

What  
is

ECOLOGICAL?

**An  
Introduction  
to  
Ecology  
Through  
Estuaries**

**Produced  
by the  
Wells  
National  
Estuarine  
Research  
Reserve**



Cover: Great blue heron, *Ardea herodias*; above: Double crested cormorant, *Phalacrocorax auritus*

# WHAT IS ECOLOGY?

## An Introduction To Ecology Through Estuaries

### Authors

Peter Taylor                      Henrietta List  
Barbara Williams                Vera A. Evans  
Michele Dionne, PhD

### Illustrator

Robert Shetterly

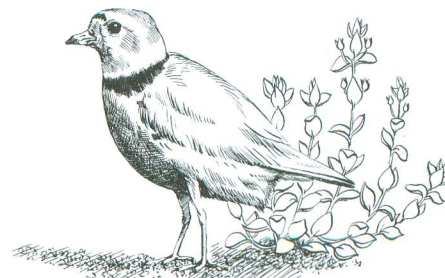
### Major Funding

National Oceanic and Atmospheric Administration (NOAA)  
National Estuarine Research Reserve System (NERRS)  
Laudholm Trust  
Fuller Foundation                      Betterment Fund



### Wells National Estuarine Research Reserve Curriculum Subcommittee Members

Alden Cheever                      Quincy Moy  
Rhoda Frederick                  Rick Kaye-Schiess  
J. Kent Kirkpatrick                Laura Stone  
Alice Elizabeth Strait



Piping plover, *Charadrius melodus*



## General Information

What Is Ecology? An Introduction To Ecology Through Estuaries is the updated Teacher Background section contained in the Discovering Ecology: Pathways To Science K-8 (DEPTHS), and Estuary-Net 9-12 Ecology curriculum produced by the Wells National Estuarine Research Reserve. All bold words found within the text are described in the Glossary and at length in the Reference Appendices found at the back of this handbook.

### Acknowledgments:

*There are those who have little and give all...  
these are the believers in life, and the bounty of life,  
and their coffer is never empty.  
There are those who give with joy,  
and that joy is their reward.  
—Kahlil Gibran*

Acknowledgment pages are usually a list of thank yous in some form or other. Thanks to I, who kept me going..., and to I, who sharpened my pencils etc... .

However, this handbook's life has been in the hands and hearts of so many, for more than a decade-tirelessly crafted, scrupulously analyzed, gently refined, lovingly passed on, resulting in a many tiered support system of appreciation. Therefore, to all who worked diligently on DEPTHS, Estuary-Net and the What is Ecology? An Introduction To Ecology Through Estuaries handbook, I offer group hugs, high-fives, and heart-felt gratitudes. — Alice Elizabeth Strait, editor

### Wells National Estuarine Research Reserve

342 Laudholm Farm Road  
Wells, Maine 04090  
Phone : (207) 646-1555  
Fax: (207) 646-2930

[www.wellsreserve.org](http://www.wellsreserve.org)

#### Design:

Deena Guillet  
Bethel, Maine 04217

#### Illustrations:

Robert Shetterly  
Brooksville, Maine 04617

#### Printing:

The Maine Press Printing Company  
Bethel, Maine 04217

#### Bradford Copy Center

Wells, Maine 04090

Fonts used LB Helvetica Black and Helvetica

Acknowledging the environmentally-friendly mill process used by Monadnock Mills, Bennington, NH 03442  
Main text stock is 70#lb Astrolite PC 100  
100% post-consumer recycled content, elemental and process chlorine free, printed with soy ink

January 2001

# Table of Contents

## WHAT IS ECOLOGY?

Introduction .....	7
What Do Ecologists Study? .....	7

## ESTUARINE ECOLOGY

An Introduction to Ecology Through Estuaries.....	8
Geological Formation of Estuaries .....	9

## SURVIVAL FACTORS

Abiotic Factors .....	9
Biotic Factors .....	10

## INTERACTIONS IN ECOSYSTEMS

Disturbance, Responses and Adaptations .....	10
Zonation, Habitat, Niches .....	11
Food Chains and Food Webs .....	12

## DAILY INFLUENCES ON AN ESTUARINE ECOSYSTEM

Watershed .....	12
Tides, Salinity .....	13

## ESTUARINE HABITATS AND COMMUNITIES

### THE RIVER

Salinity, Detritus, Aquatic Organisms, Birds and Mammals .....	14
---	----

### THE TIDAL FLATS

Formation, Mudflats and Sandflats, Benthic Lifestyles, Birds .....	15
---	----

### THE SALT MARSH

Marsh Zonation .....	16
----------------------	----

### THE SALT PANNE

Formation, Plants and Animals .....	17
-------------------------------------	----

### AROUND THE ESTUARY

Formation .....	18
Open Waters .....	18
Barrier Beaches .....	18
Rocky Shore .....	19
Mangroves .....	19
Uplands .....	20

## PEOPLE AND ESTUARIES

Human History of Estuaries .....	21
----------------------------------	----

## TODAY'S IMPACT ON ESTUARIES.....

## APPRECIATING ECOLOGY THROUGH ESTUARIES.....

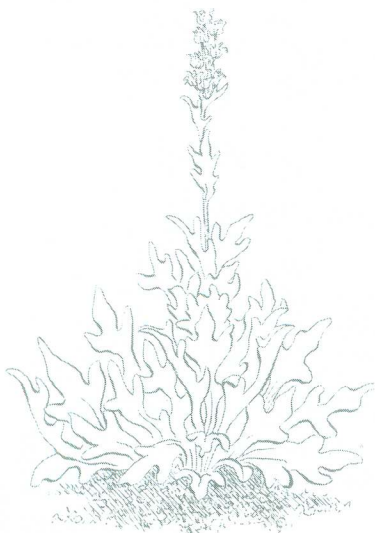
## WELLS NATIONAL ESTUARINE RESEARCH RESERVE INFORMATION ECOLOGY GLOSSARY.....

## REFERENCE APPENDICES.....

## SPECIES IDENTIFICATION MASTERS.....



# Ecology explores relationships between organisms and biotic (living) factors or abiotic (non-living) factors in the environment.



Dusty miller, *Artemisia stelleriana*

## INTRODUCTION

Despite some popular misconceptions, ecologists don't spend their working hours communing with nature, lobbying for environmental causes, or collecting discarded soda bottles from littered landscapes. Ecologists are scientists who test hypotheses about the natural world. They use the scientific method to create carefully designed experiments and then rigorously analyze the data that is produced.

The fundamental goal of ecology is to understand the distribution and abundance of organisms. Toward this end, ecology explores relationships between organisms and **biotic** (living) factors or **abiotic** (non-living) factors in the environment. Ecological interactions range from the impact of predation (a biotic factor) on clam abundance to the effect of salinity (an abiotic factor) on where a species of marsh grass grows.

The sheer number, diversity, and complexity of abiotic and biotic factors makes understanding natural systems extremely challenging. That is, nevertheless, the goal of ecology.

### WHAT DO ECOLOGISTS STUDY?

Ecologists take many different approaches to their work, but they tend to focus on three levels of organization in the natural world: population, community, and ecosystem. A **population** is a group of individuals of the same species living in a given place. A **community** is comprised of populations of different species that live together. Ecologists studying populations or communities focus on how organisms affect each other, and how they are affected by the environment.

**Ecosystem** is a term even more inclusive than community, because it

# What is ECOLOGY?

encompasses the community and its abiotic environment. Ecosystems can be extremely large or extremely small and, no matter the size, all ecosystems are connected. In this handbook we refer to an estuary as an ecosystem. When we speak of the river, marsh, and mudflat we are naming **habitats**, the places where organisms make their homes within the estuarine ecosystem.

A habitat is always considered from the point of view of an individual organism. An ecosystem, in contrast, refers to the flow of energy and nutrients through an ecological system.

Both ecosystems and habitats have abiotic and biotic features.



**Estuaries are tidally influenced ecosystems where rivers meet the sea and fresh water mixes with salt water.**

## **ESTUARINE ECOLOGY**

### **AN INTRODUCTION TO ECOLOGY THROUGH ESTUARIES**

From the largest landscape features to the smallest microscopic organisms, an estuary is a fascinating place. When viewing an estuary from the air, for example, one is awed by striking riverbends as freshwater finds its way back to the sea, the vast expanse of marsh grasses or mudflats extending out into the calm waters, or perhaps the elegant curve of an expansive barrier beach. Wherever there are estuaries, there is a rare beauty, as rivers meet the sea, and both ocean and land contribute to a unique ecosystem of specialized plants and animals.

At high tide, seawater changes estuaries, submerging the plants and flooding creeks, marshes, pannes, mudflats, or mangroves, until what once was land is now water. Throughout the tides, the days, and the years, an estuary is cradled between out-reaching headlands and is buttressed on its vulnerable seaward side by fingers of sand or mud.

Estuaries metamorphosize with the tides, the incoming waters seem to bring back to life organisms that have sought shelter from their temporary exposure to the non-aquatic world. As the tides ebb, organisms return to their protective postures, receding into sediments and adjusting to changing temperatures and exposure to differing degrees of sunlight and different kinds of weather.

Flocks of shorebirds stilt through the shallows, lunging long bills at their abundant prey of fish, worms, crabs or clams. Within the sediments, whether mud, silt, sand or rocks, live billions of microscopic bacteria, a lower level of the food web based largely on decaying plants.

Estuaries are tidally-influenced ecological systems where rivers meet the sea and fresh water mixes with salt water.

Estuaries are crucial transition zones between land and water that provide an environment for lessons in biology, geology, physics, chemistry, history, and sociology.

#### **Estuaries provide:**

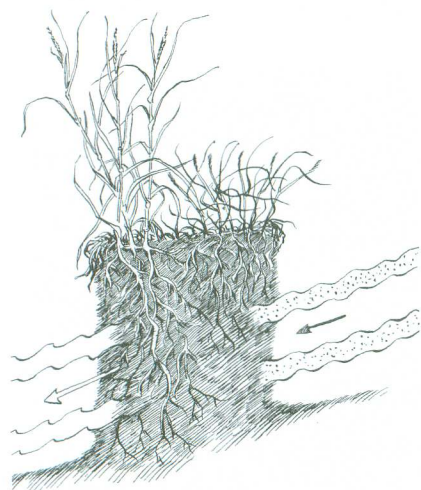
**A habitat:** Tens of thousands of birds, mammals, fish, and other wildlife depend on estuaries.

**A nursery:** Many marine organisms, most commercially valuable fish species included, depend on estuaries at some point during their development.

**A factory:** A healthy, untended estuary produces from four to ten times the weight of organic matter produced by a cultivated corn field of the same size.

**A water filter:** Water draining off the uplands carries a load of sediments and nutrients. As the water flows through salt marsh **peat** and the dense mesh of marsh grass blades, much of the sediment and nutrient load is filtered out. This filtration process creates cleaner and clearer water.

**A natural dam:** Porous, resilient salt marsh soils and grasses absorb flood waters and dissipate storm surges. Salt marsh dominated estuaries provide natural buffers between the land and the ocean. They protect upland organisms as well as billions of dollars of human real estate.



**Salt marsh peat filters water flowing off the upland, removing excess sediment and nutrients.**



## GEOLOGICAL FORMATION OF ESTUARIES

There are four types of estuaries: **coastal plain estuaries**, which formed as rising sea levels invaded existing river valleys; **fjords**, which are steep-walled valleys created by glaciers; **tectonic estuaries**, which are formed when geologic faulting or folding resulted in a depression; and **bar-built estuaries**, which are separated from the ocean by barrier beaches lying parallel to the coastline.

## SURVIVAL FACTORS

The survival of organisms is influenced by living (biotic) and non-living (abiotic) factors. Any number of factors can be responsible for the inability of a species to survive in a particular place, unless the species is able to respond through physical or behavioral change.

### ABIOTIC FACTORS

**Abiotic factors** limit distribution and abundance by affecting an organism's life processes. In an estuarine ecosystem these factors are light, oxygen, water, nutrients, temperature, salinity, and space.

**Light:** Plants use energy in sunlight to convert water and carbon dioxide into carbohydrates and oxygen. This is accomplished through a series of chemical reactions called **photosynthesis**.

**Oxygen:** Oxygen is used in **respiration**. Respiration releases stored chemical energy to power an organism's life processes. An absence of oxygen severely restricts the amount of life that can be supported.

**Water:** Without water, no organism can remain biologically active. In fact, all living organisms are comprised of 50 to 99 percent water.

**Nutrients:** Although sunlight is the fuel for food production, and water and carbon dioxide are the raw materials, plants cannot survive on these alone. Other substances, called nutrients, are necessary for the proper function of a living organism. Major nutrients, including nitrogen and phosphorous, are needed in large amounts. Trace nutrients such as iron are required in smaller amounts.

**Temperature:** Temperature is one of the best understood abiotic factors affecting the distribution and abundance of organisms. Temperature has a large impact on plants and animals because it influences their metabolic rates and affects rates of growth and reproduction. Geographic ranges of animals are often defined by temperature, and many species respond to seasonal temperature shifts by acclimating to changes or by migrating away from them.

**Salinity:** Pure water contains only oxygen and hydrogen, but in the natural world, solid substances such as salt are often dissolved in water. In an estuary, the salt content of water fluctuates continuously over the tidal cycle. It decreases drastically in the upper reaches of estuarine rivers where tidal influence lessens, and varies radically in salt pannes because of evaporation and precipitation. Organisms that spend their entire lives in estuaries need to be capable of responding to large and rapid salinity variations.

**Space:** Space is a precious resource exploited by living things. The need for space is most pronounced for organisms that need a **substrate**, or base, on which to live. Many animals require a certain amount and type of space to meet their needs, other than physical attachment. They need space for nesting, gathering food, wintering, and hiding from predators.

**Bar-built estuaries are formed when a calm bay is created behind the beach. Silt from the river and sand from the ocean accumulate, building up the sediments.**

### A time line of bar-built estuary formation

**25,000 years ago** Glacier reached its furthest extent south.

**17,000-15,000 years ago** Glacier retreated, flooding the uplands.

**12,000 years ago** Sea level began to fall rapidly as earth rebounded from the weight of the glacier.

**11,000 years ago** Sea level change reversed its trend. During the ensuing period of rapid sea-level rise, sand was shaped into unstable barrier beaches, sand islands, and peninsulas lying parallel to the coastline.

**4,000 years ago** Sea-level rise drastically slowed, and barrier beaches essentially stabilized, though they continue to be moved by the slowly rising sea.



**Estuarine organisms are influenced by abiotic and biotic factors:**

**ABIOTIC**

**Light**  
**Oxygen**  
**Water**  
**Nutrients**  
**Temperature**  
**Salinity**  
**Space**

**BIOTIC**

**Competition**  
**Predation**  
**Parasitism**  
**Commensalism**  
**Mutualism**

**BIOTIC FACTORS**

**Biotic factors** are interactions among living things that affect the survival of species. In an estuarine ecosystem these factors are competition, predation, parasitism, commensalism, and mutualism.

**Competition:** Competition occurs between organisms using a resource that is in finite supply. Competition can occur between members of different species or the same species. They may compete for food, space, light, nutrients, water, or even pollinators. Competition plays an important role in shaping communities. Species or individuals with a competitive edge have a better chance of surviving long enough to reproduce.

**Predation:** Predation is the killing and/or consumption of one organism by another. **Herbivores** eat plants, seeds, and/or fruits. **Carnivores** eat animals. **Omnivores** eat both plants and animals. Predation is a major selective force in animal evolution. Individuals are more likely to reproduce successfully if they have traits enabling them to avoid being consumed by predators or if they are effective hunters.

**Parasitism:** Parasitism is similar to predation in that one species benefits from the relationship and the other is harmed. Parasitism differs from predation, however, because parasitism is generally not fatal to the adversely affected organism.

**Commensalism:** Commensal relationships occur when one organism benefits and the other is neither helped nor harmed.

**Mutualism:** Mutualism occurs when both organisms gain from the relationship.

## INTERACTIONS WITHIN ECOSYSTEMS

**Disturbances:** Ecologists have recently begun to investigate the natural variability of ecosystems by exploring the impacts of disturbance. Ecological disturbances range in scale from something as small and transient as a footstep to an event as huge and prolonged as a hurricane, volcanic eruption, or glaciation. One outcome of disturbance is succession, progressive changes in the composition of a community. Salt marshes provide a good illustration of the role of disturbance in shaping communities. Although disturbance is a natural factor in every ecosystem, humans create additional ones. These are called **anthropogenic** disturbances.

**Responses and Adaptations:** During its lifetime, every organism encounters changes in its environment. These changes can be abiotic (amount of water, salt, light, etc.) or biotic (variations in competition, predation, parasitism, etc.). Ecological responses happen during the lifetime of a single organism. An example is the ability of a chickadee to grow about 50 percent more feathers in winter and molt them in summer. Evolutionary adaptation happens over the course of multiple individuals' lifetimes and causes changes to occur in a species' genetic makeup. This process is called **natural selection**. Speciation, the creation of a new species through natural selection, occurs when a selective force is intense. It accounts for the diversity of living things on the planet today. Genetic variation within a species can result in adaptation to local conditions.



**Zonation:** Patterns of zonation can be found in many different communities. They are created by combinations of abiotic and biotic factors. A salt marsh is an excellent ecosystem to illustrate how ecologists relate biotic and abiotic factors to the organization of living things. As one walks from upland to water through a salt marsh, **zones**, or distinct bands of vegetation, can be seen. High marsh is noted by the dominant grass, usually salt hay, which lie like cowlicks from its periodic tidal baths. At a slightly lower elevation in the marsh, smooth cordgrass is found. Its broad leaves are dappled daily with mud and salt from the tides.

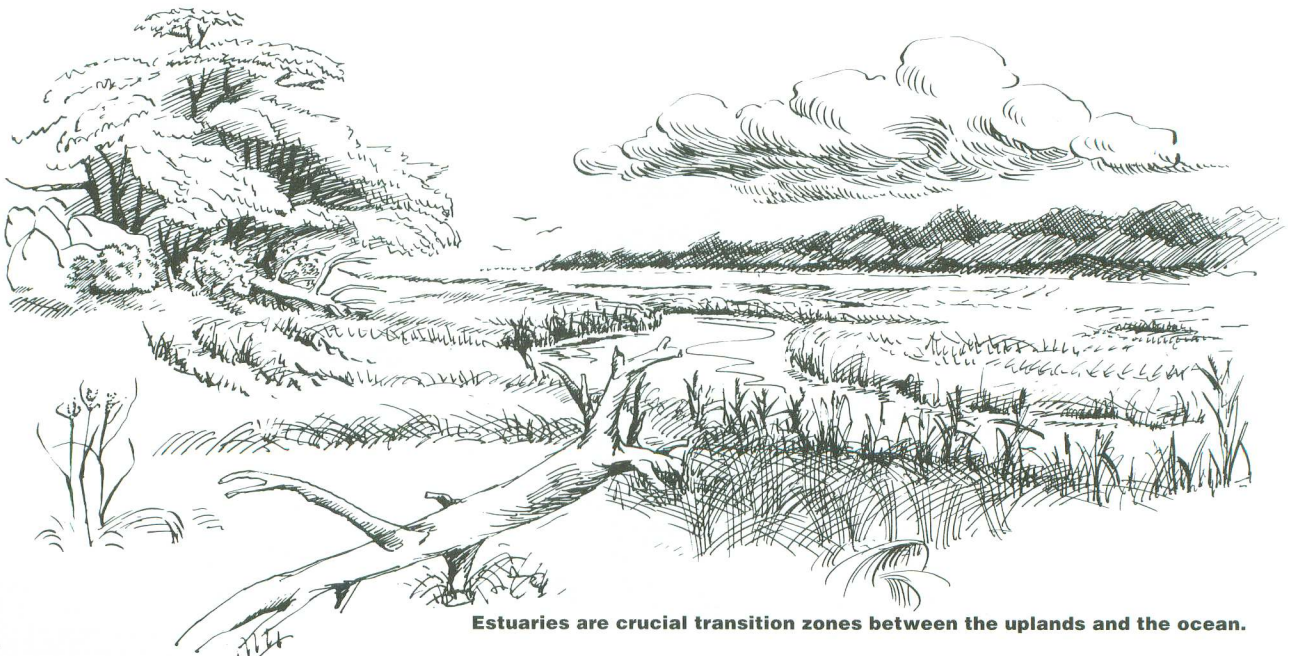
**Habitat:** A habitat is a place where an organism can successfully live. Every species has a set of abiotic and biotic conditions and resources that it needs in order to survive, and there are certain places in the world that meet those requirements. These places are habitats for particular species. Habitat requirements of an organism can be divided into two categories: **resources** and **conditions**. Resources are items such as the food and water that an organism uses during its lifetime.

Conditions are characteristics of the environment (such as temperature and salinity) that influence the survival of an organism but are not used by it. Both resources and conditions determine the suitability of a location for the survival of a species.

**Niche:** Different species coexisting in a community can avoid competition through specialized adaptations, so that each species has a unique role in the community. These roles, called **niches**, can be defined in many ways, but all of them involve using limited resources in a unique way. The concept of the niche is most evident in the way that closely related species differ in their use of space, time, and food. For example, great blue herons and snowy egrets are very similar birds who, at first glance, seem to have overlapping ecological requirements. They are both found in similar coastal habitats. Their diets are very similar, but they have evolved different nesting requirements. The great blue heron nests inland in tall trees and the snowy egret nests on coastal islands in scrubby-growth trees and shrubs.

Niches, important in the organization of communities, can be broken down

**A habitat is a place where an organism has all of the abiotic and biotic conditions it needs to survive.**



Estuaries are crucial transition zones between the uplands and the ocean.



## Energy flows through a community not just as a simple independent food chain but as a linked complex food web connecting autotrophs and heterotrophs.

into broad niches and further into smaller, more specific, niches. For example, spatial niches allow organisms that eat leaves from the tops of trees to coexist with those that eat from lower branches on the same tree. The niche concept is a useful generalization, but in the real world species are constantly invading new places as they are affected by environmental changes and other factors.

### Food Chains & Food Webs:

Energy is the most crucial resource needed by living things. **Producers** or **autotrophs** (meaning self-feeders), such as plants and some bacteria, are able to obtain energy from the sun and use it to form energy-rich material. **Consumers** or **heterotrophs** (meaning "feeding on others") are organisms, mostly animals, that obtain energy-rich materials by eating autotrophs. This relationship determines how energy flows through a community. The pattern of energy flow, in which an autotroph produces food, a heterotroph eats that autotroph, another heterotroph, and so

on, is called a **food chain**. In a natural community, however, food chains are not simple, independent units. They are linked together into complex **food webs** because every species is usually eaten by more than one species of predator, and every predator usually eats more than one type of prey.

## DAILY INFLUENCES ON AN ESTUARINE ECOSYSTEM

**Watershed:** A watershed is an area of land that drains into one river, stream, or other body of water. The watershed of an estuary contains the watershed of the river or rivers that flow into it, which may cover tens, hundreds, or thousands of square miles. It is analogous to a bowl. If you drip water onto any spot inside the rim of a bowl, it flows down to the bottom. If you drip the water outside the rim, it does not flow into the bowl.



While many creatures spend their lives in the estuary, others visit only temporarily. Food webs are complex, as is illustrated in this estuarine community.



The area contained within the bowl is the watershed. Watersheds are fed by runoff, groundwater, or surface water. As water travels through the watershed, it may transport nutrients, sediments, or harmful pollutants.

**Tides:** Within estuaries, the incidence of tides results in highly variable and constantly fluctuating salinity, currents, and water levels. These drastic variations make estuaries extremely harsh and demanding places to live. The position of the moon, sun, and earth, and the configuration of the land, all affect **tidal height**, the height above mean sea level to which the tide rises, and **tidal range**, the difference in height between high and low tides. Tidal height and range, in turn, influence the inhabitants of an estuarine ecosystem.

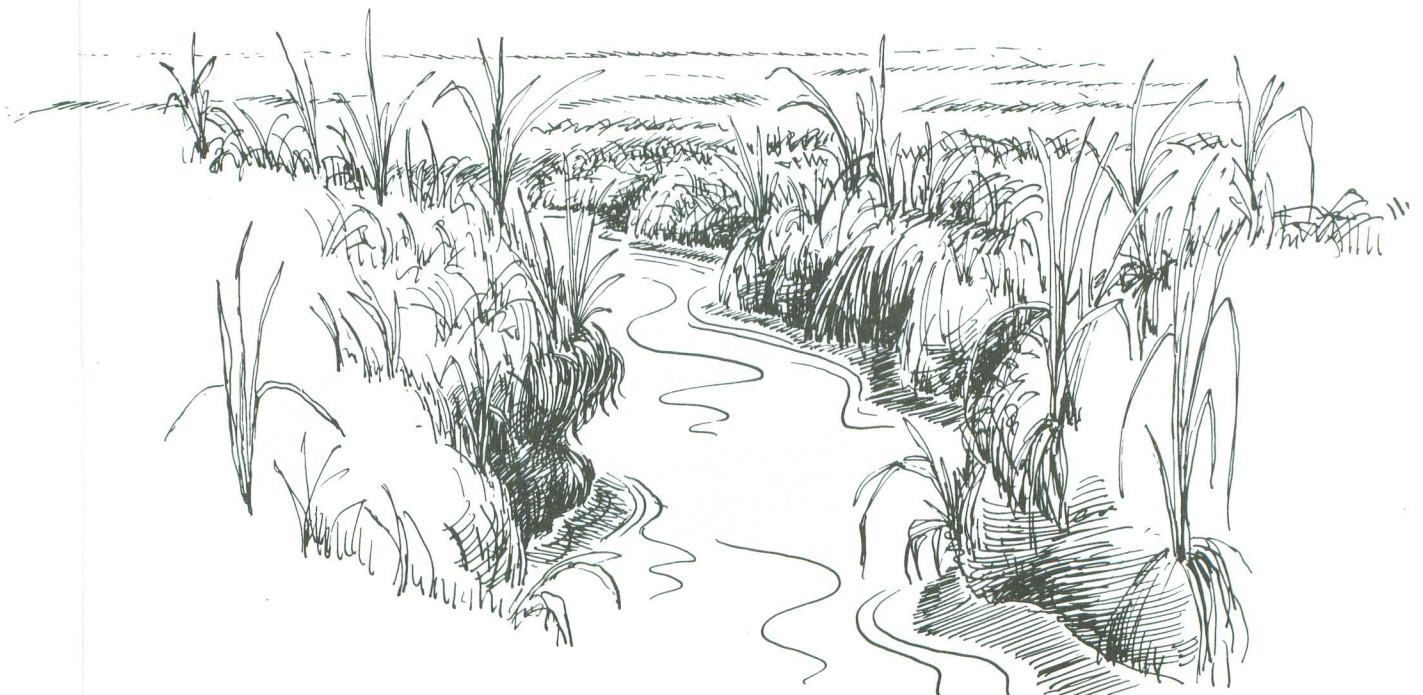
**Salinity:** Salinity is measured by the number of grams of dissolved salts in 1000 grams of water. The most

abundant salt in seawater is sodium chloride, which we know best as table salt. The primary classes of salinity are fresh water (0-0.5 parts per thousand, or ppt), **brackish** water (0.5-30 ppt) and salt water (more than 30 ppt).

In all estuaries, salinity varies with proximity to the ocean and with depth at any given spot along the river. When salt water and fresh water meet, the fresh water, due to its lower density, often floats on top of the salt water.

Salinity also varies with elevation in the marsh. Those areas with higher elevation are flooded less frequently and have less soil salinity than lower areas. Thus, plant species with salt intolerance are in areas not subject to frequent tidal flooding, or are up-river where they may be exposed to more frequent flooding but the waters are less saline.

**Drastic  
variations  
make  
estuaries  
extremely  
harsh  
and  
demanding  
places  
to live.**



**Incoming tides flood salt marshes with salt water. As tides ebb, freshwater dominates a shallower marsh. The ebb and flow results in zonation seen here in two salt marsh grasses, cordgrass and salt hay.**



# ESTUARINE HABITATS AND COMMUNITIES

The estuarine ecosystem has several different habitats: river, tidal flat, salt marsh, and salt panne. A river may be the lifeblood of an estuary. As a river approaches the sea, it is influenced by salty tides. During low tide, portions of the river bottom, or benthic zone, are exposed. These mudflats and sandflats support abundant life. The high and low salt marsh are dotted with salt pannes, irregularly shaped and sized pools of water that play an important role in the ecology of the marsh. Each of these estuarine habitats has a unique community associated with it, but all the habitats and communities are interconnected.

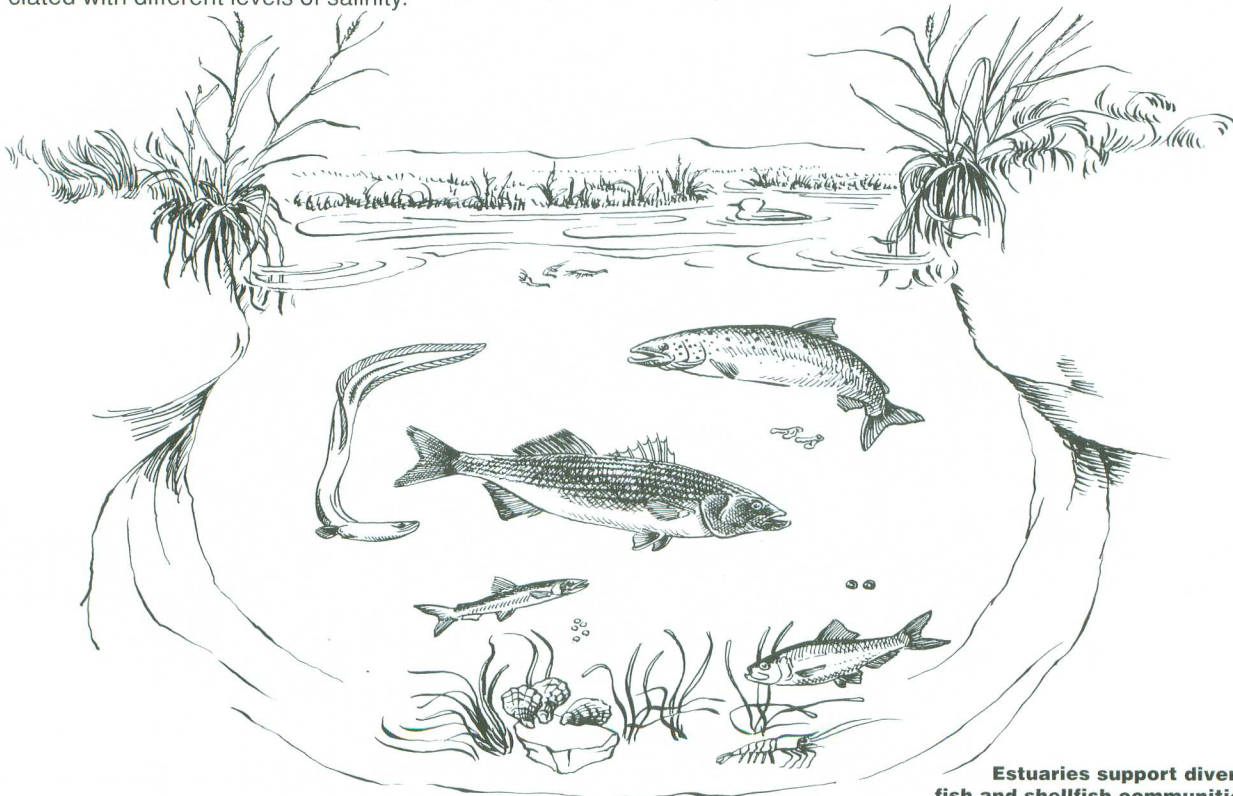
## THE RIVER

**Salinity:** Scientists classify aquatic systems according to salinity because different communities, or assemblages of living things, are associated with different levels of salinity.

In all estuaries, salinity increases toward the ocean, but it can also vary with depth at any given spot along the river. Salt water, which contains dissolved solids, is more dense than fresh water. Thus, when salt water and fresh water meet, as in an estuary, the fresh water often floats on top of the salt water, forming a "salt wedge." Many smaller rivers, however, do not exhibit the wedge effect because their narrowness, shallowness, or sudden turns create turbulence, which mixes the salt and fresh water.

**Detritus:** The riverine food web differs from that of many other ecosystems in that plants are more often eaten dead than alive. Most marsh plants die without being eaten, and their decaying remains become the major component of the organic materials that comprise detritus. As a river floods its banks at high tide, it picks up these small particles of

There are four major habitats in the estuary, each with its own plant and animal communities. They are: the river, the tidal flat, the salt marsh and the salt panne.



Estuaries support diverse fish and shellfish communities.



decaying plants and animals, which then remain suspended in the water column to provide the basic nutrients for the estuarine food web.

**Aquatic Organisms:** Aquatic organisms, plants and animals living in water, can be divided into two general groups: nekton and plankton. **Nekton** are all aquatic animals that can swim through the water against currents, such as marine mammals, fish, squid, and some crustaceans. **Plankton**, on the other hand, are all water-borne organisms that cannot swim through the water column, but are transported from place to place by currents.

Plankton are some of the most abundant organisms on earth. Coastal waters receive nutrients from inflowing rivers and regions of upwelling in the ocean where current patterns cause nutrient-rich water to surface. Plankton can be divided into two groups: **phytoplankton**, which are plants, and **zooplankton**, which are animals.

If we imagine the river to be a field, then phytoplankton are the grass and some types of zooplankton are the sheep. These "sheep" zooplankton are herbivores, while others are carnivores that eat other zooplankton. **Copepods** (a type of crustacean) are one of the most common herbivorous zooplankton. **Cladocera** are carnivores that eat other zooplankton. **Jellyfish** are one of the more familiar types of carnivorous zooplankton.

In the aquatic estuarine food web, fish and marine mammals occupy most of the trophic levels above plankton. Larger fish visit the estuary to feed or spawn. Marine mammals, such as seals often feed upon these fish.

**Birds and Mammals:** Diving and wading birds play a large role in the aquatic estuarine food web. Aquatic birds often dive in search of mollusks and other bottom-dwelling animals, fish, or shallow-bottom vegetation.

Wading birds have long legs that permit them to venture into tidal inlets to hunt for fish.

## THE TIDAL FLATS

**Formation:** In an estuary that has a river draining into it, that river will often have a bottom that shifts and squishes. Walking across it, your feet slide on the sand or sink deeply into the muck. Along the river's length are patches of silt, sand, mud, or maybe cobbles. These sediments were eroded from the uplands or washed in from the sea. They are constantly reworked into new bars.

### Mudflats and Sandflats:

There's no mistaking low tide in an estuary. Your nose will alert you as soon as it senses the rotting plant smell of intertidal **mudflats**, **sandflats**, and exposed marsh. At first glance, an exposed mudflat may appear barren and devoid of life. But take a closer look, and you'll see innumerable holes, trails, and shells, evidence of all the burrowing animals that inhabit the flats.

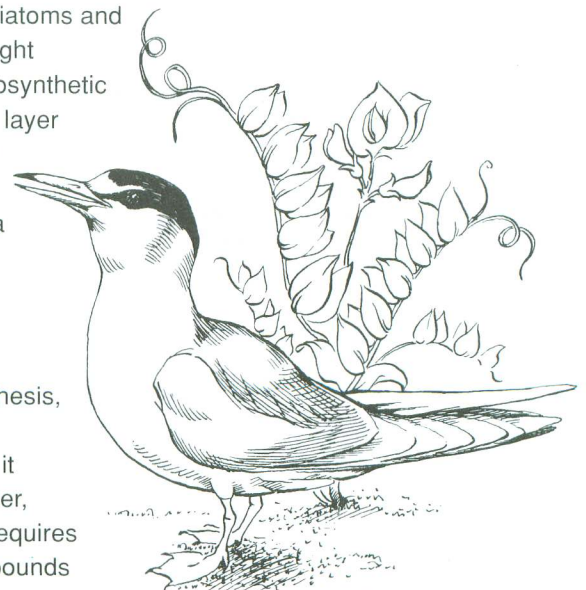
Mudflats are unusual in that they have two layers in which primary productivity occurs. The first layer is at the surface where diatoms and seaweed receive the light needed to power photosynthetic reactions. The second layer of primary productivity lies beneath the surface where bacteria live in the **anoxic** (without oxygen) sediments. Some of these bacteria are capable of chemosynthesis, a process similar to photosynthesis in that it produces organic matter, but different in that it requires certain chemical compounds instead of light.

### Benthic Organisms:

Benthic (bottom-dwelling) flora and fauna range in size from the tiniest bacteria to medium-sized worms to the highly visible clams and polychaete worms. Some benthic organisms live in the sediment and are called **infauna**, some are affixed to the surface of the sediment and are referred to as **epibenthos**, and some move around on the surface of the sediments and are called **mobile epibenthos**.

Benthic animals display a variety of feeding mechanisms such as deposit feeders who ingest sediments, while digesting the nutritious components, suspension feeders who filter food out of the water column, predators who feed upon live organisms, and scavengers who feed upon dead ones.

Suspension-feeding bivalves, such as clams, and sediment-feeding polychaete worms are examples of infauna. Suspension-feeding mussels and oysters are examples of epibenthos. Scavenger crabs; herbivorous, predatory and deposit-feeding snails, and a wide variety of amphipods and isopods are examples of mobile epibenthos.



Least tern, *Sterna albifrons*  
and Beach pea, *Lathyrus japonicus*



**BIRDS:** Birds have a large impact on the benthic community. Many birds feed on bottom-dwelling creatures, especially the abundant organisms of the mudflat. To minimize competition for this resource, shorebirds have evolved variable feeding strategies, thus filling **niches**, or unique roles, in the community. For instance, they feed in different water depths depending on the lengths of their bills and legs. Birds with long bills and legs, such as herons and egrets, tend to feed in deeper water than those with shorter bills and legs.

## THE SALT MARSH

**Marsh Zonation:** Salt marshes are a common type of wetland of extreme importance to the balance of certain estuarine ecosystems. Marshes are dominated by important grasses that provide food and shelter to marine organisms that are permanent and transient residents of the estuary. Marshes are divided into two basic zones, **high marsh** and **low marsh**, which are defined by differences in flooding and soil salinity.

Different kinds of vegetation live in the high and low marshes.

Despite its varied and lush vegetation, the marsh is home to relatively few terrestrial animals. Deer, migratory birds, grasshoppers and other animals consume marsh grasses. Small animals, such as shrews and mice, provide prey for larger mammals and birds of prey that also live in or around the marsh.

Marsh grasses are thought to be low in nutritive value and to contain toxic compounds; so even with all of these consumers, little of the vegetation is eaten. Rather, most of the plants die and are deposited on the ground to become peat. Some pieces of the plants are then washed into the water to become detritus, decaying particles coated with bacteria, which serve as a nutrient base for the estuarine food web. Detritus is consumed by filter-feeders such as clams, detritivores such as mummichogs, and deposit feeders such as polychaete worms.

**We speak of two marsh communities: the low marsh, dominated by *Spartina alterniflora*, and the high marsh dominated by *Spartina patens*.**



Estuarine habitats support prey for many different birds. Their feeding methods vary widely; some stalk on long legs, some swoop down on their prey, some dabble for plants, and some probe for invertebrates in the mud.



In general, marshes are known as hosts for abundant aquatic and avian, rather than terrestrial, animals.

## THE SALT PANNE

**Formation:** Salt pannes, pools of water that dot the marsh surface, are an important feature of some estuaries. Pannes range in size from only a foot or two in diameter to many feet across and they are irregularly shaped and sized. Panne creation is believed to begin when something kills an area of grass, either winter-time ice floes, which scour patches of vegetation from the marsh surface, or mats of debris that shield the plants from sunlight. What's left behind is an area of unvegetated peat exposed to the sun, whose heat evaporates water from the soil. This area becomes extremely saline and inhospitable to recolonization by plants. The peat subsides and a water-filled depression, or panne, is formed.

**Plants and Animals:** Glasswort and spike grass are two species of plants that have adapted to the inhospitable conditions of bare patches in the marsh. Glasswort readily tolerates higher soil salinities. Spike grass avoids the salt and dryness by receiving water through underground runners from individual plants living outside the bare patch. When glasswort and spike grass colonize a bare patch, they shade the soil, reducing evaporation and salinity. Other plants, generally cordgrass, *Spartina alterniflora*, or salt hay, *Spartina patens* can then invade, preventing panne formation.

Pannes are flooded with salt water at varying frequencies, depending on their elevation above mean sea level and whether they are connected to the river by creeks. If a panne experiences a long period without receiving rain or seawater, it can become extremely saline, warm, and low in dissolved oxygen because of evaporation and heating by the sun. This makes difficult living conditions, but mummichogs, sticklebacks, and eels

**Changes in sea level push barrier beaches inland over the marshes. This can occur in fifty years, or thousands of years, depending on the rate of sea level rise.**



Salt pannes dot the marsh surface providing a home for mummichogs, sticklebacks, and eels, which are well adapted to temperature and salinity extremes.



are well adapted to them. Salt pannes also support large populations of algae. Salt panne plants and animals provide food for diving and wading birds.

## AROUND THE ESTUARY: OPENWATERS, COASTLINES, AND UPLANDS

**Formation:** An estuary is a semi enclosed waterbody appreciably diluted by freshwater flowing into it. An estuary usually ends at the mouth of a river. The ocean is not part of an estuary. Rocky shorelines, barrier beaches, uplands and other surrounding areas all have great influence on the estuarine ecosystem. Uplands, are not part of the estuary, but they do influence it. It is important to understand the ecosystems that surround the estuary, as they are closely associated with the health and productivity of the estuaries.

**Open Water:** Interactions between open waters and estuaries that line the coast occur during the exchange of tidal waters. This periodic flushing affects salinity, transports nutrients in and out, and varies the water level in the estuary. Biological interactions occur when estuarine species venture out into open waters to feed or spawn. Many open water organisms, conversely, enter estuaries for the same reasons, and the larvae of *these species* depend on estuaries as nurseries. When estuaries are degraded by human influences such as pollution and development, the survival of numerous open water species, including many commercial fish species, is affected.

**Barrier Beaches:** Barrier beaches play an important role in the creation and survival of some estuaries. By breaking the impact of ocean waves,

they protect the estuary and uplands from waves and erosion, facilitating marsh formation and making the estuary a calm haven for animals.

A string of barrier beaches lines much of the Atlantic coast of the United States. These unique features are ribbons of sand that lie a short distance offshore, often separated from land by marsh-filled estuaries. They may be attached to the mainland at one or more points, or they may be islands.

Barrier beaches are constantly moved landward by the rising sea. Powerful waves and currents persistently rework the sands. As sea level rises, barrier islands and river inlets migrate and are continually reshaped. People are often distressed when this happens because it can mean the destruction of expensive oceanfront real estate. They attempt to counteract it by constructing elaborate seawalls and jetties. Their efforts are inevitably futile however, and often create more severe erosion by redirecting wave energy. Erosion and deposition of barrier beaches is a very powerful, fundamental part of the natural system.

Barrier beaches support interesting communities that are found in a pattern of zonation that reflects different disturbance regions. The decreasing disturbance of habitat occurring with increased distance from the ocean. The foreshore, or beach face, is the harshest part of the habitat. The dominant abiotic factors are wave action and a moving substrate, sand. In order to live on the beach, organisms must be able to tolerate these conditions.

Animals surviving in the swash zone, the intertidal zone between high and low tide, are adapted to either burrow deep into the sand or quickly reburrow after being exposed by a

wave. Higher on the beach lies the wrack line of seaweeds, driftwood and shells cast ashore by waves. **Isopods** and amphipods (small crustaceans) may occupy this region, taking advantage of the food and shade offered by the wrack line.

Behind the front line of pioneer species, plants of high salt tolerance that first colonize an area, usually lies the frontal dune and dune-building species. These plants such as dusty miller and beach grass, build dunes by breaking the flow of wind, so that sand is deposited on the ground around them. These species are adapted to sand accumulation.

Beach grass reproduces by sending out horizontal underground runners called **rhizomes**. Every few inches along the rhizome, a shoot extends up to the surface. Dune vegetation has additional adaptations to reduce the influence of windblown sand, high temperatures, and dry soil. Some plants are coated with small



Salt hay, *Spartina patens*



hairs that decrease evaporative water loss by reducing air motion next to the plant's leaves. One kind of beach grass, American beach grass, has rolled leaves which reduce surface area to prevent water loss.

Behind the primary dunes, on a barrier beach, are the back dunes, which build from the movement of sand transported over the frontal dunes during storms. These more protected areas are inhabited by pioneer plant species and, if left undisturbed, many of the frontal dune plants can thrive there. If the barrier island is wide enough, a maritime forest may lie behind the back dunes. Only the fiercest storms harm these woodlands, stunting the trees when the salt spray kills their buds and leaves and salt water permeates the sand around their roots.

**Rocky Shore:** The difference between a rocky shore and a sandy shore could not be more dramatic. Sand shifts when washed by waves, but rocks undergo limited shifting. Animals can burrow into sand, but rock is impermeable. The most important abiotic factors on a rocky coast are the pounding by waves, availability of space for attachment,

and vulnerability of organisms to **dessication** (drying out), overheating, and freezing.

Like other coastal habitats, rocky shores are influenced by tides, which create zones within the habitat. The wettest section of rock is the sublittoral zone which is always submerged. Above this is the littoral zone which is divided into two parts. The higher part is never submerged but does get splashed and is called the spray zone. The lower section which is alternately submerged and exposed by the tides is called the intertidal zone. Organisms of the rocky coast are stratified into zones that reflect species' adaptations to abiotic and biotic factors.

**Mangroves:** Another kind of shoreline runs along the southern coast of Florida, defined by thick masses of uniquely-adapted vegetation. Here, we find mangrove roots creating an intricate tangle of roots, stems and leaves, not quite land, but nevertheless the edge to the sea. Mangrove shorelines are radically different from rocky cliffs and sandy beaches found elsewhere along the coast of the United States.

**By breaking the impact of ocean waves, barrier beaches protect the estuary and uplands from waves and erosion, facilitating marsh formation and making the estuary a calm haven for animals.**



**Barrier beaches are narrow strips of sand that protect the quiet waters of an estuary from the pounding waves of the ocean.**



These fascinating plants are well adjusted to life in salt water, with specialized roots, called prop and drop roots, that bring fresh water and oxygen to the plants. These roots are either submerged in anoxic mud or under saline waters. Mangroves are not a single species, but rather a collective of different plant species, all similarly adapted to the tropical region and its specific challenges.

A mangrove shoreline is a tropical salt marsh of sorts, providing a productive coastal habitat where juvenile fish seek safety before reaching maturity and where a great number of other marine organisms make their homes. Mangroves also serve as valuable shields against the violent storms that frequent the region. The intricate tangle of mangrove roots helps to filter out pollutants flowing into coastal waters, and to prevent excessive erosion, by stabilizing sediments. Amazingly, mangroves actually replenish and build land mass, stabilizing mud and other sediment that

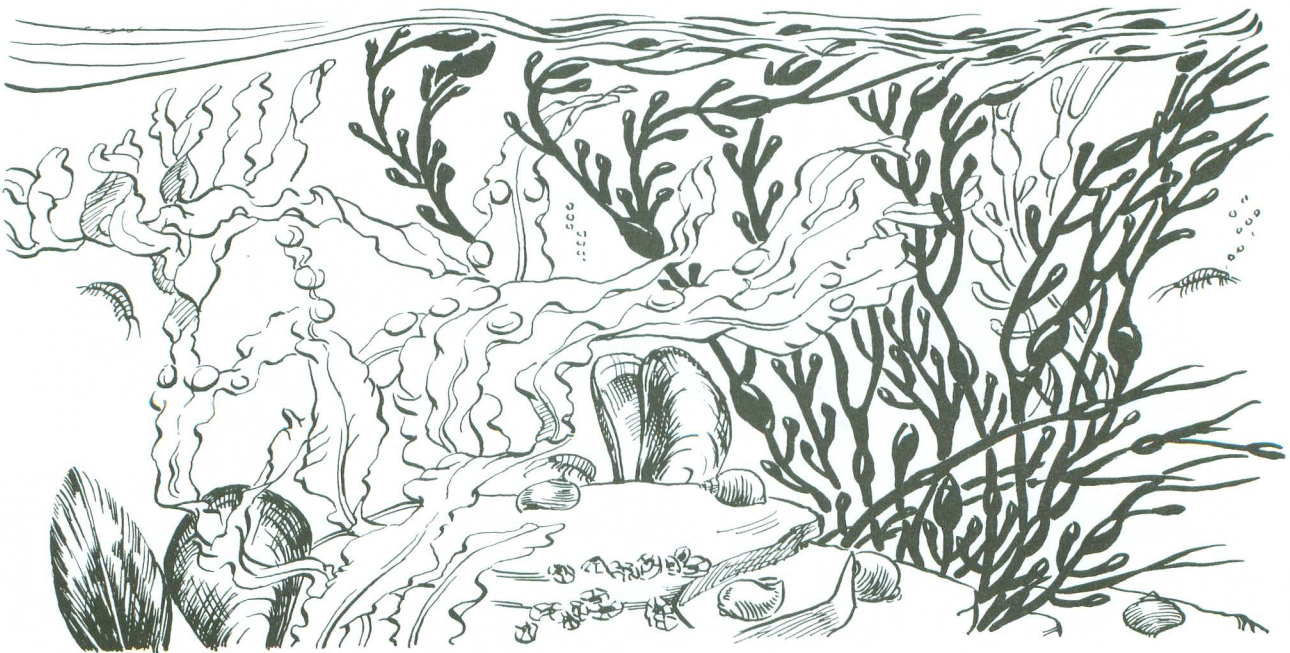
would otherwise be lost in the water through suspension.

**Uplands:** Uplands lie above the reaches of the highest tides. The ocean has no direct effect here, except perhaps through flooding or wind-blown salt from occasional severe storms. Firm, relatively dry soils support trees, shrubs, and herbs, which in turn provide shelter and food for animals. Uplands are not part of the estuary, but they do influence it.

Groundwater and runoff water flow through and over upland soils before reaching the estuary. Pesticides, fertilizers, and pollutants in the uplands are eventually transported to the estuary. Upland animals often venture out into the estuary to feed, an example of habitat interconnection.

The uplands are physically much more stable than the marsh, and there is more variety in the landscape. Consequently, more species are able to survive there.

**The ocean and the uplands are not part of the estuary, but do influence it.**



Mussels, barnacles, rockweed, and knotted wrack live on rocky shores, where they can adhere to hard substrates.



# PEOPLE AND ESTUARIES

## HUMAN HISTORY OF ESTUARIES

Native Americans were the first human inhabitants of most estuarine habitats across the United States. Use by Native Americans produced few adverse impacts. These bountiful areas provided a valuable source of food, both from the estuarine waters and the surrounding terrestrial areas.

With the arrival of Europeans, however, new concepts of private land ownership and widespread clearing for construction and agriculture posed serious threats to estuaries. Estuaries became a focal point for activity. Farmers often used salt hay from marshes as fodder for their livestock. Ditches, dams and tide gates became frequently used tools to limit tidal action and develop vast areas

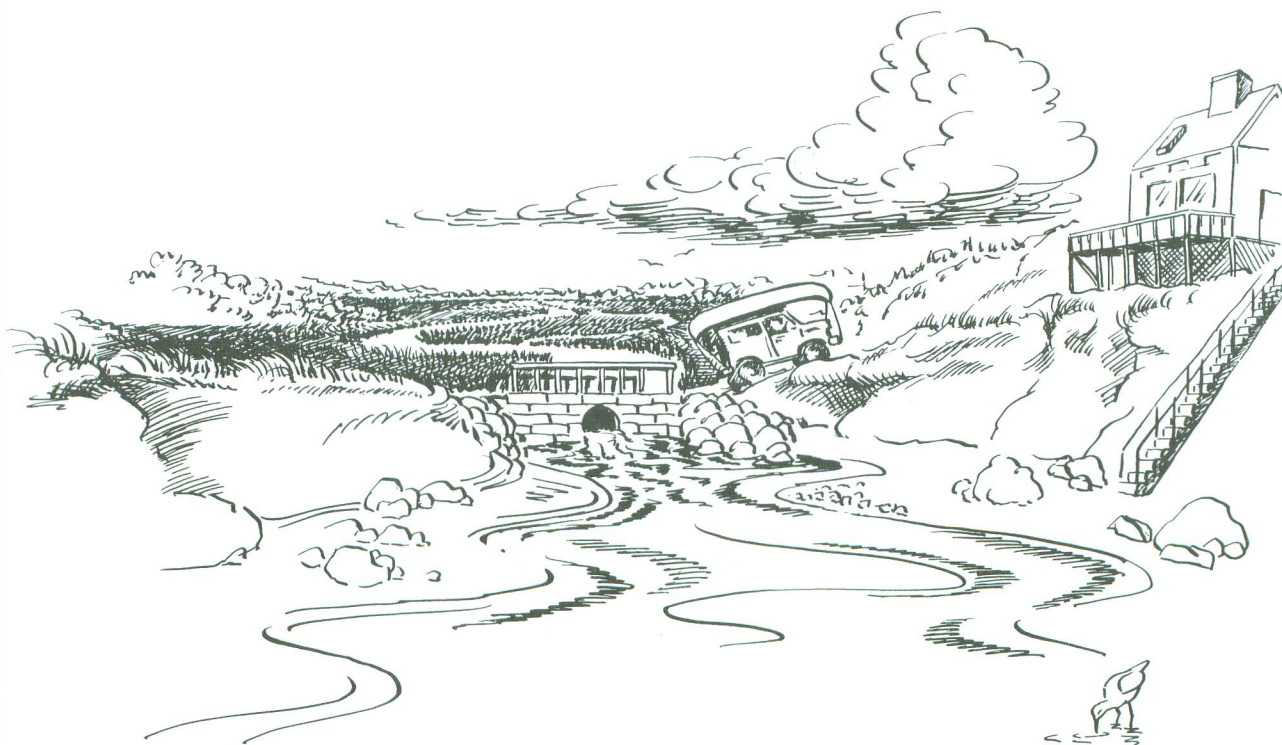
of fresh pasture. Controlling mosquito populations led to the widespread drainage of many estuarine areas. By the 1950s, fifty percent of all Atlantic Coast estuaries had been altered in some way by human activities.

A changing view of estuaries began to emerge in the late 1960s. Declines in important fish stocks and a new suspicion of the impacts from pollutants in the environment created a need to better understand not only estuarine ecosystems, but ecosystems and ecology in general. This new concern marked the beginning of a nationwide environmental movement that continues to this day.

Since the 1960s, a large number of federal, state and private programs

have responded to this concern with laws that support responsible use of estuarine areas. These same groups have assisted in the funding of an increasing number of studies, so that the dynamics of estuaries and their influences on both marine and terrestrial resources may be better understood.

In 1972, the United States Congress passed the Coastal Zone Management Act (CZMA), which included the establishment of National Estuarine Research Reserve System (NERRS). The many NERRS sites around the United States exemplify the research and educational benefits possible with private, business and government support.



**Human influence on estuaries has been profound. They have been diked, dammed, and drained, resulting in broad changes in the plant and animal communities that depend on them. When people approach estuaries as critical ecological systems, they begin to recognize their values to nature and society.**



## TODAY'S IMPACT ON ESTUARIES

Though positive measures have been taken to reduce human impacts on these coastal areas, estuarine ecosystems continue to be affected by less noticeable, yet highly detrimental problems of **pollution**. Pollution is a widespread and largely invisible problem in estuaries. Human-made debris, can adversely affect marine and estuarine environments.

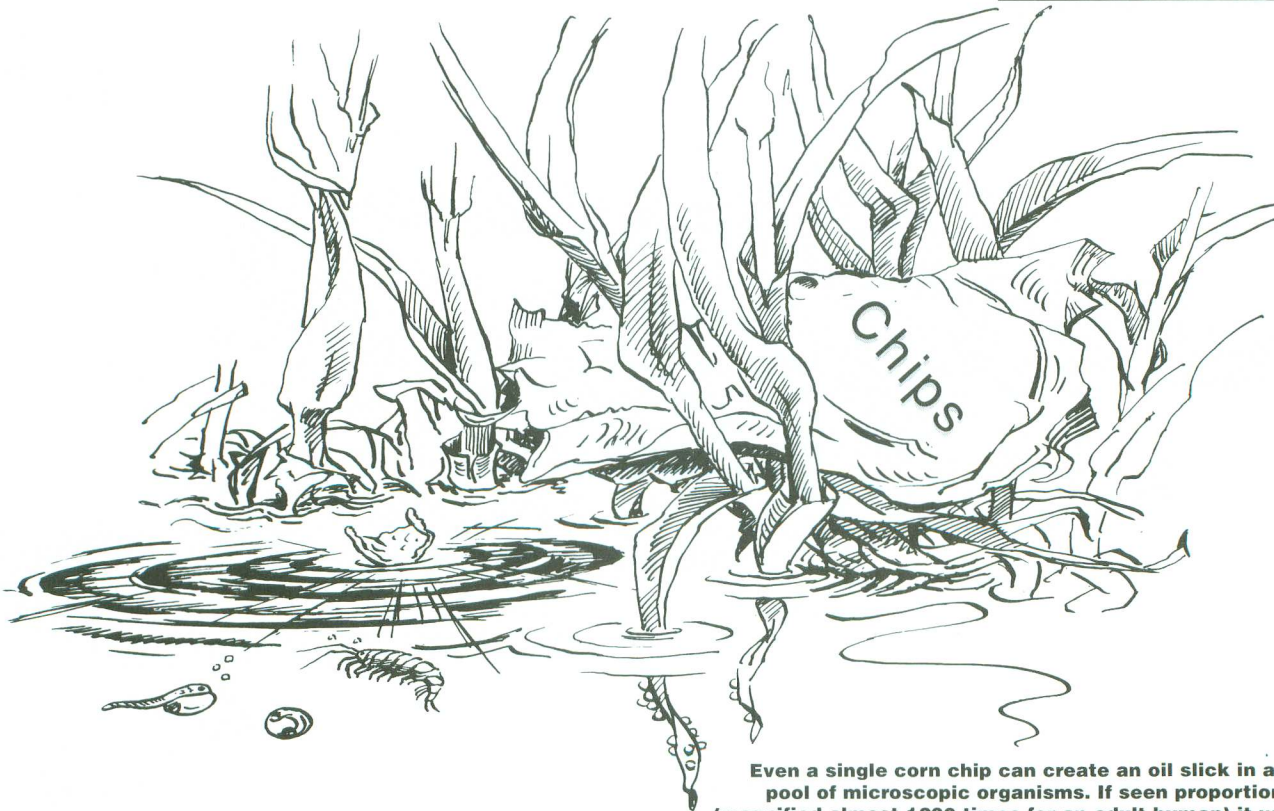
Often people become extremely concerned about such litter, without considering other types of pollution even more dangerous to marine and estuarine life, such as **coliform bacteria**, excess nutrients from **fertilizers**, **heavy metals**, **chlorine**, **petroleum derivatives**, **biocides** (pesticides and herbicides), **synthetic compounds**, **sediments** and temperature changes caused by discharge of cooling water from power plants.

Pollutants are introduced into estuaries from either **point sources** or **non-point sources**. Point sources are clearly defined, localized inputs, such as pipes, industrial plants, sewer systems, oil spills from tankers, and aquaculture ventures. They are regulated by federal and state governments. Non-point sources are indistinct inputs that do not have a clearly defined source, such as runoff of petroleum products from roadways or pesticides from farmland. They are harder to detect and control. Government efforts to deter these pollutants are challenged by their sheer number. Pollution can be reduced through individual or collective efforts to avoid or eliminate environmentally insensitive practices.

**Estuarine ecosystems continue to be affected by less noticeable, yet highly detrimental problems of pollution.**

### Try this yourself

Put a corn chip in a measured amount of water. Determine how wide a slick occurred. Compare this to the size of a juvenile striped bass (6cm.). Litter, even in small amounts, can affect the lives of organisms.



Even a single corn chip can create an oil slick in a tiny pool of microscopic organisms. If seen proportionally (magnified almost 1200 times for an adult human) it would appear as a slick almost 4 miles wide in the ocean.



## **APPRECIATING ECOLOGY THROUGH ESTUARIES**

Once we acquire a basic appreciation of our natural world, ecology provides a framework to deepen our understanding of natural systems. That understanding, in turn, reinforces our initial appreciation of nature.

Ecological processes are dynamic, shaping the living world around us.

We can use the concepts of ecology to make sense of things we see and experience,  
while we retain the sense of wonder that the natural world provokes in us.

The concepts of ecology are just as important in understanding our backyards as they are in explaining tropical rainforests, New England salt marshes, and mangrove swamps.

Ecology is directly relevant to every human life and should be an essential element of our lifelong education.

Ecology is the only science with a fully integrated world view of life on earth.  
If students are to understand ecology they must draw from diverse fields of knowledge  
and discover relationships that unify fundamental ideas.

For an educator, there could be no better vehicle than ecology for developing  
a student's understanding of these essential concepts.

Estuaries provide a spectacular setting in which to study ecology.  
The importance of estuaries in the natural world as integrated habitats, nurseries, water purifiers,  
flood controls and extraordinarily productive ecosystems, is without question.

No matter where we live, we all have personal connections to estuaries  
and can use our understanding of ecology  
to help protect them.



## **The Wells National Estuarine Research Reserve**

The Wells National Estuarine Research Reserve (WNERR; Wells Reserve), was established in 1983 to protect 1,600 acres of natural resources and to provide an opportunity for long-term estuarine research and education. Located where currents of the Little and Webhannet Rivers mingle with tidal waters of the Atlantic Ocean, it is home to a diversity of plants and wildlife in its estuarine waters, salt marshes, shoreland, and adjacent uplands.

### **Our Mission**

The Wells Reserve is committed to investigating coastal environments and increasing understanding of their ecology. Through community partnerships, we promote wise stewardship of these vital resources throughout the Gulf of Maine.

Established as a part of the National Estuarine Research Reserve System (NERRS), the creation of the Wells Reserve is an exemplary collaboration for protecting the environment. The five groups that share expertise and resources for the Wells Reserve are:

- \* Private citizens of Maine, who initiated the measures to protect the varied habitats of Wells Reserve.
- \* Laudholm Trust and the Town of Wells, which acquired the land and provide continuous support.
- \* The U.S. Fish and Wildlife Service, which protects the marshlands as habitat for waterfowl along the eastern flyway.
- \* The Maine Department of Conservation (DOC), which preserves Laudholm Beach, adjacent marsh and uplands for public access and open space.
- \* The National Oceanic and Atmospheric Administration (NOAA), which provide matching funds and designated these properties as a National Estuarine Research Reserve.



### **Wells National Estuarine Research Reserve**

342 Laudholm Farm Road  
Wells, Maine 04090  
Phone : (207) 646-1555  
Fax: (207) 646-2930

[www.wellsreserve.org](http://www.wellsreserve.org)



## THE NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

### A National Asset

The National Estuarine Research Reserve System is a network of protected areas established to improve the health of the nation's estuaries and coastal habitats by developing and providing information that promotes informed resource management. The Reserve System was created by the Coastal Zone Management Act (CZMA) of 1972 to augment the federal coastal zone management (CZM) program. The CZM program is dedicated to comprehensive, sustainable management of the nation's coasts.

### A Partnership With Coastal States

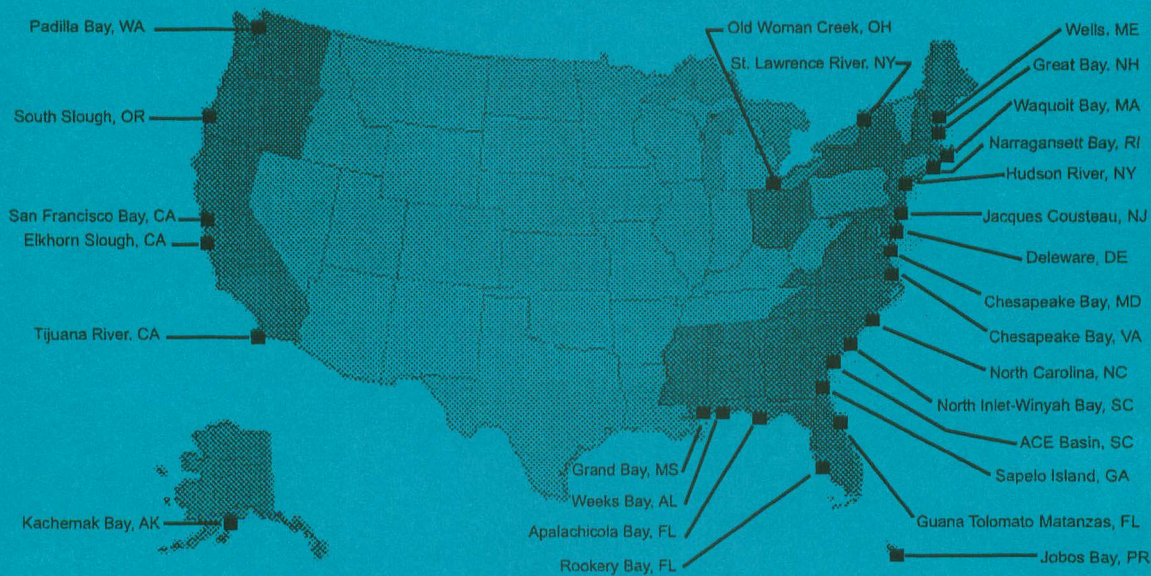
The Reserve System is a partnership between coastal states and the National Oceanic and Atmospheric Administration (NOAA). NOAA administers the Reserve System. The agency establishes standards for designating and operating reserves, supports the operation of each reserve, undertakes projects that benefit the entire Reserve System and integrates information from individual reserves to support decision-making at the national level.

Each National Estuarine Research Reserve (NERR) is jointly established by a coastal state and NOAA. A reserve is a discrete area containing key habitat within an estuary that is protected by state law from significant ecological change. Reserves are selected to represent different types of estuaries and large biogeographic regions within the nation. Reserves are operated by coastal states to work with local communities and regional groups to address coastal watershed management issues and to raise awareness and appreciation for estuaries. In addition, because reserves are designated to represent large biogeographic regions, they also provide an important source of information beyond their immediate locale.

### A National Commitment

The partnership between NOAA and the coastal states is vitally important to ensuring our nation's ability to make informed decisions about how to use and manage estuarine and coastal resources. In order to accomplish this mission, each National Estuarine Research Reserve depends on NOAA's support for operations, adequate facilities and equipment, and participation in system-wide programs and projects. NOAA's 27-year commitment to the National Estuarine Research Reserve System has resulted in the designation of 25 Reserves (with two more to be added in 2000/2001) totaling over one-million acres of estuarine waters and lands. The national benefits of the Reserve System include estuarine resource protection, monitoring water quality changes system-wide, and providing training through coastal decision-maker workshops and graduate research fellowships.

### National Estuarine Research Reserve System





# Ecology Glossary

**A** *abiotic factors*: non-living characteristics of a habitat or ecosystem that affect organisms' life processes (Section A: Abiotic Factors)  
*adaptation*: a genetically-based body feature or behavior that allows an organism to be better suited to its environment (Section F: Adaptation)  
*american eel*: *Anguilla rostrata* (Section M: River)  
*amphipods*: small shrimplike crustaceans  
*anoxic*: without oxygen, anaerobic (Section A: Abiotic Factors)  
*anthropogenic*: arising from human activity (Section Q: Pollution)  
*aquatic organisms*: organisms that live in or on the water (Section M: River)  
*atlantic silversides*: *Menidia menidia* (Section M: River)  
*autotrophs*: "self-feeders" such as plants and some bacteria (Section D: Food Webs)

**B** *back dune*: area immediately behind foredune; inhabited by mixture of grasses, beach heather and lichen (Section L: Barrier Beaches)  
*bar-built estuaries*: areas where sandbars form parallel to the shore, partly enclosing the water behind them as the sandbars become islands (Section I: Geologic Formation)  
*barrier beaches*: spits of sand that form parallel to the shore (Section L: Barrier Beaches)  
*bathymetry*: the underwater landscape, including submerged mountains and flat areas (Section P: Gulf of Maine)  
*beach/ocean interface*: where waves meet beach (Section L: Barrier Beaches)  
*benthic*: (adj) relating to the ocean bottom  
*benthos*: bottom-dwelling flora and fauna; from tiniest microbenthos (bacteria) to medium-sized meiobenthos (nematode worms) to the highly visible macrobenthos (clams, polychaete worms) (Section N: Mudflat and Sandflat)  
*biocides*: chemical compounds used to kill organisms (Section Q: Pollution)  
*biotic factors*: relationships among organisms that affect their survival (Section B: Biotic Factors)  
*brackish*: slightly salty water with a salinity between 0.5 ppt and 32 ppt





## GLOSSARY

- C** *carnivores*: animals that eat other animals as opposed to herbivores, which eat only plants (Section D: Food Webs)  
*chlorine*: poisonous, gaseous substance (Section Q: Pollution)  
*cladocera*: order of carnivorous zooplankton, crustaceans  
*coastal plains estuary*: estuary formed when rising sea level flooded existing river valley (Section I: Geologic Formation)  
*coccolithophore*: common type of phytoplankton  
*coliform bacteria*: bacteria commonly found in colon and used as an indicator of water contamination (Section Q: Pollution)  
*commensalism*: form of relationship in which one species gains from the interaction and the other is neither positively nor negatively affected (Section B: Biotic Factors)  
*community*: an association of interacting populations (Section C: Population/Community/Habitat/Ecosystem)  
*competition*: occurs between organisms using a finite resource, whether they are of the same or different species (Section B: Biotic Factors).  
*conditions*: characteristics of the environment that influence the survival of an organism but are not consumed by it (e.g., temperature, salinity)(see also "Resources")  
*consumer*: individual that eats other organisms to obtain energy rather than producing its food through photosynthesis or chemosynthesis (Section D: Food Webs)  
*copepods*: one of most common herbivorous zooplankton  
*cormorant*: *Phalacrocorax carbo*; common sea bird  
*crustaceans*: arthropods having hard-shelled bodies and jointed ligaments such as crabs, shrimp and lobsters

- D** *desiccation*: loss of water (Section B: Biotic Factors)  
*detritus*: newly dead or decaying organic matter coated with bacteria (Section M: River)  
*diatoms*: one of most common groups of phytoplankton; single-celled organism that reproduces asexually  
*dinoflagellates*: common type of phytoplankton, most abundant in fall; responsible for "red tides" as well as bioluminescence  
*disturbance*: any event that opens up space for colonization, such as the falling of a tree in a forest or removal of marsh grass by storm waves (Section E: Disturbance)

- E** *ecology*: the study of relationships between organisms and abiotic/biotic factors in the environment  
*ecosystem*: the biotic community and its abiotic environment (Section C: Population/Community/Habitat/Ecosystem)  
*epibenthos*: organisms that live on the bottom of an aquatic system (Section N: Mudflat and Sandflat)



**estuary:** a semi-enclosed body of water which has a free connection to the open sea and within which seawater is measurably diluted by fresh water derived from land drainage

- F** **fertilizer:** a substance containing the elements nitrogen, phosphorous, or potassium that is added to soil to increase plant productivity
- ffjords:** a glacial trough valley now flooded with seawater to create a steep-walled inlet (Section I: Geologic Formation)
- food chain:** a representation of the flow of energy between producers, consumers, and decomposers (Section D: Food Webs)
- food web:** a representation of the linkages between food chains in a community (Section D: Food Webs)
- foredune zone:** the area between mean high water and the crest of the frontal dune (Section L: Barrier Beaches)
- foreshore:** the area between mean low water and mean high water (Section L: Barrier Beaches)
- frontal dune:** the dune closest to the water's edge (Section L: Barrier Beach)

- G** **gastropod:** one of a class of mollusks that includes the snails and nudibranchs
- groundwater:** water contained below ground in soil and rock (Section K: Watershed)
- Gulf of Maine:** a rectangular embayment of coastal shelf water covering 90,700 square kilometers; bounded on the north and west by the coastline from Cape Cod, Mass. to Cape Sable, Nova Scotia and on the east and south by Georges Banks (Section P: Gulf of Maine)

- H** **habitat:** the place where an organism lives (Section C: Population/Community/Habitat/Ecosystem)
- haul-out:** an area on the shore where marine mammals rest
- heavy metals:** metals such as cadmium, chromium, copper, zinc, mercury, and lead that might contaminate a water body and thus endanger organisms (including people) using the water (Section Q: Pollution)
- herbivore:** an animal that eats plants (Section D: Food Webs)
- heterotrophs:** feed on others; mostly animals; eat autotrophs (Section D: Food Webs)
- high marsh:** the area of the marsh flooded infrequently by the high tides associated with new and full moon; in Gulf of Maine, dominated by *Spartina patens* (Section O: Salt Marsh)



## GLOSSARY

**I** **infauna:** organisms living between the grains of sand or mud (Section N: Mudflat & Sandflat)

**isopods:** aquatic crustaceans with flat, oval body and seven pairs of legs

**J** **jellyfish:** carnivorous zooplankton; common in Gulf of Maine and Wells Reserve

**L** **light:** energy source used by plants to form carbohydrates; an important abiotic factor (Section A: Abiotic Factors)

**low marsh:** the area of marsh flooded twice daily by tides and dominated by *Spartina alterniflora* in Gulf of Maine region (Section O: Salt Marsh)

**M** **maritime forest:** forest dominated by pitch pine and located on the mainland side of a barrier beach or island (Section L: Barrier Beaches)

**mobile epibenthos:** bottom-dwelling animals that move on top of sediments: crabs, shrimp, snails, amphipods, isopods (Section O: Salt Marsh)

**mudflat:** part of benthic (bottom) zone exposed at low tide and comprised of extremely fine sediments (Section N: Mudflat and Sandflat)

**mummichogs:** *Fundulus heteroclitus*; small salt-marsh fish common in the Gulf of Maine region (Section M: River)

**mutualism:** form of relationship in which both species involved gain from the interaction (example: lichen) (Section B: Biotic Factors)

**N** **natural selection:** the differential survival and/or reproduction of individuals within a population based on hereditary characteristics (Section F: Adaptation)

**nekton:** all aquatic animals that can swim through the water against currents: marine mammals, fish, squid and some crustaceans (Section M: River)

**niche:** the role of a species within a community (Section H: Niche)

**non-point source pollution:** water pollution arising from indistinct sources such as petroleum products from roadways or pesticides from farmland (Section Q: Pollution)

**nursery:** term used colloquially to refer to estuaries; many fish species are dependent on estuaries for part of their lives

**nutrients:** substances required by organisms in order to grow and survive (Section A: Abiotic Factors)

**O** **omnivores:** animals that feed at several levels of food web; diet includes a mix of living and/or dead plants and animals (Section D: Food Webs)

**oxygen:** used in respiration, the process in which organisms release stored chemical energy (Section A: Abiotic Factors)



**P** *panne*: small pond or pool in the salt marsh (Section O: Salt Marsh)  
*parasitism*: similar to predation in that one species benefits from the relationship and the other is harmed; differs from predation in that parasitism generally not fatal to adversely affected organism (Section B: Biotic Factor)  
*peat*: soil in marsh composed of partially decayed moisture-absorbing plant matter (Section I: Geologic Formation)  
*petroleum derivatives*: toxic pollutants from crude oil products; mixture of hydrocarbons, which are organic solvents (Section Q: Pollution)  
*photosynthesis*: process of using energy in sunlight to convert water and carbon dioxide into carbohydrates and oxygen. (Section A: Abiotic Factor)  
*phytoplankton*: floating aquatic photosynthetic organisms (Section M: River)  
*pioneer species*: plant species that first invades unvegetated area (Section L: Barrier Beaches)  
*pipefish*: elongate fish related to seahorses (Section M: River)  
*plankton*: free-floating organisms drifting in water, unable to swim against currents (Section M: River)  
*point source pollution*: pollution from a clearly defined, localized source such as a sewage outfall (Section Q: Pollution)  
*pollution*: contamination of natural environment (Section Q: Pollution)  
*population*: all the individuals of a particular species within a defined area (Section C: Population/Community/Habitat/Ecosystem)  
*predation*: the killing and/or consumption of living organisms by other living organisms (Section D: Food Webs)  
*primary dune*: foredune; dune closest to water's edge  
*producer*: autotroph; organism that creates energy-rich compounds from sunlight (through photosynthesis) or certain chemicals (through chemosynthesis); first level in any food web; in estuarine systems, most abundant producers are phytoplankton (Section D: Food Webs)

**R** *resource*: entity (e.g., food, light, water, space) that an organism uses or consumes during its lifetime (Section H: Niche)  
*respiration*: process that, using oxygen, releases stored chemical energy to power an organism's life processes; opposite reaction of photosynthesis (Section A: Abiotic Factors)  
*response*: ecological responses are behavioral and physical changes that happen during the lifetime of a single organism and increase individual's chance of survival as opposed to evolutionary adaptation, which takes place over multiple generations and is a result of a change in the species genetic makeup (Section F: Adaptation)  
*rhizome*: a continuously growing underground stem which puts out lateral shoots at regular intervals allowing the plant to spread



## GLOSSARY

**runoff:** precipitation that drains into a waterbody from the surface of the surrounding land (Section K: Watersheds)

## S

**salinity:** the concentration of salts dissolved in salt water

**salt marsh:** wetland flooded regularly by tidal, brackish water (Section O: Salt Marsh)

**sand eel:** *Ammodytes americanus*; American sand lance (Section M: River)

**sandflat:** area of bottom of aquatic system that is exposed by low tides and composed of sand - particles of sediment larger than those of mud (Section N: Mudflat and Sandflat)

**scud:** *Scud gammarus*; a type of amphipod to one inch that lives in masses of seaweed, scuttle under rocks, and swim on their sides in tidepools

**sediments:** particles deposited by wind or water (Section Q: Pollution)

**shags:** *Phalacrocorax auritus*; sea bird similar to cormorant

**silversides:** *Menidia spp*; small schooling fish that spawn in estuaries in April/May, then return to sea; young fish stay in estuary until September.

**space:** resource needed by all organisms; most pronounced need by organisms that require substrate (Section A: Abiotic Factors)

**speciation:** formation of new species through natural selection; occurs when selective force is intense; accounts for diversity of living things on planet today (Section F: Adaptation)

**sticklebacks:** *Gasterosteidae spp*; small estuarine fish named for spines that line the dorsal fin; three species found at Wells Reserve (Section M: River)

**sublittoral zone:** portion of rocky shore always submerged (Section L: Barrier Beaches)

**substrate:** the surface on which an organism grows

**succession:** progressive replacement of populations in a habitat (Section E: Succession)

**surface water:** water in streams, brooks, rivers, ponds and lakes, etc. (Section K: Watersheds)

**swash zone:** part of foreshore washed by waves (Section L: Barrier Beaches)

**synthetic compounds:** manufactured compounds (Section Q: Pollution)



**T** *tectonic estuaries*: land flooded by sea due to subsidence, not sea-level rise (Section I: Geologic Formation)  
*temperature*: important abiotic factor affecting distribution and abundance of organisms; influences metabolic rate and affects rates of growth and reproduction (Section A: Abiotic Factors)  
*tidal height*: difference between water level at high tide and mean sea level, the average height of the ocean (Section J: Tides)  
*tidal range*: difference between high and low tide (Section J: Tides).  
*tides*: periodic rise and fall of ocean waters due to gravitational pull of sun and moon, and rotation of earth (Section J: Tides)  
*trophic level*: level in a food chain, e.g., producer, primary consumer, secondary consumer, tertiary consumer (Section D: Food Webs)

**U** *uplands*: lands lying above the reaches of the highest high tides

**V** *vertical stratification*: laying of fresh water on top of salt water, also known as “salt wedge” effect; occurs when the fresh and salt water are not vigorously mixed together by turbulence

**W** *water*: a molecule-composed compound of hydrogen and oxygen, (Section A: Abiotic Factors)  
*watersheds*: area of land drained by a river or river system (Section K: Watersheds)  
*wrack line*: a string of debris stranded by last high tide; cast ashore seaweeds, isolated sources of food and shade support an important community of isopods and amphipods as well as providing food for birds (Section L: Barrier Beaches)

**XYZ** *zonation*: distribution of plants or animals arranged in zones or bands, caused by gradations of abiotic and/or biotic factors (Section G: Zonation)  
*zooplankton*: animals, often small or microscopic, that drift with the currents, may be either herbivores or carnivores (Section M: River)



# Index to Sections

<b>Section A</b>	- Abiotic Factors
<b>Section B</b>	- Biotic Factors
<b>Section C</b>	- Population/Community/Habitat/Ecosystem
<b>Section D</b>	- Food Web and Food Chain
<b>Section E</b>	- Disturbance
<b>Section F</b>	- Adaptation
<b>Section G</b>	- Zonation
<b>Section H</b>	- Niche
<b>Section I</b>	- Geologic Formation
<b>Section J</b>	- Tide
<b>Section K</b>	- Watershed
<b>Section L</b>	- Barrier Beach
<b>Section M</b>	- River
<b>Section N</b>	- Mudflat and Sandflat
<b>Section O</b>	- Salt Marsh
<b>Section P</b>	- Gulf of Maine
<b>Section Q</b>	- Pollution





## Section A

# Abiotic Factors

---

**Light**

**Photosynthesis** - Plants use the energy in sunlight to convert water and carbon dioxide into carbohydrates and oxygen. This is accomplished through a series of chemical reactions called photosynthesis. In order to photosynthesize, an organism must have a pigment called chlorophyll. The carbohydrate products of photosynthesis provide food (energy) for the plant, as well as the animals that feed on it. Therefore, photosynthesizers are essentially food factories powered by sunlight. Without the proper amount of light, they die. Light is consequently an important factor in determining the abundance and distribution of photosynthesizers.

In estuarine waters and other aquatic systems, the most important photosynthesizers are microscopic floating plants called phytoplankton. Since particles of sediment and debris floating on the water, and even the water itself, block the passage of light, the availability of light decreases with depth. As a result, phytoplankton are only found near the surface of the water. The maximum depth at which they can live varies depending on how deep the light can penetrate.

One might expect that the maximum amount of phytoplankton would be found right at the surface, where sunlight is most plentiful, but this is not the case. Sunlight contains damaging ultraviolet (UV) light. Most of the UV light, however, is filtered out by the water very close to the surface, so phytoplankton live most successfully a short distance below, where they still receive plenty of non-UV light.

**Oxygen**

**Respiration** - Unlike photosynthesis, which releases oxygen, respiration involves absorption of oxygen by an organism. Respiration results in the release of stored chemical energy powers an organism's life processes. An absence of oxygen severely restricts the amount of life that can be supported.

In estuarine mudflats, the sediment particles are so fine and compacted that there are no crevices for oxygen-laden water to squeeze into. This contrasts strongly with dry terrestrial soils, which are relatively permeable to oxygen-rich air. The result is that only the top few inches of the mudflat have enough oxygen to support life. Below that, the mud is black and anoxic; it lacks oxygen, and the most abundant organisms living there are bacteria capable of surviving in low oxygen conditions.

**Marsh Plant Adaptation to Anoxia** - Anoxia is a problem for grasses that live in a salt marsh. The above-ground part of a plant can get the oxygen it needs for respiration from the surrounding air. But root cells need to respire. When they are trapped in soil (ie peat), they are frequently



saturated with water by the tides. In the uplands, oxygen reaches plant roots by diffusing through the tiny crevices between soil particles. Since peat crevices are filled with water, airborne oxygen is prevented from reaching the roots. Water does contain some dissolved oxygen, but it is much less oxygen-rich than air. This often leads to anoxia in the peat.

Marsh plants have adapted to survive in these conditions. Smooth cordgrass (*Spartina alterniflora*) and salt hay (*Spartina patens*), for example, have developed tiny tubular spaces that run from the roots up through the leaves, where they are open to the air. These spaces allow oxygen to diffuse down to the roots.

**Animal Absorption of Oxygen** - Animals need oxygen for respiration and obtain it through a number of different adaptations. The key is to have enough surface area permitting contact between blood vessels and air. Aquatic animals such as fish, sea stars, and squid have gills to obtain oxygen from water, while many land animals have lungs to obtain oxygen from air. Gills and lungs perform the same function; both allow oxygen to come in contact with blood flowing through a huge number of tiny blood vessels in thin membranes exposed to the outside medium (water or air). The reason lungs are contained inside the body, and gills are not, is that the oxygen/blood-vessel interfaces must be moist. If the interfaces were exposed to air, the organism would lose much water through evaporation. Containment of the interfaces within the body limits waterloss. This is not a danger for organisms with gills because they live in a liquid environment.

Some animals do not use gills or lungs to acquire oxygen. Small tubes, called tracheae, permeate the bodies of insects and some other arthropods and allow oxygen to diffuse into the body. Some amphibians have very small lungs and absorb a considerable amount of oxygen across their skin, a moist air/tissue interface.

## **Water**

Without water, no living thing can remain biologically active. In fact, all living organisms are comprised of 50 to 99 percent water. The unique properties of water make it an ideal solvent for many crucial biochemical reactions. It participates in some reactions as well.

**Water Absorption by Plants** - Plants absorb water from the soil through numerous tiny hairs on the roots. The water is then transported to the rest of the plant by the xylem, a system of tiny conducting tubes. The xylem is similar to the human system of blood vessels, except it is not powered by a pump like our heart. In a plant, the water molecules form a continuous chain all the way from the roots to the leaves. The chain is pulled from the bottom of the plant to the top by cohesion between molecules; each time a water molecule in a leaf evaporates (this is called



transpiration), the next molecule in the chain takes its place and pulls the rest of the water-chain up.

Terrestrial plants must retain water and not let too much evaporate into the air. This accounts for the watertight epidermal, or outer, layer covering their surfaces. But in order for photosynthesis to occur, cells need to obtain carbon dioxide from the air. Small holes in their tissues, called stomata, are an adaptation that meets both requirements. When photosynthesis is taking place, the stomata open and allow carbon dioxide to diffuse into photosynthesizing cells. A small amount of water loss also occurs because of the air contact. At times when risk of water loss is too great (such as in the midday sun), the stomata remain closed to prevent this drying out (desiccation).

The presence of too much water can pose as many challenges to organisms as a lack of water, because of the threat of soil anoxia. Thus wetness can be an important factor in determining the abundance and distribution of organisms. Certain plants, such as red maple trees, are adapted to live in moist soils. Only a small number of plant species, however, can live in places like marshes where the soil is completely saturated with water, making oxygen essentially absent. The survival of plants in a salt marsh depends largely on their ability to withstand water-logged soil (Oxygen, previous section).

### Nutrients

Although sunlight is the fuel for food production, and water and carbon dioxide are the raw materials, plants cannot survive with these alone. Other substances, called nutrients, are necessary for proper function of a living organism. Major nutrients include nitrogen and phosphorous. Trace nutrients such as iron are required in smaller amounts.

Each nutrient plays a role in the life processes of the organism. Nitrogen is used in the synthesis of proteins, phosphorous assists the energy cycle of cells, and iron facilitates photosynthetic reactions.

Nitrogen and phosphorous often govern the productivity of vegetation. We put nitrogen and phosphorous on our gardens to increase their productivity. Coastal areas, and in particular estuaries, tend to be rich in these nutrients because they receive large inputs from rivers carrying nutrients eroded from upland soils. Ocean waters far from riverine inputs tend to lack nutrients.

The overabundance of nitrogen and phosphorous in a waterbody can result in a huge increase in the amount of algae that grows there. This phenomenon, when occurring during the growing season, often causes an algae bloom that creates a green scum on the water surface. Algal blooms often happen when nutrient-rich fertilizers wash into a waterbody from agricultural land, or when untreated or partially treated wastewater is deposited into a waterbody.

## Temperature

**Temperature and Physiology** - Temperature is one of the best understood abiotic factors affecting the distribution and abundance of organisms. It is also one of the most important. Temperature has a large impact on plants and animals because it influences their metabolic rates and affects rates of growth and reproduction. Death can occur when temperatures are either too high or too low: 1) Heat death is probably a result of damage to proteins and enzymes, and 2) Coldness can slow down life-sustaining chemical reactions and cause body fluids to freeze.

Every species has a particular range of temperatures in which it can survive. For organisms that don't maintain constant body temperature (plants and cold-blooded animals), rates of metabolism, growth, and reproduction generally increase toward the upper limit of the acceptable range and decrease toward the lower limit. One type of fish found in Antarctica can live at temperatures down to  $-1.9^{\circ}\text{C}$  and dies if the temperature goes above only  $+6^{\circ}\text{C}$ . In contrast, intertidal organisms are able to survive the wide range of temperatures to which they are exposed, a range that would kill the subtidal creatures living nearby. Barnacles, for instance, are able to endure cold winter conditions even though some of their body tissues freeze.

One of the most important aspects of temperature variation in aquatic systems is the inverse relationship between water temperature and the solubility of gases. Warm water can hold less oxygen than cold water. This has important ramifications for fish, which can be characterized as either warm-water fish (e.g., sunfish and pickerel) or cold-water fish (e.g., salmon and trout). Salmon are only able to live in water colder than  $40^{\circ}\text{F}$  because they have a high oxygen requirement. Water above that temperature is unable to hold enough oxygen for their survival.

**Temperature and Geographic Ranges** - Geographic ranges of animals are often defined by temperature. Abrupt changes in communities occur at boundaries between places with very different temperatures. The south coast of Cape Cod, for example, is influenced by the warm water of the Gulf Stream, while the north side is characterized by cold Gulf of Maine water. The marine community changes noticeably from one side to the other because of the temperature difference.

Many species respond to seasonal temperature shifts by acclimatizing to them. They adjust their metabolic rate and behavior according to the ambient temperature. This allows them to withstand a wider range of temperatures than if they did not acclimatize. An individual's ability to acclimatize is a result of evolutionary adaptation to tolerate variation in environmental conditions.



### Salinity

Pure water contains only oxygen and hydrogen, but in the natural world solid substances are often dissolved in water. When they dissolve, the solids dissociate, or break up, into electrically-charged ions. The presence of dissolved solids (or ions) in a liquid is called salinity. One of the most familiar and abundant dissolved solids in ocean water is sodium chloride, the compound we know as table salt, but other dissolved substances are also found in smaller concentrations.

**Osmosis & Diffusion** - Salinity poses challenges for plants and animals because of phenomena known as osmosis and diffusion. Osmosis is the movement of water across a water-permeable membrane. It occurs when the water on one side of the membrane has a lower salinity than the water on the other side. Water molecules passively move across the membrane from the less saline side to the more saline side, until the concentrations on both sides are equal.

Diffusion is the movement of an ion, such as sodium or magnesium, across a membrane that is permeable to that particular ion. Like osmosis, it happens when the ion concentrations of two solutions separated by a membrane are unequal. The ions always move from the concentrated side to the dilute side. In living organisms, diffusion often happens across cell membranes, causing the cell to either gain or lose ions. To counteract this, cells frequently have mechanisms that act as "pumps" to remove unwanted ions and import desirable ions.

Osmosis and diffusion present problems for aquatic organisms because the organisms' internal ion concentrations are very different from the salinity of the surrounding water. The body fluids of saltwater fish, for example, are typically only 1/3 to 1/4 as saline as seawater. Therefore, if the fish allowed chemistry to simply follow its course, water would leave the fish by osmosis and ions would enter it through diffusion, until the concentration of the body fluids equalled that of the seawater. The result would be a fish that was shriveled, salty, and dead. Luckily, fish and other marine organisms have adaptations that enable them to deal with the saltiness of ocean water by regulating water and ionic exchange. Marine fish drink seawater to get water into their bodies, and they excrete excess salt through glands on their gills. Many seabirds have a similar salt gland in their head near the top of their bill. Crustaceans have impermeable membranes on most of their body and regulate water and ionic balance at their gills and excretory organs.

Smooth cordgrass (*Spartina alterniflora*) can survive even though its roots are bathed in saline water. It maintains a very high salt concentration in its cells (even higher than seawater) so that water will diffuse into the plant, not out of it. They also excrete excess salt onto their foliage,



where it gets washed away by rain. If you look closely at smooth cordgrass leaves, you will often find salt crystals on them.

Organisms living in fresh water face different challenges because their internal salinity is higher than the water they live in. If a freshwater fish did nothing to counteract diffusion and osmosis, the fish would bloat up until its internal salinity became so low that it would die. To prevent this, freshwater fish excrete a very dilute urine, have cells that absorb salt, and do not drink any water.

**Response to Variable Salinity** - The differing physiological requirements of salt and freshwater environments make animals like eels and salmon intriguing because they deal with both conditions during their lives. American eels (*Anguilla rostrata*) are catadromous (i.e. they live most of their lives in fresh or brackish water but spawn in salt water). Adult eels migrate to the Sargasso Sea, an area of the Atlantic Ocean located near Bermuda, to spawn. Their larvae (i.e. eggs) eventually make their way back to marshes and rivers along the east coast.

During their lifetimes, the eels encounter both salt and freshwater environments. The same is true for salmon, which are anadromous (i.e. they live in salt water as adults but migrate upriver into fresh water to spawn). To survive such different salinities, these species have evolved the ability to respond physiologically to the surrounding conditions.

Organisms that spend their entire lives in estuaries need to be capable of responding to large and rapid salinity variations. Salinity fluctuates continuously over the tidal cycle, decreasing drastically in the upper reaches of tidal rivers, and varies radically in salt pannes because of evaporation and precipitation. Some large groups of related animals, such as echinoderms (seastars, sea urchins, and others), are entirely absent from areas with low salinities. They have not adapted in such a way as to be able to survive in low-salinity water. On the other hand, other groups like bivalve mollusks (clams, mussels, and others) and polychaete worms (sand worms, blood worms, and others), show only a decrease in the number of species and not a decrease in overall abundance. Those species that can respond to variable salinity are very common in estuaries.

## Space

Organisms need space in which to live. Consequently, space is a precious resource that is always exploited by living things. The need for space is most pronounced for organisms that need a substrate, or base, on which to live. Terrestrial plants are a good example of this, since they cannot live without burying their roots in the appropriate type and amount of soil. They need soil for physical support and as a source of water and nutrients. If no soil is available in a given location, no plants can establish themselves.



Rocky intertidal organisms depend heavily on attachment to a substrate. Seaweeds, mussels, barnacles, and limpets live in a turbulent, wave-battered environment and must secure themselves to rocks in order to avoid destruction. Space on rocks is therefore often a limiting abiotic factor in these communities. In addition to simple physical attachment, many animals require a certain amount and type of space to meet their needs. They need space for nesting, gathering food, resting, wintering, and hiding from predators. Standing dead trees, for example, are an important resource in northeastern forests. Upwards of thirty animal species depend on them, such as the flying squirrels that use them for nesting.

### Section B

## Biotic Factors

---

*In addition to all the abiotic factors described in Section A, the abundance and distribution of organisms are controlled by a complicated web of biotic factors that arise from other living things. Abiotic factors limit distribution and abundance by affecting an organism's life processes (physiology). Biotic factors in contrast, are relationships and interactions among living things that affect an organism's survival. In this text the term organism is limited to plants and animals.*

### Competition

Competition occurs between organisms using a resource that is in short supply. The organisms can either be of the same species (intraspecific competition) or different species (interspecific competition). Community ecologists generally concentrate on interspecific competition, while population ecologists are more interested in intraspecific competition.

Although one often thinks of organisms competing for food, competition can occur for any resource that is required for survival and is limited in availability. Plants often compete for light, nutrients, and water, but they might also compete for pollinators or space. Animals frequently compete for water, food, space, and mates.

It is important to note that animals do not have to see or hear each other to be competitors; often they do not have direct contact with one another. To be in competition, they simply must be using the same resource. In a forest, there might be two animals that both feed on insects. If, however, one species feeds on daytime insects and the other on nighttime insects, they are not in competition. They are actually using different resources. Competition plays an important role in shaping communities, since competing species threaten each other's survival and ultimately

reproductive success. If two species use the same resource and that resource is in short supply, the species cannot coexist (Section H: Niches). The more successful species excludes the other from a given system. Consequently, competition also influences the evolution of species.

Competition can produce evolutionary changes in body features and behavioral strategies so as to give individuals of one species an advantage over individuals of a competing species. The threatened species then gains a competitive edge and has a better chance of surviving long enough to reproduce.

## Predation

Predation is considered another very important biotic factor influencing community structure and dynamics. Predation is the consumption of one organism by another. It takes two primary forms:

- 1) Herbivores eat plants, seeds, and/or fruits. The periwinkle (*Littorina littorea*) is a herbivore that eats bottom-dwelling algae.
- 2) Carnivores eat animals. Snowy egrets are carnivores because they eat fish.

Some animals, called omnivores, eat both plants and animals. The mummichog is an omnivorous estuarine fish that eats a variety of foods, including vegetation and mosquito larvae.

Predation shapes communities by reducing the abundance and distribution of prey species. Kelp sometimes grows in dense, submerged forests, but when sea urchins are abundant these kelp forests are destroyed. Herbivory by urchins is thus an important controlling factor of kelp abundance and distribution. Urchin populations themselves are strongly affected by predation by sea otters (on the west coast of North America) or lobsters (on the east coast). Similarly, the blue mussel (*Mytilus edulis*) is abundant in some locations and absent in others. The main factor controlling mussel abundance is the presence of its major predators: crabs, seastars, and eider ducks. The abundance of crabs and seastars is, in turn, often limited by abiotic factors such as water turbulence and low salinity. Crabs do not have the ability to attach themselves to rocks in turbulent, wavy environments, and seastars generally cannot tolerate the osmotic stresses of low salinity.

Predation is a major selective force in animal evolution. Individuals are more likely to successfully reproduce if they have traits that help them avoid being consumed by predators. For example, many species have evolved sharp body parts (like the quills of a porcupine) or camouflage (like a mummichog's drab brown color) to deter predators.



### **Parasitism**

Parasitism is similar to predation in that one species benefits from the relationship and the other is harmed. Parasitism differs from predation, however, because parasitism generally is not fatal to the adversely affected organism. Rather than outright killing its host, a parasite may benefit by simply obtaining shelter in its body or deriving nutrition.

### **Commensalism**

When one species gains from a relationship and the other is neither positively nor negatively affected, the relationship is called commensal. Lichens often grow on tree trunks because the trunks provide solid support and exposure to sunlight for photosynthesis. The lichen clearly benefits from this relationship, but the tree is neither aided nor harmed.

### **Mutualism**

Lichens themselves are excellent examples of mutualism, where two species involved in a relationship both gain from the interaction. A lichen actually consists of two different organisms: a fungus and an alga. The fungus absorbs nutrients and water and provides support for the alga. In turn, the alga produces food for the fungus through photosynthesis. It is a give-and-take relationship.

A marine example of mutualism is found in coral, which are actually tiny animals that contain alga within their tissues. Corals provide the alga with support, and the alga supplies the corals with food from photosynthesis.



## Section C

## Population/Community/ Habitat/Ecosystem

---

Ecologists take a number of approaches to their work, but they tend to focus on three levels of organization in the natural world: population, community, and ecosystem. A population is a group of individuals of the same species living in a given place, while a community comprises populations of a number of different species living together. Populations and communities do not have rigidly defined boundaries. They are abstractions, or levels of ecological organization, rather than actual structures. So, we might have twenty individual egrets making up the egret population in our marsh, and five great blue herons making up the great blue heron population. If these are the only kinds of birds in a marsh, then these two populations comprise the bird community. We can also consider all the animals, plants, etc. living in our marsh and call them the marsh community. This is a way to collectively refer to the populations of every species of living thing in the marsh.

Ecosystem is a term even more inclusive than community, because it encompasses the community and its abiotic environment. Therefore, an ecosystem has components that are living (animals, plants, etc.) and non-living (soil, water, air, nutrients, etc.). The concept of an ecosystem refers to the flow of energy and nutrients through ecological systems, whereas ecologists studying from the population or community perspectives focus on how organisms affect each other and how they are affected by the environment. The word ecosystem is always used by ecologists when they want to refer to the interactions among one or more biotic community(ies) and the associated abiotic features. In this text, the estuary is referred to as an ecosystem, although in other instances it might be considered simply a part of a larger ecosystem. Likewise, we will refer to the river, mudflats, and marsh as habitats within the estuarine ecosystem, in other situations they might be considered ecosystems.

The habitat concept is explained more fully later in the text, but it is important to note here that, although people often define ecosystem as a combination of community and habitat, this is incorrect. Ecosystems are the sum of a community and its physical and chemical environment, while habitats are considered from the point of view of a single organism. Thus, the habitat of a worm might be the mudflat, but the habitat of a fish that eats the worm might be the river.



### Habitat

Habitat is the place where an organism lives.

Every species has a set of abiotic and biotic conditions and resources that it needs in order to survive, and there are certain places in the world that meet those requirements. These environments are suitable habitats for that species. A habitat is a place where a plant or animal lives. The habitat characteristics that a species requires can be determined by examining the places where it lives.

It is important to keep in mind that the characteristics of a place that are hostile to one species might be benign to another species. Antarctica, for example, is an extremely cold place, but many species find it a perfectly suitable habitat.

The habitat requirements of an organism can be divided into two categories: resources and conditions. Resources are entities (e.g., food, light, water, etc.) that the organism uses or consumes during its lifetime. Conditions, are characteristics of the environment that influence the survival of an organism but are not consumed by it (e.g., temperature, salinity, pH). Resources and conditions of a habitat involve the previously discussed biotic and abiotic ecological factors: light, nutrients, oxygen, moisture, temperature, salinity, and space. The ones that organisms use during their lifetime are resources and the ones that simply influence their survival are conditions.

Therefore, if we look at a habitat from the point of view of an individual plant, we should consider the factors the plant needs as resources (light, water, oxygen, nutrients, and space) and the conditions that affect its survival (temperature, salinity, and pH). A plant's habitat can be characterized by considering the overall combination of resources and conditions as they occur where the species lives. For instance, one plant species might only live in a habitat with medium moist soil and with temperature and sunlight levels varying seasonally within a specific range: a habitat such as a temperate hardwood forest. Another plant species might live only in a nearby habitat where the temperature and sunlight conditions are the same, but the soil is flooded twice daily with saline water — in other words, a salt marsh.

Habitat characteristics for animals are somewhat different. Like plants, animals need water as a resource, but they do not require light for survival. Rather, animals depend on having appropriate food sources, either plants or other animals, in order to obtain energy.

Animals often depend on plants in another way as well, as creators of space. It is no accident that rainforests, with their abundance, complexity, and density of foliage, support a large number and diversity of animals. Likewise, it is not coincidence that one finds a greater abundance and diversity of fish in the weedy part of a waterbody than in the areas with



little or no submerged vegetation. The more abundant and varied the vegetation, the more space available to the animals for shelter and protection.

Environmental conditions such as temperature and soil type (for burrowing animals) are very important in determining whether a given location is a suitable habitat for an animal species.

Habitats are also defined by their temporal and spatial characteristics. Are the resources and conditions constant, seasonal, unpredictable, or ephemeral? Are they continuous in space, patchy, or isolated? These qualities can make the difference between success and failure for a species.

In sum, a location's suitability for the survival of a species is determined by its resources and conditions. When all of the species' requirements are met, the location is a suitable habitat and the species has the potential to live there. It should be noted that every species can survive in a range of conditions, some of which cause it to flourish (i.e., maximum reproduction) and some that are marginal (i.e., minimal reproduction).

The concept of a habitat is different from that of an ecosystem, which refers to the flow of energy and nutrients through an ecological system. A habitat, in contrast, is always considered from the point of view of an individual organism. In practice, an ecologist may use either word habitat or ecosystem to refer to the same location, but his/her choice of words reflects the way he/she is thinking about the place. One should say ecosystem when discussing the relationships among all biotic and abiotic components of a place, and habitat when viewing a place from the perspective of an individual of a particular species.

## Section D

# Food Web and Food Chain

Energy is the most crucial resource needed by living things. Autotrophs (meaning self-feeders), such as plants, are able to obtain energy from the sun (or chemical compounds in the case of some bacteria) and use it, along with certain molecules, to form energy-rich material. They use this material in life processes like growth and reproduction. Heterotrophs (meaning feeding on others) are organisms, mostly animals, that obtain energy-rich materials by eating autotrophs as well as other heterotrophs. This relationship determines how energy flows through a community.

The general pattern of energy flow begins when an autotroph produces food and continues when a heterotroph eats that autotroph, another heterotroph eats that heterotroph, and so on. This pattern is called the food chain. A food chain contains several trophic ("food") levels, and each member of the food chain has a function, depending on its level within the hierarchy. Producers are autotrophs which produce energy-rich organic material from an energy source (i.e., sunlight or certain chemical compounds) and chemical building blocks. Consumers are heterotrophs that eat other organisms to obtain energy-rich organic materials. More specifically, herbivores are consumers which eat producers (plants), and carnivores are consumers that eat other consumers. A food chain looks like this:

<u>Role</u>	<u>Food chain</u>	<u>Trophic level</u>	<u>Example</u>
Producer	Green plant	1st	Phytoplankton
↓	↓	↓	↓
Primary consumer	Herbivore	2nd	Zooplankton
↓	↓	↓	↓
Secondary consumer	Carnivore	3rd	Silverside minnow
↓	↓	↓	↓
Tertiary consumer	Carnivore	4th	Bluefish

Loss of energy occurs at each stage of a food chain, so the chains rarely have more than four or five trophic levels. In addition, there are generally fewer individuals at the higher levels than the lower levels.

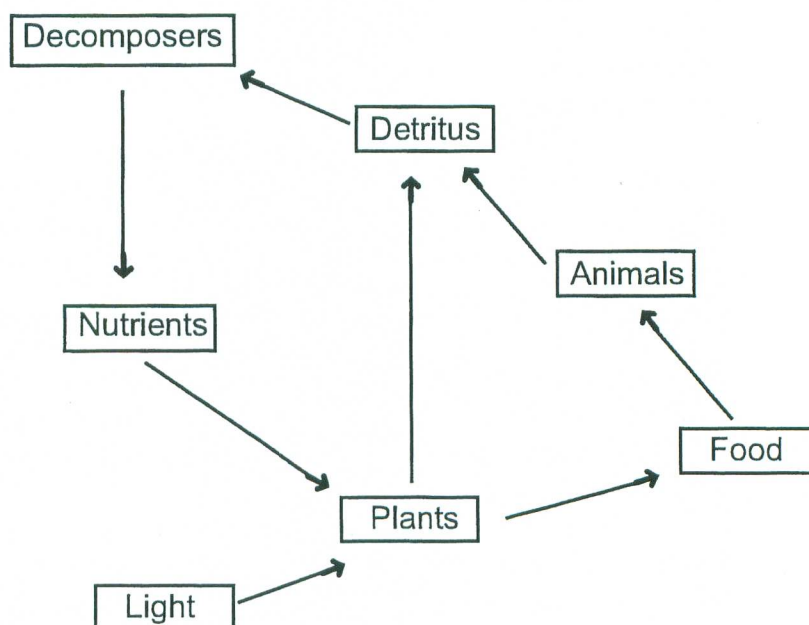
Often one organism will play more than one role in a food chain. The same species of carnivore, for example, might sometimes feed at both the third and fourth trophic levels depending on what prey species it eats and what level the prey was on. The role of an individual organism can even change during its lifetime as it grows from a juvenile to an adult.



Seldom is energy transfer in a community so simple that it can be entirely described by A eats B who has eaten plant C. In a natural community, food chains are not simple, independent units. They are linked together into complex food webs because every species is usually eaten by more than one species of predator and every predator usually eats more than one type of prey. A food web is a combination of all the food chains in a system.

Food webs describe the flow of energy and nutrients through a community. By looking at a food web, one quickly notices the interconnectedness of all the organisms in the community. Every species is affected, directly or indirectly, by all the other species. If the population of one species in a community declines through hunting, pollution, deforestation, loss of habitat, etc., there can be far-reaching effects, since all the predators who depend on that organism for food will also be negatively affected. Other organisms hunted by these predators are, in turn, affected by the decrease in predatory pressure. Thus, the human activities of overfishing, overhunting, air pollution, pesticide and herbicide use, and habitat destruction can go far beyond just a single species, sending shock waves throughout an entire community and ecosystem.

Energy Food Web



## Section E

## Disturbance

---

One reason the field of ecology is so challenging is that the natural world is always changing. For example, the competition theory states that, when two species use the same resource and that resource is limited in supply, the more successful species will exclude the other species. However, it is not that simple. Ecological communities are non-uniform, continually altering, and subject to random events of change. This makes ecology very different from chemistry and physics. Imagine the havoc if the elements in the Periodic Table had randomly changing atomic weights or if gravity unpredictably fluctuated in intensity.

Ecologists have recently begun to take the variability of natural systems into account by recognizing the importance of disturbance. Although to most people this word connotes an interruption of something pleasant, it has a somewhat different meaning to ecologists. Disturbance is defined as any relatively discrete event in time that removes organisms and/or makes available resources which can be exploited by individuals of the same or different species.

It is important not to place a human scale on disturbance. The impact of a raindrop is insignificant to a human, but it may kill a small organism. Therefore, ecological disturbances range in scale from something as small and transient as a footstep to an event as huge and prolonged as a hurricane, a volcanic eruption, or glaciation. As long as an event removes organisms from the community and/or makes resources available for exploitation, it is a disturbance. Disturbances are often a regular environmental feature, such as the pounding of waves along the coast or the fall of a tree in the forest.

Like other ecological factors, disturbance is a regulator of the abundance and distribution of organisms. In contrast to competition, disturbance limits populations whether or not the organisms were competing for limited resources. This means that disturbance interrupts competition, either preventing displacement of the inferior by the superior, or removing the superior allowing the inferior to thrive. Consequently, the less competitive species are able to survive, meaning the diversity of organisms often increases in a disturbed environment. In the absence of disturbance, the less competitive species would eventually be excluded from the community by the more competitive species.

Examples of increased diversity as a result of disturbance are common. There is frequently a very large number of plankton species in any given place in the ocean or an estuary. Ecologists have puzzled over why this is the case instead of a few species dominating through



competitive exclusion. The diversity of plankton is probably a result of the highly variable conditions of the ocean. Aquatic light levels, temperature, and nutrient concentrations change drastically from hour to hour and day to day. This variability prevents any one species from maintaining a competitive advantage, a process that has been observed in many different ecosystems.

One perceptive ecologist has even discovered that the disturbance created by a cow's hoof print in a moist field permits microbes to live in the field that would not otherwise be there. And when a tree falls in a forest, it may kill the few individuals unfortunate enough to be crushed under its bulk, but the newly-opened gap quickly becomes invaded by a rich diversity of plants that were unable to live there when the tree was standing.

## Succession

The invasion of newly opened space by new species is the first step of succession, one outcome of disturbance. Succession is the process by which newly available space is colonized by organisms and then is inhabited by a progressively changing community. The adaptations required to successfully compete change as the community changes over time. When a disturbance (e.g., hurricane, agriculture, etc.) occurs in a forest, it creates an opening that is first colonized by small herbaceous plants. If the system is left undisturbed, these plants are gradually overgrown by shrubs, then small trees, and finally by large trees that outcompete the other species. This process does not repeat until another disturbance occurs.

The size of a disturbance determines what kind of impact it has on a community. High level disturbances, meaning ones that are sizable and/or frequent (such as hurricanes), prevent a forest from ever getting beyond the early successional stage. High levels of disturbance do not promote diversity because very few organisms are able to survive in the face of repeated catastrophic events. Conversely, small, infrequent disturbances, like one person walking through a virgin forest every hundred years, have no significant impact on succession; they do not affect the survival of organisms enough to lead to maximum diversity. An important ecological concept is the intermediate disturbance theory, which says that intermediate levels of disturbance result in greater diversity than either high or low levels of disturbance. Disturbances that are intermediate in frequency or intensity prevent competitive exclusion of early successional species, yet allow continued presence of late successional species. As a result, both early and late successional species coexist, producing maximum diversity.



## Disturbance and Succession in a Salt Marsh

How does all this apply to estuaries? In addition to the plankton example mentioned earlier, salt marshes provide a good illustration of the role of disturbance in shaping communities. When one explores a salt marsh, one often finds areas in the high marsh that have much less vegetation than the rest of the marsh. These bare patches look like they have been scraped down to the soil by a bulldozer. Their formation is a result of disturbances that kill the vegetation in a given spot, such as the deposition of mats of dead plants or the grinding of ice floes in the winter. On the small-intermediate-large disturbance scale, these are large disturbances because all the resident organisms are killed, even the plants best adapted to life in the high marsh (salt hay, *Spartina patens* and black rush, *Juncus gerardii*). This leaves a patch of space available for invasion by new individuals.

However, this bare patch has extremely saline soil. It is totally uncovered and exposed to the sun, and evaporation has left behind much salt. Although salt hay and black rush are the dominant plants in the high marsh, they are not able to deal with the extreme salinity of a bare patch. Thus, a window of opportunity appears for other species that normally cannot compete with them. The pioneer species that invade a bare patch are glasswort (*Salicornia spp.*) and spike grass (*Distichlis spp.*). Glasswort is a succulent that readily grows there, and spike grass quickly follows by sending long runners into the bare patch. The spike grass tillers, or shoots, avoid the salt by receiving water through the runners from individuals living outside the patch, in less saline soils. Shade provided by glasswort and spike grass reduces evaporation and, in turn, salinity. Eventually the patch is hospitable to invasion by either salt hay or black rush, which displace the pioneers through competitive exclusion. If the patch remains undisturbed for several years, it will eventually host a pure population of either salt hay or black rush. If the patch is disturbed again, the progression of succession is reset to an earlier stage.

Looking around a salt marsh, you can identify the amount of disturbance in various places by inspecting the diversity of plants. If you see a patch inhabited only by glasswort, you can assume that area was recently affected by a major disturbance. If you find an area with a pure population of late-successional plants (salt hay or black rush), it probably has not been significantly disturbed for a number of years. And finally, if you find part of the salt marsh that hosts a diverse community of coexisting plants (salt hay, spike grass, and glasswort), it most likely indicates that the patch experiences an intermediate amount of disturbance that permits both early and late successional species to survive.

Although disturbance is a natural factor in every ecosystem and often has beneficial effects for the biota, humans additional disturbances that are very large and, as a result, very detrimental. The contrast between



natural and anthropogenic (human-created) disturbances lies primarily in the difference of scale. Storms or other natural disturbances may cause tremendous damage, but they happen randomly and usually infrequently.

Humans, on the other hand, create hundreds of acres of wetlands, methodically destroy huge tracts of rainforests, permanently pave acres of grasslands, pollute thousands of miles of rivers, and fill hundreds of wetlands. Natural communities simply cannot survive such immense and frequent disturbances. A marsh, will not be destroyed by one person walking across it just one time. However, if a group of twenty people tramps across the marsh, or if one person repeatedly uses the same route, the vegetation is adversely affected. The plants will be crushed and the peat will be compressed. Humans must recognize when their disturbances are large enough to destroy a community and respond by reducing or eliminating these disturbances.

Section F

# Adaptation

Ecologists are interested in individual organisms because they are the players in the levels that ecologists study: whatever happens to individuals affects populations, communities, and ecosystems. To an ecologist, one of the most important characteristics of an individual is how well it responds to changes in its environment in order to ensure survival. During its lifetime, every organism encounters changes in its environment. These changes can be abiotic (amount of wind, salt, light, etc.) or biotic (variations in competition, predation, parasitism, etc.). If an organism is to survive these changes, it too must be able to change in some way.

## Ecological Responses

When thinking about biological change, two different time scales are needed: ecological and evolutionary. Ecological responses happen during the lifetime of a single organism. For example, some birds are able to respond to cold winter temperatures by changing their behavior and physiology. When winter cold arrives, chickadees have about 50% more feathers than they did in the summer. These feathers trap more air, an excellent insulator, next to the bird's body. And, in winter, chickadees seek well-insulated spots such as snow-covered evergreens where they huddle with other chickadees. These behavioral and physiological responses increase the individual's chance of survival, and they happen in the course of its lifetime (i.e., on an ecological time scale). However, the range of possible responses by an individual is not infinite; it is ultimately limited by the organism's genes, which carry all the individual's behavioral and physiological information.

## Evolutionary Adaptation and Natural Selection

Evolutionary adaptation happens over the course of multiple generations of a species, and causes changes to occur in a species' genetic makeup. Adaptation occurs through a process called natural selection. Every population has some variation in the genes carried by its members. When an environmental change (either biotic or abiotic) occurs, it can act as a selective force for organisms with characteristics favorable to survival in the new conditions. Individuals that carry the genes that encode for these characteristics will survive, and those without the genes will die off before reproducing. The end result is that the genetic makeup of the population changes so that all the organisms are better adapted to (or capable of dealing with) that particular change in the environment. It is important to note that this all happens by chance. It simply depends on whether random genetic variation provides some individuals with traits that permit them to survive and reproduce more successfully than other individuals.

For example, grasses that live in salt marshes have certain adapta-



tions to the wet, salty environment. Salt marsh grasses are related, however, to other grasses that are not adapted to live in salt marshes. The two types probably have a common ancestor. Presumably, long ago, some of these ancient plants found themselves being frequently flooded by salt water. Most died or had low reproductive success because they had no way of dealing with the salinity and wetness, but a few individuals were, by chance, able to survive and reproduce. They happened to have traits (encoded by genes) that allowed them to survive the environmental change. Their progeny continued surviving and reproducing in wet, salty conditions. Eventually, these plants were genetically distinct enough that they could no longer interbreed successfully with the parental species. This is the definition of a new species. The descendants of these plants continue the successful genetic line today: we know them as salt marsh grasses.

## Speciation

Speciation, the creation of new species through natural selection, occurs when a selective force is intense, as it was in the previous salt marsh grass example. Speciation accounts for the diversity of living things on the planet today. Sometimes, however, evolutionary adaptations simply produce a population that is well-adapted to a particular environment without becoming a new species. For example, seaside plantain (*Plantago maritima*) grows tall (31.5 cm) in the marshes of Sweden (it is also found at the Wells Reserve), but plants of the same species grow in a dwarf form (20.7 cm) on the exposed cliffs of the Faeroe Islands. A significant height difference occurs even when the plants are grown side by side in an experimental garden subject to the same environmental conditions. The cliff population is evolutionarily adapted to grow shorter than the marsh plants, but it is not a different species. This is an example of genetic variation within a species that results in adaptation to local conditions.

An individual's ability to respond to its environment during its lifetime (change over an ecological time scale) is limited by the genes that it carries. Genetic makeup is in large part a result of natural selection for traits that improve an individual's reproductive success. In other words, the reason that today's chickadees grow more feathers in winter and behave to escape the cold is that some ancient chickadee ancestors happened to have genes enabling them to do this. The individuals that didn't have those genes died during the winter or had low reproductive success and the ones that did have those genes were able to reproduce. So today all chickadees, the descendants of those ancient surviving chickadees, are able to grow more feathers and find shelter in the winter. That is why adaptations on the ecological time scale are restricted by the genetic makeup of the individual.

An ecologist is interested in adaptive responses because they are important in determining where a species can live and how successful it is in a given location. This is the basis of ecology: distribution and abundance of organisms.

*Spartina patens* is a fine-leaved grass that grows 1-2 feet tall and often lies low on the ground in cowlick swirls. It dominates its zone in the high marsh, but several other plants can also be found there, including spike grass, seaside plantain, orach, glasswort, seaside arrowgrass, seaside goldenrod, sea lavender, and milkwort. Another distinct change in vegetation occurs at the transition between high and low marsh. Smooth cordgrass (*Spartina alterniflora*) -- broader-leaved and taller than salt hay - takes over from salt hay and dominates the low marsh right to the river's edge. Marsh zonation is a result of species' adaptations to the environment and their ability to compete with other species. (see Section J: Adaptations)

# ANIMALS:

Despite its lush vegetation, the marsh is home to relatively few terrestrial animals. Marsh grasses are thought to be low in nutritive value and to contain toxic compounds, so little of the vegetation is consumed by herbivores. Rather, most of the plants die and are deposited on the ground to become peat. Some are then washed into the water to become detritus, the base of the estuarine food web. Nevertheless, deer occasionally venture into the marsh to consume the grasses, as do grasshoppers. Canada geese graze heavily on marsh vegetation during their fall migration.

Raccoons and small mammals (e.g., shrews and mice) traverse the marsh in search of food. They are preyed upon by northern harriers and other birds of prey. Microbes are associated with plant roots in soil, and insects are sometimes (excessively) abundant in the air. Greenhead flies and mosquitoes are especially notorious inhabitants. But in general, estuaries are known as hosts of abundant aquatic and avian, rather than terrestrial, animals. Thus, the marsh community and food web are relatively simple, but they form an important part of the overall estuarine ecosystem.

The food web of an Atlantic coast salt marsh:		
Spartina		Spiders
Herbivorous insects	Passerines	
Dragonflies		
Bacteria	Bacteria	Bacteria
Detritus	Crabs	
	Mussels	Clapper rail
	Snails	Raccoon
Algae	Oligochaete worms	Annelid worms
Export		



**Salt Pannes:**

The salt pannes, or pools of water, that dot the marsh surface are an important feature of the Wells Reserve estuaries. Pannes range in size from only a foot or two in diameter to many feet across and are irregularly shaped and sized. Some form almost perfect circles, while others have complex shorelines. They vary in depth from a few inches to a couple of feet and have soft bottoms of sand, mud, or silt bottoms.

Panne creation is believed to be caused by something killing the grass, either wintertime ice floes, which scour patches of vegetation from the marsh surface, or mats of debris shielding the plants from sunlight or compaction. What's left behind is an area of unvegetated peat exposed to the sun. The sun's heat evaporates water from the soil, making it extremely saline and inhospitable to recolonization by plants. If no plants are able to establish themselves, the peat subsides and a water-filled depression, or panne, is formed.

Often, however, this process is interrupted when bare patches are invaded by glasswort (*Salicornia spp.*) and spike grass (*Distichlis spp.*). As a succulent plant, glasswort readily tolerates dry soils. Spike grass avoids the salt and dryness by receiving water through underground runners from individuals living outside the bare patch. When glasswort and spike grass colonize a bare patch, they shade the soil, reducing evaporation and salinity. Other plants, generally smooth cordgrass or salt hay, can then invade, preventing panne formation.

Pannes are flooded with salt water at varying frequencies, depending on their elevation in the marsh above sea level and whether they are connected to the river by creeks. If a panne experiences a long period without receiving rain or sea water, evaporation and solar heating can cause the pannes to become extremely saline, warm, and low in dissolved oxygen because of evaporation and heating by the sun. Seemingly, this would make difficult living conditions, but mummichogs, sticklebacks, and eels are well adapted to them (see Section M: River). In fact, salt pannes are an important marsh habitat, providing a home for numerous plants and animals. Often pannes teem with schools of fish and support large populations of algae and widgeon grass (*Ruppia maritima*), a submerged aquatic plant. Plants and animals of the pannes, in turn, provide food for diving and wading birds.

## REFERENCE APPENDICES

The phenomenon of species zonation is one of the most obvious examples of how biotic and abiotic factors interact to influence populations, communities, and ecosystems. But these factors shape the organization of natural systems in other less apparent ways as well. The goal of ecology is to understand these factors and the complex roles they play in the natural world.



## Section H

# Niche

---

Niche: The role of an organism in a community.

Even if a location provides suitable habitat for a species, it will not necessarily be inhabited by that species. This can be caused by any number of reasons (e.g., individuals have never happened to find that particular spot), but the absence of a species from suitable habitat is frequently a result of competition.

When two organisms use the same resource and that resource is scarce, the more successful organism will usually competitively exclude the other. Species coexisting in a community tend to avoid competition through specialized adaptations, so that each species has a unique role in the community. These roles, called niches, can be defined in many different ways, but each species uses the available resources in a unique way.

It is important to realize that while every organism has both a niche and a habitat, a niche is an abstract concept (the role of an organism within a community) whereas a habitat is a physical place that actually exists and can be seen.

The concept of the niche is most evident in the way that closely related species differ in their use of space, time, and food. For example, cormorants (*Phalacrocorax carbo*) and shags (*P. aristotelis*) are very similar birds and, at first glance, seem to have overlapping ecological requirements. Both species nest on cliffs and feed on fish but upon closer inspection, one sees that they actually have slightly different niches. Cormorants nest primarily on flat, broad cliff ledges and feed in the shallow waters of estuaries and harbors. Shags, on the other hand, nest on narrow ledges and feed mostly in the open sea. Without this slight distinction in one of the species might out compete the other for the available nesting space and feeding places.

Niches are important in the organization of communities, which can be broken down into broad niches and, further, into smaller, more specific niches. Within an animal community, the two most general niches are plant-eaters and animal-eaters. Each category can be further subdivided. The plant-eaters, for instance, can be divided into smaller niches: fruit-eaters, seed-eaters, leaf-eaters, berry-eaters, etc.

Niche separation can be extremely narrow and is not limited to differences in food sources. For example, the leaf-eater niche contains spatial niches for animals that eat leaves at the tops of trees as opposed to others that eat only the lower leaves. The coexistence of five closely-related species of warblers in New England boreal forests is an outcome of niche separation. The species feed at different heights, feed in different ways, and nest at slightly different times.

Although niche separation is most interesting to study between closely related species such as warblers, it is also important in the coexistence of less similar organisms. For instance, if nuthatches and chickadees living in the same area both use holes in trees as nest sites, and the populations of both are limited by the number of holes, there must be a difference in the kinds of holes that they use. Otherwise, one species would outcompete the other, and the less competitive species would be excluded from the habitat.

The organization of all natural communities can be traced to niches and species differentiation in the use of resources and so that each species plays a unique role in the community and tends to avoid competition. However, natural communities are never in a steady-state equilibrium (Section E: Disturbance), so the niche concept is simply a useful generalization about community organization. In the real world, species are constantly invading new places and being affected by environmental changes. Competition occurs as species vie for the available resources. When competition is less important than other limiting factors, successful species occupy unique niches.

### Section I

## Geologic Formation

---

### Geologic Formation of Estuaries

There are four types of estuaries:

- Coastal plain estuaries were formed as the rising sea invaded existing river valleys. Chesapeake Bay is an example of one such drowned river valley.
- Fjords are steep-walled valleys created by glaciers. They are common on Canadian coasts. The only fjord on the US east coast is Somes Sound in the Mt. Desert area of Maine.
- Tectonic estuaries are formed when geologic faulting or folding results in a depression, which is then flooded by the ocean. San Francisco Bay is an example.
- Bar-built estuaries are separated from the ocean by barrier beaches lying parallel to the coastline. Both estuaries at the Wells Reserve are in this category. Formation of bar-built estuaries is a two-step process: a barrier beach is created; then a marsh develops.



The creation of the present estuaries in the Gulf of Maine region began with glaciation during the last ice age. A massive ice sheet moved across the present Gulf of Maine until it reached Georges Bank between 20,000 and 18,000 years ago. At the location of the current Wells Reserve, the ice was about one mile thick.

### **Glaciers Recede**

The glacier began to slowly retreat between 17,000 and 15,000 years ago. Evidence of its decay can be found in the region surrounding the Wells Reserve. Numerous meltwater channels, crevasse fillings, and eskers (narrow ridges of gravel deposited by streams flowing within the melting glacier) are present in the area.

By about 11,500 years ago, the glacier had departed southern and eastern Maine. As the glacier moved northward, the shoreline moved with it. The glacier acted as an immense weight, depressing the land so it was beneath the sea. This, combined with the vast amounts of meltwater entering the world's oceans, caused the shoreline to move as much as sixty miles inland from the present coast. Ocean waves lapped at the edge of the receding ice, and the current Wells Reserve was covered by water approximately 700 feet deep.

### **Sediments Build**

It was during this period of submergence that the groundwork was laid for the eventual formation of today's marshes and barrier beaches. Streams of meltwater flowing through tunnels in the glacier transported large amounts of sediments to the glacier/ocean interface. These sediments settled out of the water to form a large clay/silt deposit known as the Great Sanford Submarine Fan. The material in this deposit would eventually be turned into the present marshes and beaches.

### **Sea Level Falls**

About 12,000 years ago, sea level began to fall rapidly at a rate of 5-10 cm per year. By the time the drop ended 1,000 years later, sea level in the Gulf of Maine had fallen a total of 182 feet. This sea level decrease was caused by an upward rebound of the land similar to what happens when you take a heavy weight off a seat cushion; it springs back up.

The rebound left previously submerged land high and dry above the ocean. The resulting seashore was then about 25 miles further east than it is today. Evidence of this is found in the large tree stumps that are occasionally exposed when parts of the marsh erode away. When the trees grew there (two white pine stumps in the Little River marsh have been dated to 4,500 and 3,200 years ago), they lived on dry land.

As sea level fell, however, the Great Sanford Submarine Fan was reworked by waves, storms, and tidal currents. And when sea level had decreased so far that the ocean was no longer in contact with the Fan, the sediments were eroded by the Kennebunk, Mousam, Branch,



Merriland, Little and Webhannet Rivers, which transported particles to the sea. Materials from the Great Sanford Fan were deposited on the continental shelf as they settled out of the water.

### **Sea Level Rises**

By 11,000 years ago, sea level reversed its trend and began to increase at a rate of about four centimeters per year. Sea level rise was accompanied by sand movement in the same direction; sediments originally from the Fan that had been deposited to the east during lower sea level were reworked westward by the rising waters. During this period of rapid sea level rise, the sand was shaped into barrier beaches and islands, but these formations were low, thin, discontinuous and extremely unstable. The rising sea level caused them to rapidly migrate to the west.

### **Barrier Beach Forms**

Only when sea level rise drastically slowed about 4,000 years ago did the string of barrier beaches become fairly well stabilized in more or less its present location. Migration of barriers was impeded in places by elevated spots of bedrock or glacial topography, to which the moving barriers became pinned.

Southern Maine's barrier beaches were formed primarily from inland sediments carried to sea by rivers and then transported shoreward again by a rising ocean. Rocky headlands played an important role by blocking shoreward progress of the barriers.

Headlands may have been anchoring sites from which beach spits originated, growing like sandy fingers parallel to the shore. Most of the sand came from the Great Sanford Submarine Fan, but some percentage of sand in the beaches may have come directly from sediment deposits left along the present shoreline by glaciers. These deposits are believed to have entirely eroded away as they are no longer present.

### **Marsh Forms**

The presence of a stable barrier beach led to the development of the marsh. First, a calm bay formed behind the beach. Because of the raised sea level, this bay flooded what had been a white pine forest on dry land. The barrier beach buffered the bay from ocean waves and the calm waters permitted silt and clay to accumulate on the bottom. These sediments, which came from both the river and the ocean, are comprised of very small particles, so they only settle out of very slow-moving water.

### **Peat Forms**

As sediments built up on the bottom of the bay, they allowed plants to take root and invade the water. A marsh was born. The plants then hastened the process of sediment deposition by further slowing the movement of water. Their leaves impeded water motion, causing even more sand, silt, and clay to settle out onto the bottom of the bay.



Slowly a layer of peat began to develop. Peat is a type of soil comprised largely of undecomposed plant matter. Each year, only a small amount of the annual plant growth in a salt marsh is eaten by herbivores. When the plants die, some are washed away by the tides, but much of the dead plant matter is deposited onto the ground. Microbial decomposition of the vegetation is slowed by its wetness and coldness, so bits of dead leaves mixed with sand and silt from tidal flooding gradually build up, layer upon layer, year after year. As a result, the elevation of the marsh is constantly increasing with the accumulation of dead organic matter and with the rising sea level.

Peat formation is dependent on the soil being flooded with water. Thus, peat accumulation can keep up with sea level rise but will not grow above the level of the ocean.

When you stand on the Wells Reserve marshes, you are standing on peat up to 14 feet thick. Underneath the peat lies the foundation of inorganic mud and clay left behind by the receding glacial sea. Peat accumulates very slowly, taking about twenty-five years for an inch of peat to be deposited in our marshes. The bottom layers date back approximately 4,000 years.

Geologists study the history of the marsh by examining layers of peat, which are analogous to annual rings in a tree trunk. The scientists press a tubular coring device deep into the peat, all the way to the clay foundation, and extract a pipeful of sediment. The core provides a record of past geological and biological events. By identifying preserved pollen and chemically dating layers within the core, geologists can determine what plants lived in the area in the past, how sea level varied, and how sea level changes affected vegetation.

Although the trend is for peat to accumulate apace with sea level rise, river banks in a marsh are at the mercy of the currents. Banks can quickly erode in one location and grow in another. The path of the river changes as it carves new routes through the marsh. Gouging by ice floes and storm waves can remove large chunks of peat from along stream banks and deposit them elsewhere. Creeks meander like veins, providing drainage for the marsh and hiding places for small fish.

### **Beach Migrates**

The beach associated with a bar-built, marsh-dominated estuary is called a barrier beach because it is literally a barrier between powerful ocean currents and waves, and the marsh. If the beach were not there to impede the water's motion, the marsh would not have formed. Tiny silt particles would not have settled out onto the bottom and then plants would not have been able to invade.

If the barrier beach were removed today, the marsh would rapidly deteriorate as fast-moving, energetic ocean water removes the

sediments. Even with the extra security of roots holding together the soil, the marsh would quickly erode.

Under conditions of rising sea level, barrier islands and beaches migrate toward the mainlands. Barrier migration is a separate process from marsh development, but it affects the marsh. At Wells, barrier migration has been slow, yet continuous, since the slowdown in sea level rise about 4,000 years ago. Geologists estimate that the positions of southern Maine barrier beaches have not dramatically changed in the last 1,300 years although they are still moving toward the mainland. Slowly, entire barriers shift inland, smothering ancient marshlands in the process. Evidence for this lies in the chunks of prehistoric peat that are frequently exposed when beaches are eroded by storm waves.

Barrier beach migration is caused by the continually rising level of the oceans. Each year, waves and currents reach slightly higher and carry sand further inland. This is particularly noticeable when storm waves break through dunes and create washover fans by transporting large amounts of sand into the back reaches of the barrier. Over thousands of years, this periodic transport of sediment makes the entire barrier migrate toward the uplands. This has important ramifications for owners of barrier-beach real estate properties. Unfortunately, these are in an inherently unstable environment, and practical human technology or construction effort can counteract the immense power of coastal geologic processes.

In sum, an estuary is a dynamic place, geologically speaking. Sediments eroded from the uplands continue to be transported into the marsh by the river, and sand from the ocean continues to be carried in by strong flood tide currents. Once in the estuary, sediments are constantly shifted around and new creeks, salt pannes, sand bars, and river sinuosities frequently develop. Waves incessantly reshape the beach, and a single storm can completely alter its configuration.



## Section J

# Tide

---

Tides can be the most important natural phenomenon affecting estuarine organisms. Within estuaries, the occurrence of tides results in highly-variable and constantly fluctuating salinity, currents, and water levels. These drastic variations make estuaries extremely harsh and demanding places to live.

The Gulf of Maine, like the rest of the east coast of North America, has semidiurnal, or twice-daily, tides. Approximately 12 hours and 25 minutes passes between successive high tides or successive low tides. Other parts of the world can experience different tide patterns as a result of geographic conditions that affect the movement of water. In the Gulf of Mexico, tides are diurnal, meaning there is only one high and one low tide each day. The Pacific Coast of North America is affected by mixed tides, a combination of semidiurnal and diurnal tides; places with mixed tides experience a high tide, a low tide, a higher high tide, and a lower low tide.

Tidal heights are measured relative to mean sea level, the average height of the ocean. Tidal range is the difference between high and low tide. At Wells, the average tidal range is about eight feet. The Bay of Fundy, in contrast, acts like a funnel to pile up water, and the tidal range exceeds twenty feet. Many places have small tidal ranges, and some (called amphidromic points) have a tidal range of zero. In narrow channels like an estuarine river, one often notices rapid currents arising from the tidal motion of water. A flood tide occurs when the tide is rising, and an ebb tide happens when the tide is falling. Moments of slack water (no water movement) separate flood and ebb tides.

Tides are caused by the earth, the moon, and the sun. The two major forces driving the tides are the moon's gravitational pull on the earth's oceans and the opposing centrifugal force resulting from the orbit of the moon around the earth. The sun also plays a role, but its gravitational force is smaller than the moon's because the sun is so much further away. The combined influence of these forces causes water in the oceans to be pulled into two large tidal bulges on opposite sides of the earth. As the earth rotates daily on its axis, high tide occurs when a point on the earth's surface is in one of these bulges, and low tide happens when the point moves out of the bulge.

As the Gulf of Maine moves into one of these bulges in the course of Earth's daily rotation, water level rises and we experience high tide. We have low tide about six hours, or a quarter of a day, later because the earth has spun a quarter of a rotation, and we have spun out of the bulge. As the rotation continues, another high tide develops as

we move into the other bulge. This pattern continues, causing the alternating rise and fall of the tides that we see at the seashore. Incidentally, tides also rise and fall in the deep ocean, but they are not noticeable because of the lack of a fixed reference point like land.

Tidal ranges are not constant. They vary depending on the relative positions of the sun and the moon; changes in these positions affect the size of tidal bulges on Earth. The greatest difference between high and low tides occurs during full or new moons, when the forces of the moon and the sun are in line with one another. This alignment of forces happens twice each month and the resulting maximum tides are called the spring tides. The smallest difference between high and low tides, called neap tides, happens during the first and third quarters of the moon when the forces of the sun and moon are at right angles. The forces somewhat counteract each other and produce smaller tidal bulges.

The influences of tides make estuaries extremely dynamic environments, where salinity, water level, and currents are always in flux. This variability makes them ecologically challenging places in which to live.

The strength of the moon's gravitational pull, however, is different in different positions on the earth. It is stronger on the side of the earth facing the moon (because that side is closer to the moon), and weaker on the side facing away from the moon (because that side is further away from the moon). This variation is important to tides because on the side of the earth facing the moon, gravitational attraction outpulls centrifugal force: a tidal bulge forms. Conversely, on the opposite side centrifugal force is stronger than gravity, and another tidal bulge forms.

Centrifugal force is the force you feel when you swing a ball on a string around your head; it is directed outward from the center of rotation. Centrifugal force arising from the motion of the moon around the earth is equal on all sides of the earth.

Unfortunately, these are in an inherently unstable environment, and practical human technology or construction effort cannot counteract the immense power of coastal geologic processes.



## Section K

# Watersheds

---

Watersheds are what link all of us, no matter where we live, to estuaries. A watershed is an area of land that drains into one river, stream, or other waterbody. It is analogous to a bowl. If you drip water onto any spot inside the rim of the bowl, it flows down to the bottom. If you drip the water outside the rim, it does not flow into the bowl.

In watershed terminology, the area contained within the bowl is the watershed, and the rim of the bowl is the divide. Every waterbody has an area of land from which it receives water—its watershed, or inside of the bowl. Mountains, hills, and other high-relief features form the divides, or bowl rims, between watersheds. Precipitation falls onto the watershed and flows to the body of water as either runoff over the surface of the land, groundwater through the soil and rock, or surface water in streams, brooks, and rivers. The watershed of an estuary is the watershed of the river that flows into it, which may cover tens, hundreds, or thousands of square miles.

Watersheds link habitats together, since a drop of rain falling in one place flows through many habitats during its journey to the ocean. The fallen raindrop may pass through forests, grasslands, swamps, cornfields, somebody's lawn, a parking lot, and a salt marsh before finally reaching the sea. Therefore, rivers, streams, and brooks are similar to the blood vessels in our bodies. A contaminant finding its way into one location in a watershed will eventually be transported to other parts of the watershed, so pollution introduced into one habitat may well be carried to many others and thus have wide-ranging effects. The clearly defined boundaries of watersheds make them ideal units of study for ecologists. All the populations, communities, and abiotic components are combined in an ecosystem defined by topography and a network of waterways.

Watersheds can be defined according to different size scales. A tiny brook receives water from a small watershed. The stream that the brook flows into has a watershed that includes the brook's watershed and the watersheds of all the other brooks that flow into the stream. That stream flows into a river, in turn, and the river's watershed comprises the watersheds of all the streams that flow into it. The watersheds of major rivers can be immense. For example, the watershed of the Mississippi River drains much of the Midwest. The two rivers which flow through the Wells Reserve, on the other hand, have relatively small watersheds. The Little and Webhannet Rivers have watersheds covering about 40 and 14 square miles, respectively.



## Section L

## Barrier Beach

---

A string of barrier beaches lines much of the Atlantic coast of the United States. Barrier beaches are ribbons of sand that lie a short way offshore, often separated from land by marsh-filled estuaries (Section I: Geologic Formation of Estuaries). They may be attached to the mainland at one or more points, or they may be islands. Barriers play an important role in the functioning of an estuary. By breaking the impact of ocean waves, they protect the estuary and uplands from waves and erosion, facilitating marsh formation and making the estuary a calm haven for the survival of animals and plants.

Barrier beaches are constantly battered by the pounding of the ocean. Though barrier beaches are taken for granted during summer by hordes of humans, they are unique habitats that support interesting communities of organisms. Like marsh and rocky intertidal habitats, the barrier island community displays a pattern of zonation (as discussed in Section G: Zonation).

What causes beach zonation? Numerous beach creatures struggle against the pounding waves, the gusting winds, the salty air, the shifting grains of sand, and the poor supply of nutrients. Barrier beach zones reflect species's adaptations to these challenging abiotic conditions.

Ecological disturbance and succession are also important in shaping barrier beach communities (Section E: Disturbance). A devastating amount of natural disturbance, in the form of waves, occurs at the beach/ocean interface—so much that succession is permanently prevented from proceeding. Disturbance decreases with distance from the ocean, and successional development of the plant and animal communities becomes evident. The foreshore, or beach face, is the harshest part of the barrier. The dominant abiotic factors there are wave action and the constantly moving substrate, which strongly affect the structure and adaptations of the foreshore community. In order to live on the beach, organisms must be able to tolerate these conditions.

Successful beach organisms include macroinfaunal invertebrates like surf clams, amphipods, isopods, polychaete worms, and meiofaunal organisms which are so small that they swim between sand grains. Bacteria and meiofauna are important members of the beach community and are often far more abundant than the larger, more visible animals.

The absence of substantial plant growth on the beach means that no large herbivores live in the community. Furthermore, there are few resident carnivores on the foreshore; a carnivore needs to move actively



in search of prey, and wave action precludes this life style. (Transient predators like shorebirds do occur.) Consequently, most animals living on the open beach are suspension feeders that filter food particles out of the water. These particles may be plankton, meiofauna stirred from the bottom by waves, or detritus suspended in the water. Very little detritus originates on the beach because of the lack of plant growth, but enough detritus is transported from other places that a reliable food source is provided for beach animals.

The plant community on the northern end of Laudholm Beach displays five distinct zones:

- 1) Frontal dune ridge-American beach grass, beach pea
- 2) Beach grass with beach heather, lichens
- 3) Beach grass with beach heather, lichens, abundant Greene's rush
- 4) Beach grass with bayberry, meadowsweet, cherry, shadbush, isolated pitch pines
- 5) Forest of pitch pine and tall hardwoods

Seaward of the foredune beach grass zone, nutrients provided by the wrack line (the string of debris stranded by the last high tide) support a few plants, called pioneer species, which are hardy enough to withstand extreme conditions. They are adapted to be highly salt tolerant and able to quickly establish themselves in a shifting substrate. Pioneer species in the northeastern United States include sea rocket (*Cakile edentula*) and saltwort (*Salsola kali*), annuals which grow rapidly and produce many seeds. They mark the seaward edge of the foredune zone, where flooding by spring tides and winter storms occurs.

Normally the wrack line left by the highest spring tides is the only one colonized by pioneer plants. Lower wrack lines suffer from substantial natural disturbance; frequent waves wash plants away before they can establish themselves. Wave-induced disturbance is sufficiently reduced in frequency and intensity at the higher wrack lines and therefore plant growth is possible.

Pioneer plants that invade the foredune gain a valuable foothold which permits exploitation by non-pioneer species. Behind the front lines of pioneer species lies the primary dune and the dune-building species: American beach grass, beach pea, and dusty miller. Living above the reach of spring tides and most storms, these species represent the next stage of succession after the pioneer species. They are able to survive because of the protection from disturbance afforded by the pioneer species.



Dune-building plants, especially beach grass, cause dunes to form by breaking the flow of wind. The process is initiated when a plant, log, or rock creates a wind shadow. Sand grains drop out of the interrupted airstream and are deposited onto the ground. Gradually a mound of sand, known as an embryo dune, accumulates. Over time, it develops into a full-fledged dune.

This might seem disadvantageous for the plants, which become buried. But not surprisingly, dune-building plants are adapted to deal with sand accumulation. Beach grass tolerates burial in up to one meter of sand per year. It reproduces by sending out horizontal underground runners called rhizomes. Every few inches along the rhizome a shoot extends up to the surface. This phenomenon is most evident if you can find an area of the foredune with a sparse population of beach grass. Look for plants—one large and the others smaller—lined up in a row. If you were to dig up the sand, you would find a rhizome and discover that the small plants are clones of the large one. Through this process, one beach grass plant can quickly become many, hastening dune formation. In fact, burial with sand is beneficial to beach grass, causing it to reproduce more, redirecting rhizomes to grow vertically and to send shoots through the surface.

Dune-building plants also succeed by having a variety of traits that make them desiccation-resistant:

- Dusty miller and beach heather are coated with small hairs that decrease evaporative water loss by reducing air motion next to the plants leaves.
- Succulence, a familiar characteristic of cacti, decreases a plant's surface area to volume ratio, reducing evaporation. Sea rocket, orach, sandwort, and saltwort all share this feature. The leaves of upland shrubs inhabiting dunes are more succulent than those of individuals living away from the shore.
- Curled leaves, such as those of American beach grass and broom crowberry, help prevent water loss.
- Most dune plants have a thick cuticle to seal in water. As with succulence, shrubs living on dunes have thicker cuticles than individuals of the same species living inland.
- Many plants living in dry habitats use a modified series of photosynthetic reactions, called C4-photosynthesis, that helps reduce water loss. On the dunes, sea beach orach makes use of this physiological adaptation.

Life behind the primary dune is more sheltered than on the dune itself. This back dune area is less exposed to wind and receives less salt spray. Organisms there are subjected to what could be considered intermediate disturbance, as opposed to the large amount of disturbance



on the primary dune and beach (Section E: Disturbance). Intermediate disturbance promotes biodiversity as the successional clock is occasionally reset. Competitive plants coexist with species adapted to extreme conditions.

At Laudholm Beach, the area of the back dune immediately behind the frontal dune is inhabited by a mixture of grasses, beach heather, and lichens, which are common on the Maine coast because of the fog. Slightly further inland lies a narrow band of Greene's rush. Then comes a community of bayberry, meadowsweet, cherry, shadbush, and isolated pitch pine.

Animals unable to live at the sea's edge can thrive in the backdune. Rabbits, mice, snakes, and voles are hunted by harrier hawks and owls. Sparrows and grackles forage throughout.

Maritime forest, the final stage of succession on barrier islands, occurs in the least disturbed zone. Pitch pines, maples, oaks, cherries, and alders live along the back edge far away from the sea, where only the fiercest storms reach. Trees are pruned short; salt spray kills any high branches. Cherries are eaten by robins and cedar waxwings. Raccoons nest in tree trunks, and foxes find shelter among the brush and debris. Storm waves occasionally overwash the dunes and flood back into the maritime forest, depositing sand and cobbles at the base of the trees. This is evidence of shoreward barrier island migration. It can eventually result in the formation of new inlets as well.

Human activity on dunes is highly detrimental. Trampling footsteps easily erode dunes, kill plants, and disturb animals. Two endangered bird species nest on the Wells Reserve beaches and are bothered by human presence. The piping plover (*Charadrius melodus*) makes a lined nest among grass tufts on sand and gravel beaches. It feeds on marine worms, crustaceans, mollusks, and eggs of invertebrates. The least tern (*Sterna antillarum*) must have shallow water near its nest to forage for crustaceans and insects.

Laudholm Beach is home to three unusual plant species as well. Wormwood (*Artemisia caudata*) reaches the northern limit of its coastal range at Cape Elizabeth and is uncommon in Maine, as is earthstar puffball (*Geaster hygrometricus*) which is found in only a few coastal dune areas in Maine. There are probably less than 16 acres of beach heather (*Hudsonia tomentosa*) in the entire state of Maine, but Laudholm Beach has good-sized strands of it. Beach heather is slower growing than American beach grass, making it more vulnerable to foot traffic. It takes decades for it to invade dune areas.

**Section M**

# River

---

## **The River Community**

The river community is a diverse assemblage of organisms. Creatures inhabiting the water column (meaning only the water in an aquatic system and not the bottom) include everything from intricately-shaped microscopic plants to large marine mammals. Some special terminology is needed to discuss the riverine food web, since aquatic organisms are so different from more familiar terrestrial organisms. Aquatic organisms can be divided into two general groups: nekton and plankton. Nekton are all the aquatic animals that can swim through the water against currents: marine mammals, fish, squid, and some crustaceans. Plankton, on the other hand, refers to all waterborne organisms that cannot swim through the water column and are transported from place to place by currents.

## **Plankton**

Some people define plankton as tiny microscopic plants and animals. This is a misconception that not all plankton are small, much less microscopic. Jellyfish, for example, are often relatively large, but they are plankton because they simply drift with the currents. Plankton are subcategorized based on whether they are plants (phytoplankton) or animals (zooplankton), and whether they remain plankton for their entire life (holoplankton) or just part of their life, usually as larvae (meroplankton).

Plankton are some of the most abundant organisms on earth, yet they are also one of the least familiar life forms to humans. Most plankton are exceedingly small - too small for humans to notice, even though whenever we dive into a lake or the ocean we are swimming in a plankton soup.

The abundance of plankton varies greatly depending on the local conditions, but a gallon of seawater might contain a million or two phytoplankton, several thousand zooplankton, and roughly a billion bacteria plankton. In fact, seawater sometimes appears green because it contains chlorophyll-containing phytoplankton. Plankton live within a realm of which most people are totally unfamiliar, but it is a world worth discovering for its wonder-inspiring complexity, beauty, and importance.



## Phytoplankton

Phytoplankton are most abundant in places with an adequate supply of nutrients, such as coastal waters receiving nutrients from or inflowing rivers or regions of upwelling in the ocean where current patterns cause nutrient-rich water to surface.

Phytoplankton need light for photosynthesis, so they have special adaptations to help them stay near the surface of the water where light is most abundant. Some plankton have tiny spines or wispy appendages to increase their surface area/body mass ratio and thereby enhance flotation. Others have oil in their bodies to increase buoyancy.

Diatoms are one of the most common groups of phytoplankton. When viewed under a microscope, they are undeniably beautiful. Diatoms are single-celled organisms, although they may form chains. Their exterior fits together like a shoe box, with two elegantly ornamented halves made of silica. Most diatoms are photosynthesizers, but some can also obtain food energy even in darkness by ingesting sugars and amino acids. In fact, some diatoms don't have any chlorophyll at all and are unable to photosynthesize.

Diatoms are notable for their method of reproducing. Their two walls split apart asexually and each half grows a new half. The dilemma is that the new half of each diatom is smaller, to fit inside the older one, so one line of descendants gets smaller with each generation. Once they reach a lower size limit, however, the diatoms reproduce sexually to re-establish a large size. They reproduce very quickly; a population of diatoms can grow sixty-four times larger in just one day.

Dinoflagellates are another common type of phytoplankton that are most abundant in autumn. They are single-celled creatures with two whip-like tails, called flagella, used for propulsion. Despite this animal-like feature, dinoflagellates are classified as plants.

Dinoflagellates are responsible for the only two planktonic phenomena commonly attracting human attention: one for its magic, the other for its potential harm. If you have ever gone night swimming and found that with every stroke the water lit up with a cool, blue-green, mysterious glow, you have shared the water with millions of dinoflagellates -- most likely *Noctiluca* species. Many dinoflagellate species are capable of bioluminescence, the production of light through biochemical processes. The same type of chemical process used by fireflies is utilized by dinoflagellates and other bioluminescent marine animals. No one knows exactly why some marine animals bioluminesce, although theories abound. Some suggest, for example, that a flash of light acts like a burglar alarm to protect the bioluminescent creature from predators. Others believe that it is a form of communication.



Dinoflagellates are also responsible for the dreaded “red tides” that occasionally bathe our coasts in reddish or reddish-brown water. Red tides are caused by massive population outbreaks of certain types of dinoflagellates, *Gonyaulax* species and *Gymnodinium* species, in the Gulf of Maine. These dinoflagellates contain substances toxic to humans. When they are abundant, the microscopic creatures accumulate in the organs of filter feeders like clams, making the clams dangerous for us to eat. Shellfish beds are closed during red tide episodes to prevent humans from suffering paralytic shellfish poisoning (PSP). PSP can kill animals even bigger than humans, such as whales.

Coccolithophores are a third common type of phytoplankton. They are spherical and their surfaces are covered with numerous plates of calcium carbonate ( $\text{CaCO}_3$ ), making them resemble soccer balls. Coccoliths, as they are often called for short, are more important offshore but sometimes have population spurts at inshore locations such as estuaries.

## Zooplankton

If we imagine the river to be a field, then phytoplankton are the grass and some types of zooplankton are the sheep. Just as we commonly think of sheep grazing on grass in a field, scientists often refer to the grazing rate of zooplankton on phytoplankton. It is important to note, however, that although many zooplankton are herbivores (analogous to sheep), many others are actually carnivores that eat other zooplankton (analogous to wolves). Thus, even though plankton are often too small for us to see without a microscope, some zooplankton operate relatively high on the food chain—the third trophic level (Section D: Food Webs).

Copepods are one of the most common herbivorous zooplankton. Most species eat phytoplankton as their primary food source, filtering them from the water with hairy appendages. Copepods are crustaceans, meaning they are relatives of crabs and lobsters. The family resemblance is apparent, but the glaring difference between copepods and lobsters is that copepods often have clear bodies (although some are colored, sometimes even blue). Under a microscope, one can sometimes see the copepod’s internal organs. Copepods range in size from less than one millimeter to several millimeters long. Copepods are not shrimp. A different type of zooplanktonic crustacean, the euphausiids (better known as krill, whale food off Antarctica), are a type of shrimp, but they occur mostly offshore.

*Cladocera* species can be very common in estuaries and nearshore waters, although they are less abundant than copepods in marine systems. *Cladocera* are carnivores that eat other zooplankton.



Among the more familiar types of carnivorous zooplankton are the jellyfish. True jellyfish belong to a group of animals scientifically called cnidarians, which also includes sea anemones, corals, and hydrozoans. True jellyfish are distinct from the comb jellies, or ctenophores, that are also very common in the Gulf of Maine. It is a misnomer to refer to comb jellies as jellyfish. Both have transparent, gelatinous bodies and both eat zooplankton, but jellyfish and comb jellies are different types of organisms.

Many true jellyfish, including the common moon jelly *Aurelia*, alternate between two main body forms during their life cycle. The more familiar form is the free-swimming medusa stage, characterized by a bell-shaped, parasol-like body that pulsates in order to move. The other body form in the life cycle is the polyp, which remains attached to a hard surface.

Medusae typically feed by capturing a variety of small animals, particularly crustaceans and sometimes fish, with their tentacles. Moon jellies, however, have only a fringe of small tentacles. Suspension feeders, they trap plankton on their mucus-covered surfaces. Hair-like flagella then sweep the food into the mouth.

Many people incorrectly call the notorious Portuguese man-o-war (*Physalia* species) a jellyfish. In fact, it belongs to another type of cnidarian, the hydrozoans. The Portuguese man-o-war is a member of the siphonophores, an interesting sub-group of hydrozoans. Siphonophores are actually colonies comprised of numerous individuals, each specialized for locomotion, feeding, or reproduction. The man-o-war's long tentacles are made up of many specialized individuals.

Comb jellies, or ctenophores, have a different body structure from the true jellyfish. Many are egg-shaped and have eight rows of pulsating "hairs" running along their sides to provide propulsion. Each row is a series of clusters of cilia, each of which resembles a comb—hence the animals' scientific name (ktenes means combs in Greek). Some ctenophores have adhesive tentacles used to catch prey, especially copepods. Ctenophore populations tend to increase in the summer.

All of the previously mentioned zooplankton, except for the cnidarians, are holoplankton. They spend their entire lives as plankton. Many other organisms, however, start out life as planktonic larvae, or meroplankton, and then develop into non-planktonic adults. A number of familiar creatures begin life as meroplankton: barnacles, sand dollars, sea stars, sea urchins, crabs, eels, spiny lobsters, and many varieties of fish. Magnified, the larvae often look like mysterious alien beings with little or no resemblance to the adult form we are quite used to seeing.

**Plankton  
Population  
Dynamics**

Meroplanktonic larvae float in the water until they metamorphose into adults and settle out of the water column (if they are a benthic species). Having planktonic larvae helps a species such as the barnacle to invade new territory, but mortality of larvae is great, since the probability of randomly settling onto a suitable substrate is low.

Plankton populations fluctuate on a seasonal basis. At temperate latitudes, phytoplankton populations rapidly decline in winter because of decreased light levels, which do not provide much energy for photosynthesis. The dearth of biological activity leads to an accumulation of nutrients in the water column. This permits a huge burst of phytoplankton growth, called a bloom, to occur in spring when light availability increases. The bloom is only temporary, however. The abundant phytoplankton put a great demand on nutrients, which become scarce. Phytoplankton populations decrease in size as a result.

Nutrient depletion continues to limit phytoplankton populations in the summer. The effect is compounded as the sun warms the surface waters, and the populations become separated from deeper waters by a seasonal thermocline: warm water forms a distinct layer on top of the more dense colder water. When nutrients in the surface waters are depleted by phytoplankton growth, the thermal gradient prevents them from being replenished from below. Consequently, phytoplankton are scarce during summer.

Another phytoplankton bloom occurs in autumn. Cooler surface temperatures cause the thermocline to disappear. Nutrients are then returned to the surface waters, permitting more phytoplankton to grow. The autumn bloom is smaller than that of the spring. Its size and duration are limited by decreasing light levels, as opposed to the spring bloom which is ended primarily by nutrient depletion.

Zooplankton populations increase in response to the spring phytoplankton bloom. The increased food source provided by the bloom permits rapid zooplankton population growth. Grazing by zooplankton serves to reduce phytoplankton abundance and assists in ending the spring phytoplankton bloom. Meroplanktonic larvae of benthic invertebrates may be abundant in early summer. The autumn phytoplankton bloom is too small and too late in the year to stimulate another zooplankton bloom, so zooplankton abundance steadily decreases toward the end of summer.



**FISH:**

In the water column food web, fish occupy most of the trophic levels above plankton. Some fish species are estuarine residents, spending most of their time there, while other fish come and go from the estuary. The former tend to be small fish that occupy the lower trophic levels. At the Wells Reserve these include mummichogs, sticklebacks, Atlantic silversides, American sand lance, pipefish, and American eels.

Larger fish visit the estuary to feed or spawn. At the Wells Reserve, these include bluefish, striped bass, herring, alewife, Atlantic tomcod, white hake, rainbow smelt, brook trout, brown trout, white perch, and winter flounder. Rivers along the Maine coast have been altered by humans through the construction of dams and the impoundment of marshes. Fish that were historically abundant at the Wells Reserve or in neighboring estuaries but are now rare or nonexistent include Atlantic salmon, striped bass, sturgeon, and shad.

Resident fish tend to be small and abundant. They are often called minnows, an umbrella term for small fish. Mummichogs (*Fundulus heteroclitus*) are one of the most common fish species at the Wells Reserve. They are predominantly brown, although the male has a noticeable series of vertical silver bands on his tail. Mummichogs are small, reaching a maximum length of only 75 mm.

Despite their small size, mummichogs are extremely hardy. They can tolerate low dissolved-oxygen conditions, extremely high temperatures (up to 34°C), and salinities up to an incredible 120 ppt, almost four times the salinity of sea water. This makes them well-suited for life in the variable conditions of a salt marsh. In fact, in addition to the river, mummichogs are very common in salt pannes, which have salinities ranging from almost fresh (after a rainstorm) to very salty (after long periods of hot sun without inputs of water from rain or tides). Water temperature in salt pannes fluctuates between very warm under the summer sun to freezing in the winter. Mummichogs survive the winter by burying themselves in the mud or hiding in holes in tidal streams.

Mummichogs live their whole lives in the estuary. Spawning takes place from April to August, and it occurs during the spring tides associated with new and full moons. High spring tides allow the fish to leave the isolated pannes and travel through the flooded marsh grasses to other pannes or the river.

Mummichogs are omnivores. They eat small crustaceans, worms, vegetation, small fish, and fish eggs (even mummichog eggs). They are notable for eating mosquito larvae. It is estimated that an adult mummichog can eat from 400 to 2,000 mosquito larvae per day. Mummichogs are an important estuarine food source for larger fish, birds

such as egrets and herons, and land animals that feed from the water's edge.

Atlantic silversides (*Menidia menidia*) are schooling fish that prefer sandy and gravelly shorelines. They reach a maximum length of 13.7 cm and have a long, distinctive band of silver that runs horizontally along their body. Adults enter estuaries to spawn in April and May and then return to sea. Young fish migrate to sea at the beginning of September. While in estuaries, silversides can be found swimming amongst the flooded marsh grasses at high tide. They typically live about 12 to 18 months. Silversides are carnivores that feed on copepods, worms, shrimp, and insects. Their feeding is most intense during ebb tides. Bluefish, striped bass, and many birds prey on silversides.

Sticklebacks, so named for the small spines that line their bodies, are another group of common, small (up to 75 mm long) estuarine fish. The Wells Reserve is home to three species of sticklebacks: threespine (*Gasterosteus aculeatus*), fourspine (*Apeltes quadracus*), and ninespine (*Pungitius pungitius*). Fourspine sticklebacks, which feed on plankton, have the highest salinity tolerance of the group. They are eaten by eels, mummichogs, tomcod, and other sticklebacks. Threespine (a voracious predator) and ninespine sticklebacks eat small crustaceans and invertebrates. They are preyed upon by fish, mergansers, night-herons, and small mammals. Sticklebacks are interesting for the males' habit of building nests for spawning. The nests, which are either cup or tubular shaped, are constructed out of plant bits and mucous. Females deposit eggs in the nest and the male quickly fertilizes them.

Three other small estuarine fish are notable for their unique characteristics. American sand lance (*Ammodytes americanus*), sometimes called sand eels, are thin fish that can form large schools, but also burrow into sandy bottoms. Sometimes they even remain in the sand, head sticking out, after the tide recedes. Sand lance prey on copepods, worms, fish fry (even their own species), amphipods, and isopods. They are, in turn, eaten by Atlantic cod, haddock, pollock, herring and great black-backed gulls, and mammals, including fin and humpback whales.

Pipefish (*Syngnathus fuscus*) are slender, elongate fish related to seahorses. Reaching lengths up to 30 cm, they closely resemble the strands of seaweed around which they entwine themselves. Pipefish exhibit sex role reversal, in that the male is responsible for incubating eggs in his brood pouch. The young disperse after about ten days when they are 8 to 9 millimeters long. Pipefish eat minute zooplankton and fish larvae.



American eels (*Anguilla rostrata*), which are closely related to European eels (*Anguilla anguilla*), are long, slippery, squirmy creatures. They live to be as much as eighteen years old, and grow to as long as 122 cm (females) or 61 cm (males), and as heavy as 7.3 kg. Eels are very mobile and have been known to slither over seemingly insurmountable obstacles. They cannot survive long out of water, but in the natural world they might occasionally traverse small land areas separating water bodies. Larvae feed on plankton, while juveniles and adults, which are mainly night-feeders, prey on crustaceans, worms, clams, insects, snails, and small fish.

American eels living along the eastern United States coast begin their life near the center of the Atlantic Ocean, in an area near Bermuda and the Bahamas called the Sargasso Sea, about 1,500 miles off the east coast of the United States. As meroplanktonic larvae, eels have transparent, flat, wide bodies and are carried north by the Gulf Stream. They enter estuaries around April about a year later. By that time their bodies have transformed into a rounder form, remaining clear. In this form, they are called glass eels or elvers. They swim upriver and eventually darken to a shade of black or brown. When the adults are ready to spawn a few years later, they take on a metallic black sheen and head out to sea. Their spawning destination is the Sargasso Sea, where the cycle begins anew. Thus, eels are catadromous, meaning they live primarily in fresh or brackish water but migrate to spawn in salt water (Section A: Abiotic Factors—Salinity).

Small fish find refuge in the creeks and submerged vegetation of the salt marsh, where they obtain food and hide from predators like birds and larger fish. Historically, rivers along the southern Maine coastline supported large numbers of Atlantic salmon, shad, sturgeon, and striped bass. However overfishing and pollution, including acid precipitation, have decimated their populations. The Wells Reserve research program is interested in the potential for successfully reintroducing these species, original components of a natural food web that has been ravaged by humans, to the Little River watershed.

### **Birds and Mammals**

Diving and wading birds play a large role in the water-column food web. Eider and bufflehead ducks, as well as other species, dive in search of molluscs and other bottom-dwelling animals, while geese and black ducks consume mostly shallow-bottom vegetation. Estuarine fish are preyed upon by other diving birds: mergansers, cormorants, and loons.

Wading birds have long, stilt-like legs that permit them to venture into tidal inlets and salt pannes to hunt for fish. In the Wells Reserve marshes, great blue herons (*Ardea herodias*) and snowy egrets (*Egretta thula*) can be spotted standing motionless, almost frozen, peering intently into the water. The swimming of an unlucky mummichog, silversides, eel, or stickleback provokes the heron or egret into motion. The bird darts its long neck and bill into the water to snag its prey.

An observer once reported seeing hundreds of harbor seals (*Phoca vitulina concolor*) at the mouth of the Little River. He claims his boat was surrounded by innumerable inquisitive seals bobbing in the water. Seals are common in the vicinity of the Little and Webhannet Rivers. They bask on the rocks just offshore from the Little River, and on docks and marsh banks in the Webhannet. In the water, seals pursue flounder, alewives, squid, hake, herring, other fish, and invertebrates.

### **Food Web**

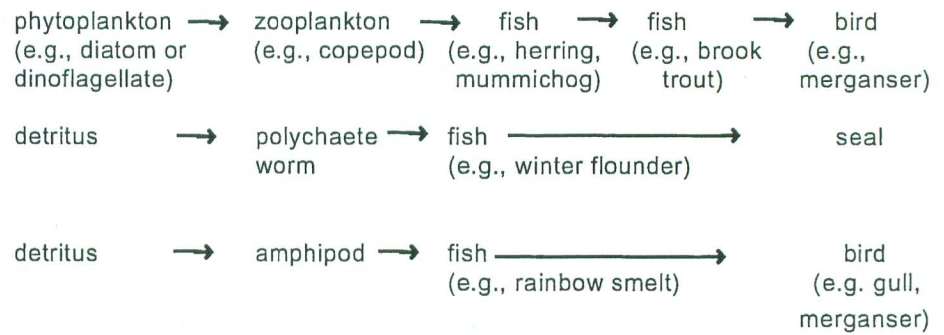
The first level in any food web are the producers. In an estuarine river, as in most aquatic systems, the most abundant producers are phytoplankton. Many species of seaweeds, or macroalgae, are also important producers in the estuarine food web. However, the estuarine food web is based primarily on detritus from decaying marsh plants rather than living plant matter.

Detritus and producers are fed upon by detritivores and herbivores. In the river, most of the herbivores are zooplankton that eat phytoplankton. A few nektonic species also eat phytoplankton, notably menhaden, a phytoplanktivorous fish.

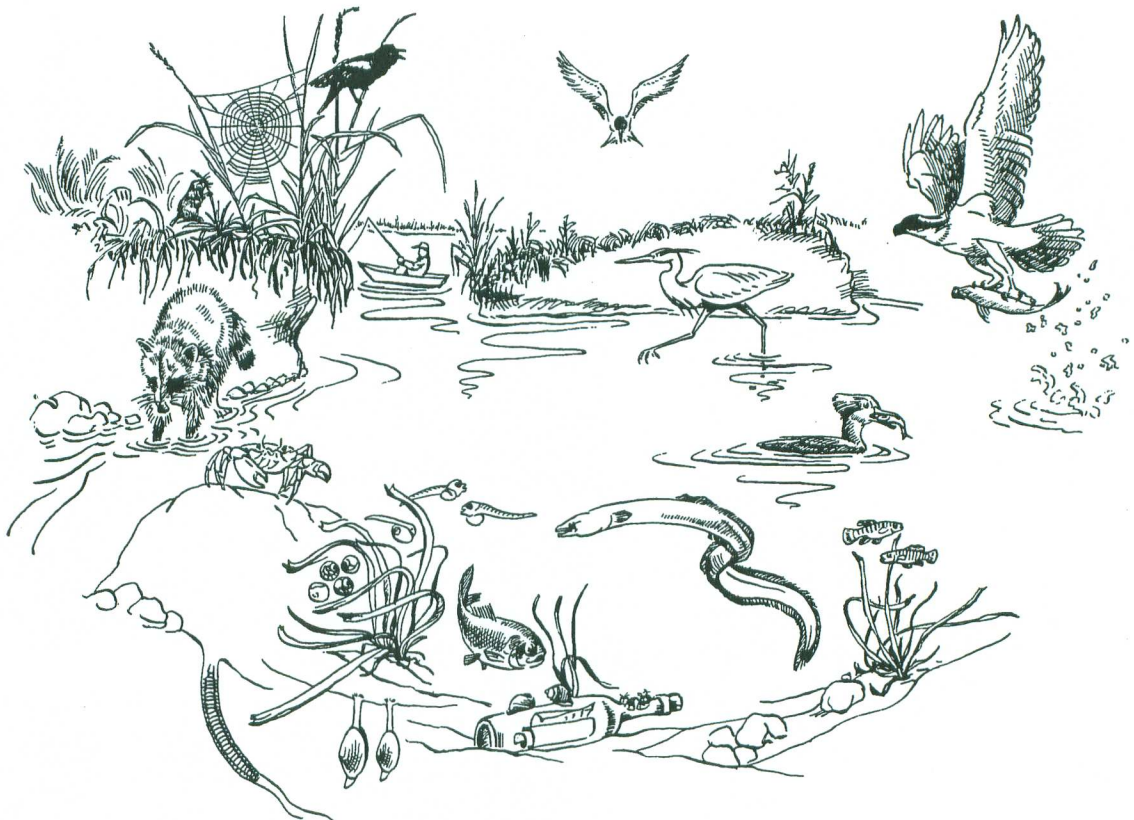
The next level in the food web is the carnivore. Some types of carnivorous zooplankton feed on other zooplankton, and many fish are carnivores that eat either zooplankton or other fish. Carnivorous marine mammals like seals venture into the river to capture fish. The riverine food web as a whole is made more complicated by the presence of several omnivores, which may feed at several levels of the food web, such as herbivore, detritivore, and carnivore.



Typical water column food chains might look like these:



Numerous food webs can be created from this information.



## Section N

## Mudflat and Sandflat

---

The bottom of an estuarine river is shifty and squishy. Walking across it, your feet slide in the sand or sink deeply into the muck. Along the river's length are patches of silt, sand, mud, and cobbles. These sediments have been eroded from the uplands or washed in from the sea. They are constantly reworked into new bars and channels on the river bed.

Parts of the benthic zone are exposed at low tide. These areas are called mudflats (or sandflats if they're sandy). There's no mistaking low tide in a salt marsh—your nose will alert you as soon as it senses the rotting plant smell of intertidal flats and exposed marsh. Despite the seemingly unpleasant features of the flats, they are an important habitat for numerous creatures, all adapted to the unique environmental characteristics of the flats.

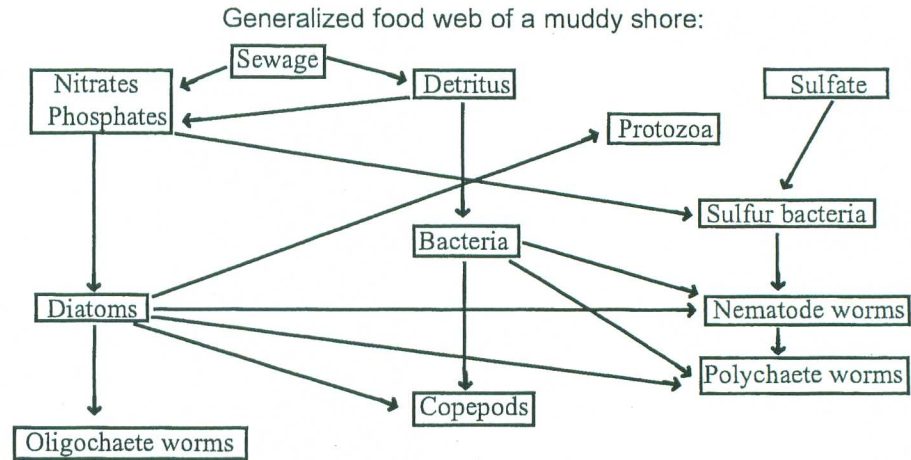
At first glance, an exposed mudflat may appear barren and devoid of life. But take a closer look and you'll see innumerable holes, trails, and shells—evidence of all the burrowing animals that inhabit the flats. You'll find scattered seaweeds and if you're lucky, patches of coloration that hint at a hidden side of the mudflats: microscopic algae carpeting the flats may be important producers in the food web. Many mudflat animals also obtain energy from detritus, bacteria, and plankton.

Some benthic organisms (infauna) burrow into the substrate, some are attached immobile to the substrate (epibenthos), and some (mobile epibenthos) move around the substrate's surface.

Primary productivity occurs in two layers on the intertidal flats, benthic diatoms and seaweed on the surface and chemosynthetic bacteria in the sediments. Benthic animals display a variety of feeding mechanisms: deposit feeding, suspension feeding, predation, and scavenging. Most noncarnivorous benthic animals feed on plankton, bacteria, or organic detritus in the sediments or water column. Predatory infauna and epibenthos feed on other benthic animals.

The most noticeable infauna at the Wells Reserve are the bivalves and polychaete worms, but meiofauna and microfauna are even more abundant. Few epifauna live in the Reserve's estuaries, but mobile epibenthos such as crabs, snails, and shrimp are common. The benthic community food web is not isolated from the other estuarine food webs; interactions of energy and nutrient flow occur between them, as when birds or fish feed on benthic invertebrates.





Razor clams (*Ensis directus*), a common bivalve, are distinguished by their narrow, elongate shells. Although other clams are also capable of moving about in the mud by using a protruding foot, the razor clam is notorious for its outstanding speed and the sharpness of its shell. They are very challenging to catch.

Polychaete worms are the other notable macrobenthic group. These infaunal creatures, which live between the grains of sand and mud, are also very capable of swimming. Polychaetes are a type of segmented worm with many appendages. Clam worms (*Nereis* species) are often used as fishing bait, but they are naturally found in bottom sediments.

Their tolerance for variable salinity allows them to be present in great numbers in estuaries. Clam worms form burrows out of sand and mucus. As herbivores on algae, scavengers on dead animals, and predators on other invertebrates, clam worms feed on a variety of organisms. They are eaten by crabs and fish, including skates.

Another common infaunal polychaete, the lugworm (*Arenicola* species) is sedentary, unlike the active clam worm. They make U-shaped burrows with openings at both ends and feed on the small waterborne particles that flow in. If you see telltale piles of coiled castings on the surface of the mudflats, it might mean that lugworms are hiding down below.

Despite being virtually unnoticeable because of their small size, meiobenthos and microbenthos are incredibly abundant in the mudflats. Microbenthos include bacteria, flagellates, diatoms, and ciliates. The term meiobenthos covers a variety of organisms, but the most common are the tiny, primitive, infaunal round-worms known as nematodes. In the upper three inches of an acre of soil there might be five billion nematodes. Estuarine meiofauna eat bacteria to obtain energy and are themselves eaten by macrofauna and nekton.

**Epibenthos** macrofauna and nekton.

Epibenthos (as opposed to mobile epibenthos) are not especially abundant in the Wells Reserve estuaries. The solid substrates they require for attachment are rare in the muddy and sandy estuaries. They are more commonly associated with rocky intertidal habitats. Nonetheless, scattered patches of barnacles, mussels, and encrusting bryozoans add to the diversity of estuarine life-forms.

Ribbed mussels (*Modiolus demissus*) are common epibenthic organisms in many estuaries, where they are found embedded in the muck among the roots of *Spartina alterniflora* plants. At the Wells Reserve, however, only a few patches of blue mussels (*Mytilus edulis*) are present. Similarly, although oysters are a common estuarine species and local populations exist in places as close as Cape Neddick, the Wells Reserve does not have any oysters.

**Mobile Epibenthos**

Mobile epibenthos are bottom-dwelling animals that move on top of the sediments: crabs, amphipods, isopods, shrimp, and snails. The most common crab in the Wells Reserve marshes is the green crab (*Carcinus maenas*), which tolerates salinities down to 6 ppt. To identify a green crab, look at the edge of the shell on either side of the eyesockets. If there are five small spikes there, exactly enough that you can spell G-R-E-E-N on them, it is most likely a green crab. (Some other crab species found offshore or along other parts of the east coast also have five marginal teeth, but their shells are rarely found on shore).

The green crab is a major predator of soft shell clams. Green crabs are not native to this area. Unknown north of Cape Cod in the nineteenth century, they have moved into Maine waters from the south within the last several decades. The other common crab at the Wells Reserve is the rock crab (*Cancer irroratus*). They prefer salinities greater than 22 ppt, so their shells normally wash up on the beach rather than in the marsh, where green crabs are prevalent.

Crabs start out life as meroplankton. The larvae, which look like microscopic alien monsters, go through several metamorphoses as they drift with the currents.

Eventually they develop into adult crabs and settle onto the bottom to live out the rest of their life as mobile epibenthos. Adult crabs grow by molting. Their exoskeleton (shell) softens and they back out of it, leaving an empty exoskeleton in their image. During summer the Wells Reserve marshes are scattered with countless crab skeletons, seemingly the carcasses of dead crabs. But in fact, they are the "outgrown clothes" of crabs.

Amphipods and isopods, closely-related types of crustaceans, are common estuarine mobile epibenthos. They are generally distinguishable



by their body shape. Most amphipods have bodies that are compressed from side to side, while their relatives, the isopods, are usually flattened top to bottom. The most familiar amphipods are the tide-pool inhabiting scuds and the beach fleas that hop along the sand. The best known isopods are the pill bugs that often live under decaying logs and roll up into a ball when disturbed. But both types of animals have species associated with the estuarine benthic community. Many species of amphipods are present at the Wells Reserve.

Isopods of the species (*Idotea baltica*) are often caught with seine nets at the Reserve estuaries. They have widely varying coloration.

The feeding habits of isopods and amphipods are diverse. Various species (which are very difficult to tell apart) are herbivores, carnivores, scavengers, detritivores, suspension feeders, and in the case of isopods, parasites. Some amphipods dig U-shaped holes in the bottom, while other isopods and amphipods simply live and feed near the bottom, particularly around globs of seaweed and other plants.

A seine net or minnow trap deployed in the Wells Reserve will often snare several mobile epibenthic sand shrimp (*Crangon septemspinosa*). With bodies depressed from top to bottom, these shrimp are shaped differently than many other shrimp. This body form makes them well-suited to benthic life, although they can scamper up into the water column as well. Sand shrimp prefer sandy bottoms and may burrow into the substrate. They are the only common shrimp in shallow estuarine waters between Cape Ann and the Bay of Fundy.

The common periwinkle (*Littorina littorea*) is a mobile epibenthic herbivore. Like other gastropods, common periwinkles have well-defined soft body parts encased in a protective shell. Their mouths have rasp-like radulas that they use to scrape up algae. Periwinkles can often be found exposed out of the water at low tide. They don't dehydrate because their protective operculum acts like a water-tight door to seal in moisture. Periwinkles, well-known rock-climbers in the intertidal zone, can occasionally be found in the marsh perching precariously on narrow cordgrass leaves.

## Birds

Birds, while themselves not benthic organisms, have a large impact on the benthic community, for many birds feed primarily on bottom-dwelling creatures. Vast numbers of beautiful shorebirds inhabit the Wells Reserve marshes—testament to the great productivity of estuaries. Thousands of migratory birds rely on marshes as feeding and resting stops during their incredibly long journeys between southern wintering grounds and arctic breeding ranges. Much of what they feed upon are the benthic organisms that are so abundant in estuaries. When marshes and dunes are developed or destroyed, the bird's survival is in jeopardy.

At first glance, all shorebirds appear to use the same food resources, but they actually divide the resources spatially so that each species can feed successfully in a different place. Shorebirds feed in different water depths. Birds with long bills and legs tend to feed in deeper water than those with shorter bills and legs. This is an example of niche separation in a community (Section H: Niche).

### Shorebirds of the Wells Reserve

Species	Eats
Great Blue Heron ( <i>Ardea herodias</i> )	fish, aquatic invertebrates, sometimes small mammals
Snowy Egret ( <i>Egretta thula</i> )	aquatic invertebrates, fish, insects
Willet ( <i>Catoptrophorus semipalmatus</i> )	aquatic invertebrates
Greater Yellowlegs ( <i>Tringa melanoleuca</i> )	small fish, insects, snails, worms
Lesser Yellowlegs ( <i>Tringa flavipes</i> )	insects, small fish, crustaceans
Sanderling ( <i>Calidris alba</i> )	marine invertebrates within top 10 mm of substrate
Semipalmated Sandpiper ( <i>Calidris pusilla</i> )	mollusks, worms, crustaceans, aquatic insects
Semipalmated Plover ( <i>Charadrius semipalmatus</i> )	mollusks, crustaceans, worms, insects
Black-bellied Plover ( <i>Pluvialis squatarola</i> )	polychaete worms, clams, other marine invertebrates



## Section O

# Salt Marsh

---

**The Marsh**

The salient features of the salt marsh habitat are its waterlogged, root-filled, springy soil and its virtually flat, grassy expanses. The salt marsh community is not as diverse as that of the riverine water column, but it does include a good number of plant species. Salt marsh plants grow in a type of soil called peat, which consists mostly of undecomposed plant matter. (Section I: Geologic Formation).

**Marsh Zonation**

Marshes are divided into two basic zones: high marsh and low marsh. High marsh is only inches higher in elevation than low marsh. The boundary between these zones lies at approximately the elevation of mean sea level. High marsh consists of peat that has accumulated on top of a foundation of ancient low marsh peat. The fringe of low marsh represents newer areas of marsh that have developed (and continue to develop) with slowly and steadily rising sea level, extending the marsh further into the bay or river. The Wells Reserve marshes are predominantly high marsh, with only fringes of low marsh lining the rivers and creeks, unlike marshes in other parts of the east coast that consist largely of low marsh.

Low marsh is flooded by every high tide, whereas the high marsh is flooded less frequently by the high spring tides that accompany new and full moons (Section J: Tide).

Variations in flooding frequency and concomitant differences in soil salinity have a large effect on the marsh plant community (Section A: Abiotic Factors — Salinity).

Different species are able to tolerate different salinities, and this affects where in the marsh each species lives. The salt marsh plant community displays a distinct pattern of zonation that is related to salinity and soil wetness. Vegetation patterns in the marsh can be traced to elevational differences of centimeters.

The highest zone lies at the upland edge of the marsh. It is home to alder, sometimes cattail, a few blueberry plants, and several grasses, all of which are less tolerant to salt and moisture than the plants in zones closer to the river. Upon entering the high marsh, the area lying between the mean water level and the extreme high tide mark, one encounters a region dominated by black rush (*Juncus gerardi*). Black rush grows in dense swaths, and its dark seed heads make it look almost black from a distance. Continuing on toward the river, one then crosses a clear line in the high marsh where salt hay (*Spartina patens*) takes over from black rush. This boundary occurs at the elevation of the highest tides of each month, the ones during the full and new moons (Section J: Tide).

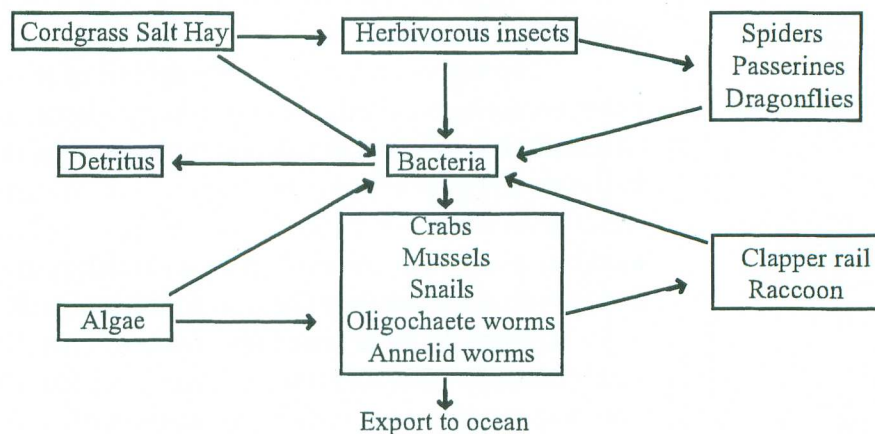
*Spartina patens* is a fine-leaved grass that grows one to two feet tall and often lies low on the ground in cowlick swirls. It dominates its zone in the high marsh, but several other plants can also be found there, including spike grass, seaside plantain, orach, glasswort, seaside arrowgrass, seaside goldenrod, sea lavender, and milkwort. Another distinct change in vegetation occurs at the transition between high and low marsh. Smooth cordgrass (*Spartina alterniflora*)—broader-leaved and taller than salt hay—takes over from salt hay and dominates the low marsh right to the river's edge. Marsh zonation is a result of species' adaptations to the environment and their ability to compete with other species (Section J: Adaptations).

## Animals

Despite its lush vegetation, the marsh is home to relatively few terrestrial animals. Marsh grasses are thought to be low in nutritive value and to contain toxic compounds, so little of the vegetation is consumed by herbivores. Rather, most of the plants die and are deposited on the ground to become peat. Some are then washed into the water to become detritus, the base of the estuarine food web. Nevertheless, deer occasionally venture into the marsh to consume the grasses, as do grasshoppers. Canada geese graze heavily on marsh vegetation during their fall migration.

Raccoons and small mammals (e.g., shrews and mice) traverse the marsh in search of food. They are preyed upon by northern harriers and other birds of prey. Microbes are associated with plant roots in soil, and insects are sometimes (excessively) abundant in the air. Greenhead flies and mosquitoes are especially notorious inhabitants. But in general, estuaries are known as hosts of abundant aquatic and avian, rather than terrestrial, animals. Thus, the marsh community and food web are relatively simple, but they form an important part of the overall estuarine ecosystem.

The food web of an Atlantic coast salt marsh:





## Salt Pannes

The salt pannes, or pools of water that dot the marsh surface, are an important feature of the Wells Reserve estuaries. Pannes range in size from only a foot or two in diameter to many feet across and are irregularly shaped and sized. Some form almost perfect circles, while others have complex shapes. They vary in depth from a few inches to a couple of feet and have soft bottoms of sand, mud, or silt.

Panne creation is believed to be caused by something killing the grass, perhaps wintertime ice floes scouring patches of vegetation from the marsh surface, or mats of debris shielding the plants from sunlight, or compaction. What's left behind is an area of unvegetated peat exposed to the sun. The sun's heat evaporates water from the soil, making it extremely saline and inhospitable to recolonization by plants. If no plants are able to establish themselves, the peat subsides and a water-filled depression, or panne, is formed.

Often, however, this process is interrupted when bare patches are invaded by glasswort (*Salicornia* species) and spike grass (*Distichlis* species). As a succulent plant, glasswort readily tolerates dry soils. Spike grass avoids the salt and dryness by receiving water through underground runners from individuals living outside the bare patch. When glasswort and spike grass colonize a bare patch, they shade the soil, reducing evaporation and salinity. Other plants, generally smooth cordgrass or salt hay, can then invade, preventing panne formation.

Pannes are flooded with salt water at varying frequencies, depending on their elevation in the marsh above sea level and whether they are connected to the river by creeks. If a panne experiences a long period without receiving rain or sea water, evaporation and solar heating can cause it to become extremely saline, warm, and low in dissolved oxygen. This would seem to make difficult living conditions, but mummichogs, sticklebacks, and eels are well adapted to them (Section M: River). In fact, salt pannes are an important marsh habitat, providing a home for numerous plants and animals. Often pannes teem with schools of fish and support large populations of algae and widgeon grass (*Ruppia maritima*), a submerged aquatic plant. Plants and animals of the pannes, in turn, provide food for diving and wading birds.

## Section P

# Gulf of Maine

---

## Open Waters of The Gulf of Maine

Beyond the mouths of the Wells Reserve's estuarine rivers lies the Gulf of Maine, a rectangular embayment of coastal shelf water covering 90,700 square kilometers with an average depth of 150 meters. The Gulf of Maine has characteristics that set it apart from the open ocean. Its northern and western boundaries are defined by the coastline from Cape Cod, Massachusetts to Cape Sable, Nova Scotia. Georges Bank, which rises within four meters of the ocean surface, forms the eastern and southern boundaries of the Gulf of Maine.

These geological features, which form a basin resembling a bathtub, restrict the movement of water in the Gulf of Maine. The Gulf receives a large amount of fresh water from the many rivers in its watershed. This water tends to stay in the Gulf and become entrapped in its counterclockwise circulation. The overall effect, since the Gulf receives so much fresh water with nowhere to go, is that salinity in the Gulf of Maine is significantly less than the open ocean. Typical surface salinities in the Gulf are between 31 ppt and 33 ppt, with even lower salinities along the coast. In contrast, the open ocean lying beyond Georges Bank normally has a salinity of about 35 ppt.

As anyone who has ever swum in the Gulf of Maine can attest, its water can be very cold. Even in August, a happy swimmer jumping off a boat moored in Penobscot Bay may be in for a rude surprise. Summertime water in the Gulf of Maine can be so cold that swimming is painful and breathing difficult. This contrasts strongly with the south side of Cape Cod, where comfortable, warm water greets the swimmer. The difference is due to the influence of the Gulf Stream, a strong current of warm water that flows northward in the western Atlantic. The Gulf Stream warms the water off the southern side of Cape Cod but turns east about 200 miles south of Georges Bank. From there it flows toward Europe. Consequently, the Gulf of Maine is deprived of the Gulf Stream's warmth.

Ecologically speaking, the Gulf of Maine is a bountiful resource. Biological productivity in the Gulf is concentrated in coastal areas receiving nutrients from rivers and, offshore, in regions of upwelling. This occurs in two general situations: 1) where two surface currents diverge from each other, deep water is "pulled" to the surface to fill the void, and 2) where bathymetry (bottom features) like underwater mountains force deep currents of water up to the surface. Deep water usually has more nutrients than surface water because most organisms live near the surface and deplete the nutrients in that zone. Also, organic matter, (such as feces and dead organisms), rain down from surface water to deeper water, where it decomposes.



This removes nutrients from the surface water. When deep water comes to the surface in an area of upwelling, it provides nutrients that allow plankton to flourish. Bathymetry-induced upwelling is the reason that places like Jeffreys Ledge, Stellwagen Bank, and Georges Bank support large fisheries and are feeding grounds for whales.

The biology of the Gulf of Maine is similar to an estuary only in that both are aquatic systems and have some species in common. Abiotic conditions (salinity, temperature, light penetration, etc.) in the Gulf are much more stable than in an estuary, so a somewhat different set of organisms is able to inhabit the Gulf. In addition, the Gulf of Maine is not a detritus-based system like an estuary. Instead, the food web is based on primary production by phytoplankton.

Generalized pelagic (open water) food web for  
cold temperate water:

Top predators:	Killer whales Seals	Porpoises Sharks	Marine birds
Predators:	Salmon	Squid	Lancetfish
Filterers:	Juvenile fish Lantern fish	Anchovies	Amphipods
Herbivores:	Euphausiids (sea butterflies)	Copepods	Pteropods
Producers:	Phytoplankton (primarily diatoms)		

There is considerable interaction between the Gulf of Maine and the estuaries lining its coast. The most frequent and obvious interaction involves the twice-daily tides that bring Gulf water into the estuaries. This periodic flushing affects salinity, transports nutrients in and out, and varies the water level in the estuary. Biological interactions occur when estuarine species venture out into the Gulf of Maine to feed or spawn and when Gulf of Maine organisms enter estuaries for the same reasons. In addition, the larvae of many species depend on estuaries as nurseries. Thus when estuaries are degraded by human activities such as pollution and development, the survival of numerous Gulf of Maine species, including many commercial fish, may be affected.

## Section Q

# Pollution

---

## Estuarine Pollution

Estuaries, like the rest of the world, are still not adequately protected from human disturbance. Salt marshes are no longer so easily filled and developed, but estuarine ecosystems continue to be affected by the less noticeable, yet highly detrimental, problem of pollution.

To the naked eye, the Little River estuary appears to be almost pristine, especially when compared to the Webhannet estuary. Even so, the Wells Reserve Watershed Evaluation Team (W.E.T.) has found that bacterial pollution in the Little River can at times far exceed acceptable levels. This exemplifies the fact that pollution is a widespread, and largely invisible, problem in estuaries.

Most people are aware of trash, the most visible form of pollution. Human-made debris, particularly plastics, can have negative effects on marine and estuarine environments. Ingestion of plastics can kill fish, birds, and mammals, and entanglement in plastics often leads to death or severe injury. Lost lobster traps and fragments of gill nets keep catching animals long after fishermen lose track of them. But often people become extremely concerned about debris (soda bottles, plastic wrappers, etc.) they see littering the beach without considering other types of pollution that may be even more dangerous to marine and estuarine life.

Coliform bacteria in the water indicate the presence of fecal matter from warmblooded animals, most likely human feces introduced by sewerage disposal systems. The bacteria themselves are not harmful to humans, but they can be associated with dangerous pathogens (disease-causing agents).

Nutrients are needed to support life. But when nutrient concentrations are unnaturally elevated in a waterbody, it can lead to a phenomenon called cultural eutrophication. Phytoplankton and other algae thrive on the additional nutrients and a bloom occurs, sometimes causing a layer of scum to cover the water.

When the phytoplankton die, they fall to the bottom in great numbers and are decomposed by bacteria, which deplete the dissolved oxygen in the water. Bottom-dwelling animals like shellfish then die from lack of oxygen.



## Types of Pollution

Heavy metals (e.g., mercury, cadmium, chromium, copper, zinc, and lead) accumulate in estuarine and marine sediments. Researchers have found high levels of heavy metals in several Maine estuaries. Human health is endangered by eating shellfish and benthic fish contaminated with heavy metals.

Chlorine, usually from water and sewage treatment plants, is toxic to estuarine organisms and even tiny amounts can affect fish migrations. Petroleum derivatives like polynuclear aromatic hydrocarbons (PAHs) cause mutations and cancer. PAH levels in Casco Bay were found to be higher than those in Boston Harbor. Biocides (pesticides and herbicides) are widely used to kill undesirable organisms and often unintentionally enter aquatic systems. Synthetic compounds like paints, household chemicals, and PCBs (polychlorinated biphenyls) can persist and accumulate in marine environments. They act alone and in combination to harm aquatic organisms.

Sediments suspended in water block transmission of light needed for photosynthesis by phytoplankton, seaweeds, and aquatic plants rooted in the bottom. The feeding structures of filter feeders (e.g., clams and mussels) and particulate feeders (e.g., zooplankton) become clogged by sediments, and fish gills can be damaged by the particles.

Temperature pollution occurs when heated water used to cool power plants is discharged into aquatic systems. It can endanger estuarine organisms.

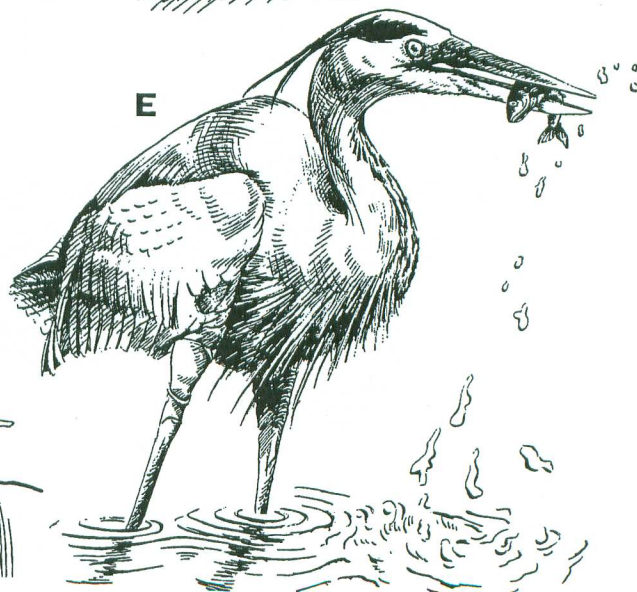
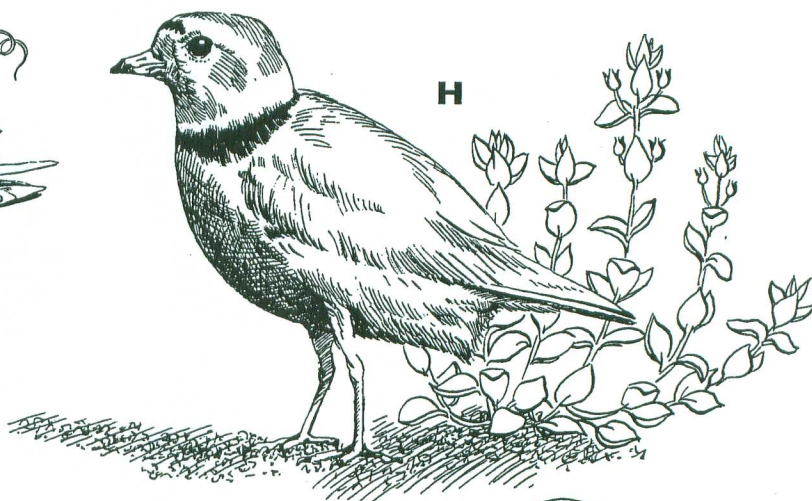
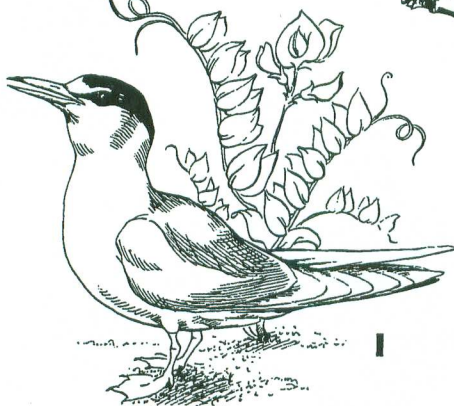
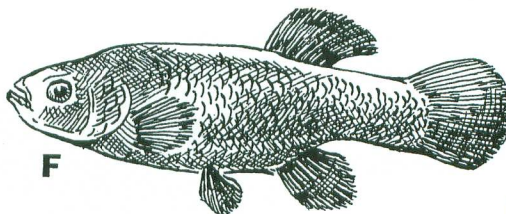
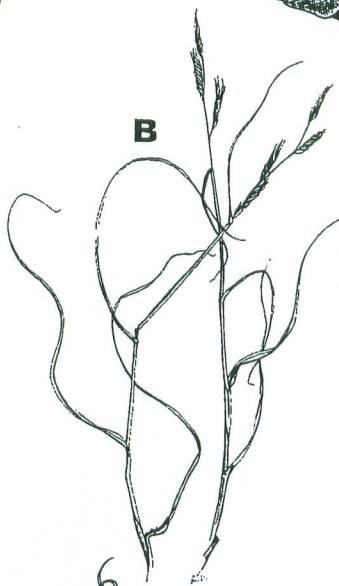
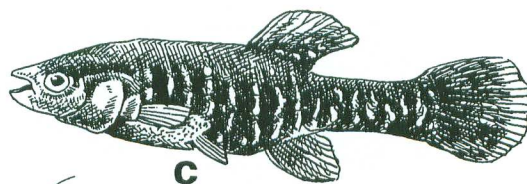
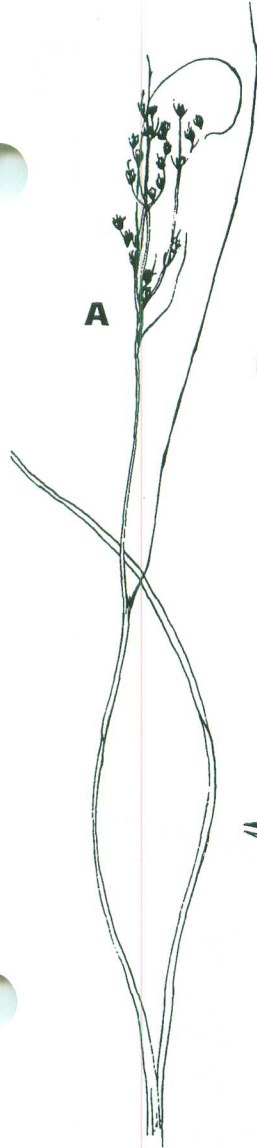
## Point and Non-Point Source Pollution

Pollutants are introduced into estuaries from either point sources or non-point sources. Point sources are clearly defined, localized inputs such as pipes, industrial plants, sewer systems, oil spills from tankers, and aquaculture ventures. They are regulated by the federal and state governments. Non-point sources are indistinct inputs that do not have a clearly defined source, such as runoff of petroleum products from roadways or pesticides from farmland. While less blatant than big, sludge-spewing pipes, non-point sources might be considered more insidious than point sources because they are harder to detect and control. A majority of pollutants find their way into estuaries from non-point sources.

Pollutants clearly pose a large threat to estuarine organisms. Government efforts to deter polluters are challenged by the sheer number of pollutants and polluters, as well as the difficulty of identifying non-point sources. Reducing pollution requires substantial individual and collective efforts. This entails changing our lifestyles and decreasing our dependence on and use of potential pollutants.



**Identification Masters**  
**Miscellaneous**  
**Species**













**PAGE 93: MISC. SPECIES**

- A. Smooth cordgrass - *Spartina alterniflora*
- B. Salt hay - *Spartina patens*
- C. Striped killifish - *Fundulus majalis*
- D. Dusty miller - *Artemisia stelleriana*
- E. Great blue heron - *Ardea herodias*
- F. Common mummichog - *Fundulus heteroclitus*
- G. Dog winkle - *Thais lapillus*
- H. Piping plover - *Charadrius melodus*
- I. Least tern - *Sterna albifrons*
- J. Double crested cormorant - *Phalacrocorax auritus*

**PAGE 94: FISH**

- A. Brook trout - *Salvelinus fontinalis*
- B. Alewife - *Alosa pseudoharengus*
- C. Sand shrimp - *Crangon septemspinosa*
- D. Common oyster - *Crassostrea virginica*
- E. Striped bass - *Morone saxatilis*
- F. Atlantic herring - *Clupea harengus*
- G. American eel - *Anguilla rostrata*
- H. American eel (juvenile) - *Anguilla rostrata*

**PAGE 95: FOOD WEB**

- A. Least tern - *Sterna albifrons*
- B. Great blue heron - *Ardea herodias*
- C. Osprey - *Pandion haliaetus*
- D. Hooded merganser - *Lophodytes cucullatus*
- E. Common mummichog - *Fundulus heteroclitus*
- F. Eel grass - *Zostera marina*
- G. American eel - *Anguilla rostrata*
- H. Northern rock barnacle - *Balanus balanoides*
- I. Common periwinkle - *Littorina littorea*
- J. Alewife - *Alosa pseudoharengus*
- K. Soft shell clam - *Mya arenaria*
- L. Zooplankton - assorted genus and species
- M. Clamworm - *Nereis spp.*
- N. Green crab - *Carcinus maenas*
- O. Raccoon - *Procyon lotor*
- P. White-footed mouse - *Peromyscus leucopus*
- Q. Redwing blackbird - *Agelaius phoeniceus*

**PAGE 96: BIRDS**

- A. Least tern - *Sterna albifrons*
- B. Canada goose - *Branta canadensis*
- C. Mallard (female) - *Anas platyrhynchos*
- D. Raccoon - *Procyon lotor*
- E. Great blue heron - *Ardea herodias*
- F. Alewife - *Alosa pseudoharengus*
- G. Mummichogs - *Fundulus spp.*
- H. Soft shell clam - *Mya arenaria*
- I. Clamworm - *Nereis spp.*
- J. Northern pipefish - *Syngnathus fuscus*
- K. Greater yellowlegs - *Tringa melanoleuca*
- L. Northern rock barnacle - *Balanus balanoides*
- M. Great black-backed gull - *Larus marinus*
- N. Blue mussels - *Mytilus edulis*
- O. Striped bass - *Morone saxatilis*
- P. American eel - *Anguilla rostrata*
- Q. Double crested cormorant - *Phalacrocorax auritus*