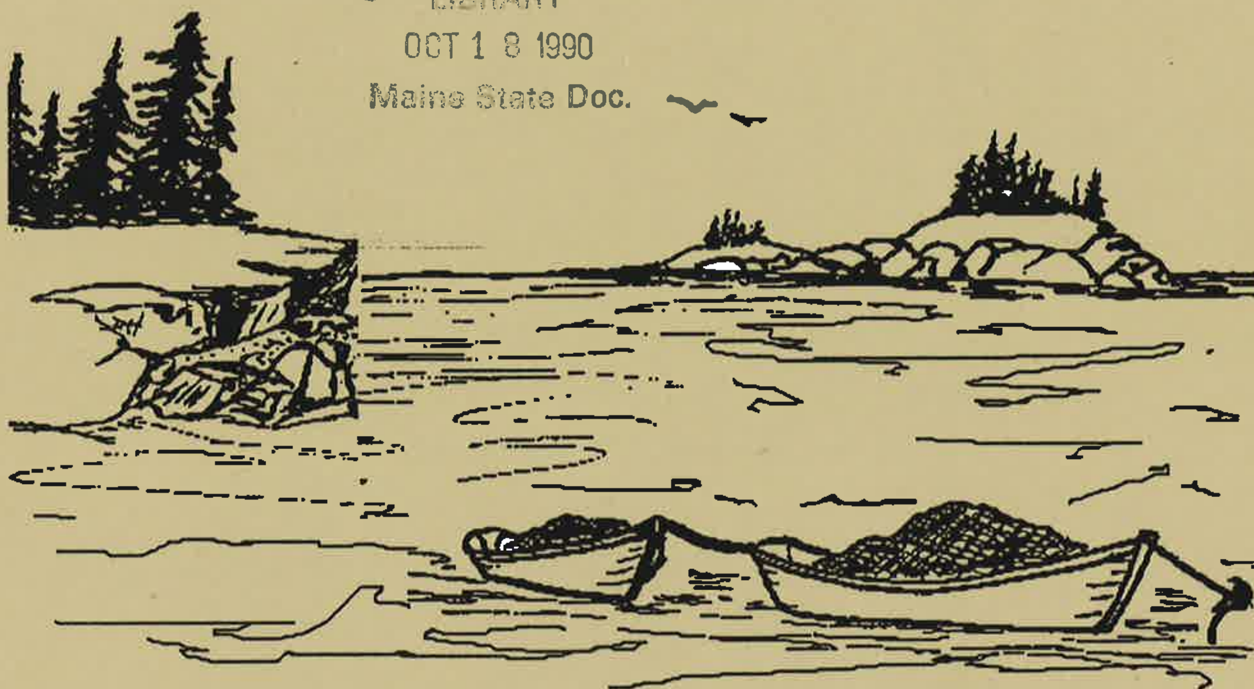
1990

Estuarine Studies : An Activities Text for Maine Schools

Education Division - Department of Marine Resources

Estuarine Studies

An Activities Text For Maine Schools



Fisheries Education Unit # 16
Produced by
The Education Division
Department of Marine Resources
State House Station 21
Augusta, Maine 04333-0021

Revised 1990

ESTUARINE STUDIES

An Activities Text for Maine Schools

The study of an estuarine area is a study in "change". The estuary is an ecosystem in motion obedient to its masters: *the force of the tides, the push of the wind, the gravity of the earth, and the biological demand of all the creatures living in it.* From moment to moment these forces are at work changing the chemical, physical and biological make-up of the estuary.

Estuaries are fragile boundaries between marine and freshwater habitats. Their value to the commercial fisheries, recreation, and shipping make them economically important. Their value to the thousands of aquatic animals and plants that live in these areas remain uncalculable.

Definition of an Estuary:

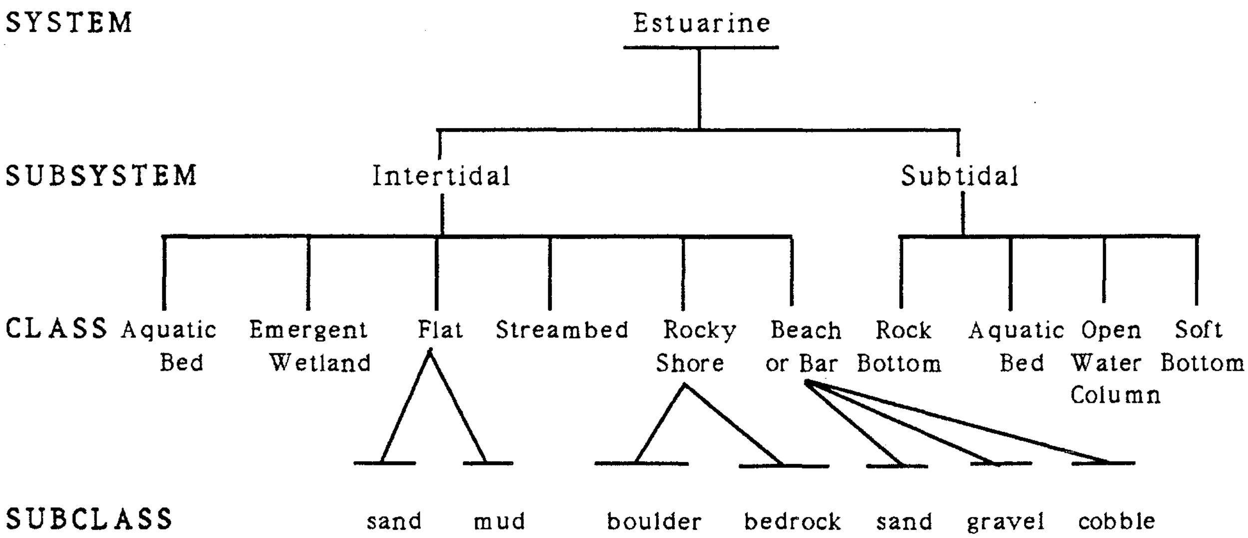
There are many definitions of an estuary. The U.S. Fish and Wildlife Service (FWS: Cowardin et al. 1979) defines the estuarine system as "deep water tidal habitats and adjacent wetlands which are usually semi-enclosed by land but have open, partially obstructed, or sporadic access to the open ocean and in which ocean water is at least occasionally diluted by freshwater runoff from the land."

"Estuaries extend upstream and landward to the place where ocean-derived salts measure <0.5 o/oo during the period of annual low flow. The seaward limit of the estuarine system is: 1) a line closing the mouth of a river, bay or sound; 2) a line enclosing an offshore area of diluted seawater with typical estuarine flora and fauna; or 3) the seaward limit of wetland emergents, shrubs or trees where these plants grow seaward of the line closing the mouth of a river, bay or sound."

Other definitions are similar. They all refer to estuaries as the area of mixing between salt and freshwater. Most estuaries tend to be semi-enclosed by land. This protects the area from strong marine impacts; thus, producing a low energy environment influenced chiefly by river runoff and tides, and only occasionally by winds and current. By this definition the entire Gulf of Maine can at times be classified as an estuary.

Estuaries are extremely harsh environments. Daily and seasonal changes in temperature, salinity, currents, and water level occur. The extent of the change depends upon the amount of freshwater inflow from the watershed, the morphology of the estuarine basin, and the tidal amplitude.

The following hierarchical classification of the estuarine system of coastal Maine (Cowardin et al. 1979) shows the variety of habitats that exist within the estuarine environment.



Estuaries are areas where fresh and saltwater are mixed. Various factors influence this vertical mixing - some of these are freshwater flow, winds, basin topography and tidal exchange. Because of the variability of these factors, the areas defined as estuarine are under constant change and not constrained by geography. That is why the entire Gulf of Maine might be considered an estuary at times.

Huge volumes of freshwater, 9.5 million cubic kilometers, enters the Gulf of Maine during peak runoff periods. Most of this water comes from the five major river systems that enter the Gulf - the Saint John, Penobscot, Kennebec, Androscoggin, and the Merrimack. This light freshwater flows over the top of the underlying cold, dense saltwater found in the bays and estuaries. The instability caused by this freshwater is partly responsible for the counterclockwise circulation pattern found within the Gulf.

Activity: ***Development and observation of a layered water system***

Layered water systems can easily be prepared if you use care. You will construct such a system and then study how the system reacts to certain conditions.

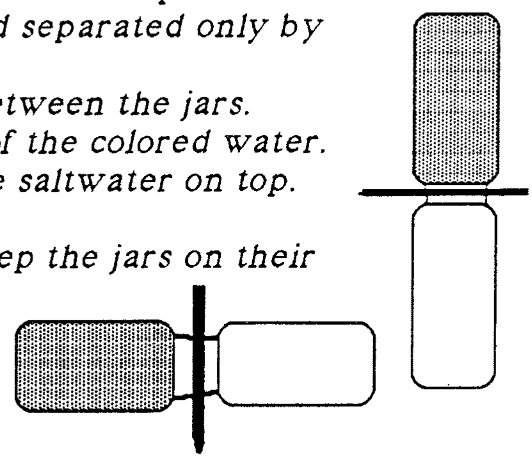
Equipment:

- *Clear rectangular dish to act as a segment of your ocean.*
- *Salt and water* — *Baby food jars - 2 per group*
- *Dropper* — *Thin cardboard - 1 per group*
- *Food coloring* — *Dish to hold freshwater*

What do you think happens when fresh river water flows into a salty ocean?

Procedure I

1. Select two baby food jars.
2. Fill one jar with freshwater and one with a solution of salt water.
3. Place a drop or two of food coloring in the freshwater. Mix well and cover with a piece of cardboard.
4. Invert the jar and place it directly over the top of the saltwater container so the tops are aligned and separated only by the cardboard.
5. Now slide the cardboard out from between the jars. Observe and record the movement of the colored water.
6. Try the same thing again but put the saltwater on top. Record the results.
7. Now try the same procedure but keep the jars on their sides. Record.



Procedure II

1. Partly fill a container of water with as much salt as will dissolve easily.
2. Fill another container with freshwater and add several drops of food coloring.
3. Very carefully pour the colored freshwater down the side of the dish containing the saltwater. (If you have a bulb-type kitchen baster, it is ideal for this work.)
4. Let stand a few minutes undisturbed.
5. Record what you observe.
6. Make up a solution of slightly salty water and color it a dark color.
7. Use a medicine dropper to add a small amount of this slightly salty-colored water to the freshwater. (Pour slowly down the side of the dish.)
8. Record what happens.
9. Add a few drops (down the side of the container) of this same slightly salty water to the very salty layer.
10. Record your observations.
11. Raise the end of the dish slightly and then let it drop back to the table. Carefully observe the results and explain.

Extensions:

1. Reverse the layering. Pour colored freshwater into the bottom of the dish and then add saltwater slowly down the side of the container.
2. Explain what happens. Could this situation occur in nature, when and how?

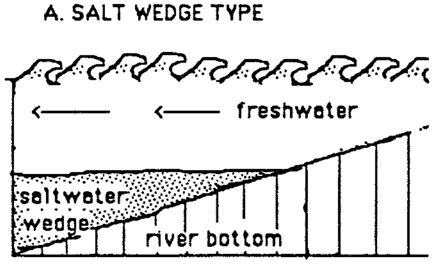
3. *Try a warm colored salt layer poured slowly into a cold freshwater layer. Reverse this system and observe.*
4. *Try layering a salty cold layer and a warm salty layer. (Use the same amount of salt in each solution. Explain what happens.*
5. *Research the existence of density currents such as the Gulf Stream, Labrador Current, etc.*

Answer the following questions:

1. *What do you think happens when freshwater flows into a salty ocean? Show by a diagram.*
2. *What happens in a freshwater river when the tide comes in?*
3. *Which water mass will sink, the more or less dense water?*
4. *Explain why a layer of river water does not cover the Gulf of Maine in the spring?*
5. *Explain how the intermediate water of the Gulf of Maine can float above the bottom water and not mix?*
6. *What are some of the outside forces that help mix river water and ocean water?*
7. *What effect will these system have on the animals and plants that live near the surface of the estuary mouth?*
8. *If a lobster pound was built just below the outlet of a large freshwater river, what could happen in the pound when spring runoff is high?*
9. *Anadromous fish must adjust their body chemistry as they enter the rivers to spawn. What part does density play in this change?*
10. *Look up the term "salt wedge" in a book on estuaries. What does it refer to?*

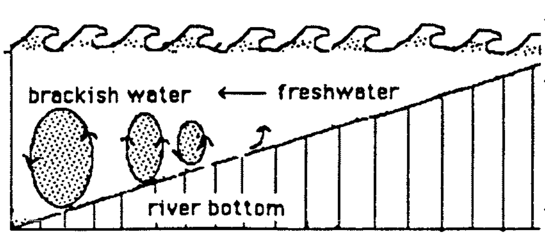
As freshwater flows into sea water it floats on top of the more dense seawater and is separated by a density interface that inhibits mixing. These estuaries are called "salt wedge" or "highly stratified" estuaries. Not all rivers develop this stratification because of the shape of the bottom, width and depth of the mouth, and orientation of the mouth to wave and tidal action.

A. SALT WEDGE TYPE



Tides moving in and out of estuaries are a primary mixing agent. In Maine these tides are of oceanic origin. Tides move as long period waves; therefore, high tide progresses up the stream. In an estuary with parallel sides and uniform depth, the energy is distributed throughout and the tidal height decreases toward the riverine end.

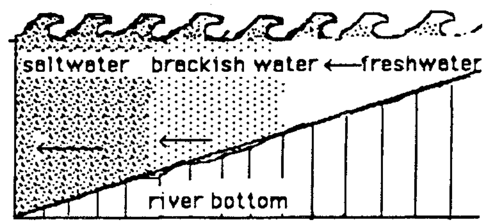
B. PARTIALLY MIXED TYPE



Where estuaries become narrow toward the riverine end, the tidal wave narrows and the tide becomes higher as it moves upstream. When the tidal wave reaches the bottom, turbulence occurs and mixing results.

If the tide is high enough and the bottom shallow enough, the tidewave breaks and moves up the estuary as a tidal bore. (The famous tides in the Bay of Fundy are good examples of this action.)

C. FULLY MIXED TYPE



When tidal friction is low, the turbulence is only great enough to push saltwater up into the layer of freshwater. The result is brackish water. The underlying seawater is not diluted and moves up the estuary to replace that lost by entrainment.

The salinity in an estuary varies with the tidal cycle. Highly saline water protrudes into an estuary on the flood tide and the highest salinities are found on a high tide. The extent to which the salinity protrudes into an estuary varies seasonally. During the spring runoff, the salinity intrusion is pushed down river. During low river flows in the summer and winter months the salinity intrusion extends for great distances upriver in most estuaries. In addition, the amplitude of the tide and therefore the extent of the salinity intrusion is dependent on the lunar cycle with the highest tides (spring tide) occurring during the full and new moon. Tides of the least amplitude occurring semi-monthly are called "neap tides."

The direction and strength of wind also influences the tidal amplitude in an estuary. Winds blowing onshore push water up the estuary because of increased pressure gradients. Under severe conditions this pressure gradient can hold the water back and cause extreme flood tides, especially if the storm surge occurs at the same time as either a full or new moon.

Tides provide the energy to mix water but the topography determines where the mixing occurs. The height of the tide at any point in an estuary is dependent on the morphology of the estuarine basin. In a broad triangular shaped estuarine basin such as that of the Penobscot River the mean tide level increases as you go upriver until you reach Hampden. In a narrow estuary with constrictions in the basin like those in the Kennebec River, the height decreases as you go upriver. The morphology also affects the time of high and low water. High tide occurs four hours later at head-of-tide (Augusta) on the Kennebec River than at the mouth (Fort Popham). The time difference in high tide between Fort Point and Bangor on the Penobscot is approximately ten minutes. The salinity profiles of the two estuarine systems are also quite different. Because the Kennebec River is narrow and turbulent, the water column is fairly well-mixed and there is not much difference between surface and bottom salinities. Stratification takes place on the Penobscot with a difference of over 10 ppt (parts per thousand) between the surface and bottom salinities. The Kennebec River is a unique system in Maine because true estuarine conditions (>.5 ppt) extend 20 miles from the mouth to Merrymeeting Bay except during extreme drought. The next 20 miles to head of tide are essentially tidal freshwater.

Tides are major factors for changing the water temperature, resupplying nutrients and changing the salinities in the estuaries associated tidal flats, marshes and beach areas within the Gulf of Maine. The variation in height from about four feet on the north shore of Cape Cod to nearly fifty-feet in the Bay of Fundy is extreme when compared with other areas of the world.

The volume of water which is moved contains vast amounts of potential energy. Long recognized as a possible source of electric power, many plans for harnessing the energy in the Bay of Fundy and Passamaquoddy Bay have been proposed.

<u>FIELD ACTIVITY:</u> ***Measuring Tidal Changes***

An investor is interested in the development of a small tidal power station. You are one of the scientists asked to gather information about the tides and the beaches in your area to see what the rate of tidal change is in that area. From this information and the vertical drop, you may try to approximate the potential for a power dam in the bay.

Equipment:

Watch   Four foot stakes   Meter sticks   100 inch sticks   Level

Pre-field trip:

Each group should prepare a stake for their tidal measurement. Mark them off in centimeters. Every ten centimeters should be a bright color for easy reading.

Tide Staff

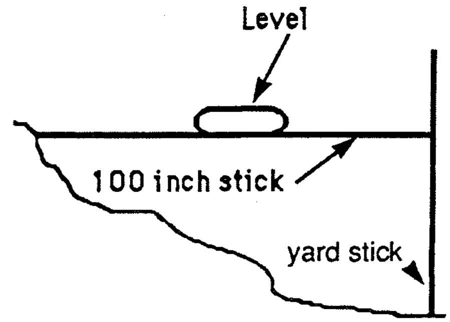
Procedure:

Select an area where the class may investigate several beach types and slopes.

1. Determine the rate of tidal change on your segment of beach. At the face of your beach, drive a stake into the bottom so the water covers the lower part of the tide stake. Record this value. Every five minutes record the change in tidal height (this is the difference in height at beginning and end of each five minute interval). Also measure the distance from the bottom of the stake to the edge of the water and record.

2. The slope of the beach must be determined if the effect of slope on tidal rise is to be studied. This can be easily done with a 100 inch stick, a yardstick, and a carpenter's line level.

At the same site as activity 1, tie a piece of string to a stake driven into the beach at high water mark. Run the string down the beach perpendicular to the water. Drive a stake in the water at the same distance from shore as your stake. Measure your slopes along this string. Place a mark at every outstanding change in the slope. Record the rise on these stakes and record.



Place the 100 inch stick as shown with the end just touching the beach. Level the stick and measure the vertical height in inches with the yardstick.

The slope of the beach = the height in inches / 100 inches x 100 = ________%

Questions:

1. What was the rate of change of water level at stake Number 1? (Suggestion: Plot the data on a graph). Was the rate constant? Why or why not?
2. How does the rate of rise at each reading compare? Can you suggest reasons for variation?
3. Look at the data on linear distances measured every 5 minutes. Explain the results.
4. Is there any relationship between slope changes, linear distance and tidal height change? Plot your information on the same graph and see what occurs. Explain.
5. Were there any differences in beach structure where the slope changed abruptly? What were they? Is there any relationship to the tidal change rate?

Extension:

Investigate several different beaches. Did they all have equal rates of tidal change?
What was the final height on each beach?
Can you explain why the location of "head-of-tide" varies from river to river?
Tidal energy production requires a continual flow of water. What other factors are necessary to produce this constant flow?
Is tidal power a relatively new concept? Research and find out.

Tides provide the energy to mix water in an estuary but the morphology determines where the mixing occurs. In an estuarine basin such as that of the Penobscot River which is a broad triangular shaped estuary, the mean tide level increases as you go up the river until you reach Hampden. In the Kennebec River which has a narrow estuary and constrictions in the basin, the tidal height decreases as you move up river. The morphology also affects the time of high and low water. High tide occurs four hours later at head-of-tide (Augusta) on the Kennebec River than at its mouth (Popham). The time difference in high tide between Fort Point and Bangor on the Penobscot is approximately 10 minutes. The salinity profiles because of tidal mixing are also quite different. The Kennebec is narrow, constricted and thus turbulent, therefore, the water column is fairly well mixed and there is little difference between the surface and bottom salinities. Stratification takes place on the Pennobscot with a difference of over 10 ppt (parts per thousand) between the surface and bottom. (The Kennebec River is a unique system in Maine because the true estuarine conditions with salinities >0.5 ppt extend 20 miles from the mouth to Merrymeeting Bay except during drought. The entire next 20 miles are essentially tidal fresh water.)

The estuaries of Maine are well protected from most large storm waves because of the physical structure and orientation of the Gulf of Maine to open ocean. However, northeasterly winds do send storm waves through large expanses of Gulf water and these high energy waves crash upon the beaches causing extensive damage. Because of the orientation of the rivers entering the Gulf, these winds tend to blow along the axis of the estuaries. Storm winds and resultant surface waves can cause strong vertical mixing, drive saltwater higher into the estuary, and keep the water within the estuary for long after the tidal cycle has changed. These radical changes from the normal are felt throughout the estuary and tidal freshwater area. The resultant effect upon the high marshes, salt ponds and coastal freshwater marshes can be devastating or life-renewing depending upon the amount of salt infiltration.

ACTIVITY: ***What Makes a Wave Go?***

Wave energy is an important energy source within the estuary. The waves mix nutrients back into the entire system, help to distribute the seawater through vertical mixing and help to build beaches, salt marshes and mud flats by sorting and shifting the sediments.

There are several types of waves. Those caused by tides, by wind and by earth movement are the most common.

Wind blowing across the mouth of the river can generate waves that move rapidly towards the opposite shore. The waves formed are similar to those produced in a dish pan when you pick up one side and then let it drop. At times there can be large differences in the water level between *one shore and the other.*

Materials Needed:

Long, shallow pan (the best size is 18" x 10" x 2"), timer, and water.

Activity 1 - Fill the glass dish almost to the top with water (about 2 " deep). Gently tip the dish at one end to set up wave energy motion. Time how many times the wave energy travels from one end to the other in 30 seconds; then in one minute. Record your data in the table below.

Activity 2 - Fill the glass dish half full of water (about 1" deep). Gently tip the dish at one end to set up wave energy motion. Time how many times the wave energy travels from one end of the dish to another in 30 seconds; then in one minute. Record.

Activity 3 - Fill the dish quarter full (about 1/2 " deep). Repeat the experiment as before. Record your data.

Depth	Number of times wave energy travels length of the dish		
	in 15 seconds	30 seconds	1 minute
2 inches			
1 inch			
1/2 inch			

Questions:

1. *Look at the data you have collected. How does the speed of the wave change with the depth of the water?*
2. *As the ocean waves move from deep water to shallow water, what happens to the speed?*

Extension:

Surface waves move fastest. When waves intersect the bottom, friction slows the wave. Water piles up and then the wave breaks. Research Topic: When does a wave strike bottom?

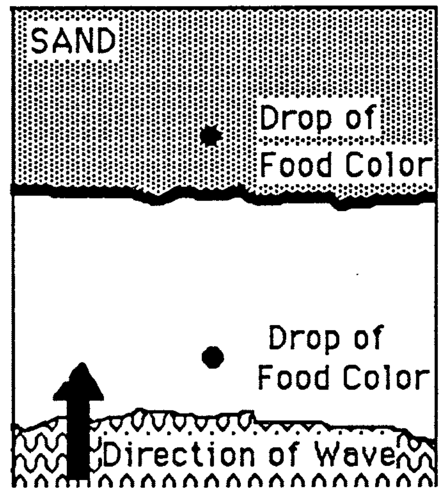
Activity: ***Waves on the Beach in the Classroom***

Materials Needed:

Clear Plastic boxes at least 2 feet x 2 feet. (These can be easily made in the woodshop. Cut a piece of board to desired size. Using plastic aquarium sealant or bathtub sealant, glue strips of plexiglass to the sides making a relatively water tight box at least 4" deep.)

Beach sand, food coloring (different colors), water, and a paint paddle

Directions:



Profile

1. *Place about 3" of sand at one end of clear plastic box.*
2. *Add a large drop of food coloring about mid-center of the sand.*
3. *Fill the container with about an inch of water and add a drop of food coloring. (Use a different color than on the sand.)*
4. *Using the paint stick, make easy waves parallel to the beach front. Observe what happens to the food coloring in the water as the waves pass through it. How does the water move where the food coloring is located? Explain.*
5. *Continue making waves for three to five minutes. Observe what happens to the beach. Look at the beach from the side, top, and bottom. What happened to the food coloring on the sand? What is the motion of the water once it breaks upon the beach? Trace a profile (side view) of the beach with a grease pencil right on the box.*
6. *Increase the height of the wave and continue for three to five minutes. Draw another profile. (This is equivalent to a winter beach.)*
7. *Experiment to see what changes occur if the waves strike at an angle. Draw a new profile.*
8. *What would happen if there was an island in front of the beach? Try this, a rock makes a great island. Draw the profile.*
9. *Try the activity after placing a jetty or groin in the beach. Draw these profiles.*

Write a summary of your activity, referring to the effects upon the beach.

ACTIVITY: ***A Simple Wave Machine***

Waves in slow motion provide an insight into their development and propagation that is not usually seen.

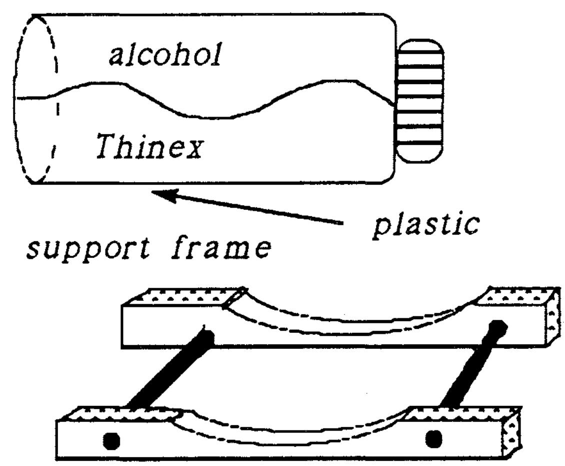
Materials Needed:

> **Denatured alcohol and Thinex (clear) paint thinner, a clear plactic bottle with straight sides and blue food coloring or methylene blue indicator.*

> **BOTH OF THESE LIQUIDS ARE INFLAMMABLE PLEASE USE EXTREME CARE. FOR YOUNGER STUDENTS USE :* MINERAL OIL AND WATER.

The slow motion effect of the waves is achieved by using two non-mixing liquids, one slightly more dense than the other. Since the liquids are almost identical in density, only very slowly can the heavier one displace the lighter one. So much flow resistance occurs at the interface, waves are cast up and slowly fall to rejoin the heavier liquid.

1. *Fill 1/3 of the jar with alcohol. Add a few drops of blue color and mix.*
2. *Fill the jar to the top with paint thinner. (You must allow for expansion of the liquids if they will be used at a higher temperature than the ones present when you built the machine. Leave an air space at the top equal to about 10% of the total volume.*
3. *Move one end upward and observe the results.*



Analysis:

1. *Is the wave that forms between the two layers the same exact shape as that at the surface? Explain.*
2. *Draw a diagram of your wave and research out the names for the high points and low points in the wave.*

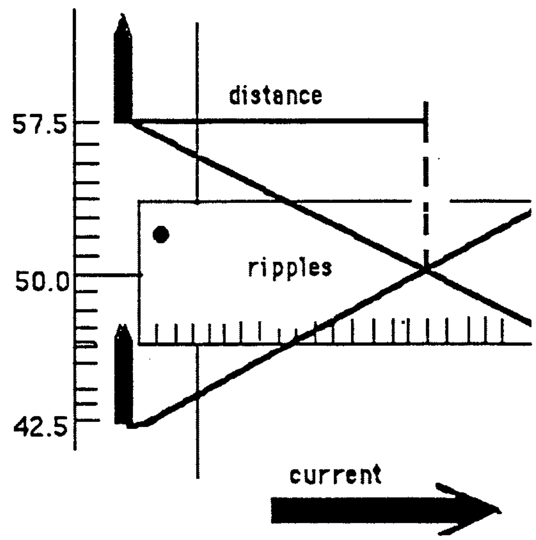
Currents in rivers move at various velocities depending upon a wide variety of factors such as the gradient of the land, the density of the water, the tidal cycle, bottom composition, shape of the confining walls at that point, force of the wind, earth rotation and even atmospheric temperature and pressure. These currents are extremely important since they move nutrients, sediments, salinity, oxygen and pollutants around.

Fish are often found feeding along the interface between two currents. Larval fish, mollusks and crustaceans use these currents to move themselves about in the search for food. Herring larvae ride tidal currents into the marsh areas and utilize density currents to stay in these areas for months.

The speed of these currents may vary greatly and the direction of the currents depends upon many factors. For example, when a tide pushes into a river the saltwater may move in while the fresh water is moving out. These currents may be one above the other or even side by side.

ACTIVITY: *Measuring Surface Currents*

When a small object is placed in a current, a V-shaped ripple is formed. The stronger the current the farther downstream one finds the point of the V. If two objects are placed in the water side by side, the ripples will cross at some point.



Materials needed:

2 meter sticks fashioned into a T shape with 2 nails located at the 57.5 cm and 42.5 cm points.

Procedure:

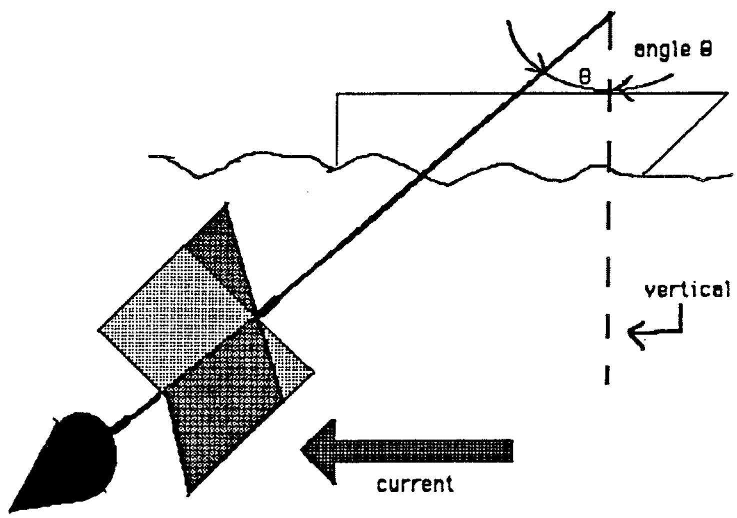
1. *Hold the meter stick apparatus with the two nails pointing upward. Submerge the apparatus until only the nail tips are out of water and the long part of the device points upstream. Let ripples form.*
2. *Take a reading on the meter stick where the two ripples cross.*
3. *Convert the reading to current speed using this table:*

Length (cm)	Current speed (m/sec)	Length cm	Current speed (m/sec)
0.7	0.05	10.2	1.5
1.4	0.2	10.9	1.6
2.0	0.3	11.6	1.7
2.7	0.4	12.3	1.8
3.4	0.5	13.0	1.9
4.1	0.6	13.6	2.0
4.8	0.7	17.0	2.5
5.5	0.8	20.5	3.0
6.1	0.9	23.9	3.5
6.8	1.0	27.3	4.0
7.5	1.1		
8.2	1.2		
8.9	1.3		
9.5	1.4		

This method measures only surface currents. To obtain more detailed results, current meters should be utilized. These are expensive so most schools can't afford one. However, a biplane-cross can be built and utilized for good results.

Procedure:

1. *Obtain two sheets of 1/2 inch plywood four feet wide and three feet high. Assemble these so that either plane bisects the other.*
2. *Suspend a 30 pound weight below the apparatus to provide negative buoyancy.*
3. *Place an eye-bolt in the center and attach a cable.*
4. *To use suspend from an anchored boat or platform by a thin cable.*



The biplane will swing in the direction of the current at that depth. The speed of the current can be computed from the angle of the suspended wire according to the formula: $U = k\sqrt{\tan\theta}$ *where U is the current velocity in knots, k is a constant whose value is 1.04 and tan θ is the tangent of the angle formed between the support wire and the vertical.*

Remember that currents always have direction and one mass of water may be flowing above another. Always try different depths to find all the currents.

Currents can be produced by the force of rotation of the earth acting upon something moving over the surface of the earth such as a river. This force is known as CORIOLIS and in the northern hemisphere it tends to turn moving objects to the right.

The earth constantly rotates on its axis. Since the earth is nearly spherical, different areas of the earth must travel through space at different speeds. (What would happen if they all traveled at the same speed?) At the equator the velocity of rotation is 1040 miles per hour. At a point approximately 31 miles from the pole, the speed is 16.8 miles per hour. As you can see, the rate of change of velocity increases constantly from the pole southward in the northern hemisphere. The force that results (Coriolis) can act upon any object moving upon the surface of the earth.

This Coriolis force acts upon the water flowing from a river into the

Gulf of Maine. The result is a turning of the water to the right as it enters producing a long shore current. This current tends to carry the nutrients, sediments and organisms in the water along the shore rather than dispersing them into the open Gulf thus keeping them available to the intertidal area.

ACTIVITY: ***Coriolis Force***

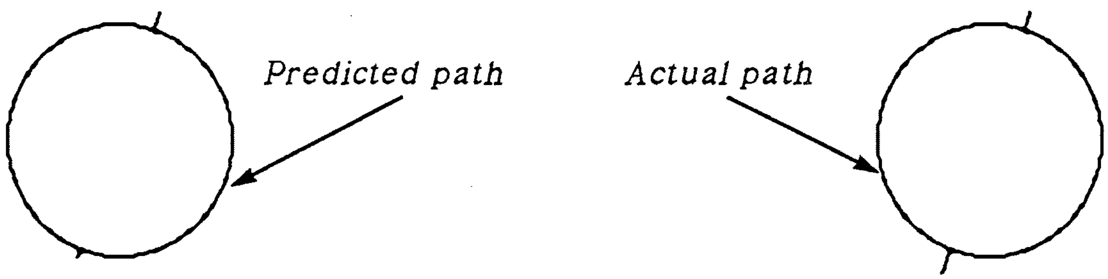
Materials Needed:

An old globe or similar ball shaped object, a medicine dropper or kitchen baster, and a container of water.

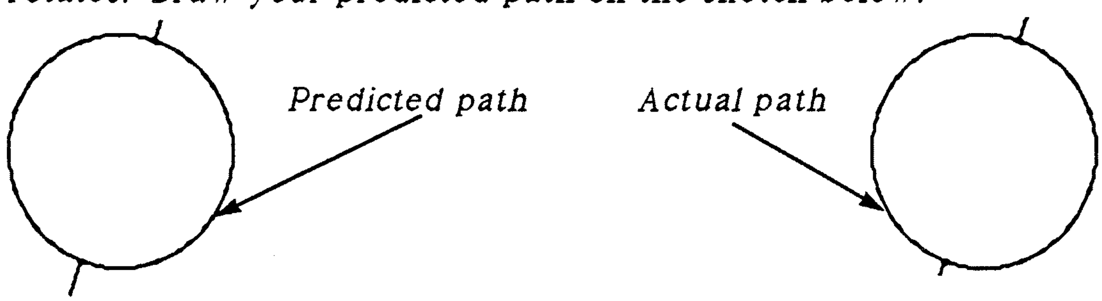
Procedure:

1. *Predict how a stream of water will flow if it runs from north towards the equator on the surface of the globe. Draw the predicted path on the sphere below.*

2. *Now, using the baster, let a stream of water run towards the equator. Draw the path on the sphere below.*



3. *Look at the sphere again. Predict what will happen if the sphere rotates. Draw your predicted path on the sketch below.*



4. *Using the baster, let a stream of water run down over the globe as the globe rotates. Draw the actual path on the sketch.*

Based upon your observations, which way will the water from the Kennebec River move when it enters the ocean?

Look at the map of Maine and notice how many rivers enter the Gulf of Maine. What effect will this have on the water in the entire Gulf of Maine?

Water from the Gulf Stream can not enter the Gulf of Maine because of the Coriolis force. Can you explain why?

Pressure increases with the depth of water. The force created by increased pressure can modify bottom currents and influence bottom activity. Organisms that live in deep water must be able to withstand pressure changes as they move from deeper to shallower areas.

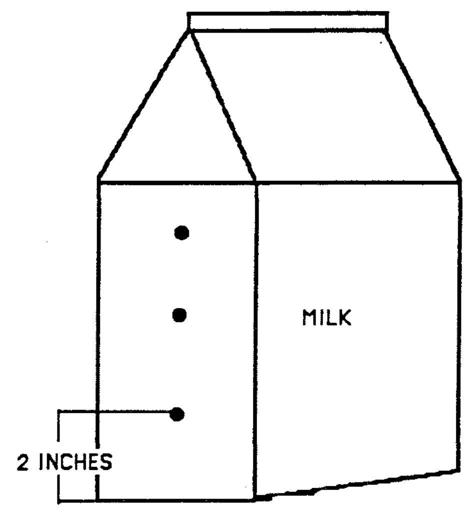
<u>ACTIVITY:</u> ***Pressure-Depth Relationship***

Pressure is caused by a force acting against a surface area. As an animal dives deeper into the water, the more force from the water above and the greater the pressure on its body.

Materials:

Empty milk carton (quart or half gallon), pin, small nail, ruler, water and sink.

Procedure:



1. *Make three pin holes in the milk carton as follows: Place one hole two inches from the bottom, another two inches above the first, and a third two inches above that.*
2. *Take the small nail and push it straight in through the pin hole making sure that each hole is the same size.*
3. *Put the carton in the sink. (Better still take them outside.)*
4. *Fill the cartons with freshwater and observe the results.*
5. *Measure and record the distance the water jets from each hole.*
6. *Do you think the water will jet the same if you use salt water? Fill the container and record the results.*

Analysis:

1. *If you were a fish swimming in the ocean 50 feet below the surface and you moved into an estuary at the same depth, would you notice any pressure change? Explain.*
2. *What if you continued up river into fresh water maintaining a constant depth of 50 feet?*

Temperature is a limiting factor for many marine organisms. Fortunately water requires the gain or loss of large amounts of energy before any change in temperature occurs. For this reason one finds aquatic organisms living in very shallow environments such as tide pools without large amounts of stress.

ACTIVITY: ***Heating and Cooling Comparison Between Fresh and Saltwater***

The time it takes to heat up an equal amount of fresh and saltwater to an equal temperature is a simple measure of the amount of heat needed to alter the system.

Materials :

2 shallow pans, 2 thermometers and a timer, fresh and saltwater

Procedure:

1. *Select 2 shallow pans. Fill one with freshwater and the other with an equal volume of saltwater.*
2. *Place a thermometer in each pan and record the temperature of each.*
3. *Place the pans outside and record the time. (In the winter the water will cool quickly, in other seasons the temperature will rise if you place the pans in the sun.)*
4. *Record the temperature every five minutes from the start. Let the water in the pans warm or cool 10°F.*

Data Analysis:

1. *Which pan of water cooled or warmed the fastest?*
2. *What do you think makes the difference?*
3. *In the spring of the year, which area would warm the fastest, a river, an estuary or open ocean? Explain your answer.*

Research Topic:

Does the Gulf of Maine freeze? Explain your ideas.

An estuarine system is dependent upon nutrients supplied by chemical, geological and biological processes. These nutrients affect the primary production of the systems.

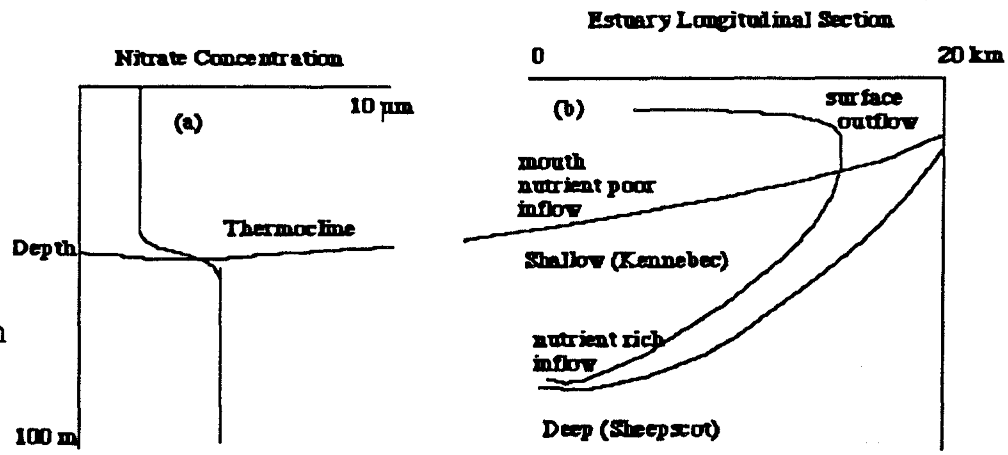
Photosynthesis is the fundamental process by which energy and essential nutrients enter the estuarine food chain. Plant growth continues until some basic requirement limits that growth. Nitrogen availability tends to be a limiting factor on primary production in estuarine and marine environments. Sources of nitrogen are complex and may vary among estuaries. The supply of nitrogen in any estuary depends on the circulation.

Three major external sources of inorganic nitrogen to an estuary are: 1) inorganic nitrate nitrogen introduced in the bottom flow of saline water from the ocean; 2) nitrate (and possibly ammonia) that enters from agricultural use in runoff; and 3) sewerage derived nitrogen (both nitrate and ammonia). Regenerated nitrogen from within the estuary can also be an important source for plant growth.

Nitrogen leaves the estuary with surface outflow in the form of inorganic nitrogen, detritus, phytoplankton, zooplankton and migration of fish and birds.

Nutrient distribution is related directly to the density of the water. The amount of nutrients in the saline water inflow depends on the depth from which the saltwater came. Deeper water tends to have more nutrient, therefore, in areas of upwelling large quantities of nutrients are returned to the surface for recycling.

The effect of depth of the mouth on the nutrient supply of an estuary having a two layer flow regime from off shore waters in summer.

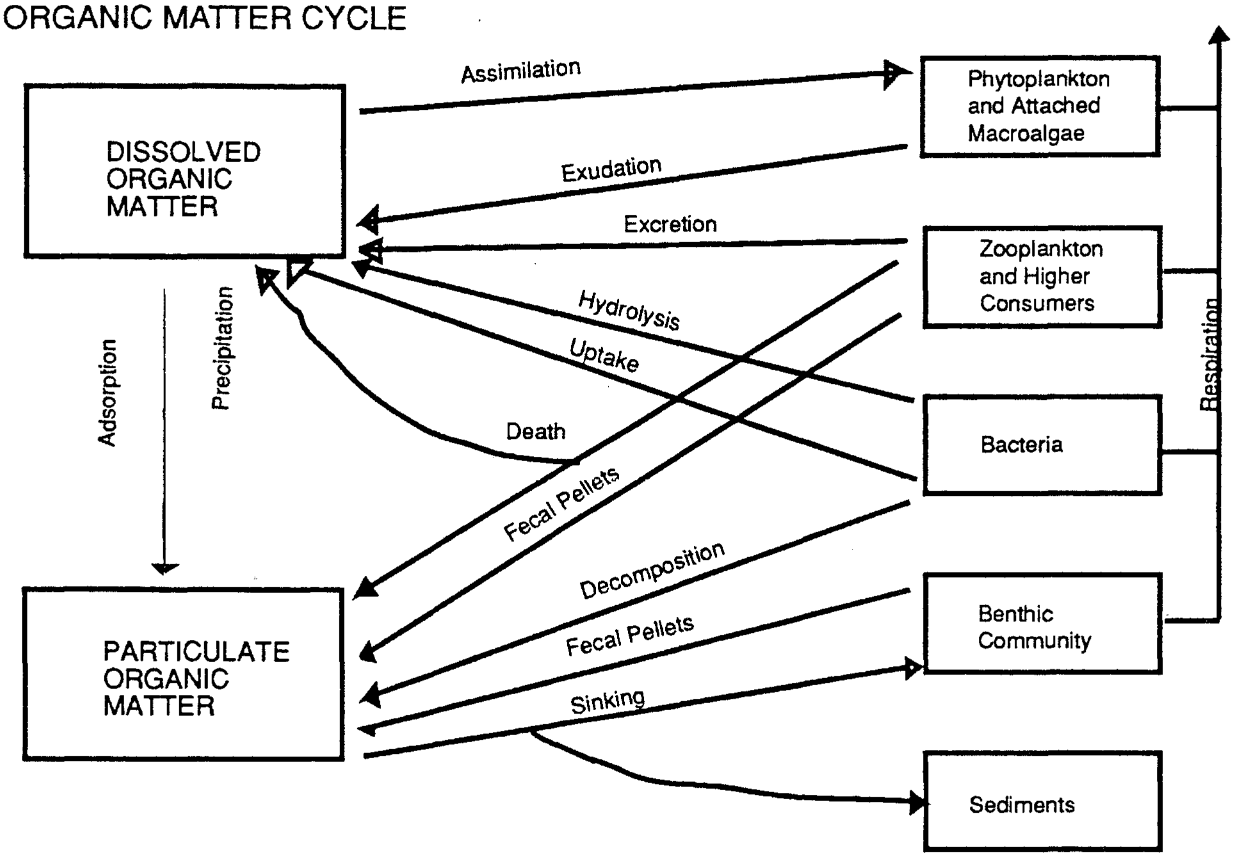


The relationship between depth of water and nitrate concentration (a) and the subsequent nutrient character of the marine waters entering the Sheepscot and Kennebec estuaries; (Garside, unpublished).

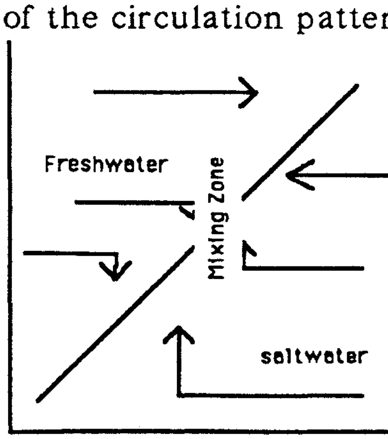
Regeneration of nutrients by heterotrophic activity may pass some nutrients back to the food chain. The process is as follows: nutrients in the surface layer are utilized by phytoplankton for growth. These phytoplankton drift downstream with the surface currents and either die and sink or are grazed. The resultant detrital material from either activity settles to the bottom layer of the water column or the bottom sediments. In the bottom water layer the detrital particles will be transported upstream, decomposing as it moves. The material that fell to the bottom will decompose and the soluble materials will enter the bottom water.

The regenerated nutrients from both situations are moved upstream in bottom flow and progressively mixed back to the surface layer.

ORGANIC MATTER CYCLE

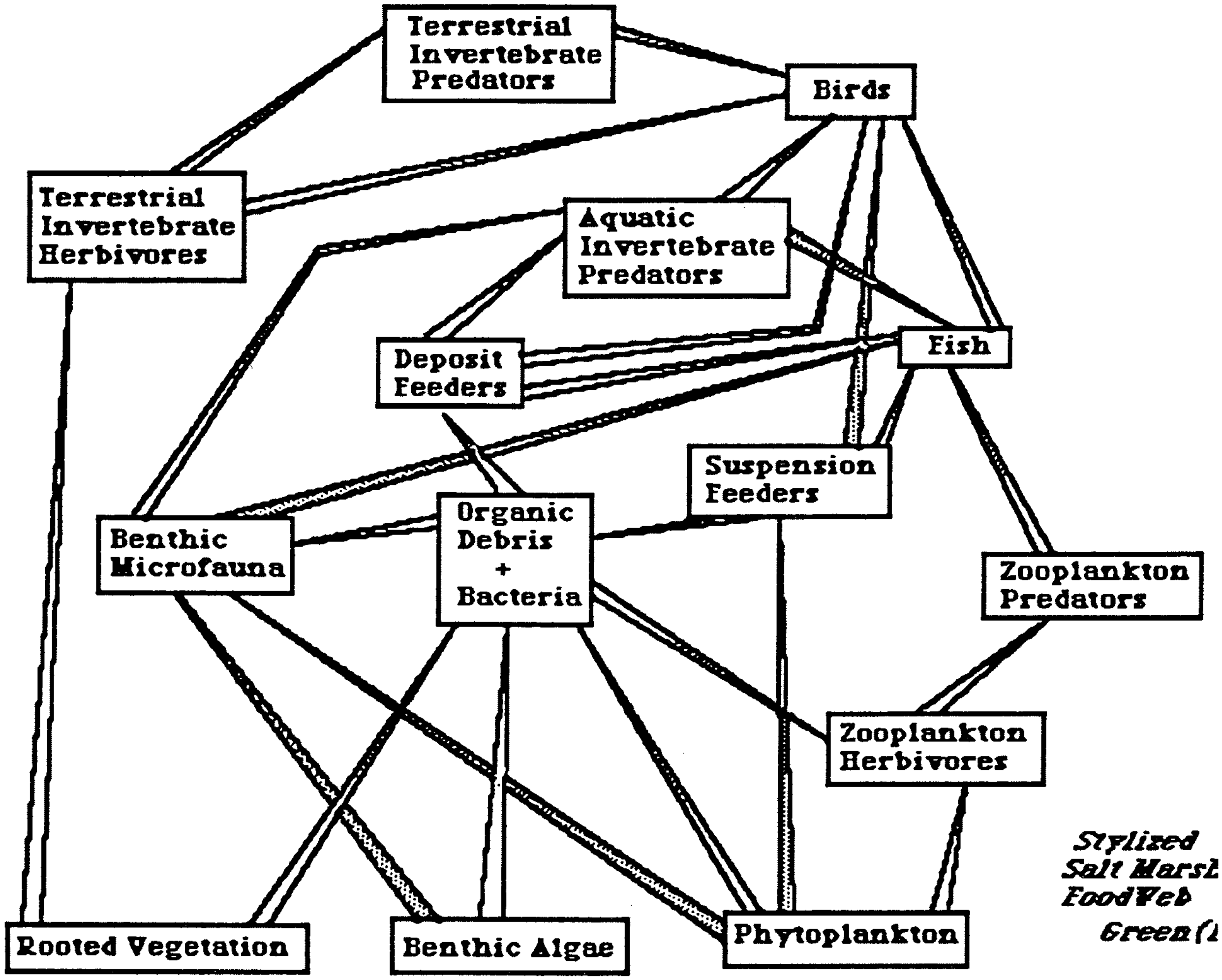


Most of the nutrients in Maine estuaries are supplied by the nutrient rich ocean rather than the low freshwater input of the rivers. For this reason, circulation patterns, mixing and upwellings are extremely important to the nutrient revitalization of the estuaries. These soluble and solid organics are recycled and kept within the estuary primarily because of the circulation pattern driven by the tides. The salt marshes capture the soluble nutrients and convert them primarily to organic matter in the form of phytoplankton, marsh grasses and benthic algae. These plants inturn serve as the base of the food chain and are converted to higher organics as they are used for food by higher animals. The solid organics are captured and serve as food for the filter feeders, bacteria and fungi within the marsh, eel grass beds or associated mud flats. These in turn are used as food for the higher organisms. Some of these higher organisms are permanent residents of the estuary, going through the entire life process here. Thus a vast amount of the nutrients are recycled within the estuarine area several times. Other



Circulation pattern in a typical estuary which results in retention of nutrients.

organisms are transient populations using the estuary as a feeding station, nursery area or staging point for migration. These animals remove organic materials from the estuary.



Estuarine food webs are very complex. Note this simplified version that shows how these organic materials maybe recycled over and over.The estuarine environment has two basic physical components: the intertidal zone and subtidal area. The estuarine subtidal zone is permanently flooded by ocean water but the salinities are usually less than 30 ppt.

This subtidal area has three components: the water column, rock bottoms, unconsolidated bottoms and aquatic beds. (The central Maine region contains more than one-fourth of all the subtidal area in Maine.) Subtidal areas exhibit relative physical stability and this permits the establishment of diverse, highly organized communities. Tidal currents that contain suspended sediments and detritus are an important component of this subsystem.

This subtidal area has four components: the water column, rock bottoms, unconsolidated bottoms and aquatic beds. (The central Maine region contains more than one-fourth of all the subtidal area in Maine.) Subtidal areas exhibit relative physical stability and this permits the establishment of diverse, highly organized communities. Tidal currents that contain suspended sediments and detritus are an important component of this subsystem.

The subtidal water column is the habitat for pelagic organisms. They may be permanent residents such as copepods or temporary residents such as the larvae of the benthic species. The currents found in this area often transport organisms into and out of the estuary and into more marine habitats. The benthic organisms found here depend upon the overlying water column for oxygen, food, the removal of waste and to support and transport the larval stages around the estuary.

Subtidal unconsolidated bottoms comprise most of the benthic habitat found in Maine estuaries. They are made up of submerged glacial deposits, deposits originating from present day marine processes and/or deposits originating from freshwater inflow. These bottoms range from pebbly gravel to mud depending upon the currents traversing the area and the source of the sediment. Usually rich in organic materials and bathed in nutrients, these bottoms produce a diverse biota. Most of the plants on these bottoms are rooted types such as eel grass. The rocky and sandy areas provide suitable support for filter feeders.

Rocky subtidal bottoms result from submerged or exposed bedrock. These areas are generally swept free of sediments by the currents. The biota found here must be able to attach themselves firmly to the rock and resist the abrasion action of tides and waves. Macroalgae prefer the clean, stable attachment surfaces and grow well in these areas provided the salinity is high enough. Brown, red and green algae are all found in these environments in the lower estuary. Other organisms such as barnacles, limpets, and mussels whose structure resists damage by waves and currents find these rocky bottoms ideal.

ACTIVITY: ***Investigating the Distribution of Macroalgae***

The large algae collectively known as macroalgae are important to those animals that utilize the intertidal zone by providing them with protection, shade, food, and oxygen. The algae also reduce the energy of the waves by the motion of their fronds. This lowered energy level makes it a less violent environment for small organisms.

The distribution of macroalgae within the intertidal environment varies from area to area. This activity is designed to determine what factors influence this distribution.

Materials:

Twine for transect lines, compass, notebook, thermometer

Procedure:

1. *Select a section of the beach for your study. Set up three to five parallel transect lines through your site.*
2. *Use the compass to determine the direction of the lines (face of the beach). Record your data on a rough sketch of the area.*
3. *Move down each line. Record the location and the type of algae encountered.*
   (Concentrate your study on Ascophyllum nodosum and Fucus.)
4. *At each site note the type of substratum, exposure to sunlight, the amount of wave energy, and any other factors you think might influence the distribution.*

Analysis:

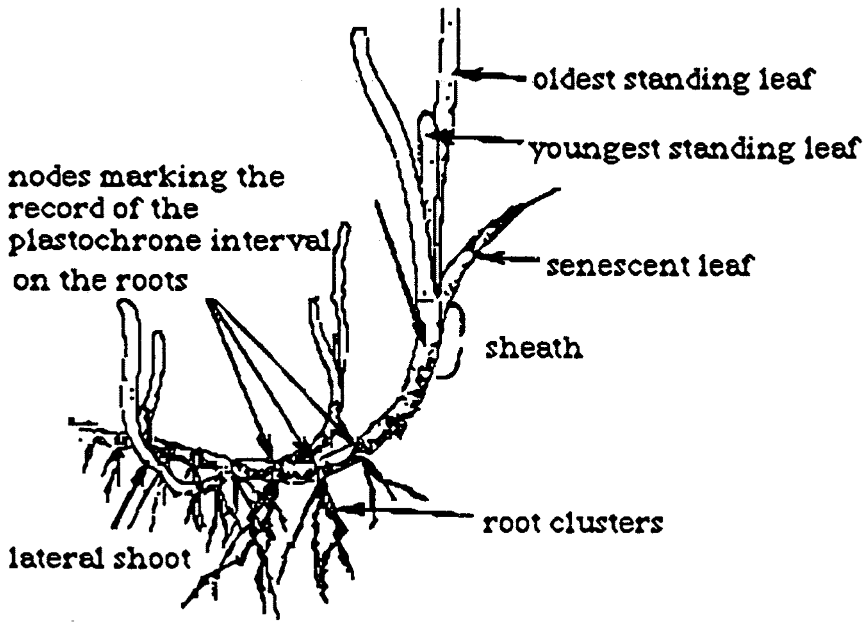
Look at the data you collected in each transect.

1. *Graph each of your transects showing the distribution of macroalgae along the transect line..*
2. *In what sections do you find a predominance of one species over another?*
3. *What was the substratum and the tidal height at each site?*
4. *What was the exposure level to wave energy?*
5. *How much direct sunlight did these areas receive?*
6. *Are there any other common factors?*
7. *Compare your findings with others to detect the common factors.*

Subtidal aquatic beds in Maine are generally composed either of eelgrass or kelp. Eelgrass beds are found in shallow subtidal areas with mostly muddy substrata located from mean low water to several meters of depth. Kelp inhabits rocky high energy areas.

Zosteria marina, eelgrass, grows in areas protected from strong wave surges or currents. Its grass-like leaves and extensive root and rhizome system enable it to live in a shallow marine environment where waves, tides and shifting sediments exist. Forming vast meadows, these eelgrass beds provide shelter and food resources for many small marine organisms. The leaves provide surface for organisms to attach; for the absorption and release of nutrients, and to reduce water velocities thus lowering wave energy thus increasing sedimentation in the area.

Seagrasses are monocotyledonous angiosperms that have returned to the sea and live totally submerged, completing their entire life cycle in seawater. Two adaptations permit this plant to survive; linear grass-like leaves and an extensive root and rhizome system. Because of turbid water conditions and low light energy, the thin lightly buoyant leaves are highly pigmented on the upper surface level. Gas and nutrient diffusions are possible because of the thin cell structure of these same leaves.



Major features of the morphology of Zostera marina

The root and rhizome system anchor the plant to the bottom and absorbs nutrients from the water found in the sediment. The oxygen required for the roots is obtained from the leaves and moves downward to the roots; thus, the roots can be anchored in anaerobic conditions.

Seagrass beds contribute to a large portion of the total productivity of the coastal ecosystem. This organic matter is transferred to secondary consumers through three pathways: herbivores eat the living plant material; detritivores utilize dead material and the micro-organisms on this material as particulate organic matter; and, micro-organisms use seagrass derived particulates and dissolved organic compounds. The grass blades provide attachment sites for many epiphytic organisms such as bacteria, fungi, algae, macroinvertebrates and detritus. In fact, the total biomass community on the blade can exceed that of the leaf itself. The beds also provide protection because of the variety of living spaces in the vertical and horizontal structure of the grass bed.

This combination of food and shelter results in a complex and dynamic system that provides a primary nursery habitat for organisms that are important to both the commercial and recreational fisheries. An eelgrass meadow is a multi-dimensional structure. The flat leaves of various sizes stretch upward into the water column supported by cylindrical shoots. Every movement in the water reshapes the canopy thus hiding the inhabitants in an ever changing pattern. The roots attach this canopy to a tangled mass of organic matter providing even more hiding spaces.

The intertidal subsystem in an estuary covers the area between extreme high and low tide. The substratum is exposed twice daily. In Maine it makes up just under fifty percent of the estuarine system.

This is a very harsh habitat that varies greatly in the composition of the substrata and hence the type and distribution of organisms. Adaptions to live in these environments requires methods for controlling moisture loss, wave exposure, rapidly varying salinities and temperature. Even with these harsh conditions, the intertidal area has a high diversity of organisms.

Intertidal Investigations - Field Studies Activities

A great deal of information can be learned about a population of animals, and an area, by obtaining a sample of organisms. Repeat sampling over a period of time can provide information on the population of the area, its size, age and weight composition and the species diversity. Scientists use a wide variety of activities to study intertidal populations. The following exercises are examples.

ACTIVITY: ***Beach Seining***

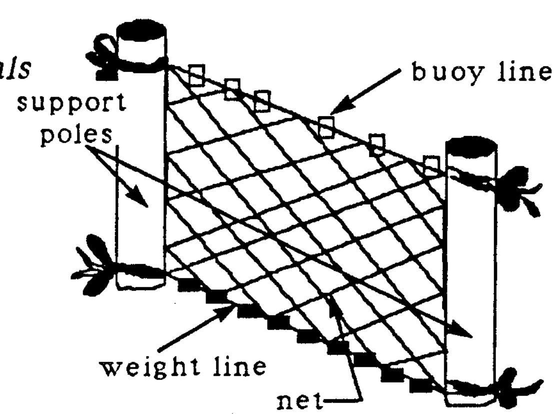
A sampling method utilized on sandy and muddy bottoms to obtain organisms from the shallow water segment of a beach is beach seining. It involves the use of a small mesh net that can be stretched out and dragged through a portion of the water to obtain a sample. Small fish and crustaceans such as shrimp are easily caught with this method.

In this activity we will make a population study of a portion of the sandy beach using a beach seine. The beach seine is a fine-meshed, long rectangular net that is set out near the shore. The net is then hauled toward the shore trapping all the organisms within the area.

All the organisms caught are identified, weighed and measured.

Materials Needed:

A beach seine approximately 10 feet long, buckets to collect and hold animals caught, two poles about 6 feet long for the ends of the beach seine, 2 personal floatation devices for the safety of the sampling crew, and notebooks.



Procedure:

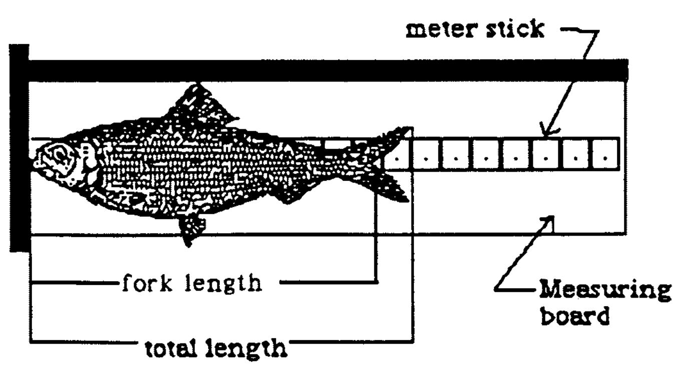
1. *Choose a segment of beach relatively free from large rocks.*
2. *Select two student samplers and have them put the personal floatation devices on.*
3. *Samplers should keep the seine rolled upon the support rods. Holding the net out of the water, have students move one behind the other out into the water until at least waist deep. Unroll the net (floats to the top) perpendicular to the shoreline and weights near the bottom.*
4. *Now the person farthest from the shore should walk that end in an arc. When parallel to each other, both ends should be walked inward until the organisms are surrounded by net and shore. (LET A SMALL BOW FORM IN THE NET - KEEP THE WEIGHTED EDGE ON THE BOTTOM - DON'T WORRY ABOUT THE TOP.)*
5. *When the bottom of the net gets close to shore, have the other students help pull the net by the bottom line up onto the dry beach. DON'T LIFT THE BOTTOM OR THE ANIMALS WILL GET AWAY.*
6. *Quickly capture all the animals and place in buckets of water.*
7. *Sort by species, identify, count and measure all the trapped animals. WORK RAPIDLY TO KEEP YOUR ANIMALS ALIVE. Record your data. Make sure your record sheet also gives the location where sample was taken, state of the tide, the temperature, date, direction of wind and the weather. Explain why all this information is important.*

ONCE YOUR DATA IS OBTAINED RETURN YOUR SPECIMENS TO THE WATER. RETAIN ONLY A FEW FOR LATER TESTING IF NEEDED.

TECHNIQUES:

Measuring fish - Using a measuring board to record length of fish.

1. *Place fish on measuring board. Tip of nose should just touch the end of the board. Squeeze tail together and read where the tip crosses the meter stick. Record the total length or fork length of each fish.*
2. *Note the species and any other observations.*
3. *Work as rapidly as possible to keep the organisms alive.*



All data should be recorded on a standard data sheet and all measurements should be the same.

Data Sheet:

Names of samplers:--------------------------------------
Date: -------------------- *Weather* ---------------------
Place Sample Taken:------------------------------------
State of tide:------------------ *Time* ----------------

TOTAL LENGTH IN CENTIMETERS OF FISH CAUGHT IN SEINE NET

----- ----- ----- ----- ----- ----- ----- ----- -----
----- ----- ----- ----- ----- ----- ----- ----- -----

OTHER ANIMALS CAUGHT IN SEINE:

---------- ---------- ---------- ---------- ---------- ---------

Analysis of data:

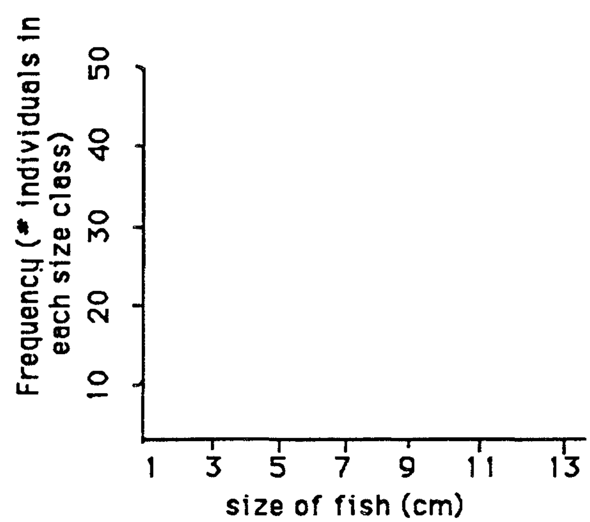
Construction of a tally type data sheet showing how data taken can be used to indicate class size.

Size Limits (example Table)	*Tally(No. in that size)*	*Frequency*
1.0 - 2.9	\\\	*3*
3.0 - 4.9	~~\\\\~~	*5*

Construction of size-frequency distribution graph with the size classes on the X axis and the number of individuals on the Y axis.

These are guidelines that will help you:

1. *The more individuals in your sample the better your graph will be. If you have less than 20 individuals don't try to graph your data.*
2. *Divide your data into equal class intervals. The example above shows an equal division. Don't use different intervals for different parts.*
3. *Choose your class intervals so there will be no overlap. Note the above example 1.0 - 2.9 NOT 1.0 - 3.0.*



4. *Divide your measurements into the best number of classes. Usually no more than 15 and no less than 5.*
5. *A frequency histogram is formed by drawing rectangles over the class intervals or a line graph can be plotted using the midpoints of each class.*

Tidal marshes are extremely valuable segments of the estuarine environment serving as a nutrient trap and a supply house for the water column. These areas have heavy concentrations of plant growth.

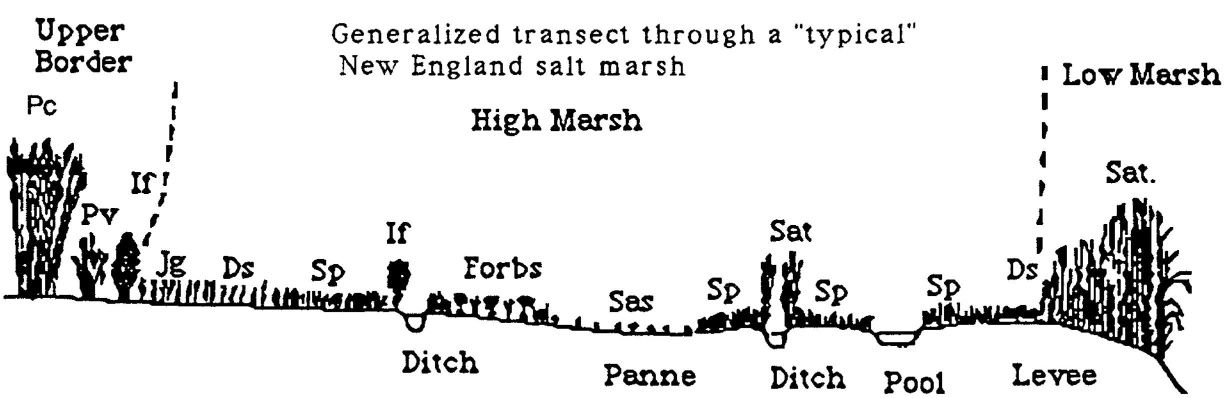
One of the most obvious factors about a salt marsh is the zonation of the plant life. Many physical factors interact to cause this zonation such as physiography, tidal inundation, height of water table, soil type, seepage, drainage, aeration, salinity, nutrients and climate.

Tidal inundation is probably the most important of the factors. It is dependent upon the elevation, slope of the land and proximity to the water source. The length of time that tidal water stays in a marsh is influenced by the height of the water table, the soil type and hence how fast seepage and drainage occur.

Climate, latitude and position relative to wind direction are also important factors when discussing salt marshes. For example, southern marshes may produce two or three crops of vegetation a year because of the length of season where northern marshes can produce only one crop. Thus, productivity is related to climatic conditions.

Salinity in a marsh is partially controlled by tidal inundation and the amount of freshwater input from the land. This salinity variation, in turn, partially controls the amount, and type of plant life present. Nutrients and their distribution also play an important part in the distribution of tide marsh plants. For example, Spartina alterniflora grows only where salinity concentrations are at a specific level.

Generally, as one moves from dry land toward the water, elevation tends to decrease and salinity increase. Several features within the marshes are important because of the exceptions they pose. For example, hummocks are natural or man-made rises. They provide sites for plant colonizations atypical to the area. Pannes are shallow depressions that collect water. Evaporation is often the only way water can be lost from



Sat = tall Spartina alterniflora; Sp = Spartina patens; Ds = Distichlis spicata; Sas = short Spartina alterniflora; If = Iva frutescens; Jg = Juncus gerardi; Pv = Panicum virgatum; Pc = Phragmites communis.

these features and results in increased salinity and nutrient levels. Pannes are often filled with mats of decaying materials that cause increased acidity and anaerobic conditions which in turn controls the organisms that live there.

At the level within the marsh where salt is not present in the soil, but salt spray may be in the air, land plants begin to dominate. Here is where bayberry, Eastern red cedar, seaside goldenrod, rugosa rose and the giant reed (Phragmites communis) are found.

The next zone is covered by saltwater during periods of highest tide. This area supports the salt meadow cordgrass (Spartina patens), glassworts (Salicornia), and salt grass (Distichlis spicata).

The zone covered by saltwater at every tide supports tall salt marsh cordgrass (Spartina alterniflora). Behind this tall form is the short form salt meadow cordgrass (Spartina patens) that occupies slightly higher elevations and thus less salt. These grasses use the salt to provide osmotic pressure within the plant to stiffen it against the tidal currents. These same plants remove the excess salt from their cells through reverse osmosis, leaving it as deposits on its leaves. Another plant that also relies upon salt water coverage each tide is glasswort (Salicornia, sp.).

Because of the large variation in temperature, salinity and exposure within a marsh, the animals that are permanent residents must burrow to survive during periods of low water or adapt in other ways. Most organisms prefer to migrate into the marsh in search of food and out to live. The marsh environment is extremely rigorous and very few organisms spend their entire life cycle here. In our marshes the ribbed mussel, mud snails, periwinkles and green crabs seem to be the dominant residents and even these hardy organisms spend their larval stages in the plankton within the estuary.

The value of the salt marsh is its abundance of plant life. The algae and grasses produce huge amounts of organic food that is available directly within the marsh and indirectly outside of the marsh as a result of flushing by the tides. The algae enters into the estuarine food web through the planktonic grazers. However, decomposers must act upon the grasses and reeds before they are ready to enter the aquatic food chain. This often requires a long period of time and some physical destruction to break the stems and leaves up enough for the bacteria and fungi to act.

The decomposition rates for the roots in a northern marsh are quite high even under anaerobic conditions and the accretion rate is therefore low. The nitrates produced in the decomposition process are made available to the system through percolation and flushing.

ACTIVITY: ***Salt Marsh Transect***

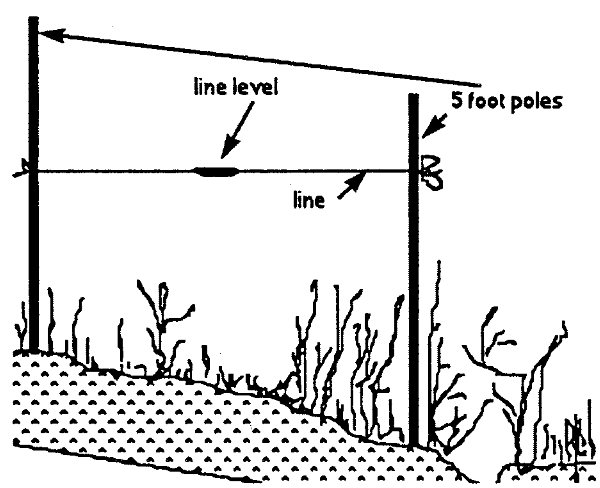
A salt marsh transect can be an effective method of gaining information about the relationships and influence of elevation and salinity on a wet area.

Materials required:

Two five-foot poles ; twenty-five feet of string; graph paper, pail, fine mesh dip net or pole with strainer attached to one end , meter stick and a carpenters line level.

Procedure:

1. *Divide students into groups of five and assign the following duties:*
   Team members - two pole attendants.
   - person to measure height of string above the surface.
   - two persons to graph the flora and fauna in conjunction with elevation.
2. *The twenty-five foot string is tied in the middle of each pole. Place the line level in the middle of the string.*
3. *Beginning at the edge of the marsh and perpendicular to the water, stretch the string taut between the poles and adjust the string at one end until the line is level. Measure the distance between the bottom of marsh and the stretched string at fixed intervals of one meter. Record the values.*
4. *Move the first pole to the spot occupied by the second pole. Stretch the string out taut once again, make the line level, and measure at one meter intervals once more. Record the values. Continue this procedure until you have reached the end of the marsh.*



5. *Measure off a square one meter on a side at each meter interval and record everything contained in that meter. Record the vegetation type, animal life and any other factor with in that meter interval. (Remember to look below the grass.)*
6. *Repeat the process along three additional transects at least 25 feet apart. and parallel to the first.*
7. *Sketch your segment of the marsh onto your data sheet and identify any out standing features. This will help you analyze your data at a later date.*

Analysis:

1. *Using the data you collected, draw a profile of the marsh on the graph paper.*
2. *Locate and name the principal plants and animals found along the transect.*
3. *In your transects what plants dominate the zones of greatest salinity?*
4. *What plants dominated the areas of greatest slope change?*
5. *How does slope change affect the plant communities? Does it also effect the distribution of animals and insects? How?*
6. *Compare your profiles with other members of the class. What similarities and differences occurred?*
7. *How does your profile compare with the diagram of a "typical" marsh?*

ACTIVITY: ***Scientific Sampling of a Beach Site***

When one wishes to obtain population counts for an area, scientific sampling techniques are employed. These involve making accurate counts of organisms in a small area and then multiplying to obtain a population estimate for the total area.

These counts may be taken randomly using some type of random sampling method. At other times the counts are made along transect lines crossing the area.

In this activity you will use one of these established methods to ascertain the population of various organisms within the area.

Materials needed:

One coat hanger per group	*(Coat hangers pulled into a square make excellent plot markers of fixed size.)*
Yardstick or meter stick	*100 ft. of twine marked off in regular intervals.*
Wooden stakes	*Notebook*
Field guide	*Compass*

Procedure: Random plot sampling -

Your study plots must be chosen randomly for this method to work.

1. *To obtain your plot, stand along the edge of the site, close your eyes and throw the coat hangers into the plot.*
2. *Count and record all the plants and animals found inside the frame. Any plant or animal that has one half or more of its body inside the frame should be counted.*

3. *Close your eyes and throw again, proceeding in the general direction of the opposite side of the study site. Repeat the counting procedure and record. Continue this process until you have a minimum of 5-10 plots (agree on the number beforehand).*
4. *Analyze your data as described below.*

Systematic sampling. (Transect method).

1. *Select your study site. Stand at the water's edge and using a compass sight across the marsh perpendicular to the beach face. Stretch the rope into the marsh along this line. Using a coat hanger as a marker, take a plot sample at meter intervals along the rope. (Any plant or animal within the square or more than halfway in the square should be counted. If there are too many to count of one type, count the number in a square inch, then multiply by the number of square inches in the plot.) Make a note of inanimate evidence of life found in a plot such as seashells, detached seaweed, bird feathers, animal droppings, etc., as part of your data.*
2. *Data should be recorded in a notebook along with the date, time, location, weather conditions, etc. Data for each plot should be kept separately. Make a sketch of the site for later use.*

Data analysis:

1. *Produce bar graphs of your results to show the graphical relationship that exists between the plants, animals and the distance from the shore.*
2. *To compute the average number of plants or animals per plot, divide the total number recorded by the number of plots sampled. (For example, 50 ribbed mussels were recorded in a total of 100 plots, therefore, the average number of ribbed mussels is 0.5 per plot.)*

3. *To figure the number of animals or plants on the entire study site, use the formula:*

$$\text{Total square inches in study site} = \frac{\text{Total number of plots taken}}{\text{Total square inches in a plot}}$$

Total creatures on study site = Average number of organisms per plot x total number of plots

Analysis:

1. *Compare the population counts obtained by each sampling method.*
2. *What is the dominant organism on the marsh?*
3. *How do the plant populations compare to the animals?*
4. *If you were asked to describe a marsh in four words, what would they be?*

ACTIVITY: A Transect Study of a Beach

A transect study made across the beach provides a quantity of information about this transitional area. The difference in elevation, structure, kinds and numbers of living things are a few of the topics that can be studied using this technique.

Materials:

Compass, long string or rope, topographic map of area, notebook, small spade or trowel, several stakes and a field guide

Procedure:

1. *Select an area for study by random methods and make a sketch of the area.*
2. *Establish a bench mark and locate it in reference to natural features using your compass. Locate north and the bench mark on your map.*
3. *Run a line through the bench mark perpendicular to the water and up the beach to the shore. Secure the ends to a stake.*
4. *On your map locate the study points in reference to the bench mark.*
5. *Record the position of the waters edge on the map, the approximate level of the tide and the time. Note the location of strand-lines and record.*
6. *Place a quadrat down at regular intervals along the transect line. Count the number or the percent coverage of each species of plant and animal found in the quadrat. Record.*
7. *Take sediment samples at regular intervals along the line and analyze as to composition, for example: sand, silt, shell, etc..*
8. *Make other measurements along the transect that might be related to your study (such as temperature, salinity, peat depth, and pH). Record.*
9. *Measure the vertical elevation and horizontal distances of points along the transect line.*

Analysis:

1. *On a large piece of paper, redraw your sketch map to scale and place your data on that map.*

2. *On this map place zonation lines using the dominant animal as the indicator. What percentage of the beach is occupied by each zone?*

3. *What happened to the slope of the beach in these zones?*

4. *How did the sediment composition relate to the different zones?*
5. *Did the composition of the strand line consist of the same organisms as found on the beach? Explain.*
6. *Compare your map to those constructed by your classmates. What were the similarities and differences?*

Extension:

A diversity index can be developed from your data to show the changes in numbers of organisms from zone to zone. To compute this value, use the following scheme: record an "x" for each specimen you found of the same species, then an "o" for each specimen when the species changes, and repeat.

Example: Four of one species within a zone followed by six of a different species in the same zone and three of a third species would be recorded as follows: XXXXOOOOOOXXX.

The diversity index = $\frac{N}{a^2 + b^2 + c^2 + \ldots}$

N = Total species
a^2 *= Species 1*
b^2 *= Species 2*
c^2 *= Species 3, etc.*

$$\frac{13}{4^2+6^2+3^2} = \frac{13}{16+36+9} = \frac{13}{61} = 0.21$$

The closer the diversity index is to1, the greater the diversity. A seashore community of high diversity is regarded as being more stable and therefore healthier. Communities with a single species indicates a mono-culture and would have an index of one but it is unstable. Why?

PRIMARY PRODUCERS

Energy inflow in most natural marine systems is downward from the surface. In the estuarine environment the energy from the sun is used along with the nutrients dissolved in the water for plants to grow and reproduce. The primary producers in Maine estuaries are the macroalgae, eelgrass and other emergent rooted grasses, phytoplankton, benthic diatoms and some microbes. (This is a major difference between the estuary and the marine environment where phytoplankton dominate.) Estuaries have higher productivity than coastal marine water because production is maintained over a longer period of time because of mixing. This plant material, either in living or dead form, is the base for the transfer of energy throughout the entire system by means of the estuarine food chain.

Plants require adequate sunlight, nutrients, particular ranges of water temperature and salinity. Seasonal changes in these conditions control growth. For example, in winter deep mixing may carry phytoplankton in the mouth of the estuary below the level of sufficient sunlight to support growth and the phytoplankton either die or do not reproduce. The depth that this occurs is called the critical mixing depth which is three times the depth of the photic zone.

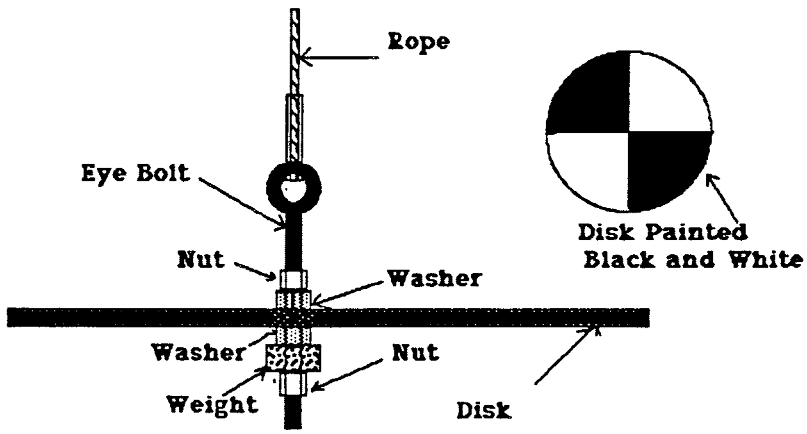
In either fresh or oceanwater area, plant life can grow only in the lighted zone (Photic). To find the limiting depth of light penetration, a piece of equipment called a Secchi Disk, may be used.

ACTIVITY: ***Measuring the Depth of the Photic Zone***

The amount of light available for plants to use in photosynthesis is influenced by many factors such as the amount of sediments being transported in the water, the angle of incidence of the sun, the amount of plant life in the water and more. Plants can grow to the bottom of this light penetration. A Secchi disk can be used to determine how deep down in the water column the light penetrates.

To build a Secchi Disk obtain the following materials:

1. *The lid from a gallon paint can, aluminum sheet, or plywood that can be cut to a diameter of 8 inches (20cm). Divide the circle into quarters.*
2. *Paint every other quarter black and white.*
3. *Drill a hole through the center and assemble as shown in the diagram.*
4. *Obtain a light weight rope, mark it off in yards or meters and attach to the eye bolt.*



PROCEDURE:

1. *Lower the disk over the shadowed side of the sampling platform. If you have a viewing tube (piece of PVC pipe with a piece of plexiglass glued to one end), place it in the water next to the rope and look down to see the disk.*
2. *When the Secchi disk just disappears from your sight, STOP, and pull the disk back towards the surface until it JUST BECOMES VISIBLE.*
3. *Record the depth from the disk to the surface as the depth of light penetration in the data sheet. (Remember the marked rope lets you read the depth easily.)*

4. *Also record any visual factors you can see that might affect light penetration, for example, mud or lots of plants (greenish color to water).*

Rooted vegetation can not grow below this depth. Phytoplankton can actually live to a depth of three times the depth of this zone but they do not reproduce or produce food below the critical depth.

In Maine estuaries diatoms occur most frequently and in larger numbers than other groups of phytoplankton. (Diatoms have cell walls of silica and tend to have a lower mortality level than other plankton). The next most abundant type of phytoplankton is the dinoflagellates who prefer higher salinity levels. These plankton have some mobility because of their flagella. Paralytic Shellfish Poisioning, "Red Tide," is caused by one of these organisms.

Benthic diatoms may play a large part in the total productivity in the estuarine system, however, no one knows for sure to what extent. These organisms cling to the sediments, vegetation and other stable objects in vast numbers. Studies are needed to determine their abundance. It is known, however, that they are essential to the food chain and are eaten by common periwinkles, mud snails, and other bottom feeders.

Winter water temperatures are limiting factors for all plants, floating or attached. For phytoplankton the photosynthetic rate is altered by fifty percent for every change in temperature of approximately 18°F between 32°F and 68°F.

Planktonic feeders probably use some of the microbal producers (bacteria and fungi) as food. Some of these microbal producers are photosynthetic and are thus part of the basic food chain. However, because of their size bacteria and other micro-organisms suspended in the water column have received little study.

The consumers in the estuarine food chain are very diverse. However, zooplankton, benthic invertebrates, squid, fish, birds and marine mammals make up the major portion.

Zooplankton are a diverse assemblage of animals that float or swim weakly in the water column. The currents serve as their principal means of motion. These organisms feed heavily upon the primary producers as well as the smaller zooplankton. In the process they release organic matter, nutrients, nitrogen, and phosphorus and excretory products that aid in the growth of the phytoplankton and other estuarine plants. Zooplankton tends to be a major trophic link between the primary producers, phytoplankton and other estuarine plants, marine microbes, detritus, and the aquatic carnivores such as jellyfish, comb jellies, arrow worms, larval fish, the herring family, mackerel, and other zooplankton (larval stages of mollusks, gastropods, etc.).

Benthic invertebrates may live in (infauna) or on (epifauna) bottom strata. The majority of benthic estuarine animals in Maine fall into three groups (annelids, mollusks and crustaceans). These organisms take the direct and indirect products of primary production and convert them to animal protein. During the feeding and burrowing activities of these animals, they alter the sediments permiting water and oxygen to enter the sediments. This is essential for the infauna who are dependent on the overlying water to supply oxygen and remove waste.

The primary factor influencing distribution and abundance of benthic species is the nature of the substratum and the salinity. Substratum requirements are related to feeding type and mode of living. For example, detrital feeders are most abundant in fine sediments of silt and clay rich in organics. They pass these sediments through their body, digest bacteria and excrete fecal material that is again colonized by bacteria and reconsumed. Filter feeders, such as, oysters live attached to the substrata and depend upon the currents to bring food their way.

Estuaries tend to have lower diversity of fish then the ocean. Temperature variations and salinity fluctuations are major factors determining the seasonal and/or local distribution of fish in the estuary.

Fish are important components in the energy flow of the estuarine system because of their abundance (biomass) and representation on many levels of aquatic food chains. Estuarine systems are dominated by dermersal/demidermersal species followed by nektonic and then planktonic. Fish populations in Maine's estuarine systems are dominated by resident dermersal (bottom dwelling) species such as Atlantic tomcod, flounders, sculpins, skates, cunner, rock gunnel, and sea ravens. Seasonal fish are best represented by the anadromous fishes (alewives, American shad, blueback herring, sturgeon(Atlantic and shortnose sturgeon), Atlantic salmon and sea lamprey) and the catadromous American eel. Cunner and Atlantic cod are both nektonic and dermersal. The herring family is an example of planktonivores. Menhaden and sand-launce are water column feeders that feed on pelagic crustaceans (copepods, mysids, euphausiids and amphipods). Nektonic feeders consume pelagic crustaceans and fish. Most of the areas summer migrants hake, spiny dogfish, bluefish, mackerel, and striped bass as well as Rainbow smelt, Atlantic salmon and white perch are nekton feeders. Dermersal feeders are the flounders, codfish, skates, sculpins, eels, tomcod, sturgeon and sticklebacks. Rainbow smelts are the primary year-round residents in the upper estuary.

ESTUARINE - PROJECT WORK

Project work organization and safety.

Teacher part:

1. Be involved in the selection of the project to be studied.
2. Act as an advisor during the project.
3. Supervise the work and make sure safety precautions are taken.
4. Organize projects to insure that they concern the same sites. This makes for better supervision and greater discussion.
5. Always work in groups never alone. Make sure all the students realize the danger of tides and sediments.
6. Teachers should familiarize themselves with the study area previous to taking the students there.

The following are techniques for studying: a) salinity, b) sediment types, c) turbidity and suspended solids, d) oxygen and B.O.D., e) coliform bacteria, f) nitrogen and phosphorus, and g) distribution and abundance of organisms.

a) Salinity:

Salinity is a measure of the total weight of salts dissolved in a kilogram of water. Open seawater has a salinity of 35 parts per thousand (35 oo/ooo). However, the salinity in an estuary will fluctuate with the tidal cycle, the volume of freshwater runoff, the season and the position of study within the estuary, and the depth. This variation in salinity is a dominant factor affecting the distribution of organisms.

To determine the salinity, titration of a sample of seawater with a silver nitrate solution using a chromate indicator will precipitate the halides, mainly chloride, and the salinity may be calculated from Knudsen's Formula: $S = 0.03 + (1.805 \times cl)$ where S= salinity (parts/103) and Cl = total weight in grams of halides per kilogram of water.

A convenient method which avoids the necessity for calculation is to titrate 10 cm^3 of sample water with a silver nitrate solution containing 27.25 g/l. The volume of the silver nitrate in cm^3 required will roughly equal the salinity of the sample.

There are several packaged and highly portable test kits that will permit the determination of salinity in the field and that determine the salinity simply by counting the drops.

The salinity may also be determined using a hydrometer, a thermometer and a conversion table. (Obtain a copy of this procedure from DMR.)

The salinity in an estuary varies with time, distance from the sea and depth. Each of these parameters must be checked if a total picture of the estuary is to be developed.

To obtain water samples at different depths, a boat or suitable positioned bridge is usually necessary along with a water sampling bottle. The type of sampling bottle used doesn't matter. Several different types may be built in class and utilized for this task.

b) Sediment Analysis:

Sediments provide food and protection for large populations of benthic animals. Current speed is a determining factor in the nature of sediment distribution. Sediment particle size is often crucial in determining the species and biomass present in a particular area, some animals having definite preferences for particle size.

The nature of sediment as a habitat for interstitial animals is influenced in a number of ways by particle size; for example, fine sediments form greater organic content and tend to retain water at low tide. Those organisms that use detritus as food would prefer this environment to one where the organics are constantly being removed.

There are many scales used to determine sediment particle size, but for most work the following can be used:

Gravel and stone >2mm
Sand 63 m - 2mm
Silt and clay <63 m

To determine sediment size, the sediment samples must be dried first to a constant weight. Then 100g of dry sediment is sifted through a series of sieves and the weights determined.

c) Turbidity and Suspended Solids:

Method 1

Suspended particles are a major part of the estuarine water. This suspended load may be composed of living (plankton) and non-living (detritus). Detritus may contain dead organisms and such material as sand or clay particles. Suspended solids decrease the amount of light penetrating the water and thus limit the depth to which plants may grow.

A Secchi Disk lowered vertically into the water until it just disappears can be used to determine the depth of light penetration. The rate of decrease in illumination is known as the extinction coefficient (K). $K = 1.7/d$, where d is the maximum depth in meters at which the disk is visible. For most situations, reading the depth is sufficient to establishing the depth of light penetration.

Method 2

A simple optical method of measuring "turbidity" requires a clear tube at least 70cm long with a flat bottom. A disc of white paper with a central black cross having line 1 mm wide is stuck to the bottom of the tube so the cross can be seen by looking down the tube. A well-shaken sample is poured in until the cross disappears when looking down through the water, the depth of the water is then measured in millimeters.

d) Oxygen and B.O.D.

Oxygen meters are the fastest methods for determining oxygen concentrations in the field but are expensive. Determinations of the oxygen concentration using the Winkler titration method may also be used. This titration method is described in most books of standard methods or chemistry books. The same results can be obtained using the pre-packaged oxygen test kits that may be purchased. Oxygen analysis techniques are used for a variety of determinations.

Oxygen depletion in estuarine waters by micro-organisms, fish, organic decomposition, temperature increase or pollution can affect the quantity and type of organisms found there. The oxygen content of the water column and of the interstitial water in the sediments is often not the same. The particle size of the sediment influences the oxygen content of the water found there. Many fine estuarine deposits have anaerobic conditions only fractions of an inch below the surface. Animals living in such layers must generate their own water currents from above in order to live here.

When organic material is in the water, aerobic micro-organisms oxidize the organics causing some depletion of the oxygen content of the water. The biochemical oxygen demand (B.O.D.) is the amount of oxygen taken up by one liter of water over a five day period at 20°C. It is important that oxygen is not in short supply during incubation so all dilutions are made with well aerated tap water. (Generally polluted water requires four volumes of tap water per volume of sample).

B.O.D. = (Initial oxygen concentration (mg/l) - the oxygen concentration after incubation (mg/1) x (No. of volumes of dilution water per volume of sample + 1).

The following descriptions of B.O.D values are used to describe the water: 10 Badly polluted; 5 Suspect quality; 3 Fairly clean; and, 2 Clean.

e) Coliform Bacteria

A group of organisms typically found in the gut and in sewage effulent are the coliform bacteria, Escherichia colii, a harmless bacteria that ferments sugar producing gas as it does so. Detection of this bacteria in the water indicates pollution of that water by fecal coliform. The abundance of these bacteria gives an indication of the degree of pollution.

The presence of these bacteria may be determined using an agar jell contained in a tube. The jell in the tubes contains a nutrient suitable for coliform fermentation, an acid indicator, and bile salts which inhibit the growth of other micro-organisms. A small glass tube is inverted in these tubes. When incubated for 48 hours at $37^{\circ}C$, fermentation occurs if coliform is present as denoted by an acid reaction color change and gas in the small tube.

A similar test can be run using an agar jell on a Petri dish and counting the number of coliform colonies that develop. Caution should be used in either method, since you are working with bacterial pollution.

f) Distribution and Abundance of Estuarine Organisms

Certain terms are used when defining the types of habitats available to estuarine organisms:

Benthic organisms	- organisms living in association with the bottom.
Pelagic organisms	- organisms living within the body of water
Plankton	- organisms that are moved about by the water currents and winds (they have poor locomotion of their own).
Nekton	- able to move about freely against the water currents.
Interstitial organisms	- live mainly within the sediments.
Epibenthic	- live on the surface of the bottom.

Simple plankton nets can be used to obtain plankton samples from sites along the shore, off bridges, docks and piers. These nets may be constructed of a variety of materials, however, the finer the mesh the smaller the organisms caught. To obtain phytoplankton, mesh as fine as silk must be used.

Beach seining, where possible, can provide a sample of the nekton and epibenthic fauna. Dip nets, screen sieves, bait traps and fishing tackle can also be used.

Distribution of the macro-benthos can be obtained by doing quadrats and transects. Transect work will reveal the zonation of species and is often very pronounced.

Mud samples can be removed at intervals along a transect and sieved through a frame covered by window screen. Animals retained are considered macro-benthos.

Projects conducted in estuaries are easily repeated at a variety of sites or even seasons of the year. The data will produce more questions and more projects. Data can be stored in computers and comparisons made over several years may produce even more projects.

The information obtained may be of interest to Sportsmen's groups, Fish and Wildlife, and Marine Resources Scientists. Exhibits, displays and reports could lend themselves to good school/community interactions.

For additional materials and project techniques, contact the Education Division, Department of Marine Resources, State House Station # 21, Augusta, Maine o4333.

SPORT FISH RESTORATION

This program receives Federal financial assistance in Sport Fish and/or Wildlife Restoration. Under Title VI of the 1964 Civil Rights Act, Section 504 of the Rehabilitation Act of 1973, the Age Discrimination Act of 1975, Title IX of the Education Amendments of 1972, the U.S. Department of the Interior prohibits discrimination on the basis of race, color, national origin, age, sex or handicap. If you believe that you have been disciminated against in any program, activity, or facility as described above, or if you desire further information please write to:

The Office for Human Resources
U.S. Fish and Wildlife Services
Department of the Interior
Washington, D.C. 20240

Printed Under Appropriation No. 3140.3260