BY THE SEA

A GUIDE TO THE COASTAL ZONE OF ATLANTIC CANADA

MODULE 5: TIDAL MUDFLATS

Canada

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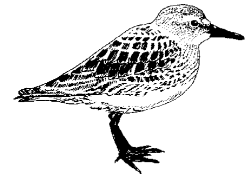
THE MODULES

TABLE OF CONTENTS

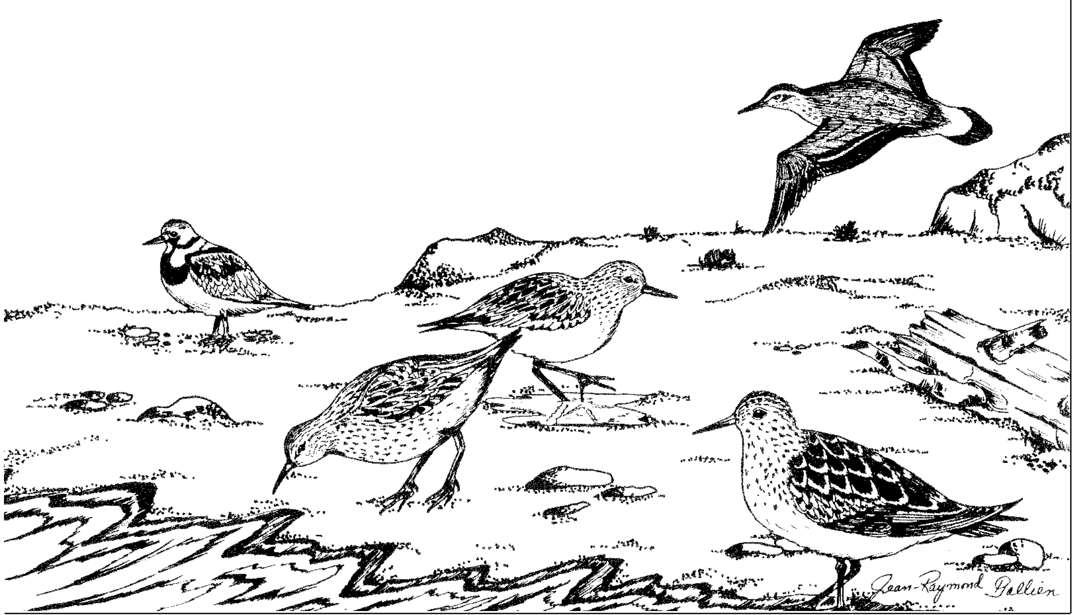


TIDAL MUDFLATS

What is a Tidal Mudflat?

The image most would have of a mudflat is probably a literal definition of the word, a flat area mostly comprised of mud. This definition is correct. However a mudflat is much more than just mud. It is a dynamic living system. One in which animals have evolved a unique range of marvellous adaptations to deal with the daily changes in environmental conditions. Mudflats are usually associated with marine environments, especially in situations where tides expose an expanse of shore. The shore must be a gently sloping intertidal area, consisting primarily of fine sediments (silt, clay, and fine sands).

see activities 5, 8



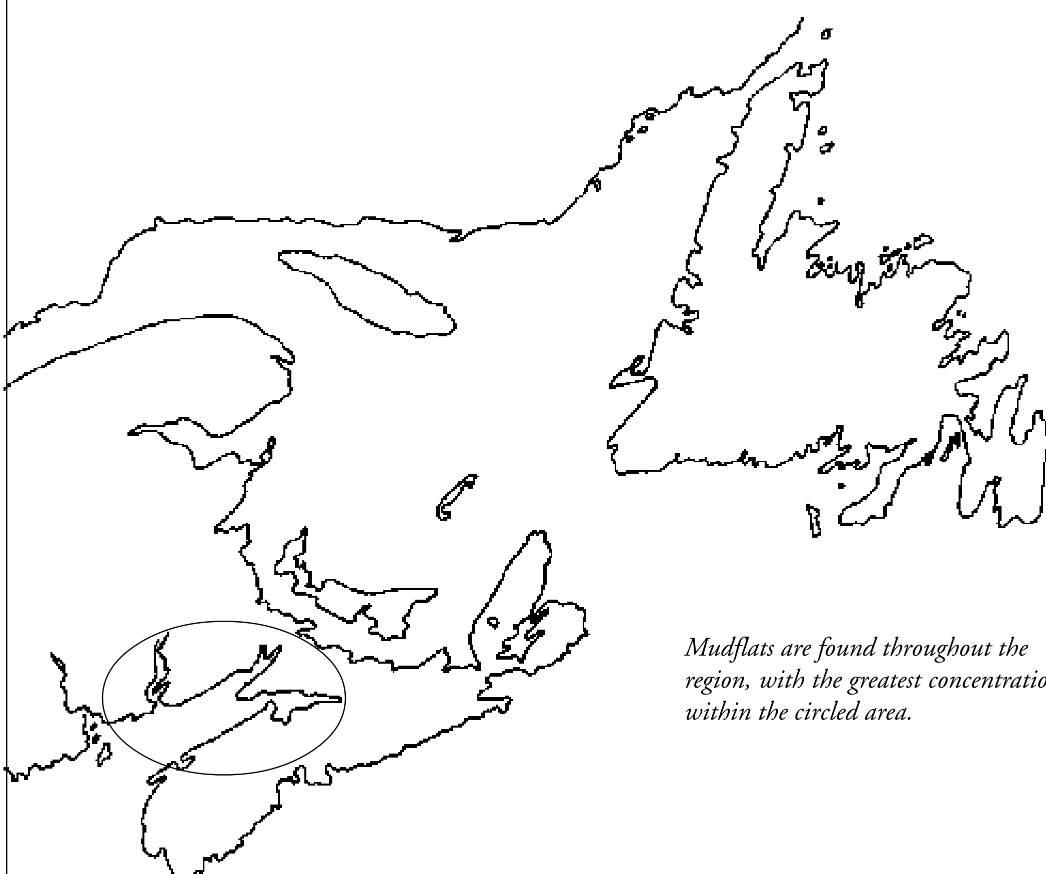
The Mudflat within the Coastal Zone

Mudflats are places where nutrients and sediments from other areas are deposited. Mudflats usually occur in association with estuarine environments and salt marshes. Both of these are environments where sediments are primarily deposited and are protected in some way. The mudflat can be the starting point for a salt marsh, providing the initial sediment for the establishment of salt marsh plants. The top of the mudflat may, in fact, be ringed with a variety of salt marsh species, such as the cord-grasses and sedges.

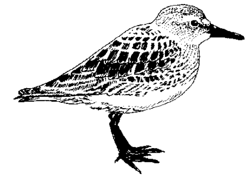
Location

Mudflats in the Maritimes of Atlantic Canada occur primarily at the head of the Bay of Fundy in the Minas Basin and Chignecto Bay. Small pockets of mudflat associated with small salt marshes, protected coves and estuaries also exist in the lower Bay of Fundy, along the Northumberland shore of New Brunswick, and in Newfoundland.

Major mudflat area of Atlantic Canada



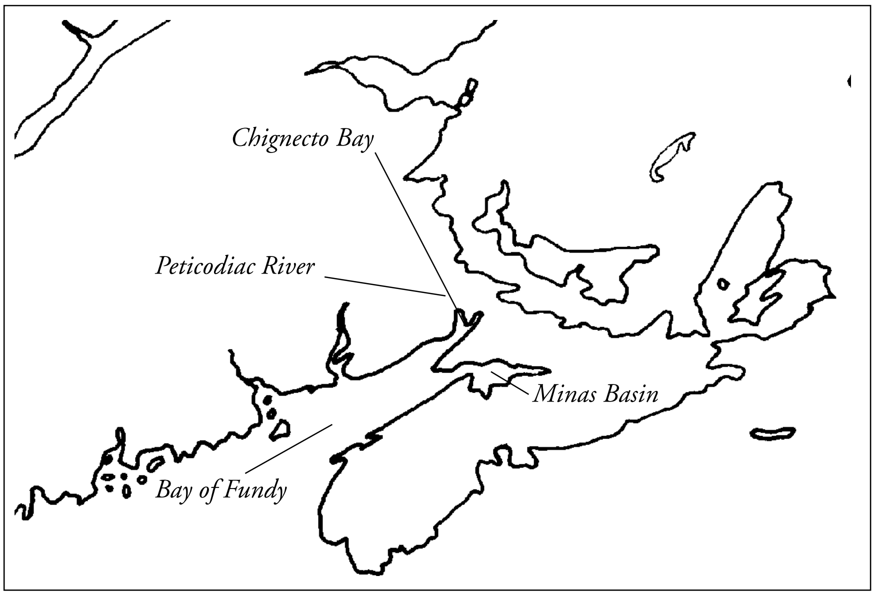
Mudflats are found throughout the region, with the greatest concentration within the circled area.



THE PHYSICAL ENVIRONMENT

Formation

The mudflats of the upper Bay of Fundy are a result of the erosion and deposition of the surrounding coastal bedrock. Primarily composed of weak sedimentary rock, the coastline in this region is constantly changing and much of the sediment that lines the entire Fundy coast has its origins at the head of the Bay. Sediments in the Minas Basin are derived from the erosion of the southwestern shore of Nova Scotia. Chignecto Bay on the other hand derives its sediments from its own shoreline and the Peticodiac watershed which exports sediment into the Bay of Fundy.



In the upper basins, flat lowland areas have given rise to extensive salt marshes that extend intertidally into mudflats. The gently sloping intertidal areas create an environment with low wave and tidal action. These so-called low energy environments result in sediments falling out of suspension and being deposited along the shore. The extreme tidal ranges at the head of the Bay of Fundy create a situation in which some of the world's largest mudflats have been created.

Physical Characteristics

A range of physical characteristics affects what happens to a mudflat ecosystem. These physical characteristics keep mudflats in constant flux, making them dynamic and fascinating systems. Catastrophic events sometimes create situations that completely
alter the properties of a mudflat for short periods of time.

Currents

Currents, as a result of both tides and associated estuaries, can affect the rate of sedimentation (deposition) or rate of erosion of the mudflat itself or the bedrock that marks the boundary of the shore. Mudflat sediments are extremely small (0.07 mm in diameter or less). They are easily thrown into suspension as the tide recedes or advances. Sediments therefore are constantly redistributed. Sediments in suspension can affect the ability of mud-dwelling filter feeders to feed effectively.

For more information on currents please refer to module 1: Introductory module.

Ice

Ice does not completely cover the Bay of Fundy nor any of its upper basins in winter. Coastal ice does form, however, and on the mudflats of the upper Bay ice scouring is a major factor affecting the physical and biological structure of the habitat each year. Ice gouges measuring up to 0.5 m deep have been observed in the Minas Basin.

Gouges of such size are the result of large blocks of shore ice that break away with the tides or river ice rafting into the basin from local estuaries and 'bulldozing' the soft sediments that make up the mudflats. The resulting indentations are channels for incoming or outgoing tidal water and may change the structure of the mudflat at that location. In addition, 'fast ice'-that ice which freezes to the mud itself-may also affect benthic (bottom) organisms, and it can transport considerable amounts of sediment away. In severe winters the mudflat will freeze below the depth at which most animals can live during a single tidal cycle.

Salt

Salt is everywhere in the marine environment. As a physical characteristic it is one of the greatest stresses that both plants and animals of the mudflat have to contend with. As daily temperatures increase during the summer months so does evaporation. Greater evaporation increases the concentration of salt. This increases the level of stress on organisms living in this habitat.

see activities 3, 11, 37

Many mudflats are associated with salt marshes and estuaries. In these situations increased salinity may not be the problem. Instead, decreases in salinity may occur as a result of increased freshwater input. In addition, precipitation will change salinity levels of the mudflat quite dramatically, especially if it occurs during a low tide. Unlike a rocky shore where precipitation would tend to run off, a mudflat 'captures' the rain and snow, and the fresh water infiltrates the surface.

For more information on salt please refer to module 1: Introductory module, and module 13: Activities.

Sediment

Sediments are the basis of the mudflat. They are transported to these extensive flat intertidal regions as a result of the erosion of adjacent shoreline (often sedimentary cliffs) and the fine grains that make up the sediment load of local rivers.

Sticky sediment

The sediments of a mudflat tend to stick together. This is a result of a number of factors including the presence of diatoms (single-celled plants), particle size, and moisture content. Small particles have a greater attractive force especially in the presence of water. All of these factors help to prevent water from draining through the mud easily. A mudflat therefore has supersaturated conditions. This has an effect on the relative amounts of oxygen available as well as the presence of compounds such as hydrogen sulphate. Low oxygen levels will affect the range of animals suited to living here and their distribution within the sediment itself.

Sediments in the Minas Basin, for example, are derived from local shores and imported into the system from the erosion of the southwestern shore of Nova Scotia. Sediments in Cobequid Bay are primarily derived from its shores and the Peticodiac River. Sediment from this system is exported into the rest of the Bay of Fundy.

Increased inputs of sediment into the upper Bay of Fundy system would likely have some effect on the expanse of the mudflats in that region; the export of sediment out of the upper basins would influence the rest of the Fundy system.

Temperature

Temperature, like salinity, affects the physical nature of the mudflat. In extreme conditions, high summer temperatures can affect those organisms living in the mud and consequently the mud's physical characteristics. In addition, high temperatures may also dry out the upper extreme of a mudflat and, if accompanied by a strong wind, may result in some wind-

For more information on temperature please refer to module 1: Introductory module.

Tides

see activities 4, 14

The tides affecting the Fundy mudflats are among the highest in the world. In some locations the vertical range exceeds 16 m. Consequently, the mudflats themselves are also among the largest in the world, reaching between 3 and 4 km wide in places.

The rising and falling tides create a variety of localized current patterns. These current patterns may change with the effects of ice scouring, erosion by rivers, or their own action. As a result tides can, in association with these other factors, affect the physical structure of the mudflat.

For more information on tides please refer to module 1: Introductory module, and module 13: Activities.

Waves

Mudflats are characterized as low energy environments as explained earlier. Mudflats are areas of deposition. If they were constantly affected by large waves the sediments that constitute the mudflat would be transported elsewhere.

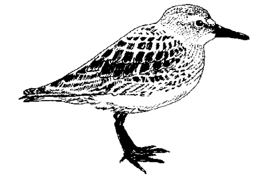
On occasion, storm waves create exceptional turbulence that throws a greater load of mud particles into suspension. This increased level of turbulence and mixing and sediment content can increase stress on the fauna in the mudflat (possibly removing large populations of organisms) and alter the system's morphology (shape) for short periods of time.

For more information on waves and their effects on coastal ecosystems please refer to module 1: Introductory module.

Wind

The effects of wind are manifested most in the creation of waves. Waves constantly change the physical structure of the mudflat. In extreme situations, storm waves will cause abnormal changes on a mudflat. These may alter for short periods of time populations of organisms, sediment loads, and the morphology (shape) of the mudflat.

Wind can also lower air temperatures, aiding in the formation of ice in winter. In summer, wind will help to dry out sediments.



BIOLOGICAL FEATURES

Who Lives Where?

Zonation

In mudflat environments, most organisms live unseen in the mud. As a result, a pattern of zonation is not as apparent here as in rocky intertidal communities. However, zonation does occur on mudflats due to varying degrees of physical and biological stresses on flora and fauna, which will create situations that are better suited for some organisms than others.

Mudflats are environments of extremes. The overriding stresses in these systems are fluctuating salinity and changes in the particle sizes of the substrate. Organisms are found where they are best adapted to these variations. The most tolerant occur at the upper end of the intertidal zone, the less tolerant closer to the low tide mark.

see activites 16, 17, 19

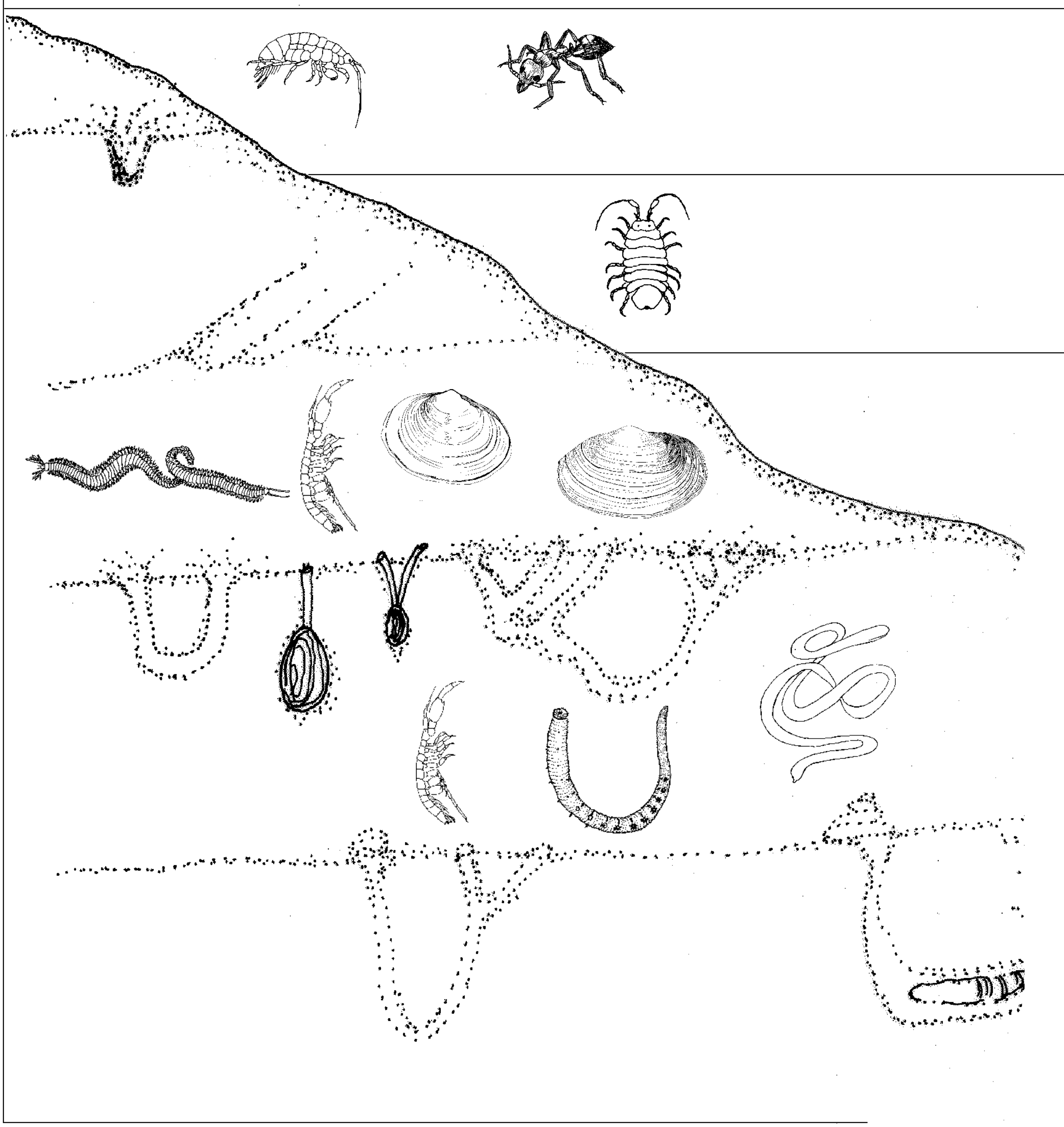
The diversity of organisms that can be found in these situations is limited. However, low diversity does not necessarily result in low abundance or productivity. Mudflats are often extremely productive, some supporting thousands of organisms per square metre. Those in the Bay of Fundy are no exception.

The mudflat supports a high density, low diversity of benthic (bottom-dwelling) invertebrates. These are dominated by deposit feeders, unlike a rocky shore which has a mix of active predator-prey relationships as well as detrital feeders and first order
consumers. Less than 45 species of large bottom-dwelling invertebrates have been identified for the upper Bay of Fundy.

In addition, a range of microscopic plants (phytoplankton) and animals (zooplankton) can be found in association with mudflats.

The most common are described below.

On the Fundy mudflats five different zones have been identified.



Upper ‘beach’

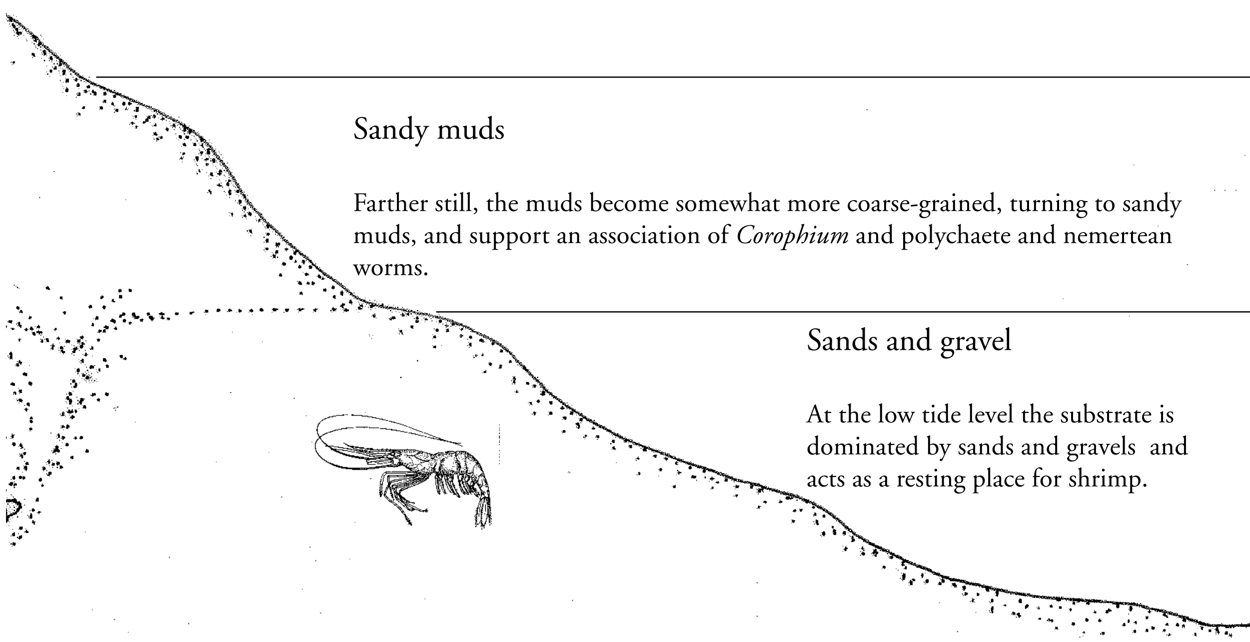
Here an association of ant and sand hoppers burrows into the sediment.

‘Trilobite’ zone

This area is dominated by the isopod *Chiridota caeca*, an organism with a likeness to the extinct group of arthropods, called trilobites.

‘Bioturbated muds’

A muddy substrate characterized by ‘bioturbated muds’ is dominated by the bivalve molluscs (clams), the burrowing amphipod *Corophium volutator*, and a predatory polychaete worm, Nereis virens (clam worm). Bioturbated muds refer to all the biological transformations that occur within sediments caused by organisms.



Sandy muds

Farther still, the muds become somewhat more coarse-grained, turning to sandy muds, and support an association of *Corophium* and polychaete and nemertean worms.

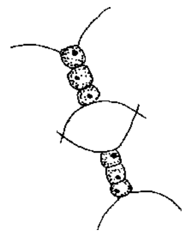
Sands and gravel

At the low tide level the substrate is dominated by sands and gravels and acts as a resting place for shrimp.

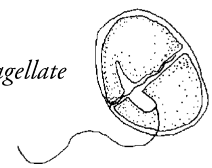
Plankton

Phytoplankton come in two principal forms: i) free-floating phytoplankton including oceanic diatoms (microscopic unicellular algae) and dinoflagellates (marine unicellular organisms), which drift in the surface waters and ii) benthic (bottom) phytoplankton which include diatoms and dinoflagellates that live on the surface of the mudflat.

diatom



dinoflagellate

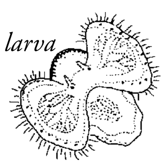


see activities 9, 25, 26

The amount of free-floating oceanic phytoplankton produced in the upper Bay of Fundy is low compared to the outer bay and to that produced on the mudflats themselves. The limited production of these free-floating forms is a result of sediment in the water restricting the penetration of light.

Zooplankton or animal plankton drift into and away from mudflats with the incoming and outgoing tides. Many of the animals living on the mudflat have planktonic stages in the early part of their life history. Therefore at specific times during the year the water covering the mudflats will be filled with very young molluscs, crustaceans, and worms.

mollusc larva



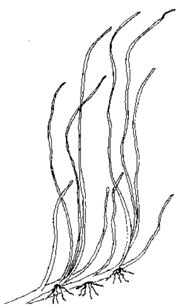
crab larva

For more information on plankton please refer to module 1: Introductory module and module 13: Activities.

Plants

Benthic microalgae are everywhere in the sediments of the mudflat. These single-celled plants often form algal slicks at favoured sites. All of these survive in the top centimetre of mud where oxygen and light will allow them to photosynthesize. The amount of phytoplankton produced in this situation is great compared to that produced in the water column adjacent to mudflats. This is in part a result of the amount of time mudflats are exposed to light during a tidal cycle.

Large plants do not have the same degree of importance or visibility in this coastal ecosystem as in many others. The dominant feature of the mudflat is the mud itself. For the most part the animals that live here are not seen because they are infauna(living in the mud). Seaweed is not abundant because most species require a hard substrate to fasten to. As a result this eliminates the rockweeds that are so conspicuous on the rocky shore. But wave action and currents are not as prevalent on the mudflat so a number of green macroalgae species can often be found in extensive mats. Most often found are those species that can tolerate lots of fresh water, an appreciable amount of drying out, and some freezing, such as hollow green weed, Sea Lettuce, and Green Thread Algae. Vascular plants such as Eelgrass and a number of salt marsh plants may also be found in association with mudflats - the salt marsh plants primarily because marshes are found adjacent to the mudflats on many occasions, and Eelgrass because its roots are able to take hold in the mud.



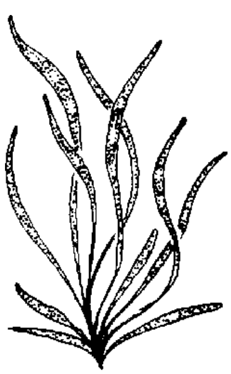
Eelgrass

Eelgrass has long blades that can be seen floating in the water or washed ashore in large heaps.

see activity 31

Sea Lettuce

Sea Lettuce is a sheet-like green seaweed that looks like lettuce.



hollow green weed

Hollow green weed is a brightly green seaweed that is especially tolerant of freshwater input.

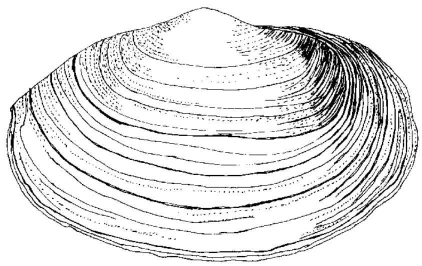
Green Thread Algae

Green Thread Algae is a threadlike, single-stranded or branching seaweed that comes in different colours, such as brown, green, olive, rust.

Molluscs

Molluscs are especially abundant on the mudflats.

For more general information on molluscs please refer to module 1: Introductory module, and module 13: Activities.

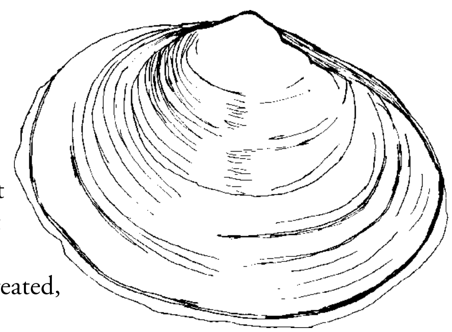


Soft-shelled Clam

The Soft-shelled Clam siphons food from the water and not from the bottom. Its feeding therefore is dependent on being surrounded by water. To 10 cm.

Baltic Macoma

The Baltic Macoma clam buries itself in the mud and sticks a long incurrent siphon out of the mud and over the surface to suck up organic material that settles on the mud. The processed mud is blown out of an excurrent siphon. Continued feeding in this manner results in small shallow depressions being created, which in turn trap fine sediment. To 5 cm.

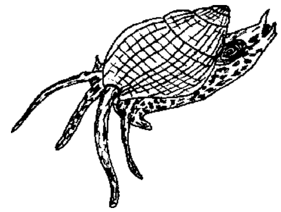


Molluscs in abundance

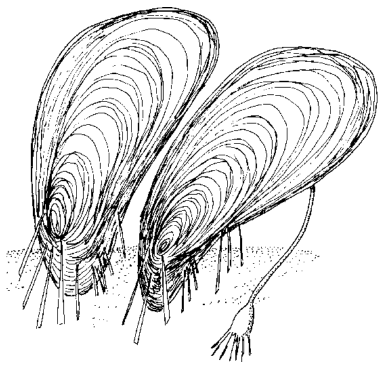
In the Minas Basin and Chignecto Bay a Baltic Macoma (*Macoma baltica*) community has been identified. This small (< 3 cm) clam is a deposit feeder and has been counted in densities of up to $3{,}500/m^2$, yielding estimated populations of greater than 30×10^9 individuals in the upper bay. Dense populations of these small bivalves produce a definite pattern in the mud that can be observed from a distance. The pattern is that of a series of starbursts in the mud.

The Soft-shelled Clam (*Mya arenaria*) is a suspension feeder also found in large numbers on the Fundy mudflats. The density of these has ranged close to 600 individuals/m^2. Surviving best in coarser sediments with a muddy veneer or surface layer, estimates of their total population in the upper bay range to 4×10^9.

Dog Whelk

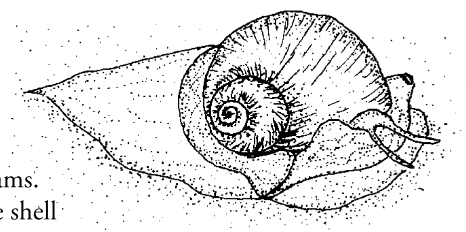


The Dog Whelk is a predatory snail that drills holes in the shells of other molluscs. The shell is rough to the touch. To 2 cm.



Blue Mussel

The Blue Mussel often grows in clumps through out the lower areas of the mudflat. This bivalve will attach itself to anything solid in the mud by hair-like byssal threads. Mussels will often create multilayered 'bars' in areas where oxygen-rich water and food with little suspended sediment will enhance and not impede their growth. These 'bars' also provide a substrate on which other animals can live and grow. To 10 cm.



Moon Snail

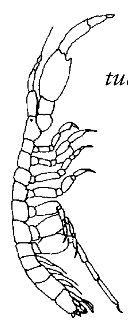
This burrowing snail has a huge muscular foot to dig into the mud and search for clams. Upon finding its prey it drills a hole in the shell of the clam. Once the hole has been drilled a digestive enzyme is secreted into the clam and the meat is dissolved and taken in by the snail. To 10 cm.

Crustaceans

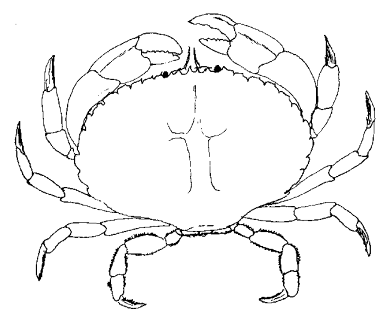
Some of the burrowing amphipods found in other sedimentary environments are not common on the mudflats. Because the sediment grains are so small and tend to adhere to one another, the burrowing animals that are most successful are those that build a tube to live in.

The most important inhabitant of the mudflat and among the most numerous is the small tube-building amphipod, Corophium volutator. It is found in densities up tp 63,000/m^2 living in its u-shaped tube under the surface mud, coming out to forage at low tide. On mudflats where dense populations can be found they can also be heard. At low tide the mudflats resound with a snap, crackle, and popping sound. This amphipod is the major source of food for the hundreds of thousands of sandpipers and plovers that use the Fundy mudflats as their staging area before migrating to South America.

The common shore crab of this coastal ecosystem is the Jonah Crab. It can be found sporadically in mudflat areas as can the isopod *Chiridotea caeca*. These, however, are not found in the same numbers as the tube-building amphipod.



tube-building amphipod (Corophium)

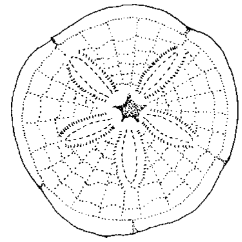


Jonah Crab

Echinoderms

Echinoderms are virtually absent from intertidal mudflats. The only example that occurs with any regularity is the Sand Dollar. It usually prefers sand to silt-sized sediments and so like the Soft-shelled Clam is somewhat more restricted in its distribution.

Sand Dollar

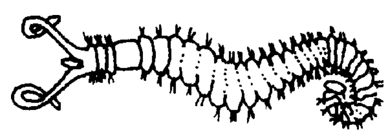


Worms

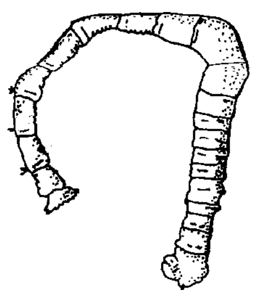
Worms make up the most diverse group of organisms in muddy intertidal areas. The most common worms are segmented annelid polychaetes, and slender nemerteans or round worms. The polychaetes and nemerteans may be deposit feeders, scavengers, or predatory carnivores.

Burrowing polychaete worms living in mudflat intertidal areas are extremely abundant. Common on Fundy mudflats are two species, the mud worm and the bamboo worm. Both are tube worms that construct their protective coverings from the tiny sediment grains of the surrounding mud.

mud worm



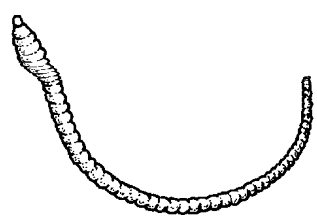
The mud worm is a deposit feeder that uses two horns to pull detrital matter into its 5 cm long tube. They are most common in sandy areas of the mudflat and have been observed in aggregations of 330,000 individuals/m^2. 10 cm.



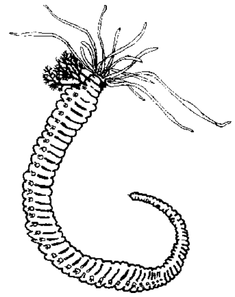
bamboo worm

The bamboo worm is an upside-down deposit feeder. Its mouth is at the deep end of its 10 cm tube. Its population has been recorded at 425/m^2. 15 cm.

capitellid thread worm



Also common are the thread-like polychaetes, the capitellid thread worms. These tiny deposit feeders grow to about 10 cm and live close to the surface.

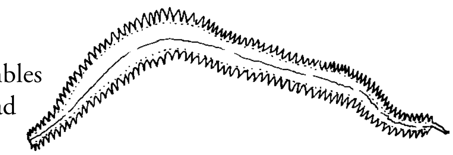


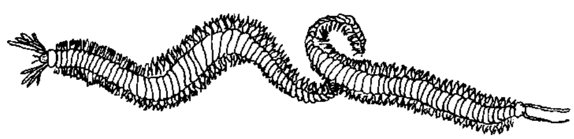
terebellid worm

Other deposit feeders and scavengers include the tube-dwelling terebellid worms. These burrow into the mud, but leave their head exposed. From the head radiate numerous long, white, grooved and mucous-covered feeding tentacles. These reach out in all directions. Particles of mud and organic material that brush against them stick and are transported back to the mouth. Another conspicuous feature of this annelid is the red bush-like gills that also extend from its head. 15-20 cm.

red-lined worm

The red-lined worm is a predator. It resembles the clam worm but the tentacles on its head are poorly developed. 30 cm.



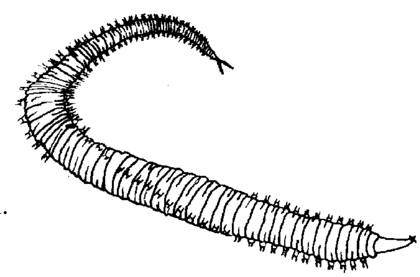


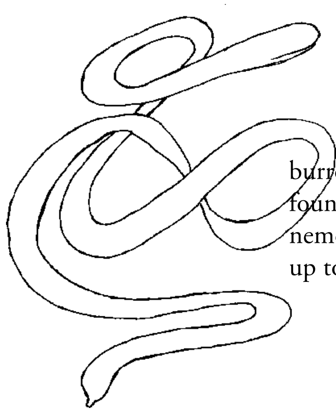
clam worm

The clam worm has several well-developed antennae on its head, and a trunk that is armed with two hooks that it uses to capture its prey. 20 cm.

blood worm

These worms are also known as 'beak throwers' because of their ability to evert a long-jawed proboscis. They feed primarily on other worms and on the diatoms and dinoflagellates (benthic microalgae) that are found in the mud. To 37 cm.





Milky Ribbon Worm

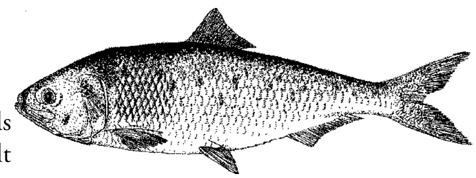
The Milky Ribbon Worm is another mudflat resident that burrows in the mud and preys upon other burrowing organisms found in intertidal and subtidal muddy substrates. As a nemertean it is not segmented like the polychaetes. It can reach up to 1 metre in length.

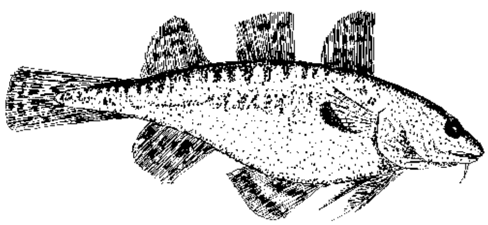
Fish

Fish are visitors to the mudflat, using them at high tide to search for food. Striped Bass, American Shad, Atlantic Tomcod, skates and a number of flatfish (flounder) feed on the abundant molluscs, worms, and tube-building amphipods living in the mud. Shad move southward to winter off the Atlantic Coast of the United States. In the spring they move northward to their spawning rivers. They are found in all rivers along the eastern seaboard and many make their way to the Bay of Fundy and its upper basins every year to feed.

American Shad

The American Shad is a member of the herring family that resembles the Gaspereau. Body elongated with strongly compressed top and bottom. Back is dark blue or green. Breeds in fresh water and lives the rest of its life in salt water and estuaries. 50 cm.



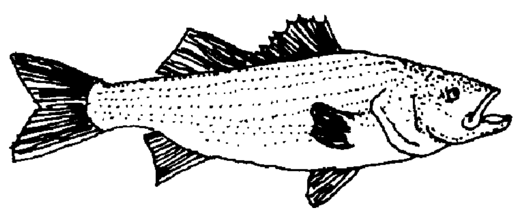


Atlantic Tomcod

The Atlantic Tomcod resembles a small cod and feeds on shrimp, amphipods, and worms in shallow water. It lays its eggs on sand or gravel. Breeds in early winter or mid-winter, spawning inshore at the head of the tide. To 30 cm.

Striped Bass

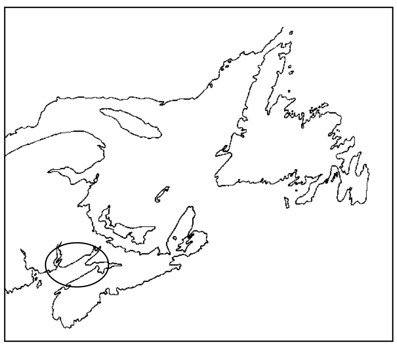
The Striped Bass is olive-green to dark blue. Its sides are silvery, upper sides with 6-9 dark uninterrupted stripes. It is a voracious and opportunistic feeder. To 100 cm.



Birds

Birds are migrant users of the mudflat. The abundance of worms and amphipods make muddy intertidal systems important feeding areas for a number of shorebirds.

The most common birds found in association with the mudflat are dowitchers, plovers, sandpipers, herons, and gulls. Most of these are visitors to the mudflat at only certain times of the year, usually mid- to late summer. Here they build up fat reserves for their long migrations as far south as South America. Their bills and long legs are well-adapted to feeding on a mudflat for those organisms that bury themselves in the soft mud. The abundance of these mud burrowers at the head of the Bay of Fundy has made it a region of international importance for shorebirds.



Important autumn migratory routes

The Bay of Fundy with its extensive mudflats is especially attractive for migrating shorebirds. Birds gather in the hundreds of thousands in certain areas. Other mudflats in Eastern Canada host smaller numbers of shorebirds (in the thousands) but nevertheless are still important feeding areas.

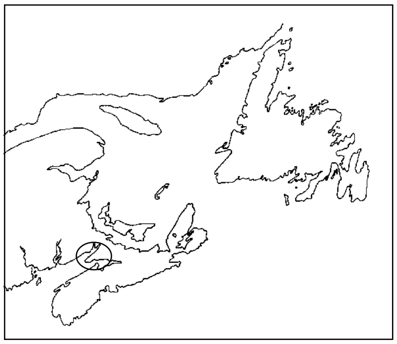
Migration

Shorebirds use the mudflats as staging areas, or as feeding areas to build their energy levels for the long migratory flights from Atlantic Canada to South America.

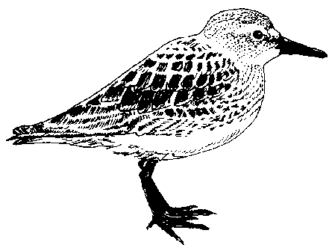
Birds have a very high metabolic rate, meaning that the rate at which they use up energy is very high. Thus they have to eat great quantities compared to their body weight. Flying thousands of kilometres to South America is even more demanding. Despite this high metabolic rate birds use energy far more efficiently than any plane or machine.

Birds use mudflats for staging and resting during migration or during the summer. Before they fly south shorebirds will double the amount of fat in their body tissues: necessary fuel for the flight.

For more information on migration please refer to module 6: Sandy Beaches and Dunes.



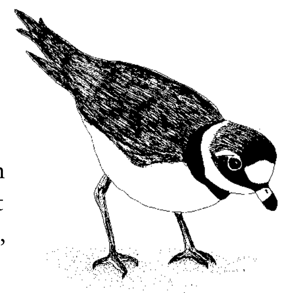
In the Bay of Fundy, Mary's Point in Shepody Bay and the southern shore of the Minas Basin are internationally renowned stopover sites for migrat ing shorebirds. As many as 2 million shorebirds use the Bay during the southward migration in any given year. Between 50 and 95% of the world population of Semipalmated Sandpipers feed here on *Corophium volutator*, a tube-building amphipod.



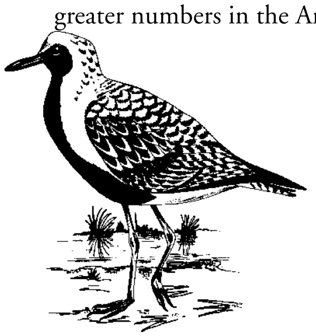
Semipalmated Sandpiper

Semipalmated Sandpipers make up 95% of all shorebirds that use the Bay of Fundy. Sometimes looking like pebbles on the beach, they are greyish above and white below with a black bill. 'Semipalmated' refers to the partially webbed feet. 14 to 16 cm.

Semipalmated Plover



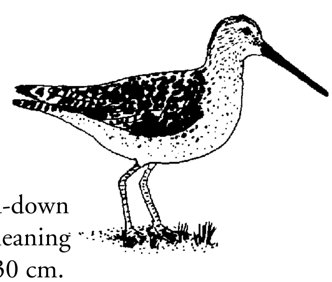
The Semipalmated Plover is a striking, plump bird that looks like a miniature Killdeer except that it has only one band around its upper breast, not two. The back is brown and the legs and base of the bill are dark yellow. They nest on some dark-coloured cobble beaches of New Brunswick, Nova Scotia, and Prince Edward Island, but nest in far greater numbers in the Arctic. 16 to 19 cm.



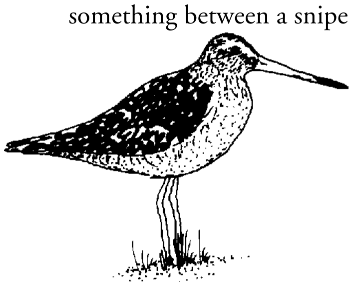
Black-bellied Plover

The Black-bellied Plover is a sharp looking, plump plover with black breast and speckled back. Listen for its drawn-out, mournful, three-note whistle across the mudflat. 26 to 34 cm.

Short-billed Dowitcher



The Short-billed Dowitcher is a long-legged and long-billed bird seen often with other shorebirds. They probe deeply with their beaks with an up-and-down motion in shallow water. Dowitcher is Iroquoian meaning something between a snipe and a shorebird. 26 to 30 cm.



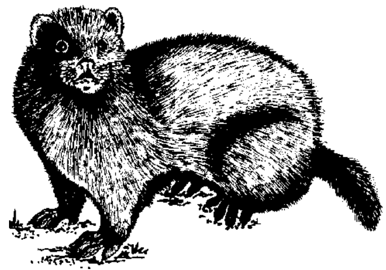
Hudsonian Godwit

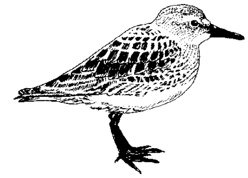
The Hudsonian Godwit is a large bird with a slightly upturned, long bill used for probing into the mud, sometimes up to their eyes. 38 cm.

Mammals

Other than those that come from the land to harvest the occasional meal, such as raccoons, mink, or humans, mammals are virtually absent from the mudflat.

Mink





ECOLOGY

As with any intertidal situation, mudflats provide an opportunity to study a range of ecological interactions. Animals and plants living in a habitat dominated by mud have developed a unique and fantastic range of adaptations to deal with factors such as a high sediment load and extended exposure to sun, wind, and rain.

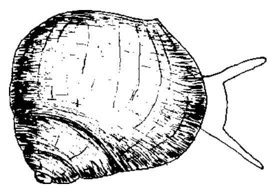
Stress and Survival

Drying Out and Heating Up

In some places at low tide the mudflats of the upper Bay of Fundy extend out 4 km from the beach. Many of the organisms living here do not occupy the surface but have evolved specialized mechanisms for living in the mud. On the surface they would be exposed to extreme wind and sun conditions with no seaweed or rocks to hide under.

Those that do live on top of the mud have protective shells: gastropod molluscs like the periwinkle.

periwinkle



The seaweed that grows and survives in muddy environments does so more frequently at times of the year when drying out would be less of a problem: the late winter and early spring.

Most mudflat animals protect themselves from extreme heat by burying themselves in the mud. Here they are surrounded by water, which helps to moderate temperatures. The burrowing and tube-dwelling animals of the mudflat also have the ability to dig deeper if conditions warrant, seeking cooler temperatures and more moist conditions. However this too has its limitations since at greater depths oxygen is depleted.

Changing Salinity

One of the greatest stresses that both plants and animals of the mudflat have to contend with is changing salinity. As average daily temperatures increase during the summer months the potential for evaporation increases. Greater evaporation creates increased salinity. This can be lethal. The shelled molluscs can close up and await the next tide. Many worms and the tube-building amphipod don't have this ability. Some worms build protective tubes of sand and mud that would help to decrease the stress of increased salinity, and the amphipods burrow into the mud.

Many mudflats are associated with salt marshes and estuarine habitats. In these situations increased salinity may not be the problem. Instead decreases in salinity may occur as a result of increased fresh water input. In addition, precipitation will change salinity levels of the mudflat quite dramatically especially if it occurs during a low tide. Unlike a rocky shore where precipitation would tend to run off, a mudflat 'captures' the rain and snow, and the water infiltrates the surface.

Those seaweed species found on the mudflat - hollow green weed, Sea Lettuce, and Green Thread Algae - are very tolerant of fresh water and in fact seem to thrive in its presence.

Light and Dark

Light is a physical factor affecting the ability of many plants and animals to survive. In the water above a mudflat at high tide light and light penetration or the lack of it affects the phytoplankton (single-celled plants) most.

Mudflats consist of fine sediments. These sediments are thrown into suspension with each incoming tide. This affects the ability of sunlight to penetrate the surface and provide essential light for these plants. Phytoplankton growth within the water column is not great over mudflat ecosystems. Conversely the production of benthic microalgae, those diatoms and dinoflagellates growing on the surface of the mudflat at low tide, is relatively abundant. This abundance increases with length of exposure (i.e. upper sections of the mudflat produce more benthic diatoms than lower sections).

Holding On or Losing Out

Mudflats provide little stable substrate for animals and plants to hold on to. The adaptations that organisms have evolved reflect this. Mudflats do not support a large contingent of surface dwellers or epifauna. Those that live in the mud have bristle-like adaptations that help them burrow in the mud and also keep them there if affected by currents and waves. Large plants such as seaweed and Eelgrass would colonize the most stable parts of the mudflat, in places where turbulence and moving water were not a factor.

Mudflats are particularly susceptible to the ravages of storms and waves. Observations have indicated that catastrophic mortalities of shallow burrowing organisms have resulted from heavy rains and storms.

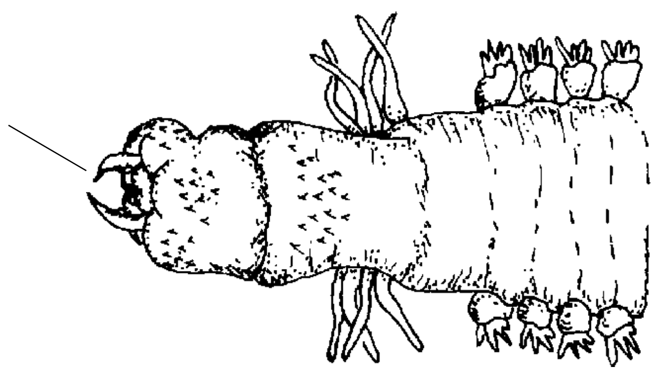
There is Only So Much Room

The mudflat produces associations of animals in very high densities. As a result many of the animals are relatively small and orient themselves vertically in the mud. Instead of laying across the substrate and covering a large area they increase the surface area available for colonization by digging burrows.

Eating and Being Eaten

The mudflat supports primarily a deposit-feeding and scavenging community of animals. Some mudflat predators, such as the clam worm and the blood worm, have evolved special feeding apparatuses. The clam worm, for example, has a set of effective jaws enclosed in a proboscis that is everted when a prey species is found. The jaws seize the prey and draw it into the worm's mouth.

proboscis of a clam worm

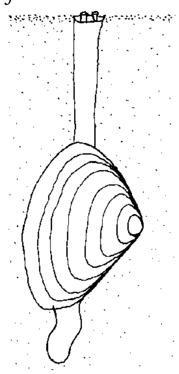


The deposit feeders have a unique range of adaptations that contributed to their successful colonization of this habitat. Worms such as the terebellid worm have a series of long mucous-covered tentacles that reach out across the substrate picking up particles of food to be relayed along the tentacles back to the mouth. The tube-dwelling mud worm has a set of 'horns' at the opening by its head that pull surface detritus in to its mouth.

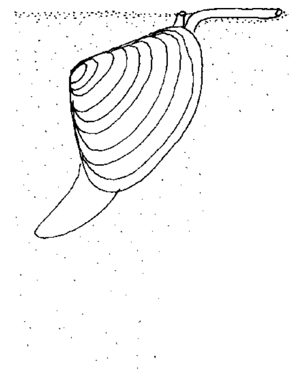
terebellid worm

The molluscs feed using a siphon tube. In the case of the Baltic Macoma, its siphon acts like a vacuum cleaner and sucks up food particles lying on the surface sediments. The Soft-shelled Clam, on the other hand, siphons particles out of the water flowing just above the mud.

Soft-shelled Clam

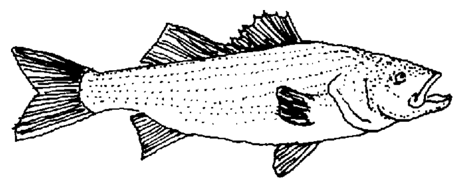


Baltic Macoma



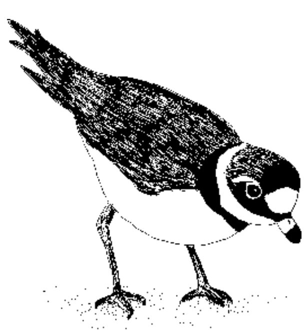
The predators of many of the mudflat dwellers are animals that arrive only during high tide. Flatfish, Striped Bass, American Shad, squid, and skates come ashore to feed on the tube-building amphipods, clams, and worms that inhabit the substrate.

Striped Bass

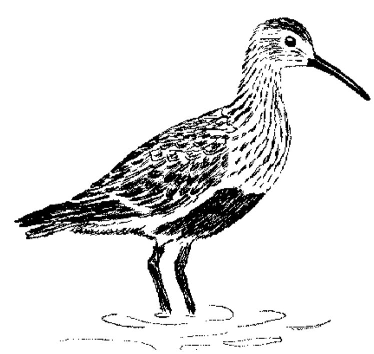


Shorebirds are also predators of the mudflat. These, however, are even less frequent users of this habitat than the fish. Shorebirds are effective feeders in muddy substrates because of their long, pointed beaks, which are capable of probing below the surface to find worms and especially Corophium. The beaks have very tactile senses that detect movements in the mud.

Semipalmated Plover



Dunlin



Producing Offspring

Distribution and survival is determined in part by the various reproductive strategies that organisms have evolved. In the marine environment most animals have evolved mechanisms by which they release their gametes into the water column at specific times during the year. This is usually determined by temperature. Spring is the season in which most mudflat organisms reproduce. The gametes (sperm and eggs) are released into the water where the eggs are fertilized and then float in offshore surface waters as meroplankton (usually four to six weeks). After this larval stage the animals return to the mudflat via incoming tidal currents and settle on the bottom where they begin their adult life.

Most mudflat inhabitants will release thousands if not millions of gametes. This is to ensure their survival. Most of these will perish as larvae or as young adults. The remaining will have to deal with the stresses of the mudflat.

Death after reproduction

The blood worm has a unique reproductive cycle. In the spring of the year when high tides occur in the afternoon the females and males will leave their mud burrows and swim to the surface in swarms. Here their rapid swimming causes the females to rupture and release up to 10 million eggs. The males release sperm and both die of exhaustion.

Productivity

Productivity in the Fundy mudflats is little understood but some information has been gathered. There are high densities of animals such as clams and worms. Densities of 60,000 to 300,000 animals/m^2 are not uncommon in some mudflat areas.

In many systems the availability and production of phytoplankton and the production of seaweed gives some indication of an ecosystem's productive capabilities. The Fundy mudflats have little seaweed and the production of phytoplankton in the water column is limited by the high sediment content of the water. However benthic microalgae are numerous and measurements indicate that they provide up to 50% of the primary production in some mudflat systems.

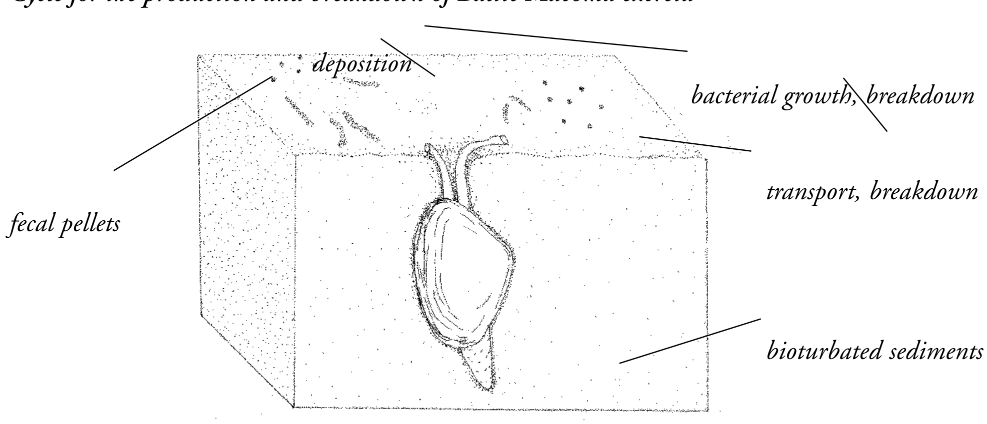
This in turn has limited the production of zooplankton. Zooplankton that are associated with mudflat systems have little or no fat reserves. Input of organic material from adjacent ecosystems, salt marshes, and estuaries is also limited but important. The tube-dwelling amphipod for example depends on organic materials exported to the mudflat from adjacent salt marshes.

What is also likely is that bacteria play an important role in converting materials such as chitin(bits of shells), and plant matter (cellulose and lignin) into useful products that are fed on by deposit feeders. Population densities of the Baltic Macoma, for example, are strongly correlated with populations of bacteria.

The importance of clam faeces

While feeding on surface detritus Baltic Macoma produce incredible amounts of faeces (droppings). The total daily production of Macoma droppings in the Minas Basin may be as much as 6 x 106 kg of dry sediment. What this provides is a surface around which bacterial colonies can grow and become a valuable food source.

Cycle for the production and breakdown of Baltic Macoma excreta



Links with Other Coastal Ecosystems

Mudflats are linked with many other ecosystems primarily through a variety of feeding relationships and from a sediment perspective as well. Fish and birds are visitors to the mudflats - the former during high tides and most often during seasons of high productivity (summer, fall) and the latter for short periods at times of peak biomass production. These predators depend on the mudflat for the energy it supplies them and without these systems much of the hemispheric shorebird population (especially sandpipers) would be in jeopardy. The same may be said for a number of fish species. Shad, for example, migrate from every major river along the Atlantic seaboard to the Bay of Fundy to feed on the mudflats of the upper bay.

Sediments from the upper bay are also important. They are transported out of the immediate area and distributed to other regions of the Bay of Fundy. The gently sloping mudflats and the sediment provide an initial base for the formation of salt marshes. The head of the Bay of Fundy has the largest salt marshes in Atlantic Canada. This in part is the result of this low energy situation allowing for the deposition and accumulation of sediment necessary for salt marsh plant growth and development.

Although the Bay of Fundy mudflats are bordered by salt marsh and salt marsh debris (i.e. plant material from cord-grasses) is found on the mudflats, values of organic carbon and nitrogen in the sediments are low.

Food Web

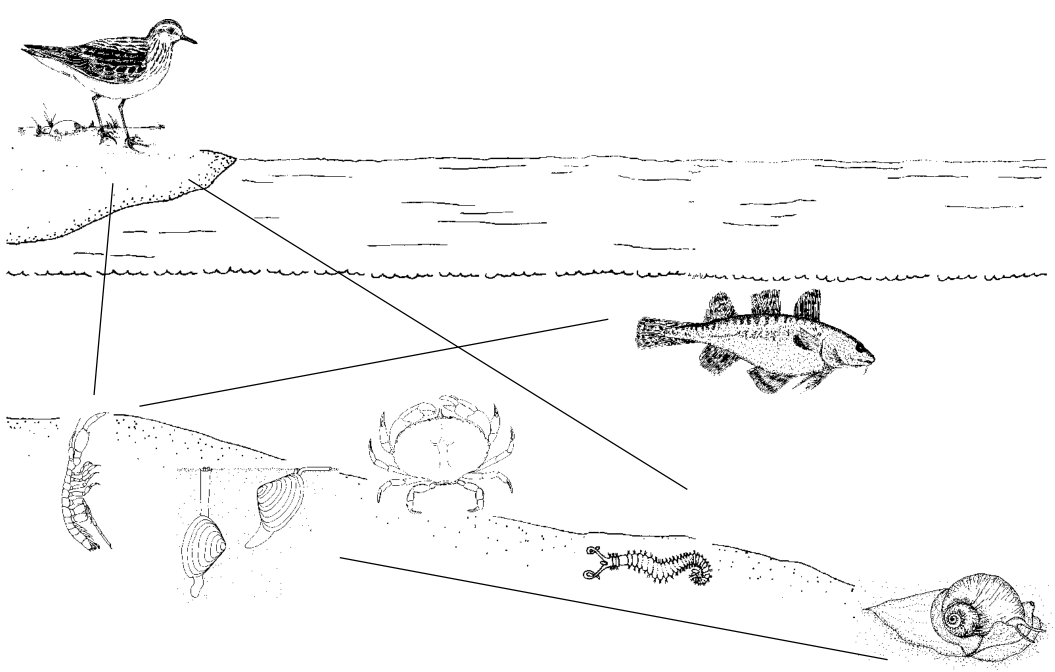
On the mudflat, the trophic structure is not the same as on a rocky shore. For example, instead of a complicated web of feeding relationships and competition the mudflat is comparatively simple. Many of the animals are not predators but deposit feeders,filter feeders, or scavengers. Because of a relatively small number of predator/prey relationships the numbers of mud-dwelling organisms can increase dramatically.

see activity 40

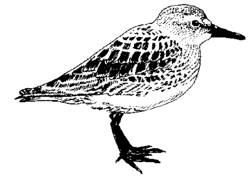
The food webs that have been identified involve the influx of animals from adjacent ecosystems. For example studies of the stomach contents of a variety of fish have indicated that large populations of small flatfish and tomcod are feeding mainly on amphipods (*Corophium*). Larger flatfish eat mainly Baltic Macoma. Most flatfish in turn are eaten by anglerfish. Striped Bass eat the Sand Shrimp and skates and rays come in on a high tide to forage on worms. The birds that use the mudflats feed primarily on the tube-building amphipods and the clam worm.

Simple food relationships on the mudflat

Arrow: indicates direction of food/energy



MUDFLATS AND US



Mudflats support communities of commercially important marine species such as clams, shad, bait worms, and Striped Bass. They are also important because they help to maintain ecosystems elsewhere. The shorebirds that feed on the mudflats are residents of ecosystems in the Arctic as well as the southern hemisphere. Without the Fundy mudflats the populations of avian fauna could undergo drastic changes.

The relationship of the mudflats to the formation and maintenance of salt marshes has been important to human populations over time. Not only do mudflats and salt marshes help to support natural coastal systems, they also support human agricultural systems.

Again so often overlooked is any ecosystem's importance as an educational resource. Although the immediate value of this use cannot be tabulated, providing opportunities for interested individuals to study or experience a mudflat will have benefits in the future. No benefit will result if no opportunities are given.

Problems in the Ecosystem

The problems associated with the Fundy tidal mudflats are both natural threats and those associated with human activity. Mudflats are always being assaulted by the ravages of storms and ice. These are not so much problems as they are part of an evolving and constantly changing system.

Many problems result when natural rates of change are increased or are offset by human activity. The region bounded by the mudflats of the upper bay also experiences the highest tides in the bay. For years thought has been given to the possibility of harnessing the energy of these tides. Tidal power generation would involve constructing a barrage (dam) and a series of turbines. Flooding tidal waters would move through openings in the dam and would be held in the basin as the tide began to fall. Electricity would be generated when this water was released through the turbines to the low water level on the opposite side of the barrage. A project of this magnitude would generate serious changes for the mudflats.

The high densities of organisms on the mudflats are a result of the high production of bacteria and benthic diatoms on the surface of the flats. A decrease in tidal range would upset this cycle. The present mudflats would be covered for extended periods of time, reducing the availability of food for shorebirds. In addition, a tidal barrage would change current patterns, increase sedimentation, and destroy habitat.

The tube-building amphipod, *Corophium volutator*, the dominant invertebrate of the mudflat, is the main food source for shorebirds and may be very sensitive to changes in sediment patterns. These amphipods need very fine sands but not with any other sediment particle size. They need sediments to construct stable burrows and a surface for food such as diatoms and bacteria attached to sediments. Any changes in sediment patterns could reduce the numbers of these amphipods and in turn, the numbers of shorebirds, or change their feeding behaviour (i.e. force them to move elsewhere).

In some areas the digging up of clams for commercial purposes coincides with shorebird migration. Shorebirds are easily disturbed by these activities.

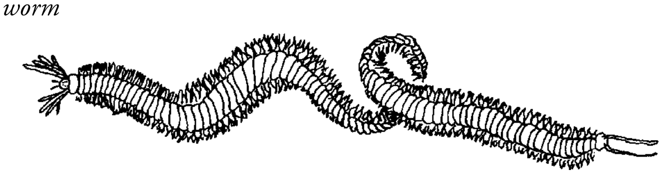
Changing mudflats

When the causeway was constructed across the Avon River at Windsor, Nova Scotia, a decrease in water speed caused by this obstruction produced a mudflat immediately below the causeway. In six years sediment accreted more than 10 m. The dominant organism in the mudflat is a polychaete worm, *Heteromastus filiformis*, a deposit feeder. Populations of the tube-building amphipod, *Corophium volutator*, and Baltic Macoma occur but in densities about one-fifth of those considered typical for a mudflat.

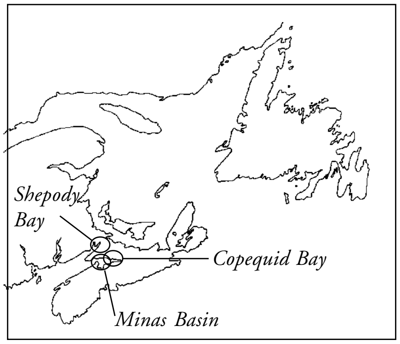
Threats to worms

The clam worm, an inhabitant of the mudflats, is collected for bait and has been decimated in the United States. Thus pressure on the Canadian population is increasing. The worm is used as bait in the sport fishing industry along the eastern seaboard. Besides removing food for shorebirds the collection of bait worms also disturbs the sediments, negatively affecting other invertebrate populations and the stability of the mudflats.

clam worm

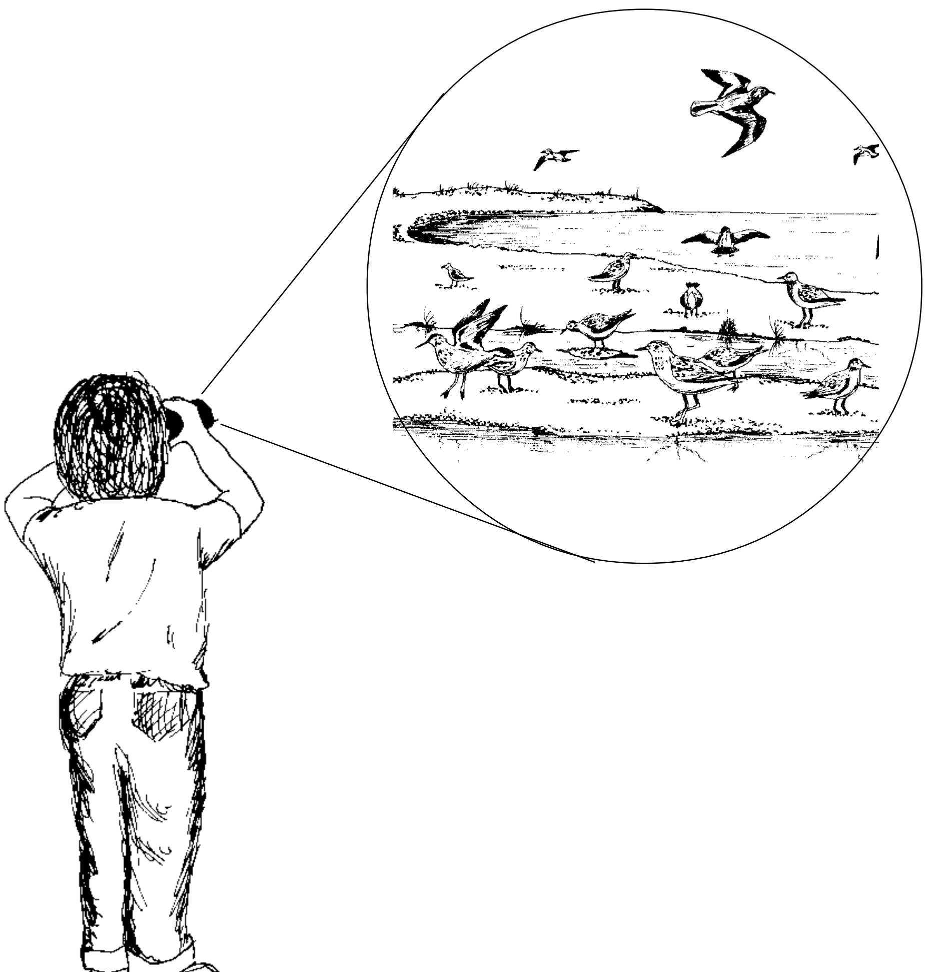


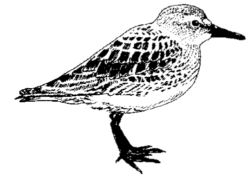
Protection of the Ecosystem



In 1985, the Western Hemisphere Shorebird Reserve Network (WHSRN) was created to provide a network of reserves linking the main wintering, staging, and breeding areas of western migrant shorebirds. The map illustrates three reserves in the Bay of Fundy.

Tidal mudflats are extremely important ecosystems for migrating birds. Thousands of sandpipers and plovers can be found here during migration. Mudflats are unique areas, visited by many people for the purpose of observing these birds. Mudflats, invisible during high tide when covered by water, have always inspired people to come exploring. This valuable ecosystem merits our protection.





SPECIES LISTS

The following lists are by no means a complete account of the organisms living in this ecosystem. They were chosen as representative species, ones that would most likely be observed when visiting the mudflat. There are also great regional and local variations, and we realize the difficulty in accommodating all of these.

Plants

Seaweeds

Green Thread Algae	*Chaetomorpha sp.*
hollow green weed	*Enteromorpha sp.*
Sea Lettuce	*Ulva lactuca*
Knotted Wrack	*Ascophyllum nodosum*

Molluscs

Baltic Macoma	*Macoma baltica*
Soft-shelled Clam	*Mya arenaria*
Blue Mussel	*Mytilus edulis*
Common Periwinkle	*Littorina littorina*
Mud Dog Whelk	*Nassarius obsoletus*
Common Northern Moon Shell/ Moon Snail	*Lunatia heros*

Crustaceans

tube-building amphipod	*Corophium volutator*
isopod	*Chiridotea caeca*
Sand Shrimp	*Crangon septemspinosa*
Jonah Crab	*Cancer borealis*

Echinoderms

Sand Dollar	*Echinarachnius parma*

Worms

mud worm	*Spiophanes wigleyi*
bamboo worm	*Clymenella torquata*
clam worm	*Nereis diversicolor*
clam worm	*Nereis virens*

Milky Ribbon Worm	*Cerebratulus lacteus*
lugworm	*Arenicola marina*
terebellid worm	*Amphitrite sp.*
red-*Nephtys incisa*	
capitellid thread worm	*Capitella capitata*
capitellid thread worm	*Heteromastus filiformis*
mud worm	*Polydora ligni*
blood worm	*Glycera dibranchiata*

Fish

Striped Bass	*Roccus saxatilis*
Atlantic Tomcod	*Microgadus tomcod*
American Shad	*Alosa sapidissima*

Birds

Short-billed Dowitcher	*Limnodromus griseus*
Black-bellied Plover	*Pluvialis squatarola*
Ringed Plover	*Charadrius hiaticula*
Least Sandpiper	*Calidris minutilla*
Semipalmated Sandpiper	*Calidris pusilla*
Dunlin	*Calidris alpina*
Greater Yellowlegs	*Tringa melanoleuca*
Lesser Yellowlegs	*Tringa flavipes*
Great Egret	*Casmerodius albus*
Snowy Egret	*Egretta thula*
Little Blue Heron	*Florida caerulea*
Great Blue Heron	*Ardea herodias*

Mammals

Human	*Homo sapiens*