum (Gosner 1978). They are tolerant of low oxygen and high hydrogen sulphide conditions; as a result, they are often used as indicators of organic pollution/enrichment (e.g., areas where discharges from sewage outfalls, fish plants and/or salmon cages accumulate) (Pearson and Rosenberg 1978).

Mobile predatory fauna such as the mud crab (*Rhithropanopeus harrisii),* the scale worm (*Lepidonotus squamatus)* and the rag worm (*Neanthes succinea)* may benefit from the increased surface complexity as they can find shelter against predation among the shell debris of oysters, and simultaneously encounter ample food in small epibenthic animals associated with the oyster matrix. For instance, the mud crab was often found hiding among the oyster shells and feeding on small barnacles, oyster spat and juvenile blue mussels. As we were sampling sites 21 and 22, we observed various species of fish feeding on or in the vicinity of the oyster reefs, especially sculpins and various flat fish.

4.3.4 Cocagne Bay

Cocagne Bay, like all the other bays described in this report, is a shallow bay partially separated and protected from the Northumberland Strait by a barrier island, Cocagne Island, and Cocagne Cape (Fig. 15). The Cocagne River, as well as a number of small brooks (i.e. Gueguen, Murray, and Babineau Brooks) empty into the

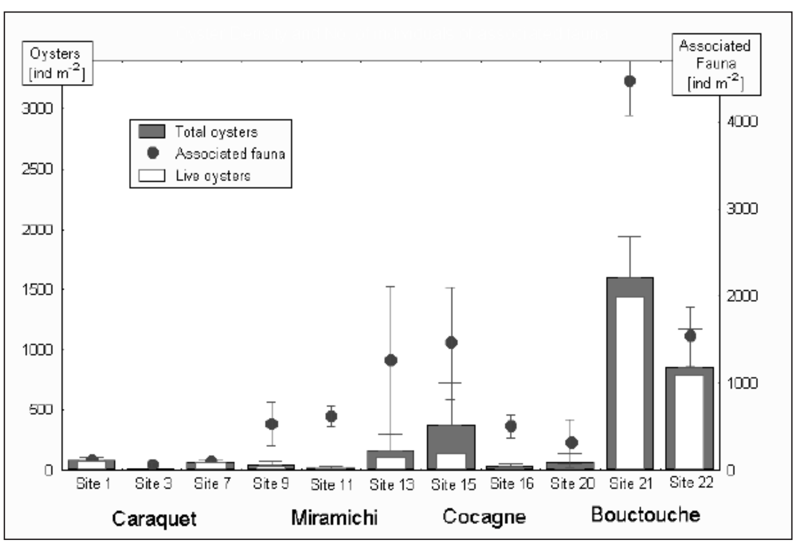


Fig 14: Overall oyster densities ('Total oysters'), live oysters and number of individuals of associated fauna (excluding oysters) for all sites sampled. Variation is given as standard deviation in all cases.

bay. Cocagne Bay covers a surface area of approximately 22 km^2.

When Nicolas Denys, the 17th century French naturalist and explorer, was traveling along the coast of what is today New Brunswick, he came upon a river that was so abundant in food - on land and in the sea - that he named it the River of Cocagne, one of the few lasting memorials of Denys's historic visit to North America (Denys 1672). Although now spelled differently, Cocagne means land of the greatest abundance. Over 300 years later, the natural diversity and abundance of species in and around the Cocagne River and Bay can no longer be described in superlatives. Virtually all of the forest area around the bay and river have been cut to create communities and farmland. Game, fish and shellfish are found at greatly diminished levels. According to one resident, Cocagne, at one time, had an excellent smelt fishery where many fishermen collectively caught 1 to 1.5 mt of smelt per day. Today, only one fisherman fishes smelt and it is said he barely gets enough to eat.

Historically, Cocagne Bay was a significant oyster-producing bay in New Brunswick, exceeded only by Neguac, Bay du Vin and Bouctouche. Oyster harvests in 1910 reached 198 mt (Stafford 1913). Both the Bay and the River were highly productive oyster areas. In a 1973 survey of the area, it was reported that 4 mt of oysters were harvested from Cocagne Bay (England and Daigle 1975). By 1991, there was no major commercial harvesting of natural oyster beds in the bay and only 4 or 5 oyster fishermen worked the natural beds (GTA 1993). Most oyster harvested from the Bay are sold to the local public (GTA 1993).

Like the Bouctouche River, the Cocagne River has been closed to oyster harvesting for decades because of fecal coliform bacterial contamination. Richard et al. (1992) identified the following sources of contamination:

"The shoreline of the Cocagne River estuary is dominated by numerous clusters of cottages and summer homes located varying distances from the shore, Most of these cottages are served by on-site septic systems of unknown condition. Some cottages have pit privies and some discharge to ditches.

Agriculture operations are limited, but all are located within close proximity of shore or have streams and ditches coursing through the property. In a number of cases, livestock have direct access to the shore or to a tributary stream.

The village of Cocagne does not have a central

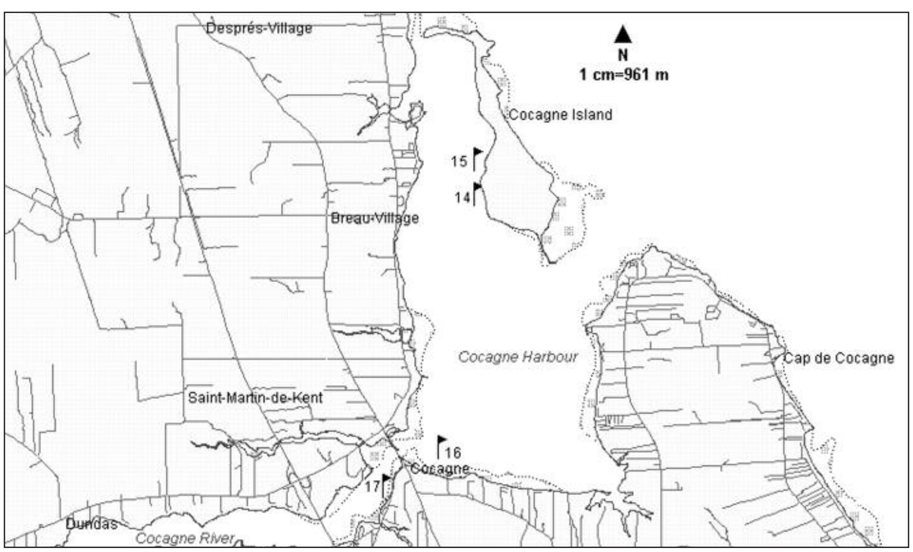


Fig. 15. Cocagne Bay (flags indicate sampling sites).

"I have named this river the River of Cocagne, because I found there so much with which to make good cheer during the eight days which bad weather obliged me to remain there. All my people were so surfeited with game and fish that they wished no more, whether wild geese, ducks, teal, plover [pluviers], snipe large and small, pigeons, hares, partridges, young partridges, salmon, trout, mackerel, smelt, oysters and other finds of good fish. All I can tell you of it is this, that our dogs lay beside the meat and fish, so much were they satiated with it. The country there is as pleasing as the good cheer. The land is flat and covered with trees which are very fine, as well in their stoutness as in their height, of all the kinds which I must have already named. There are also great meadows along the river, which runs about five or six leagues inland. The remainder is only navigable by canoe, and many more pines than other trees are found there."
Nicolas Denys 1672

sewage treatment or collection system. Most homes are served by on-site systems of varied adequacy. A few establishments have evidence of discharge pipes running to ditches and small wetlands. In addition, there are two fish plants with discharge pipes leading directly to the river."

Although many residences have installed, replaced or upgraded private septic systems over the past 10 years, coastal areas such as Cocagne and Bouctouche have been experiencing increased population growth, much of which is seasonal. The warm, shallow, sandy beaches, close proximity to one of New Brunswick's fastest growing regions - the Moncton/Dieppe area - and an aggressive provincial tourism marketing program have combined to make the east coast one of the most popular tourism destinations in New Brunswick. The result has been a boom in the construction of commercial cottages and cottage complexes, marinas, and eco-tourism projects which has increased the requirement for sewage treatment. Not all facilities have adequate sewage treatment.

Recreational boating, which is rapidly increasing in this area, is another source of untreated sewage. There is no mandatory requirement for sewage holding tanks on boats.

In 2000 as a result of high coliform levels in the river, the five active oyster fishermen in the area were able to harvest oysters only 4 to 5 days out of a six-week season that spans February to March.

In addition to contamination, siltation of the oyster beds has been a barrier to the recovery of the oyster fishery in Cocagne. England and Daigle (1975) reported that more than 100 old oyster beds of various sizes in the bay were silted over completely and all were barren. They reported that the river still had good concentrations of oysters in the channel and along the channel banks. Today, coastal residents report that the sediment loads in the river have increased, the river appears to be filling in and becoming more shallow, and many of the good oyster beds in the river are now covered over with sediment. According to residents, clearcutting in the watershed of the Cocagne River has resulted in increased erosion of forest soil and more silt being released into the rivers. The installation of a new natural gas pipeline and alteration of the coastline for cottage development were also identified as sources of sediment into the river.

Out of four sites visited in Cocagne Bay, two sites (15 and 16) were sampled. Sites 14 and 17 both had eelgrass beds (*Zostera marina*), but low oyster densities. Generally, they were more similar to site 15 than to site 16. Sites 15 and 16 were characterized by sandy substratum (medium sand at site 15 and fine sand at site 16) and the presence of an eelgrass bed at site 15. The blades of the eelgrass plants appeared covered in mud particles, possibly as a result of its sheltered location just west of Cocagne Island,

Serge LeBlanc

Improper road construction causes sediment loading into the northwest branch of the Cocagne River.

where flow appeared to be reduced most times. The blades were also covered in epiphytic algae which were impossible to identify due to the preservation techniques used in this study. In contrast, site 16 was located near the flow channel of the Cocagne river.

Oyster densities at site 15 were high (379 ± 342 ind. m^2) and only surpassed by reef densities in Bouctouche Bay. Site 16 had significantly fewer oysters (35 ± 24 ind. m^2). The relative abundance of legal oysters (>75 mm) was low for both sites (ie., 0% at site 15 and 1% at site 16) (Fig. 18). The shape of oysters from sites 15 and 16 was nearly identical and fairly rounded. This is reflected in an LWR_{50} of 1.76 and 1.72 for site 15 and 16 respectively (Fig. 16). Figure also demonstrates a large recruitment of small oysters to site 15. Individuals <25 mm contributed substantially to the overall population densities.

Lawrence Taylor - Biodiverse Canada

Eelgrass in Cocagne Bay was smothered in epiphytic algae and sediments.

The diversity of species associated with sites 15 and 16 differed significantly. Site 15 had very high species richness (average of 27), the second highest richness after Site 21 in Bouctouche Bay (Appendix 1). In contrast, site 16 had only 18 species associated. When expressed as Shannon-Wiener diversity index (*H'*), diversity was higher at site 16 (2.18) compared to site 15

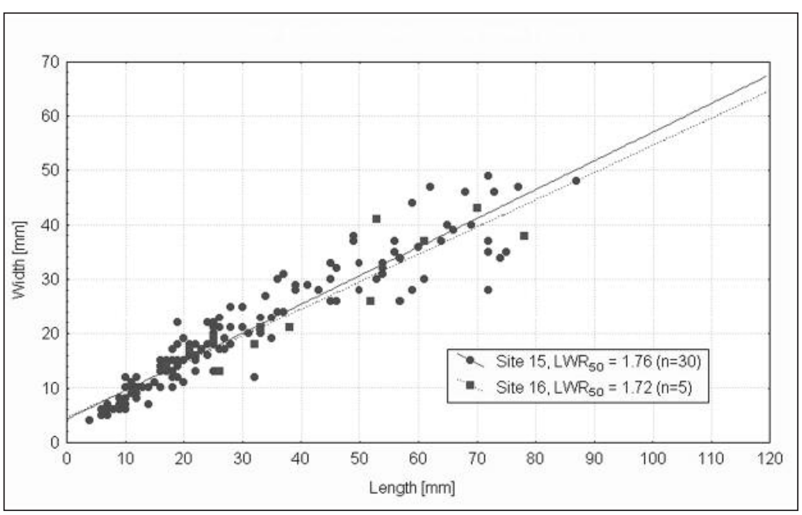


Fig. 16: Size distribution of oysters (length to width) in Cocagne Bay for sites 15 and 16. Length to width ratio for oysters >50 mm (LWR_{50}).

(1.86). What appears as a contradiction is explained by the more even distribution of individuals among species at site 16 compared to site 15 (Appendix 4).

The assemblage of species associated with the oysters at sites 15 and 16 was strikingly different from the reef sites in Bouctouche Bay, although species richness is in the same order of magnitude. At site 15 especially, endobenthic fauna remains an important component of the species assemblage where oysters are abundant in clumps but do not form a continual and rigid matrix on the sea floor. Hence, the presence and high densities of other bivalves living in the sediment is not precluded as it is on the dense oyster reef in Bouctouche Bay (site 21).

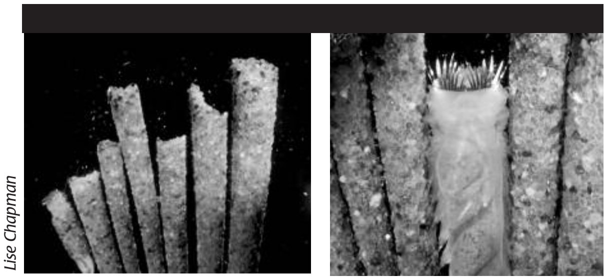
The quahog, *Mercenaria mercenaria*, was very abundant at site 15; in fact we observed *Mercenaria* harvesting near the site while we were sampling. Also, the soft shell clam, *Mya arenaria*, and the false angel wing, P*etricola pholadiformis*, both endobenthic (living in the sediment) bivalves, were more common at site 15 than at most other sites (Appendix 4). In contrast, the epibenthic (surface-dwelling) suspension feeders common at site 21 in Bouctouche Bay (barnacles, *Balanus crenatus*, and blue mussels, *Mytilus edulis*), were almost absent at site 15 in Cocagne. Under conditions with less water movement and probably higher sedimentation rates, such as site 15 in Cocagne Bay, attachment of larvae to the surface of oysters and consequently spat recruitment might be impaired.

Site 15 had a high number of capitellid thread worms, *Heteromastus filiformis*; Bouctouche sample sites 21 and 22 had the highest number of thread worms. This species is often associated with low oxygen, high sulphide and high organic enrichment conditions and, in our study, with very high oyster densities which might promote such microclimatic conditions.

The presence of oysters and eelgrass creates a certain degree of structural complexity, both on the sediment surface and below. However, not all benthic space is covered with rigid oyster shells, and instead part of the benthic volume is filled by sediment. This can be utilized by burrowing and tube-building polychaetes and suspension-feeding bivalves.

Ten species of polychaetes belonging to various functional groups and distinct feeding guildswere found at site 15. Some species are sessile or semi-sessile tube builders (e.g. *Pectinaria gouldii* and *Polydora sp.*), others are highly mobile and predatory, such as the ragworm (*Neanthes succinea)* or the scale worm (*Lepidonotus squamatus)*.

The high abundance of *Pectinaria gouldii* at site 15 indicates high stability of the sediment, as this species builds a delicate cone-shaped tube that is easily broken under very dynamic conditions (Fig. 17). The roots and rhizomes of eelgrass stabilize the sediment below, and oysters add complexity especially on the surface. Additionally, the presence of seaweeds attached to secondary hard substratum, such as oysters, promotes the abundance of herbivorous crustaceans (e.g. gammarid amphipods).



Lise Chapman

Fig. 17: Pectinaria gouldii with its conical tubes. Tubes (up to 50 mm (2 inches) long) are located vertically in the sediment with the wider opening (and the animal's front end) pointed downward.

As in Bouctouche Bay, sites 15 and 16 were characterized by 8 and 7 species of seaweed respectively. The invasive oyster thief, *Codium fragile ssp. tomentosoides*, was found at site 15; most other species were red algae (*Ceramium sp., Chondria baileyana, Gracilaria tikvahiae, Lomentaria baileyana* and *Polysiphonia sp.*). At site 16, the red alga *Griffithsia globulifera* was particularly abundant, and it formed very dense and finely branched vegetation above the oyster bed.

4.4 Summary and Discussion

A comparison between the oyster beds visited in four bays along the North Eastern shore of New Brunswick reveals large differences in nearly all characteristics of these beds. However, despite the fact that each bay is governed by a unique combination of local environmental factors and human impacts, some generalizations with regard to oyster beds as habitats in shallow estuarine systems stand out.

Oysters

Comparing our survey data with data on landings from as early as 1876, it becomes apparent that overall oyster densities have declined dramatically. The relative and total contribution of ´legal´ oysters (>75 mm) varies between 0% and 3% for most of the sites sampled in this study. With total abundances of oysters on public beds and private leases surveyed being generally below 500 ind m-^{2}, the relative contribution of market size oysters is extremely low (Fig. 18).

The main exception to our observation of low oyster densities in areas which once supported a substantial oyster fishery, were two oyster reefs in Bouctouche where densities averaged 848 and 1603 ind. m^{2} respectively. More than a quarter of these individuals were larger than 50 mm in both cases. These high densities change both the arrangement of shells on the bottom as well as their average shape. Most individuals, instead of lying on their left shell, are oriented vertically into the water column and grow into elongated individuals. Similar changes of shape (expressed in this study as the average length to width ratio of larger size individuals –LWR_{50}) are observed in other benthic organisms such as barnacles, which, when crowded, grow upwards and increase more in length than in width (Bertness 1999). For oysters, a major feature of a reef versus a bed structure, is that individual oysters extend further into the water column and may be able to avoid temporarily oxygen depleted conditions immediately near the sediment surface (Lenihan and Peterson 1998).

Figure 19 shows the correlation of oyster shape (increasing elongation) with abundance of larger sized oysters (>50 mm). Smaller individuals (spat) do not contribute extensively to crowding effects and do not interfere with adult space occupancy below a certain size limit. The fact that the oyster beds in Bouctouche Bay (sites 21 and 22) were able to develop a proper reef structure reflects the fact that they have not been fished regularly in recent years. Regular harvesting of oyster beds interferes with a developing oyster matrix in that the cementation between individuals is continually broken as the bottom is disturbed manually or by various harvesting gear.

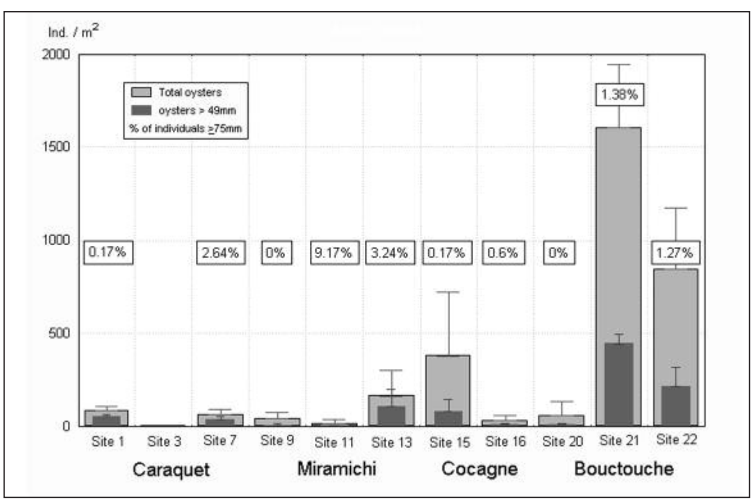


Fig. 18: Overall oyster densities ('Total oysters'), oysters ≥49 mm and percentage of 'legal' oysters (>75 mm) for all sites sampled. Variation is given as standard deviation in all cases.

Associated Flora and Fauna

In an environment dominated by mobile sediment, oysters provide secondary attachment substratum for organisms that need to settle on a firm base either temporarily or permanently. Such organisms include most species of seaweed, invertebrates, (i.e. barnacles, sponges, hydroids), and a few polychaetes and gastropods. As well as a hard surface in a soft bottom environment, oysters and their shell debris also create structural heterogeneity (variation) on the surface that may be used as shelter against predation by mud crabs, mud whelks and numerous species of polychaetes. Oyster beds function as habitat for numerous benthic species.

We tested whether (1) the overall abundance of oysters and (2) the abundance of oysters >50 mm was correlated to the diversity of associated species on the oyster beds. For this assessment, we included only samples from Miramichi, Bouctouche and Cocagne bays, as sampling techniques in Caraquet likely underestimated diversity.

Species richness (flora and fauna) increased significantly with increasing oyster density (both total and individuals >50 mm). At low oyster densities, richness of associated species was more variable and likely influenced by other factors (e.g. flow rate, sediment, seagrass presence etc.). When we measured the overall number of other individuals of invertebrate species against the total abundance of oysters (live and dead). We found an even stronger correlation that reflects the importance of oysters as habitat structure in this environment (Fig. 20). The same relationship holds true if only live oysters are assessed, however the correlation is slightly less strong (Fig. 20).

Clearly, even dead oyster shells have an ecological value as habitat for a broad range of benthic species. It is not surprising that oyster, clam, or mussel shells spread over the sea bottom are used as a foundation for restoring oyster beds. The value of having live oysters and a functioning associated benthic species community is that the living organisms contribute to the removal of sediment and other particulate matter from the shell surface of oysters, keeping the substratum accessible for new settlers (oyster larvae, seaweed propagules and sessile invertebrates). The habitat value of oysters and other epinenthic bivalves (i.e. mussels) is severely impaired once oyster shells become smothered and gradually buried (Kennedy 1996b; Albrecht 1998).

A secondary effect of sediment burial is an increasing chance of oxygen depletion and subsequent development of hydrogen sulfide (H_2S) which is toxic to most living organisms (Vismann 1991; Bagarino 1992). This process is more likely to occur and at a faster rate in the presence of organically enriched sediments (e.g. from sewage and fish plant inputs) and simultaneous low flow conditions. Site 22 in

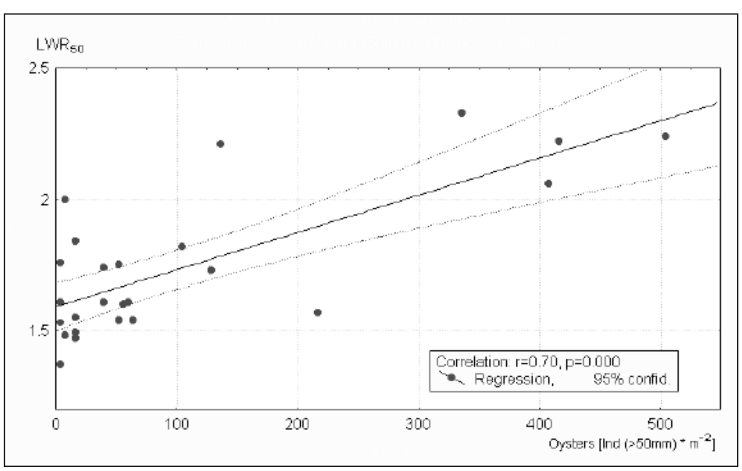


Fig 19: Correlation between the density of oysters (>50 mm) and their shape expressed as the Length/Width – Ratio (LWR_{50}). The larger the LWR_{50}, the more elongated the shape of the oysters.

Bouctouche Bay was characterized by the presence of a blue-green algal mat on many of the oysters. This green blanket caused increased sediment accumulation on the oysters and blackened shell surfaces underneath, indicating the formation of toxic hydrogen sulfide in several instances. The much reduced benthic invertebrate species richness and fewer individuals on this reef compared to Site 21 (Barnes Bed) nearby is likely a consequence of the reduced availability of substratum surface on these oysters. Site 21, located immediately near the main river channel, likely experiences similar levels of pollution as site 22; however, this site is exposed to higher flow conditions which may prevent the accumulation of detrimental levels of silt and the growth of green-algal films. Subsequently, it supports higher benthic diversity and a much denser oyster population.

As oyster beds change to oyster reefs through increasing oyster density, we noted a change in the species composition, from fauna dwelling predominantly in the sediment to surface-living species. The presence of a rigid three-dimensional oyster matrix in a reef structure prevents larger burying species to establish themselves among the oysters. Instead, shell surface area for secondary attachment of epibenthic species is increased substantially. On the oyster beds, where clumps of oysters are usually interspersed with extensive pockets of sediment, other buriers such as endobenthic bivalves (the quahog, *Mercenaria mercenaria*, the soft shell clam, *Mya arenaria*) and the trumpet worm (*Pectinaria gouldii*) can persist. These species may be further enhanced in the presence of eelgrass (*Zostera marina*) in an oyster bed. Eelgrass provides sediment stability through roots and rhizomes, reducing re-suspension of surface sediments that might inhibit suspension feeders (Peterson 2001). Eelgrass also increases sub-surface complexity, attracting herbivores that feed directly on the blades, or on the attached epiphytic seaweeds and sheltering benthic endo- as well as epifauna from predation (Irlandi and Peterson 1991; Irlandi 1994, Irlandi et al. 1995). Hence, siphon nipping of fish on quahogs was significantly reduced inside an eelgrass bed, compared to outside (Peterson 2001). Also, the presence of eelgrass enhances settlement of bivalve larvae from the water column through alteration of hydrodynamics (Wilson 1990). In oyster beds, this applies both to oyster larvae as well as other associated bivalves such as quahogs, mussels and soft shell clams.

In conversation with local fishermen, it became apparent that the presence of eelgrass on commercial oyster beds is considered a nuisance as it interferes with harvesting. However, our results and studies in the literature show that eelgrass increases habitat heterogeneity and overall species diversity in most cases (Orth,

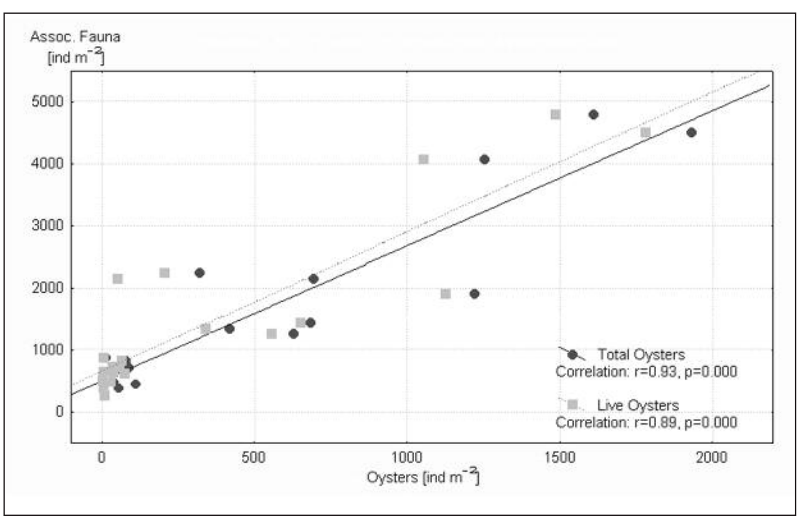


Fig 20: Correlation between (1) overall oyster densities ('Total oysters') and the number of individuals of associated fauna (excluding oysters) – circles and solid line; and (2) densities of live oysters and the number of individuals of associated fauna (excluding oysters) – squares and dashed line. Caraquet samples not included.

1977; Thayer et al., 1979; Peterson, 1979; Fonseca et al. 1996). Our study shows no reduction in oyster densities in the presence of eelgrass (Appendix 2-5). In relation to bivalves in eelgrass beds including oysters, effects of eelgrass presence are variable and mainly relate to overall food supply and hydrodynamic conditions (Peterson 2001). The benefits of eelgrass-oyster associations for the ecosystem outweigh the problems in most cases. In order to address the problem of eelgrass presence for harvesting operations, cutting of blades just before harvesting was tested experimentally and potentially to be an effective method (Robichaud and Robichaud 1976).

5.0 Conclusions

Over the past fifty years, natural oyster production in New Brunswick has gone from being a resource that placed the province as a Maritime leader in oyster production to a resource on the verge of disappearing from the estuaries of northern and eastern New Brunswick. Today, hundreds of natural oyster beds and reefs are buried under many metres of sediment and existing beds are threatened with the same fate. Add to this situation the largely unregulated discharge of nutrients from a wide range of sources and some bays are poised to shift from being biologically diverse to simple ecosystems dominated by annual seaweeds, jellyfish, bacteria and worms.

The failure of natural oyster populations to recover from the effects of the Malpeque disease epidemic in 1950's did not go unnoticed by federal and provincial resource managers. Rather than address the impacts of fishing technology and the by-products of human development on oyster beds, the response of government managers was to shift effort from harvesting oysters on natural beds to farming oysters. In doing so, research effort shifted from examining the restoration, recovery and ecological importance of natural oyster beds or reefs to aquaculture-oriented topics such as oyster-seed supply, new seed-production technology, grow-out techniques, predator and disease control and genetic engineering. This technological approach to addressing resource depletions - replacement versus restoration - now appears to be the major policy tool for addressing species declines. Atlantic salmon, striped bass, sturgeon, and cod are just a few of the species that have experienced population collapses in recent years and are now the focus of extensive aquaculture research and development. Despite considerable efforts to substitute wild species with their farmed counterpart, the wild populations of these species, like the oysters, continue to decline. The ecological implications of their decline remains largely unexamined.

Every species has a complex ecological role to play in the ecosystem which, it appears, cannot be replicated or mimicked by a technological fix such as aquaculture. The oyster is perhaps one of the best examples confirming this statement. Oysters and the habitat they create have a structural and functional role in the ecosystem that is more important than their abundance alone suggests. The permanent habitat created by oysters has ecological value for an astonishing range of epibenthic and bottom-dwelling species in an environment that, without oysters, appears largely unstructured and depleted. While this study did not examine fish utilization of oyster reefs, other studies have demonstrated the importance of oyster reefs to a large suite of estuarine fishes (Harding and Mann 1999; Lenihan et al. 2001).

Accelerating changes in coastal environments - mostly human-induced - are threatening the integrity of oyster habitats, and estuarine ecosystems as a whole in northern and eastern New Brunswick (Milewski and Harvey 2000). Given the key functions oysters play in the health of estuaries and the fact that all estuaries show a loss of production of many commercial and non-commercial fish species, a major oyster restoration effort for all estuaries is warranted. Restoration work must also be coupled with a concerted effort to ensure that legislation and regulation are in place to protect oyster habitat from land-based sources of pollution and coastal development. Oysters are more than a harvestable resource. Restoring oyster beds and estuaries will create benefits that will cascade throughout the entire ecosystem.

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