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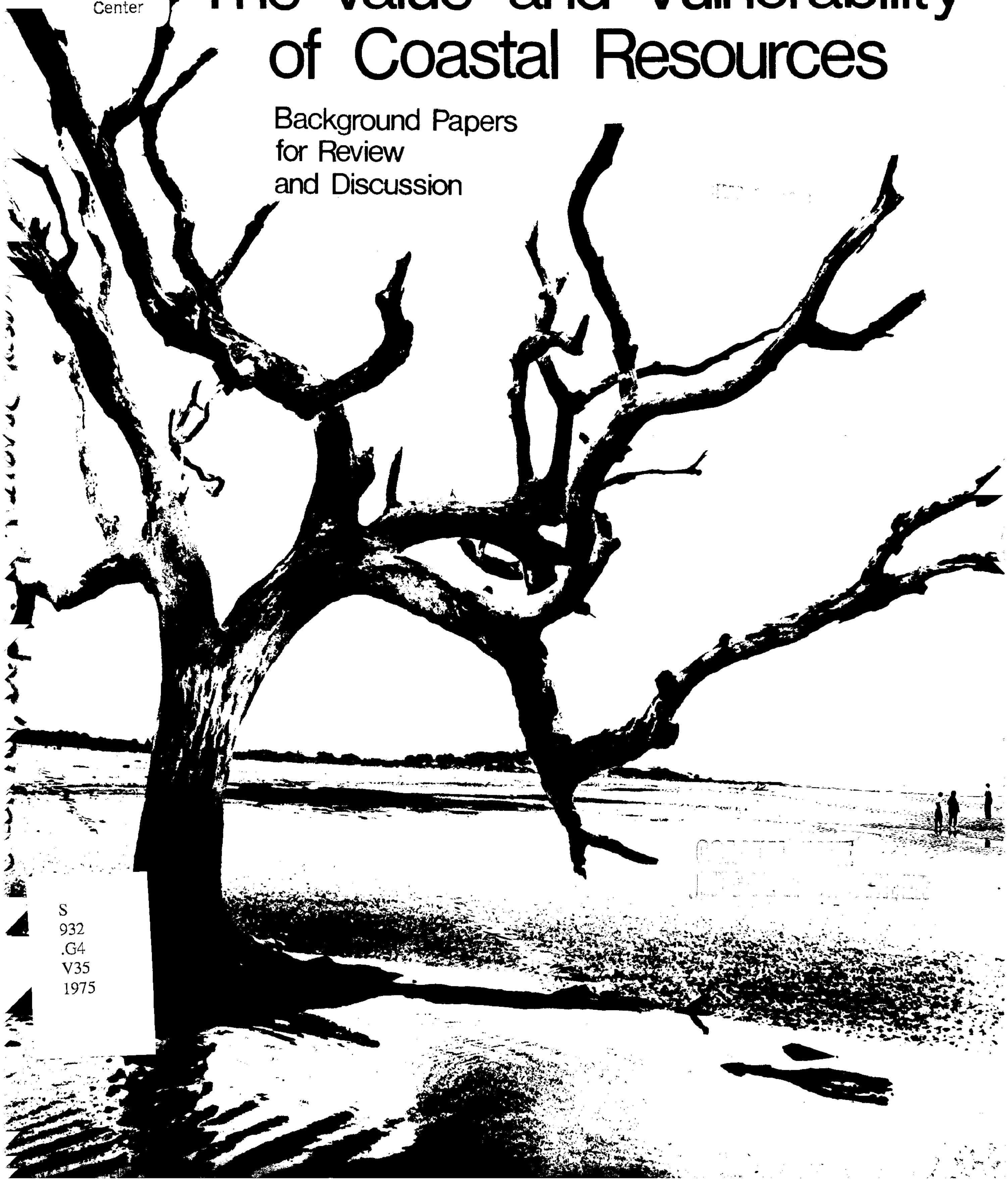
The Value and Vulnerability of Coastal Resources

Background Papers
for Review
and Discussion



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Identification of the values and vulnerabilities of natural resources is an important first step in resource planning. Policies and programs for managing and utilizing resources should be based upon such information. The purpose of these background papers is to highlight important characteristics of Georgia's coastal resource features and systems including resource values and vulnerabilities.

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Joe D. Tanner
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June 15, 1975

I am pleased to present to you a series of background papers on "The Value and Vulnerability of Coastal Resources." These papers were written by individual scientists and researchers in the University system of Georgia and in the Department of Natural Resources, for the Georgia Coastal Zone Management Program. The purpose of the papers is to present, in summary form, available information on the benefits resulting from the natural functioning of coastal resources, and the susceptibility of these resources to change. This is important background information that should be used in developing coastal zone management policies and programs.

These papers were prepared in draft form in January, 1975, and circulated to interested scientists and researchers for review and comment. Based on the comments received, I feel that these papers are very useful statements of the values and vulnerabilities of coastal resources.

Sincerely,

Joe D. Tanner
Commissioner

JDT/ldp

THE VALUE AND VULNERABILITY OF COASTAL RESOURCES

BACKGROUND PAPERS FOR REVIEW AND DISCUSSION

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May, 1975

Coastal Zone Management Technical Committee:

Brunswick-Glynn County Joint Planning Commission
Board of Regents of the University System
Chatham County-Savannah Metropolitan Planning Commission
Coastal Area Planning and Development Commission
Georgia Department of Community Development
Georgia Department of Human Resources
Georgia Department of Natural Resources
Georgia Department of Transportation
Georgia Forestry Commission
Georgia Ports Authority
Georgia Soil and Water Conservation Committee
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CHAPTER 1

a Resource Planning Process for Georgia's Coast

by

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Purpose of Background Papers

Identification of the values and vulnerabilities of natural resources is an important first step in resource planning. Policies and programs for managing and utilizing resources should be based upon such information. The purpose of these background papers is to highlight important characteristics of Georgia's coastal resource features and systems including resource values and vulnerabilities.

A resource system is a unified physical or biological environment that is characterized by interacting features and subcomponents and dynamic flows. Beaches, sand dunes and offshore sand bars, for example, are classified as a system because of the dynamic sand flows that link the individual subcomponents of the system together. A resource feature is a single characteristic of the environment that can be displayed on a map. Resource features, such as soils, vegetation, and topography, are important elements of resource systems.

An individual background paper has been written for each of the following systems and features:

Coastal Resources Systems:

* Coastal Beaches, Sand Dunes and Offshore Sand Bars
* Coastal Island Ecosystems
* Fresh Water Ecosystems
* Ground Water Conditions (aquifers)
* Coastal Marshlands (excerpted from An Ecological Survey of the Coastal Region of Georgia, with permission)
* Estuarine and Open Marine Waters (excerpted from An Ecological Survey of the Coastal Region of Georgia, with permission)

Coastal Resource Features:

* Soils
* Vegetation
* Wildlife
* Cultural Resources (Historical and Archaeological)

Although separated into individual papers, many of these resource systems and features are interrelated.

A Resource Assessment for Georgia's Coast

In order to assess the importance of natural resources, as well as the conflicts and compatibilities between man's activities and coastal resources, coastal natural resource planning is being undertaken by the Georgia Department of Natural Resources, in cooperation with other federal, State and local agencies participating in the Coastal Zone Management Program. The purpose of resource assessment is to provide background information on natural resource capabilities and on the environmental impact of proposed activities. This information is essential for the development of coastal policies and programs.

Resource analysis terms must be defined carefully before they can be used. The following definitions are being used in coastal resource assessment:

<u>Value</u> - The contribution of an ecosystem or resource feature to the cultural or biological environment, especially contributions which affect the public health, safety and welfare.

<u>Vulnerability</u> - The natural sensitivity or susceptibility of an ecosystem or resource feature to change.

<u>Capability (also called carrying capacity)</u> - The ability of an ecosystem or resource feature to support a particular use or activity, based upon the natural characteristics of the resource.

<u>Environmental impact</u> - The type of change in the ecosystem or resource feature caused by a specific use or activity.

<u>Compatibility</u> - The degree to which two activities or uses can co-exist in harmony with each other.

<u>Suitability</u> - The appropriateness of a proposed activity for a particular resource or location, based upon a variety of factors. (Usually these factors include social, political, and economic considerations, as well as natural resource considerations.)

These terms, in turn, help to define the steps in a resource assessment process.

Step 1 - Assessment of Value: An important prerequisite to the development of plans and programs is an identification and understanding of the multiple values of coastal ecosystems and resource features. As expressed in the Congressional findings of the Coastal Zone Management Act, "the coastal zone is rich in a variety of ... resources that are of value to the present and future well-being of the Nation." An understanding of the value of resources to the health, safety and welfare of Georgia citizens leads in turn to an understanding of why management of the resource by various levels of government is important. Although values may be defined in both quantitative and qualitative terms, descriptive qualitative terms are commonly used due to a lack of information about dollar values.

Step 2 - Assessment of Vulnerability: Vulnerability factors relate to the basic forces that provide energy to the ecosystem. They are the "lifelines" of the ecosystem, without which the system would not exist. Hence they provide essential information for capability analysis and environmental impact assessment. They are defined in natural terms, without a specific use or activity in mind. Information on ecosystem vulnerability can be interpreted most readily from scientific reports.

Step 3 - Capability Analysis (or Carrying Capacity): The most difficult step in a resource assessment process is the identification of the ability of the resource to support a particular activity. Extremely fragile resources can support only a few "low-impact" activities without causing great changes in the system. Other resources can sustain a wide variety of activities.

Important prerequisites for a capability analysis are: (1) a precise definition of the use or activity being considered; (2) information about resource vulnerabilities; and (3) an understanding of how resource features can be displayed on a map to reflect vulnerabilities. The capability analysis is an assessment of the amount and type of certain activities which can be supported without changing the ecosystem. Capability analysis can greatly assist the appraisal of environmental impact. In turn, any information available on environmental impacts contributes to capability analysis.

Step 4 - Environmental Impact Assessment: Information concerning the values and vulnerabilities of coastal ecosystems and the capability of natural resources to support various activities is useful in evaluating environmental impact. The accuracy of the environmental impact assessment is determined by the accuracy of the information on vulnerability and capability.

A variety of methodologies for assessing environmental impacts have been used in the past, such as checklists, computer models, matrices and networks and map overlays. The particular method to be used should be selected carefully, bearing in mind available time, funding and information. The impact assessment identifies the nature of changes in resource systems or resource features which will be caused by the proposed activity. The impact assessment does not evaluate the significance of these impacts.

Step 5 - Compatibility Analysis: The degree to which two activities or uses can co-exist in harmony depends upon the environmental impact of each activity. If one activity destroys the resource base upon which another activity depends, then the two activities are not compatible. For a comprehensive compatibility analysis, the social, economic and political factors which affect activities (in addition to environmental factors) should be considered. In fragile resource areas, such as coastal marshlands or beach and sand dune systems, natural resource factors play the major role in determining compatibility. In essence, capability becomes equivalent to compatibility, since uses which destroy the resource itself are not compatible with other uses which depend upon the resource base.

Step 6 - Suitability Analysis: The appropriateness of a proposed activity for a particular location should be determined from a variety of factors. Capability analysis (as described above) is in fact "natural" suitability. For a complete suitability analysis, additional factors, such as economic demand for certain activities, existing community uses and activities and community goals, should be considered. The criteria that are used in determining suitability should be established in an open forum where many persons and groups may participate.

Resource Policies and Programs

All of the steps in resource planning, as outlined above, provide information useful in developing policies and programs for coastal resources. The steps of the analysis also provide a factual basis for comparing alternative plans and programs.

Information about the capability of resources to sustain certain uses, the compatibility of resource uses with each other, and the suitability of proposed resource uses for particular locations (according to a variety of criteria) is especially useful for developing policies for the use and conservation of natural resources. However, these analyses are difficult to accomplish without a careful consideration of resource values and vulnerabilities.

A major purpose of this report is to make information on resource values and vulnerabilities readily available to interested officials and citizens. These papers summarize more lengthy research reports and books, but contain selected bibliographies for the reader interested in more detailed information about a particular subject.

Management programs must be based upon an understanding of resource values and vulnerabilities. A wealth of information currently exists for the development of policies and programs for coastal Georgia. However, all policies must be periodically re-evaluated to incorporate new information and new societal values.

CHAPTER 2

the Value and Vulnerability of Coastal Beaches, Sand Dunes, and Offshore Sand Bars

By

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Introduction

Coastal dunes, beaches and offshore sand bars are all part of an interacting and interdependent sedimentary environment. Each of these areas is a separate sub-environment but each is also dependent upon the two other parts of the system. In this summary the terms beach, dune, offshore sand bars and shoals will be used as defined below.

Beach - The relatively thick prism of loose sediment, predominantly sand, located between the limits of lowest low water and highest high water.

Coastal dunes - Mounds of sand deposited along a coastline by eolian processes and often covered with sparse pioneer vegetation. Coastal dunes are located landward of the limits of highest high water and may extend into the tree line.

Primary dune ridge - The most seaward continuous dune ridge running generally parallel to the shoreline.

Foredunes - Individual mounds of sand located seaward of the primary dune ridge.

Semi-stable dunes - A variety of coastal dunes located between highest high water line and the tree line. Mounds in this zone are subject to periodic erosion by storm waves and rebuilding by eolian processes.

Stable dunes - A variety of coastal dunes that have been stabilized in position by a dense vegetative cover. These dunes are generally located landward of the semi-stable dunes.

Offshore sand bars - Mounds of sand deposited by the action of waves and currents. This sand moves up the beach slope in response to wave action. Offshore bars are emerged during low tide and submerged at high tide.

Offshore shoals - Submerged mounds of sediment that are elevated above the surrounding surface of the ocean floor. In this report they are defined as extending from -12 feet (mean low water) to mean low water.

Since the dunes, beaches, and offshore bars are all part of an interdependent sediment system, the system will be referred to as the dune-beach-bar system within this technical summary.

The extent of the dune-beach-bar system is variable, depending on its location along the Georgia shoreline. In some eroding areas there are no semi-stable dunes; only narrow beaches, and a few small offshore bars. In other areas, zones of semi-stable dunes are over 1000 feet wide, beaches are over 400 feet wide, and large areas of offshore bars are over 3000 feet from the shoreline. In general, these extremes are local in occurrence and a complete gradient exists in between.

Nature of Existing Information

Information on the dunes, beaches and offshore bars of the Georgia coast is scant. This is because much of the existing generalized information on dunes, beaches and offshore bars may not apply to the unique Georgian environment. Some of the parameters characterizing this environment include: 1) a broad shallow Continental Shelf; 2) relatively low wave energy; 3) moderately high tidal ranges; 4) numerous islands and inlets; and, 5) a large semi-diurnal exchange of water between marsh-lagoons and shelf waters. Much of the early research neglected these parameters and for this reason it is not entirely applicable. Presently portions of the University System of Georgia are conducting research on the interrelationships between offshore bars and distributions of wave energy. The study of processes relating sediment transfer between Georgia dunes, beaches and bars is also still in the initial research stages.

The areas adjacent to Tybee Island and Sapelo Island have received the most research attention because of their proximity to the Oceanographic Institute and the Marine Institute.

Reports on the Tybee work are available through the Marine Extension Service on Skidaway Island, whereas, the reports of work conducted on and adjacent to Sapelo Island may be found in the collected reprint file of the Marine Institute on Sapelo Island. Selected scientific publications by John Hoyt, V. J. Henry, J. D. Howard and G. F. Oertel are also sources from which valuable information can be extracted.

Although a good deal of data is available, much of it has been obtained in order to answer some specific scientific question. Relating this information to assessment of the value, sensitivity and vulnerability of an ecosystem is difficult. Initially, environmental inventories must be made to determine the natural or present condition of the system. In some cases, this may involve detailed surveys on numerous critical parameters, as has been and is being done in the marshlands. Process studies for the shorelines are also required, for erosion and accretion are natural phenomena that apparently vary for each of the Georgia islands.

The Value of Dunes, Beaches and Offshore Bars

Dunes, beaches and offshore bars are valuable to many facets of the environment. To thoroughly evaluate the true value of these areas, we must consider them in terms of education, aesthetics, ecology, recreation, tourism, sedimentology and property.

Many of these values are interrelated and, as such, are often confused. While this report is intended to outline only the sedimentologic value of dunes, beaches and offshore bars, a few examples of other types of values may serve for purposes of clarification.

Ecologically, the dunes serve as nesting grounds for turtles and numerous species of birds. Numerous other animals live, hunt and graze in the dunes. The beaches and offshore bars are dwelling sites for polychetes, sand shrimp and various isopods, decapods, bivalves and gastropods.

Aesthetically, the dunes, beaches and offshore bars offer an unlimited wealth to artists, photographers and writers. The flowing lines of the dunes capped by sea oats, the beach with racks of straw, and the white water over offshore bars have produced pleasing subjects for many local artists. Every year thousands of Georgians and other tourists also visit the shore to enjoy this beautiful natural setting.

Educationally, the dunes, beaches and bars are a natural classroom for geologic and ecological processes. The relationships and dependencies are easily seen between plant life and animal life in the dunes, beaches and bars. The Savannah Science Museum, the Georgia Conservancy, the Georgia Geological Society, and portions of the University System of Georgia have repeatedly visited the shoreline to describe the various physical and ecological processes of the area.

Recreationally, the shoreline serves large portions of the local population for boating, bathing, surfing, sunning, etc. These activities apparently play an important role in relieving the social pressures of urban living.

All of the values described above enhance the tourist value of the dunes, beaches and bars. Tourists are generally attracted to the shoreline because of the aesthetic and recreational value of this area; however, their activities on the shoreline often result in a better understanding of the local ecology. Tourist and recreational activities also often put stresses on the ecological and sedimentological functions of the shoreline. For this reason, planning and management programs for protecting these systems are important for the future.

From a sedimentologic point of view, the dune-beach-bar systems of Georgia are valuable for at least three major reasons (see Figure 2-1). First, the system is a barrier that protects land behind it. Second, the system maintains a sediment budget that determines the stability of the shoreline. Third, the system dissipates the energy of major storm waves before the total energy of these waves can be directed at the property above the beach.

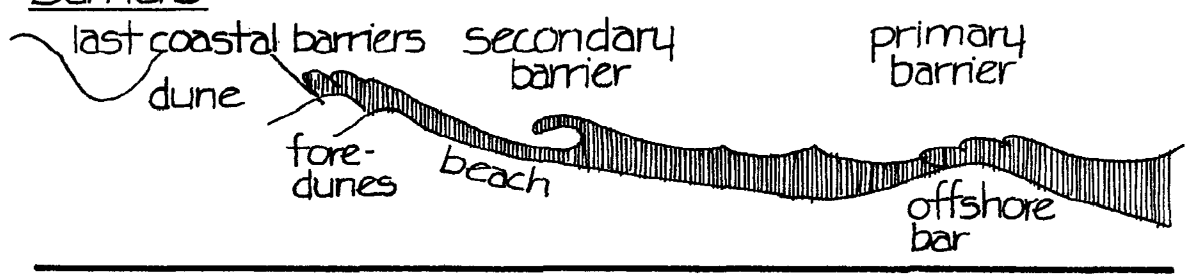
The Barriers: Although offshore shoals and bars are not present along the entire Georgia shoreline, there are some areas of shoreline that illustrate extensive system of offshore shoals and bars. These shoals and bars are the initial barriers to high energy storm waves and much of the wave energy is diverted as waves collide with these bars. In response to this diversion of wave energy by the sand bars, sediment is often redistributed over the surface of the bar by wave currents.

Figure 2-1

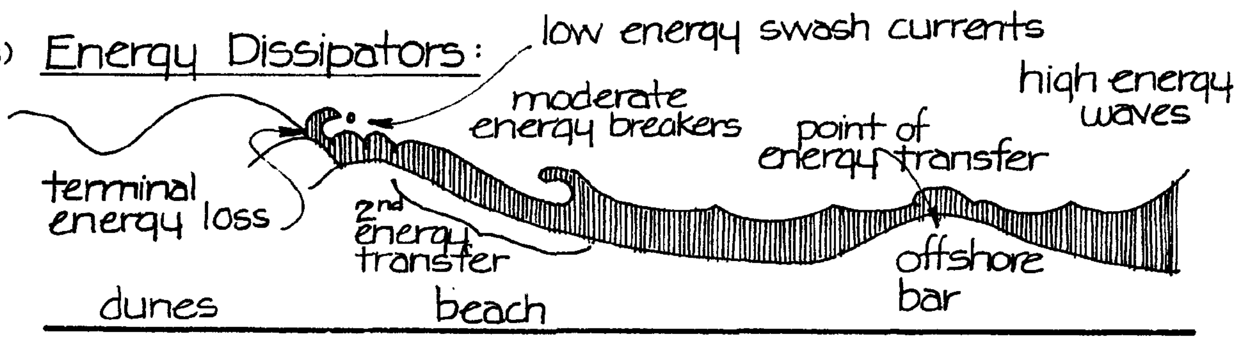
Basic Functions of a Beach-Sand Dune-Offshore Sand Bar System

As illustrated in the three diagrams below, the Beach - Sand Dune - Offshore Sand Bar System serves three basic functions. (A), the system serves as a barrier to high energy storm waves; (B), the system dissipates the force and energy of waves as they move shoreward; (C), the system maintains a sediment budget that determines the stability of the shoreline.

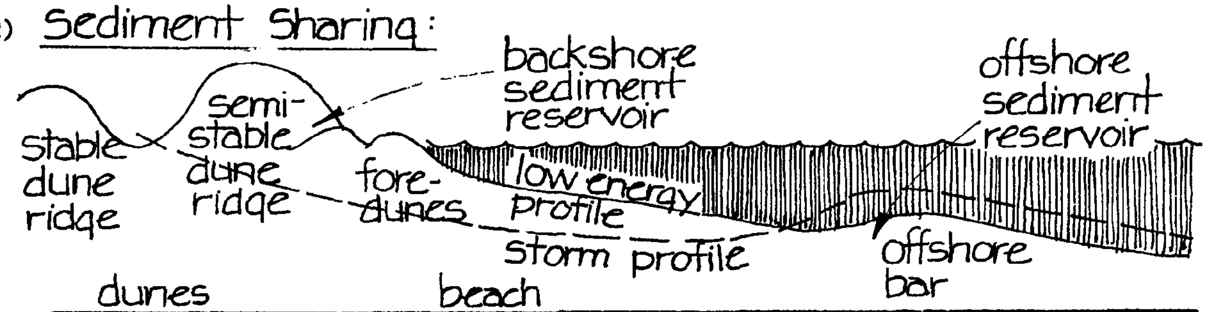
(A) Barriers:



(B) Energy Dissipators:



(C) Sediment Sharing:



Source: G. F. Oertel.

The beach is the second barrier to high energy storm waves. After some of the wave energy is diverted by moving across the sand bars, the waves collide with beach. Since beaches are inclined surfaces and waves generally approach at some angle to the shoreline, wave energy is redirected along the shoreline in the form of a longshore current.

During large storm surges, the dunes often function as the last barrier to the sea. If this barrier is destroyed, then the land and structures behind it may be inundated by flood waters and storm waves. This last barrier also redirects the energy of storm waves in an offshore direction or in an alongshore direction. The redirection of wave energy by the dune barriers generally results in the longshore flow of water.

Energy Dissipation: The dunes, beaches and offshore bars are also natural devices that dissipate wave energy as waves move landward. As described above, a portion of the wave energy is redirected parallel to the shoreline when it interacts with the offshore bars. As waves cross over offshore bars, a portion of the wave energy is also transferred into the mobile sediment bed on the shoal surface. This transfer produces a temporary suspension of sediment above the bottom and a redistribution of sediment over the surface of the bar. Redistributed sediment is often transported landward, thus producing landward displacement of the bar.

When waves are squeezed into the shallower water over shoals, some of the waves "break" at the surface and some wave energy is dissipated. The loss of energy is often illustrated by white water or "white caps" along the crests of waves. This is one reason why shorelines that are protected by massive offshore shoal and bar systems appear to suffer less erosion during storms than shorelines that are exposed to the direct attack of waves.

The beach is the second major portion of the energy dissipating zone of the shoreline. As noted above, beaches are inclined surfaces, and as waves move up this inclined surface, the orbital motion of water in waves is transferred to a lateral motion (current). As a result of this transfer, some wave energy is lost and the force of the waves is somewhat diminished. The dissipation of wave energy at the beach is easily observed as "rolling" waves are transformed into "breaking" waves. The resultant longshore current often carries a relatively large load of sand parallel to the beach. The periodic breaking of waves at the beach slope (swash) and then rush back down the beach slope (backwash).

During very large storms, breaking waves may extend up into the dunes and swash currents may flow up the dune slopes. Waves that reach the dunes are channeled through, over and around foredunes. The rerouting of water through this intricate maze of foredunes further slows the water and dissipates the eroding ability of the waves. The primary dune ridge, located landward of the foredunes, is a barrier to storm wave surges all along the shoreline. When the waves collide with the primary dune ridge, water rushes up the dune slope and then slides back down. This dissipates wave energy further and most of the wave surge is redirected seaward.

The Sediment Budget: The dunes, beaches and offshore shoals and bars also maintain a sediment budget that determines the stability of the shoreline. When a sediment deficit is produced in this budget, the shoreline retreats by erosion. When a sediment excess is produced, the shoreline advances seaward by accretion.

At a stable shoreline, processes of both erosion and accretion maintain a dynamic equilibrium in the sediment budget. For example, during portions of the year, erosional processes may cause the shoreline to retreat; however, during other portions of the year, depositional processes cause the shoreline to advance seaward. The net change in shoreline position after a complete year is often negligible, and the location of the shoreline remains stable on a year to year basis. Sedimentary processes governing this equilibrium involve sediment transfers between the dunes, beaches and offshore bars. The "sand-sharing" capabilities of each of these sub-environments are critical to maintain the stability of the shoreline.

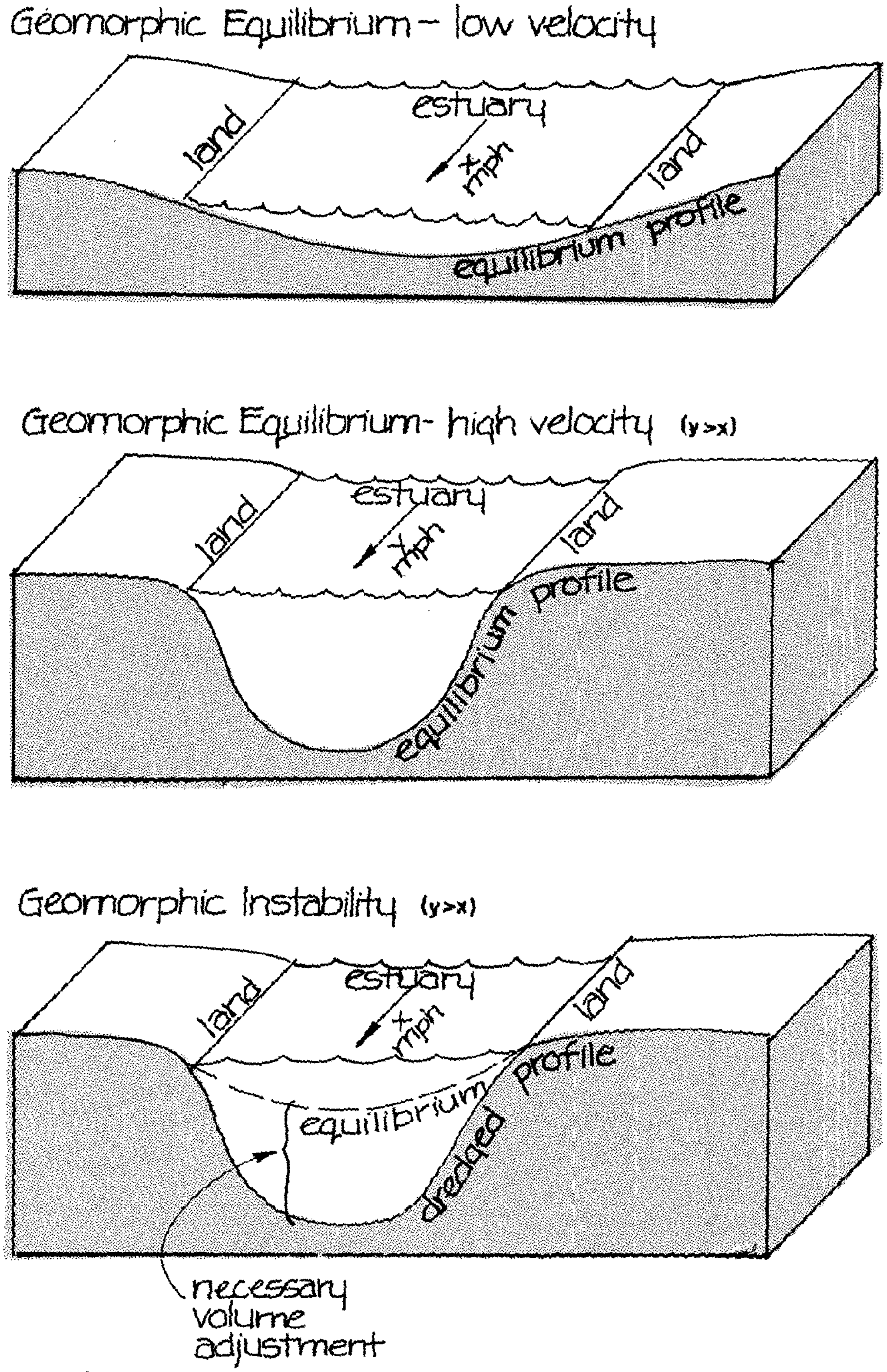
Each of these sub-environments undergoes a sequence of sedimentary events during storm conditions and low energy conditions. During low energy conditions, offshore bars migrate landward. Low energy, long-period waves redistribute sediment over the surface of the bars in a semi-continuous movement up the beach slope. This results in the bars' attachment to the uppermost portion of the beach. As more bars are "welded" to the upper sections of the beach, the beach accretes seaward to produce a broad, low-elevation, high-tide beach. During storm conditions, the beach face is eroded and a part of the sediment from the beach is transported seaward toward the offshore bars. This redistribution of sediment or "sharing" is necessary to maintain the stability of the shoreline.

It is also apparent from these processes that the beach and nearshore zones have different profiles of equilibrium during low energy conditions and during storm conditions. The realization that the beach and nearshore topography adjust to the local energy conditions is very important for considering the effects of various stresses on the system. For example, the beach profile adjacent to a channel with high velocity currents is steep, whereas the profile adjacent to a channel with low velocity currents is gentle. Since the profile is in equilibrium with the velocity of water flowing through the channel, the channel will adjust to the pre-dredging form in order to achieve equilibrium conditions between energy and topography (see Figure 2-2). This adjustment will, in turn, result in a lowering of the adjacent beach profile.

A sediment-sharing relationship also exists between the beaches and the semi-stable dunes. During low-energy conditions when the beach is broad, the dry sand on the high tide

Figure 2-2

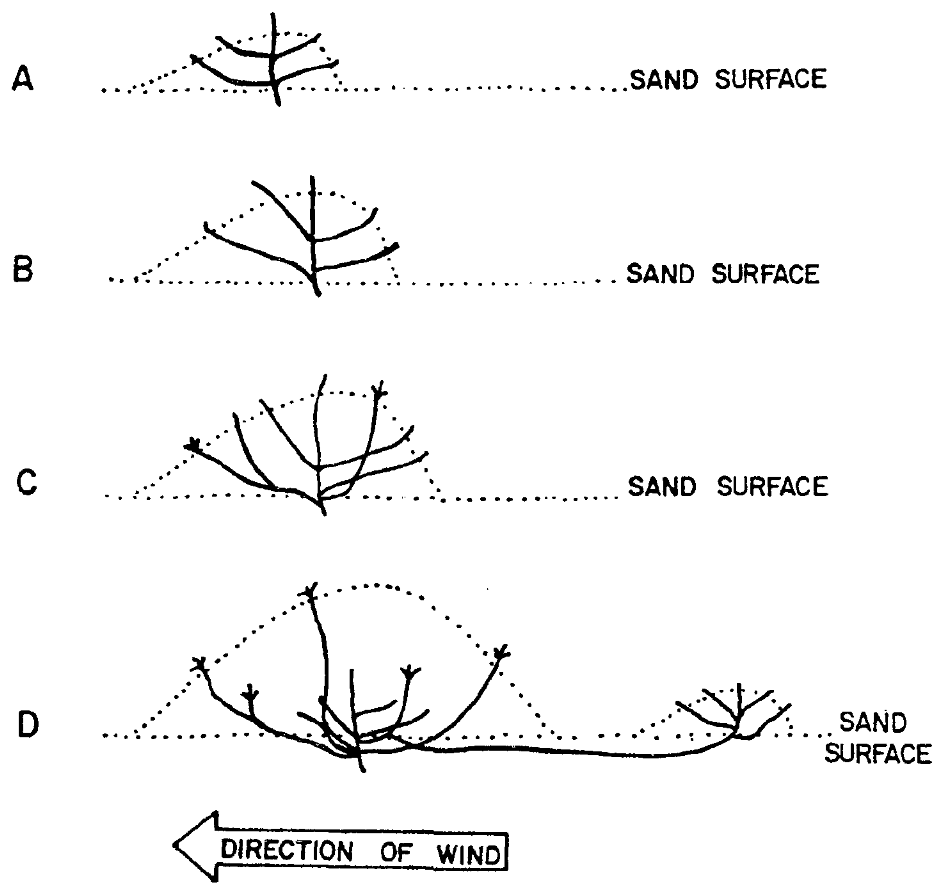
Profiles of Shoreline Equilibriums



Source: G. F. Oertel.

Figure 2-3

Sand Dune Stabilization with Vegetation



Dune vegetation such as sea oats (Uniola Paniculata) binds sand through the development of extensive horizontal and vertical rhizome systems.

Source: Based on diagram in D. S. Ranwell, Ecology of Salt Marshes and Sand Dunes, Halsted Press, 1973.

portion of the beach is transported by the winds. When the winds are offshore, sand is transported down the beach slope and into nearshore waters where it is deposited or redistributed by nearshore currents. When winds are in an onshore direction, sand is transported up the beach face and is often deposited in the dunes. This process also affects the incipient development of new dunes. Mounds of beach straw that accumulate behind the spring tide berm are obstructions that disrupt the lamina flow of air over the beach. As wind-blown sand comes into contact with these obstacles, a portion of the sediment is deposited in the straw mounds. These accumulations of sand increase in size with time and form small foredunes. Eventually, the sand may completely bury the straw mounds that initiated their development. The proximity of these foredunes to the sea deems them very vulnerable to erosion during even very minor storms. If the shoreline is relatively stable, then pioneer plants may spread into these dunes by rhizomatous development or seed growth. The organic material buried in the dunes holds moisture and supplies nutrients to seedlings. Relatively large plants that grow from the seedlings form new wind baffles. These baffles disrupt the air flow in a manner similar to that described for the straw mounds; however, the plants are higher and disrupt more of the air flow. This process produces more deposition of sand and accelerates expansion of the foredunes. The accumulation of sand by this process makes it less likely that foredunes would be completely destroyed during minor storms. If this process is left to continue with only minor interruptions, foredunes may coalesce and form a continuous dune ridge. Tall grasses and large plants form the vegetative caps of these ridges, and enhance the entrapment of much of the remaining sand that is in windblown transport up the beach. The root systems of the grasses and plants also function as holdfasts that partially secure the dunes and help to bind the loosely packed sand grains together. The final result of the sediment-trapping processes is the accumulation of relatively large quantities of sand above the spring high-tide line.

During high energy, storm conditions, the beach face is lowered as sediment is transported offshore into bars. The lowering of the beach face also results in the retreat of the shoreline. Eventually storm waves begin to attack the berm and structures located progressively landward of the berm, such as the mounds of straw and sand, the plant-covered foredunes and the dune ridges. Sediment eroded from these structures can minimize the losses from the beach. The concept of the equilibrium profile is also in effect in this zone. During a storm, the equilibrium profile of the beach gets steeper as the energy increases and sediment is transported offshore. This adjustment often causes the shoreline to retreat and the dune to erode. Sediment from the dunes is temporarily transported to sediment-poor portions of the beach that have suffered from severe erosion. In minor storms, sand from the foredunes and from a portion of the primary dune ridge is often redistributed over the beach surface. In major storms, the entire sediment reserves of the primary dune ridge and a portion of the second dune ridge may be redistributed over the beach face. Sediments from each successive dune ridge are redistributed over the beach face as is required by the "sand-borrowing" system between the beach and the dunes. Thus the sand-borrowing system helps to maintain a profile of equilibrium at the beach without an accelerated retreat of the shoreline. After storms subside, sedimentary processes begin to restore the dune-beach-bar system to a profile of equilibrium that is quasi-stable with daily low energy conditions. These processes reconstruct the beach and dunes and prepare it for the next series of storms.

Critical Features

There are a number of features that are critical to the functioning of the dune-beach-bar system. Dune plants are one of the more obvious features. If these plants are destroyed, the accumulation of sand in coastal dunes is inhibited and the recovery of dunes between storms is slowed down considerably (see Figure 2-3). The stabilizing function of plant roots is also critical for inhibiting the migration of dunes. Dunes that are not partially stabilized by vegetation may migrate considerable distances in response to winds. The migration of dunes could in fact cause the burial of large structures located down wind of dunes.

The shapes of dunes and offshore sand bars also have a considerable impact upon the function of the dune-beach-bar system. The efficiency that a barrier has in protecting structures behind it is dependent upon its height, strength, and continuity. If dunes and bars are reduced in height, their effectiveness as a barrier is reduced. If the continuous nature of a dune ridge is breached by a path or roadway, storm surges can flow through these breaks and endanger structures behind the ridges. Breaks also permit winds to transport tongue-shaped dunes landward of the dune ridges. These tongue-shaped dunes also present burial hazards to the structures behind the dune ridges.

The shapes of offshore bars and shoals are also important since they often determine the paths of tidal flow and ultimately of sediment transport. For example, if the shape of a shoal is altered in a manner such that it redirects current energy, then sediment transport patterns are also likely to be altered. The final result could potentially cause the shifting of a navigational channel, or the accelerated erosion or accretion of adjacent areas of beach. The response to changes in the shapes of sand bars and shoals, would be quite variable with actual changes depending on the specific case. However, it is important to note that the geomorphic character of offshore sand bars and shoals is a feature that is critical to the functioning of this portion of the system. In this regard, the shape of the bars and shoals must be considered in view of its effect on the function of these sand bodies as potential barriers, energy dissipators, sediment reservoirs and as a pathway for controlling the distribution of tidal energy.

There are several criteria that are very important to the functioning of the dune-beach-bar system. One criterion is the unhampered exchange of sediment among all parts of the system. If barriers are established restricting the exchange of sediment and wave and current energy between portions of the system, then the efficiency of the system is endangered. The unhampered exchange of sediment between all parts of the system is of particular importance to the interrelated functions of the dunes, beaches and bars described above.

Sensitivity and Vulnerability

The dune-beach-bar system is self-adjusting to small changes in physiography, sediment input and energy distribution. This coastal sediment system is relatively sensitive to change and responses can be seen in physiographic adjustments.

The type of stresses which affect the functioning of the dune-beach-bar system are closely related to the critical features described above. The most obvious stresses on the system are the periodic increases in physical energy due to storms. These increases may produce very radical changes in the shoreline; however, much of the original form of the shoreline may be restored during low energy conditions. In general, storms produce only short term modifications to the shoreline; however, locally, long term modifications are produced by large storms. A good deal of the recovery process is dependent upon the unimpeded transport of sediment by natural processes. Seawalls, groins, dredging and channeling are all stresses which impede the transport of sediment by natural processes. Each of these stresses has a different impact on the system and the system adjusts in a different manner to each type of stress. For example, groins entrap sediment on their updrift sides and produce erosion on their downdrift sides. Eventually the shape of the shoreline will come into equilibrium with these obstructions and new routes of sediment transport along the beach will result.

While seawalls protect lowland areas from storm waves, they also restrict the exchange of sediment between the beaches and dunes and in this regard they also inhibit recovery of sediment to a storm-eroded beach. Seawalls also reflect much of the energy from storm waves directly back toward the beach. These high energy waves redirected toward the beach without much energy loss may accelerate the erosion of the adjacent beach until a new equilibrium profile is created for the new energy condition. In many cases, both groins and seawalls are effective methods of stabilizing portions of beach, however, their design and installation must be considered carefully. Design and installation must be effected in a manner to produce stress on the mechanisms of erosion with as little impact as possible on the functioning of the ecosystem. In general, an area of shoreline erodes because of some imbalance in the energy-sediment budget. Groins and seawalls cannot solve the problem because they generally do not balance the budget.

Dredging and channeling are also stresses that may affect the system. These activities may take sediment out of the system, change shoreline profiles and produce a redistribution of wave and current energy. The degree of influence produced by this type of activity is dependent upon the magnitude of the activity. The construction of an extremely large channel or hole adjacent to a beach could have extensive erosive effects upon the offshore shoals and the shoreline. In order to adjust to the previous profile of equilibrium, sediment from the adjacent shoreline may be transported into the channel.

The creation of deep water adjacent to a previously shallow water shoreline allows high energy waves to collide with the shoreline before any energy can be dissipated on sand bars and shoals. The redistribution of water flow through dredged channels also may form new sediment transport patterns and cause shifting of offshore shoals and bars. Ultimately these adjustments may influence the sediment budget of adjacent areas of shoreline and produce new erosion and accretion trends.

The dunes are also vulnerable to stresses that affect the functioning of the system. The active portion of the dunes plays a very important role in the functioning of the dune-beach-bar system. If the natural shapes of these dunes or the interdependent plant species of these dunes are destroyed, then the dunes may be destroyed. In general, the natural characteristics of the active portions of the dune system must be preserved in order for the dunes to function in the ecosystem.

A Buffer Zone

A buffer zone necessary to protect the various components of the dune-beach-bar system is difficult to define for the Georgia coast because of the extreme variability of the system's characteristics. In general, the buffer zone should be located on the landward margin of the beach and on the seaward side of the offshore shoals and bars.

While the width of buffer zone landward of the dunes cannot be defined uniformly for all areas of the coast, the relationship of the dunes to the sedimentary activity of the system can be used to develop general guidelines. The buffer zone for the dunes is variable along the length of the shore and is dependent upon the long range fluctuations of the shoreline, and the seasonal fluctuations of dune character. On stable or accreting shorelines, the buffer zone should extend to at least halfway between the first and second continuous and semi-stable dune ridges landward of the ocean. In historically retreating or unstable areas, the width of the buffer zone should be based upon the 100 year rate of shoreline retreat and the seasonal variability of the shoreline and dune ridges.

The buffer zone for offshore bars and offshore shoals is probably the most difficult to define because relatively little is known of the processes of sediment transfer between these features and the beach. Offshore bars often play an important role in the exchange of sediment between the nearshore and the beach, thus, all offshore bars in the intertidal zone should certainly be encompassed within the buffer zone. Around tidal inlets, shoals from 0 feet to -12 feet also play important roles in transferring sediment between the inshore zone and the beach. Tidal currents and wave currents are the major mechanisms of sediment transport at these shoals. If the paths of these currents are in some way altered, then the natural exchange of sand between the offshore and the beach could be impeded or temporarily delayed. The area outlined by the -12 foot (mlw) contour should be considered relatively important in defining a buffer zone for the seaward limit of the dune-beach-bar system. Although this eliminates most of the Georgian inlets (because they are greater than 12 feet deep) it must be realized that extreme increases of inlet volumes would have an adverse effect on the stability of the -12 foot surface. The adjustment of inlet volumes by dredging must be considered in the light of the natural profiles of equilibrium for the area.

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CHAPTER 3

Terrestrial Ecology of the Georgia Barrier Islands

by

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The Island Experience

A visitor, upon arriving for the first time on one of Georgia's wild barrier islands, is immediately struck by a feeling of isolation, a feeling that he has left the mainland far behind and has entered another world. He is probably closer than he will ever be again, standing on the beach at that moment, to sensing the real fabric of the island ecosystem. The sculptured trees leading back from the dunes, the pounding surf, the salt on his face left by the wind, the raccoon taking one more egg from last night's turtle nest, all add to the inescapable knowing that here is a world which has been born of the physical forces which surround it.

The visitor is correct, for islands are different from the mainland. Island communities are molded and remolded by the winds, by the sand and salt, by the very isolation which makes an island what it is. The tragedy is that man's emotions are soon left to children and artists, and his priorities shaped by his need for comfort. Our visitor will probably end his island stay more annoyed by blowing sand which ruined his picnic lunch than impressed by the dynamics of a dune community. He will return home with a dose of chiggers and fail to support a controversial environmental protection bill. When he again returns to the island, he may find a comfortable ocean-front motel but no dunes. He will find the ocean but perhaps no beach. He may drive to his motel over a new causeway and not visit an island at all.

At another time and another place, our friend might have made his first visit to a Cumberland Island National Seashore or the equivalent. Hopefully, he will still arrive by boat, and his first impression will still be one of remoteness, of island forests and pounding surf. His first view on the ocean beach will be from a raised trail through sea oat dunes and not from a car window. His lodging that night may be comfortable, but it will not be a motel with a protective seawall. Most important of all, his initial inspiration and curiosity will be caught and reinforced by an interpretive program of coastal ecology, with all of its fascinating ramifications.

A knowledge of coastal ecology is essential for establishing development guidelines and constraints, and for working within the natural community without destroying its identify. Our visitor may be one of several thousand to visit Cumberland Island that day, yet his impression can still be one of isolation and natural beauty. A knowledge of coastal island ecology also has an important educational role. Strong supporters of wilderness and open-space are often those who have learned to read and enjoy a natural ecosystem as one would read and enjoy a book. Awareness breeds appreciation and respect.

This paper summarizes what we know about the terrestrial ecology of Georgia barrier islands, the physical environment which shapes the island community, and the strategies of survival employed by its members. Also discussed are values of component parts to the natural island system and the vulnerability of the system to changes by man. The description of terrestrial island ecology as a means of increasing man's awareness of his environment is a self-evident value.

Physical Factors Shaping Coastal Island Ecology

A community develops in response to the forces which act upon it. Some communities (deserts, tundra) must respond primarily to physical forces such as extremes in temperature and humidity. Other communities (tropical rain forest) develop where physical forces are consistently optimum and respond primarily to biotic forces which develop within the community.

Georgia coastal island communities fall somewhere between these two extremes and respond to a variety of physical and biotic forces. However, as one moves from the adjacent mainland to large Pleistocene islands, and then to small Holocene islands, there is a distinct shift in community structure in response to the increasing intensity of several physical factors.

1. Geologic Factors

The geology of Georgia coastal islands has been summarized by Hoyt (1967, 1968), although aspects of his thesis are currently being debated. A number of specific points are applicable to coastal ecology:

a) barrier islands are probably formed by dunes and not off-shore bars. This is based on the observation that the parent surface material of the islands is almost pure quartz sand, with little clay, silt, or shell material. The adjacent mainland consits of a variety of relic lagoonal and barrier island complexes, adding diversity to mainland soils relative to island soils.

b) the present coastal islands are of two historical ages (Figure 3-1). The larger islands are primarily Pleistocene (25,000-30,000 BP) and have eroded over the years to form a rather flat terrain. Eastward of this chain is a second chain of smaller islands formed during the Holocene (5000 BP to present). Additional material of Holocene origin has also been deposited on the eastward or ocean side of most Pleistocene islands. The topography of

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$   8  300      320 p. : 'b ill. ; 'c 28 cm. %
$   9  500      Papers written by individual scientists and researchers in the
University System of Georgia and in the Dept. of Natural Resources, for the
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Holocene formations consists of dune ridges and swales that have changed little since the islands were formed. Drainage patterns are highly dissected. The drainage on dunes is very rapid. Soil conditions on Holocene formations are less developed (see description of island soil).

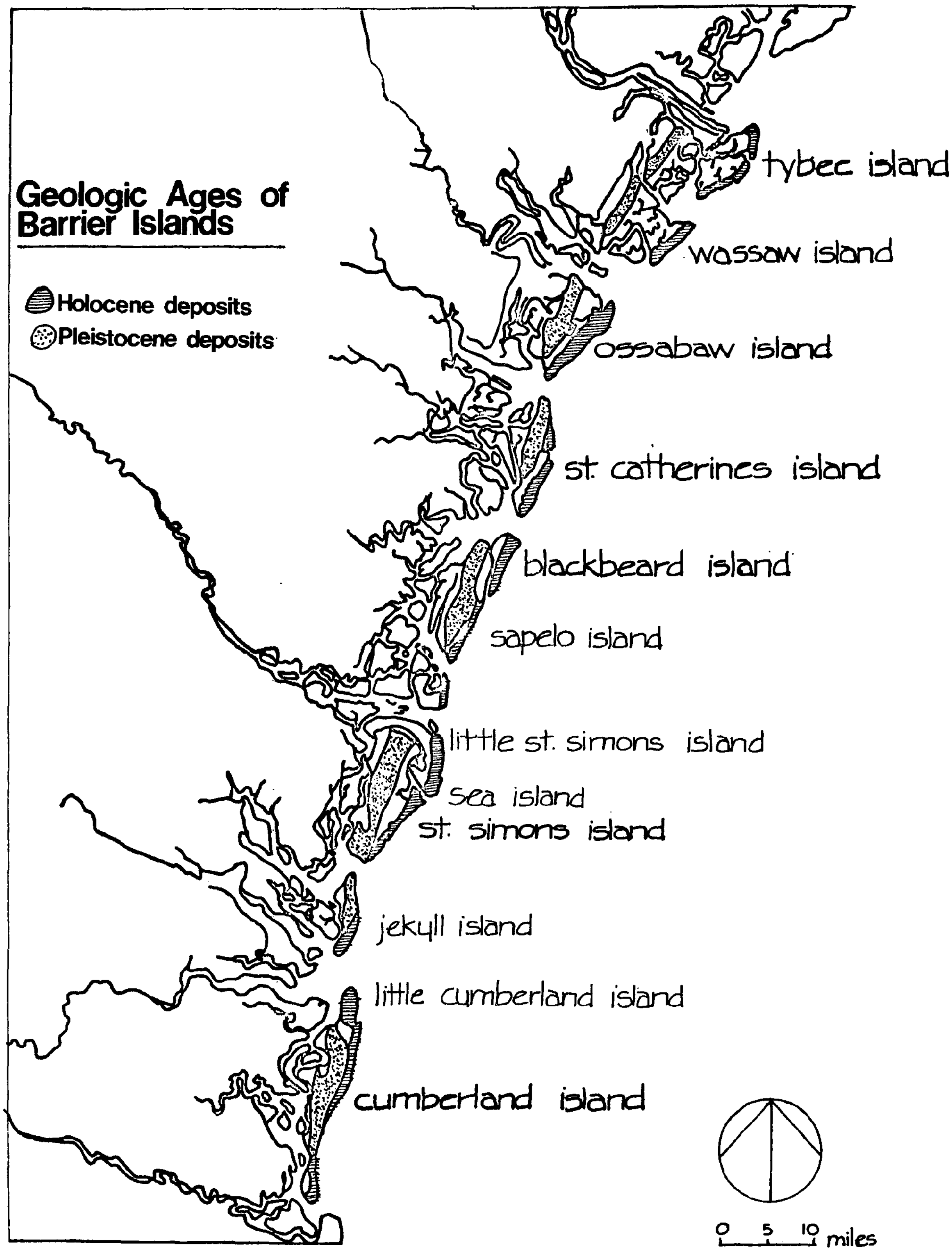
c) there is a continual reworking (erosion and deposition) of natural shorelines, differing in intensity from island to island, which can amount to the addition or removal of hundreds of acres of elevated (above tidal inundation) island terrain within a few years. Such reworking affects both Holocene and Pleistocene formations. Areas of recent deposition have virtually no soil profile and are described and mapped as "coastal beach" (Wilkes, *et al.*, 1974).

Twelve barrier islands are listed in Table 3-1, along with estimates of total non-salt marsh acreage (Johnson, *et al.*, 1971) and a very rough approximation for each island of the percentage of Holocene versus Pleistocene deposits, based on Figure 3-1 (Hoyt, 1968). Several observations can be made:

a) Pleistocene islands, as used in this paper, are barrier islands which consist roughly of fifty percent or more of Pleistocene deposits, the remainder being Holocene in origin. There are six islands in this category: Cumberland Island, Jekyll Island, St. Simons Island, Sapelo Island, St. Catherines Island, and Ossabaw Island.

b) Holocene islands, as used in this paper, are

Figure 3-1



Source: Hoyt, J. H., 1968, "Geology of the Golden Isles and Lower Georgia Coastal Plain," in the Future of the Marshlands and Sea Islands of Georgia. Edited by D. S. Maney, F. C. Marland, and C. B. West. Published by the University of Georgia Marine Institute and the CAPDC. pp. 18-34.

Table 3-1

Summary of Total Acreage and Geologic Ages of Georgia Barrier Islands*

Island	Total Acreage **	Holocene (less than 5000 years)		Pleistocene (20,000 to 40,000 years)	
		Pct.	Acreage	Pct.	Acreage
Tybee	3,100	100%	3,100	0	0
Wassaw	2,500	100%	2,500	0	0
Ossabaw	11,800	50%	5,900	50%	5,900
St. Catherines	7,200	40%	2,880	60%	4,320
Blackbeard	3,900	100%	3,900	0	0
Sapelo	10,900	10%	1,090	90%	9,810
Little St. Simons	2,300	100%	2,300	0	0
Sea Island	1,200	100%	1,200	0	0
St. Simons	12,300	10%	1,230	90%	11,070
Jekyll	4,400	20%	880	80%	3,520
Little Cumberland	1,600	100%	1,600	0	0
Cumberland	15,100	10%	1,510	90%	13,590
TOTAL	76,300	37%	28,090	63%	48,210

* Total acreage estimates are from Johnson, A. S. *et al.*,(1971). Acreage distributed to Holocene and Pleistocene are approximated from map (Figure 1) of the coastal islands in Hoyt, J. H. (1968).

** Includes forested area, pastures, beaches, and dunes, and freshwater marshes and ponds. Does not include salt marsh.

barrier islands which consist entirely of Holocene deposits. There are six islands in this category: Little Cumberland Island, Sea Island, Little St. Simons Island, Blackbeard Island, Wassaw Island, and Tybee Island. There are numerous other, minor islands in addition to the ones listed here.

c) "Holocene deposits" refers to the geologic origin of the subsoil and represents a condition which is found on all twelve islands. Likewise, "Pleistocene deposits" is a geologic term referring to the origin of specific subsoil deposits on a portion of the six Pleistocene islands.

d) As a general rule, large islands support more species of plants and animals than small islands (MacArthur and Wilson, 1967). The Georgia Pleistocene islands represent larger land masses, averaging four times the land mass of Holocene islands. However, Blackbeard Island (3900 acres), the largest of the Holocene islands, is almost as large as Jekyll Island (4400 acres), the smallest of the Pleistocene islands. In addition, the Pleistocene islands exhibit the added diversity of both Pleistocene and Holocene terrain, providing another reason for a greater floral and faunal diversity on the larger Georgia islands.

e) Isolation is another important phenomenon which affects island ecology (MacArthur and Wilson, 1967). The Georgia barrier islands are isolated from the mainland and from each other by varying distances of salt marsh, tidal creeks, and estuaries. Obviously, these islands are not equally isolated, but there has been no attempt to measure the varying degrees of isolation. How the isolation factor affects coastal island ecology will vary from island to island and depends on the mobility of the species of plant or animal in question.

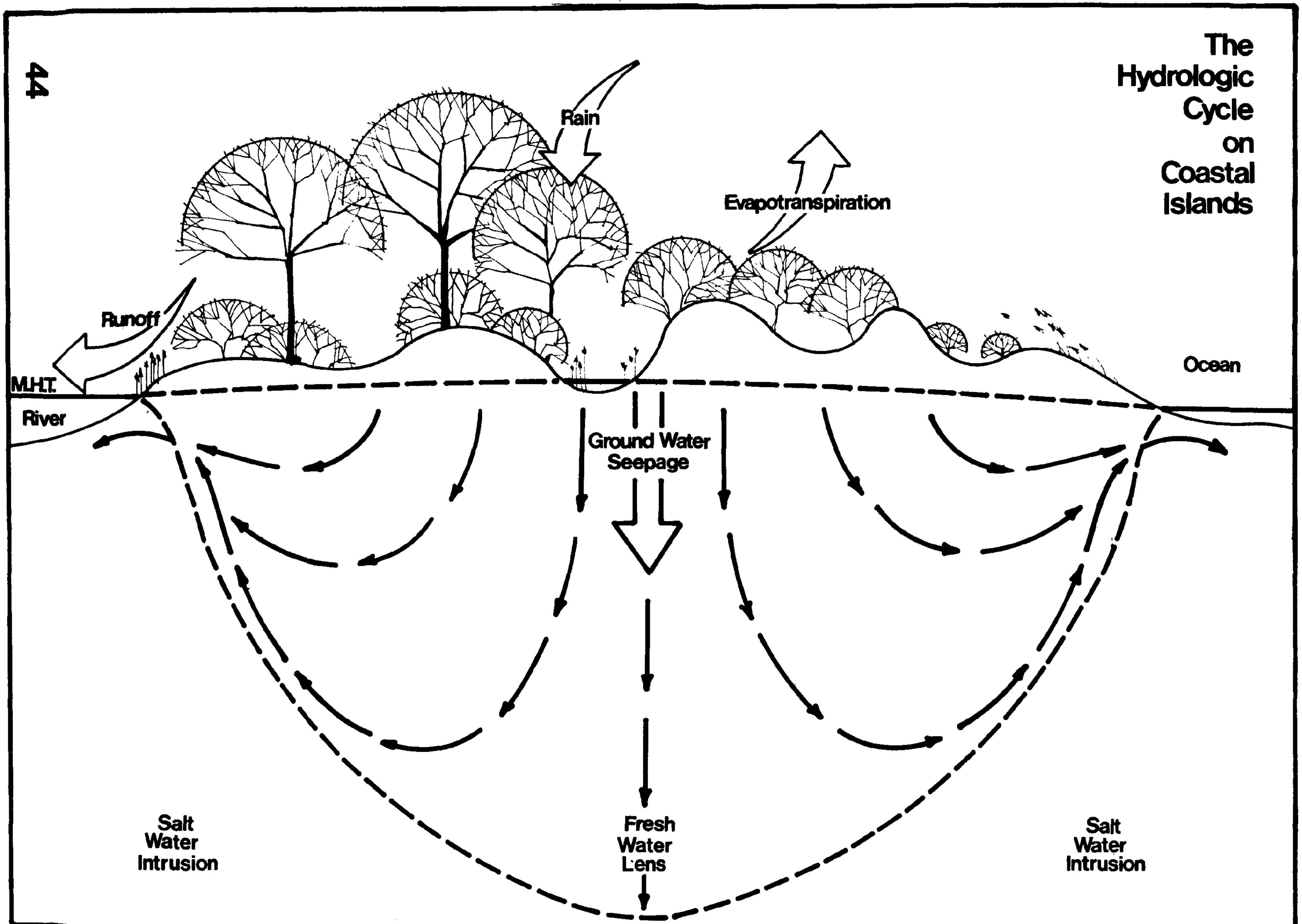
Two points must be kept in mind. First, the thesis of isolation and island ecology (MacArthur and Wilson, 1967) has been developed primarily for isolated oceanic islands and not continental islands such as the Georgia islands which are in close proximity to populations on the mainland. Secondly, the Georgia Pleistocene islands were connected to the mainland prior to their insularization by a rising sea level (Hoyt, 1967, 1968). Thus, a full complement of mainland flora and fauna was probably originally present, while any species absent today may represent extinctions due to man or the restructuring of the habitat and not to the inability of mainland species to cross salt water barriers.

2. Hydrologic Factors

Artesian water below the coastal island provides the primary source of water for human consumption (McCallie, 1908). Wise management of the principal artesian aquifer is essential to the future of man on the coastal islands. Except for artificial irrigation, however, this source of water is inaccessible to island plants and animals. The natural island ecosystem depends on a shallow, island water table.

The island water table (Figure 3-2) has been described as

Figure 3-2



Source: Brown, J.S., 1925, "A Study of Coastal Ground Water," U.S.G.S. Water Supply Papers. 537.

a lens of fresh water floating on salt water within the porous material of the island subsurface (Brown, 1925; Crandell, 1962). The concept of a fresh water lens is particularly applicable to small, sandy coastal islands (Brown, 1925). Because the specific gravity of fresh water (sp. = 1.00) is less than that of salt water (sp. = 1.025), the fresh water lens behaves like an iceburg, floating some forty feet below sea level for every foot above sea level.

Rain is the only source for recharging island ground water. As rain collects on the island, its weight induces a flow of water down and laterally, ultimately discharging below sea level along the margins of the island. This one-way flow of water prevents salt water from intruding into surface layers where high chlorinity would kill the dense mat of roots.

The existence of a fresh water lens has been assumed for a permeable barrier island south of Long Island, New York (Art, 1973) and will be assumed in some form for Georgia coastal islands. The existence of such a fresh water lens requires uninterrupted permeability of ground water to a depth 40 times its height above sea level as well as contact along its lower surface with intruding salt water. The presence of impermeable barriers such as limestone strata reduce the size of the reservoir but do not change the concept of a large, underground reservoir which ameliorates fluctuations in the ground water level, prevents salt water intrusion, and induces a lateral flow of fresh water to the ocean.

The level of the water table above sea level is lowered as ground water is removed from the system by lateral flow, evaporation, and transpiration (Figure 3-2). The water table rises when rain recharges the supply of ground water. The ratio of surface (size of island) to volume (quantity of water in the lens) explains why a given amount of rain induces a magnitude of change in the water table which is inversely proportional to the size of the island. In other words, water levels on small Holocene islands will be more critically affected by rainfall than on larger islands of primarily Pleistocene origin.

3. Wind and Salt

Scientists have debated the relative effects of wind and salt on dune communities for years. Several papers (Art, 1973; Boyce, 1954; Martin, 1959) go a long way in resolving differences and establishing facts.

a) Tiny droplets of salt water are ejected into the air from breaking waves. Wind speeds generally in excess of ten miles per hour carry great quantities of these droplets onto the islands. Most of the airborne salt is deposited within 350 meters of the surf line (Martin, 1959). At 1000 meters, airborne salt is approximately one percent of the concentration measured at the surf line.

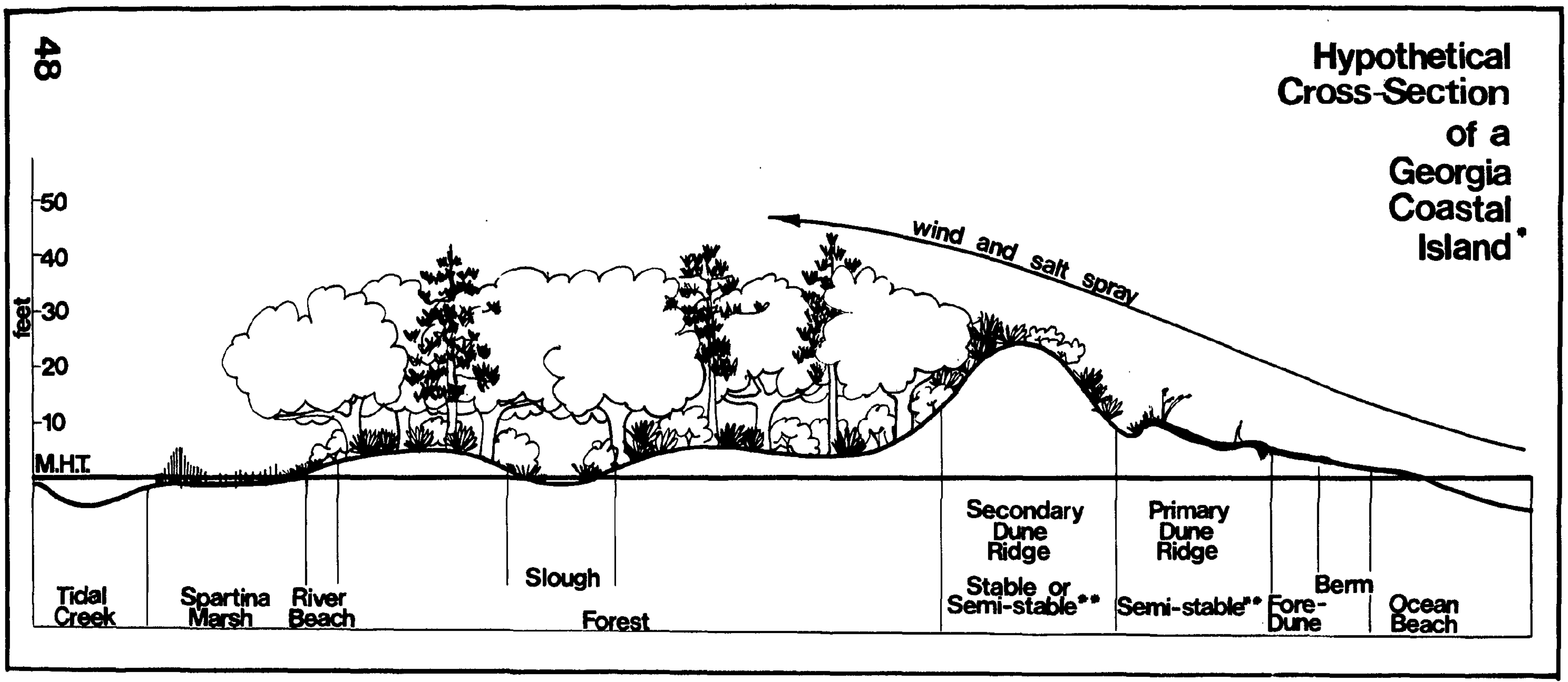
b) Airborne salt deposited on leaf and twig surfaces is injurious to plants, depending on the concentration of salt and the susceptibility of the species involved (Boyce, 1954). Tolerant species are selected in the exposed foredunes. Exposed twigs and leaves of less resistant species are killed, causing a natural pruning effect which results in the characteristic shape of the island canopy facing the ocean. Fine structures (grass blades, pine needles) collect greater salt concentrations than broad surfaces (oak leaves). Given equal tolerances, pines will be killed before oak trees.

c) A number of mineral nutrients essential to plant growth are made available to the island community only in the form of airborne salts deposited on foliage (Art, 1973). Thus, airborne salts must be considered as an essential nutrient source as well as an injurious defoliant.

d) Eventually, there is formed over the leading edge of the coastal islands a characteristic forest canopy which is smooth, dense, and shaped like an airfoil (Figure 3-3). Concentrations of airborne salts beneath the canopy are very low relative to the air stream above (Boyce, 1954). Disruption of the canopy, natural or otherwise, exposes trees which are not acclimated to high salt concentrations and wind buffeting. Severe trauma and injury to foliage is the common result.

e) Relative to big islands, a greater percentage of vegetation on small islands is affected by airborne salt, based on the estimate that salt droplets rarely travel farther than 1000 meters from the surf line. Smaller Holocene islands represent a more rigorous salt-affected

Figure 3-3



* dimensions and features vary from island to island.

** A semi-stable dune or dune ridge is constant in terms of position on the shoreline, but functions as part of the sand-sharing system.

A stable dune or dune ridge is a dune which has reached its peak elevation and is covered with woodland vegetation.

Source: Clement, C. D., 1971, "Recreation on the Georgia Coast: An Ecological Approach", Georgia Business: Vol. 30, no. 11, p. 1-24. Adapted by Mr. J. R. Richardson environment relative to larger, primarily Pleistocene islands and the distant mainland.

f) Salts do not accumulate to toxic levels in exposed soils because periodic rain leaches the salts from the upper levels of sand (Boyce, 1954). Salts generally affect plants by direct contact with leaf and stem surfaces.

g) Airborne salt is directly related to the proximity and intensity of surf. Dramatic changes in dune plant communities should be anticipated as fluctuations in shoreline and offshore sand bars affect local surf patterns.

h) Nitrogen in a form available to plants is missing from airborne salt and appears to be a limiting nutrient in the dune community. Artificial application of nitrogen will induce a significant increase in plant growth. However, there is a corresponding decrease in resistance to salt toxicity by those plants treated with nitrates. Application of nitrate to stimulate dune vegetation could result in increased salt sensitivity and loss of certain species which normally survive in exposed areas.

In general, any fertilization of the dunes can be expected to change the associated plant community. Natural vegetation may be replaced by a typical species, such as the invasion of camphorweed on the North Carolina Outer Banks following fertilization experiments (Graetz, 1973). The loss of beach by the overstabilization of beach grass (<u>Ammophila</u> <u>breviligulata</u>) dunes within Hatteras National

Seashore is a well known case of management repercussions. Based on the above experience, fertilization of dunes in Georgia should be handled with great caution.

4. Fire and Lightning

Fire is a physical factor which is primarily responsible for perpetuating the pine-grassland community of the coastal plain. The role of fire on coastal islands is less clear, though there is abundant evidence for the regular occurrence of fire on these islands in the past. Most island burns seem to be restricted in area because of sloughs and slow burning live oak stands.

The ecological effect of a fire depends on how it burns (crown vs. ground fire) and how hot it gets. Heat depends on the quantity and quality of fuel (litter, dried grasses, oak leaves), the amount of wind, and the amount of moisture. Infrequent fires tend to be hotter fires since there is ample time between burns for fuel to accumulate. Since natural fires are usually ignited by lightning and since the number of times an island is struck by lightning should be directly related to the size of the island, it could be assumed that the smaller Holocene islands are burned less frequently but more severely than the larger Pleistocene islands.

Ground fires that are fueled by grasses are injurious to broad-leafed shrubs and trees and select for pines. Fires fueled only by leaf litter tend to be creeping fires, producing insufficient heat to kill larger hardwoods. Palmetto (Serenoa repens), if infrequently burned, produces a very hot fire. Holocene islands tend to support understories predominated by grasses, shrubs, and palmetto; infrequent burns will be severe. Pleistocene islands frequently support mature forests of live oak with very little understory. Fires in these areas will be mild, perhaps even contributing to the maintenance of live oak dominance (Laessle and Monk, 1961). If a Pleistocene live oak forest is cleared and replaced with a pine-grassland community, regular ground fires will be sufficiently hot to perpetuate the latter community (Johnson, *et al*., 1971).

When a ground fire burns grass and litter, it affects soil nutrients in a number of ways (Lewis, 1974). As much as 60% of the total nitrogen in forest litter is volatilized and lost to the atmosphere. That which is left in the ashes, however, is more readily converted to nitrate by soil bacteria. The assets of soil nitrate enrichment must be balanced against the liability of total organic nitrogen depletion.

The solubility of important cationic nutrients (Ca^{++}, Mg^{++}, K^{+}) is increased many times. Pleistocene soils with a significant humic content in the upper layers could be enriched by this conversion, but Holocene soils may be depleted by the rapid leaching of surface nutrients. Thus, frequent ground fires burning over Pleistocene soils may serve to release nutrients and stimulate productivity, while infrequent ground fires over inadequate soils (Holocene conditions) could deplete soil nutrients and injure a larger percentage of forest trees.

The value of fire in selecting particular forest associations on coastal islands is a subjective, poorly understood topic which requires more study. The role of fires, soils, and island nutrient budgets should also receive further study.

Lightning, in addition to starting fires, is an important killer of southern pines (*Pinus palustris*, *P. elliotti*, *P. taeda*) (Baker, 1973). A pine which is struck by lightning usually dies, although lightning is generally the indirect cause (Komarek, 1973). Most pines are weakened by the strike and succumb to beetle infestations. Oak, on the other hand, generally survives a lightning strike.

Under natural conditions, pines tend to be infrequently scattered throughout the forest community of coastal islands. Pines also tend to be considerably taller than the associated hardwoods and are thus more susceptible to lightning strike. By selectively injuring pines which are not particularly abundant, lightning may play a significant role in affecting the distribution of pines on coastal islands.

Values and Vulnerabilities of the Physical Factors Shaping Coastal Island Ecology

1. A fresh water lens is the best description available for explaining the dynamic, fluctuating behavior of the island water table. It seems evident that island communities have probably developed in response to the magnitude of fluctuations in the water table. Activities which would alter natural flow patterns (fill, causeways, drainage ditches, landscaping, etc.) would be expected to have a

dramatic, perhaps damaging effect on the natural behavior of the water table. Excessive removal by pumping of island ground water (depths less than 60 feet) can result in a cone of depression and possible salt water intrusion.

2. Contamination of shallow ground water supplies is a potential hazard on coastal islands for several reasons:

- island soils are highly permeable to water, permitting rapid dispersal of contaminants to surrounding areas
- island soils have low filtering and ion exchange capacity
- seasonally high water tables would discharge accumulated contaminants into sloughs.

3. Plant communities exposed to ocean wind have probably adjusted to a nutrient supply from airborne salts. Disruption of air flow by surfside construction would be expected to alter (reduce) the nutrient supply to the leeward of the construction. Conversely, removal of acclimated vegetation exposes remaining vegetation to lethal doses of salt, with rapid foliage death.

4. Forests are pruned by wind and salt to form a dense canopy shaped like an airfoil with leading edge to the prevailing winds. Clearings in the canopy could expose forest trees to damaging storm winds, with a resulting high mortality of trees on the clearing perimeter (Graetz, 1973).

5. Effects of airborne salt are related to surf activity

and the distance between the surf and the affected plant species. Construction of piers, groins, seawalls, and offshore bars will change surf patterns, the salt distribution profile, and probably shift the equilibrium between plant community and salt distribution.

6. Fire stimulates herbaceous growth and selects fire-adapted species. The effects of fire on coastal islands, however, may be detrimental since litter is a critical link in nutrient cycling. Coastal island soils do not have the well-developed B horizon needed for trapping nutrients released by a fire.

7. On the other hand, historical fires may have been an important factor in shaping the island community. Research should be carried out to determine the effects of island fire and its historical role on the Georgia coastal islands.

Soils

A knowledge of island soils is important to the understanding of island ecology. Soils are involved in water movement and nutrient cycling. The chemical and physical characteristics of soil influence the distribution of flora and fauna. Island soils are closely associated with the island water table; identification of soil type can provide information on the frequency of flooding and the proximity of the water table to the surface of the terrain in question. The following is a brief description of factors influencing soil information on Georgia coastal islands (Wilkes, *et al.*, 1974;

Byrd, *et al.*, 1959).

1. Soils develop from a parent material which largely determines the chemical and mineralogical composition of the soil. Most Georgia island soils have developed from a near homogeneous quartz sand deposited during the geologic formation of the barrier islands. Quartz sand is highly resistant to weathering, with poor water retention qualities and a low capacity for nutrient storage. At least one soil type found in depressions of older, Pleistocene formations contain significant quantities of clay, implying an earlier and unique (for coastal island soils) association with tidal streams or estuaries. In addition, a soil type found along the marsh-island interface consists of a sandy-clay which has developed as a result of occasional tidal inundation over low sandy areas.

2. Climate affects soil in several ways. Mineral nutrients are released from parent material by weathering, but this is not an important factor with quartz sand. A warm climate promotes rapid decomposition of organic matter, leaving few organics to accumulate in the soil. Abundant rainfall leaches cations (Mg^{++}, Ca^{+}) from surface layers, replacing them with hydrogen ions which increase soil acidity. This is particularly true on the slopes of steep dunes where leaching is greatest.

3. Topography primarily affects the rate of leaching. Narrow ridge tops and slopes have soils low in organics

while depressions and flat areas are correspondingly higher in organics. In low, poorly drained areas, consistently wet soil retards decomposition of plant tissue. Oxygen is lower in saturated soils than in well drained soils.

4. Plants and animals play an important role in affecting soil development, particularly within coastal island quartz sand soils that are particularly inert to physical and chemical changes. Plants produce organic matter, primarily as surface litter in forest soils. Litter decomposes to humus, and humus chemically traps and binds essential mineral nutrients.

5. Time is an important factor in soil development. Soils develop when organic (decomposition) and inorganic (weathering) products leach from an upper A horizon and collect in a lower B horizon, ultimately developing a characteristic identity which differs from the parent material or C horizon beneath. Weathering of quartz sand is too slow to register differences among the various island soils, but certain organic compounds highly resistant to further decomposition have accumulated in significant amounts in one Pleistocene soil, providing this soil type with a stable B horizon.

The above information can be summarized by listing characteristics of Georgia coastal island soils and their effects on coastal ecology. Almost all these characteristics derive from the fact that most of the coastal island soils are nearly pure quartz sand and this explains why Georgia coastal island soils are considered as one soil association unit.

Low Water-Retention Capacity: Sandy soils have a reduced ability to hold water by capillary action. Thus, well drained soils loose soil moisture quickly and are characterized as droughty. Plants associated with such soils must be drought-resistant species.

Rapid Permeability: Water passes through sandy soils with little resistance. Impounded water, where it exists, is usually not trapped by impermeable soils but represents the current level of the island water table. Droughty ridges adjoin saturated depressions. For this reason, soil associations on coastal islands consist of soils which differ from each other primarily by the amount of drainage which, in turn, is directly related to elevation, the frequency of flooding, and the proximity of the island water level.

Poor Ion Exchange Capacity: There are very few sites on sand grains where essential mineral nutrients (for example, cations of K, Na, Ca, and Mg) can be absorbed (chemically trapped and bound) for subsequent uptake by root systems. Humic materials provide additional sites for nutrient absorption but these materials generally exist only in a shallow, upper A horizon.

Vulnerability To Leaching: Nutrients released by surface litter decomposition and not quickly reabsorbed by soil fungi and higher plants are apt to be leached to subsurface layers probably corresponding to the island water table level. A portion of these nutrients is probably recycled to the surface by the action of deep tap roots or periodically high island water levels, but data to this effect are not available.

Absence of the B Horizon: Most coastal island soils are characterized by the complete absence of a B horizon. The B horizon represents a zone of accumulation where the mineralized products of weathering and decomposition are trapped. The absence of a B horizon means that soil nutrients leached from surface litter are not routinely trapped in a zone available to root systems but pass with excess water to ground water reserves and possibly lost to the community. The absence of a B horizon also means that island soils do not have a nutrient reserve bound in clay or loam. Sandy soils are vulnerable to rapid nutrient depletion if a continuous nutrient input from decomposing litter is interrupted.

Low pH: Most coastal island soils are characterized by acidic conditions which develop for a number of reasons (Buckman and Brady, 1968).

a) abundant precipitation: rain leaches appreciable amounts of exchangeable bases (Mg^{++}, Ca^{++}) from the surface layers of well drained soils, replacing the absence with hydrogen ions;

b) the presence of organic complexes (humus): hydrogen absorbed on the humus dissociates into the soil solution with comparative ease (older, more level soils);

c) the production of inorganic acids (H_2SO_4 and HNO_3) as a biproduct of organic decay (low, poorly drained soils).

A low pH is indicative of the following conditions (Buckman and Brady, 1968):

a) a loss of exchangeable bases (Ca^{++}, Mg^{++}) from well-drained soils;

b) increased solubility of trace elements (Al, Fe, Mn) to levels perhaps toxic to certain plant species;

c) a loss of available phosphate (a low pH causes phosphate to complex as insoluble compounds);

d) a reduction in the activity of bacteria and actinomycetes, reducing, for instance, the rate of bacterial nitrogen fixation. Fungi are seemingly not affected by low pH and continue to function in decay, aminization and ammonification reactions, all important steps in the nitrogen cycle;

e) a reduction in total soil nitrogen, probably correlated to reduced nitrogen fixation.

Conditions which seem unfavorable at first glance (low pH, reduced microbial activity, etc.) may be necessary under conditions of island quartz sand soil. For instance, it has been shown that humic material provides most of the ion exchange capacity in pure quartz soils and that humus is vulnerable to leaching when reduced to molecular levels. As a conjecture, reduced microbial activity in the upper soil horizons may slow the mineralization of humus, thereby increasing the retention time of humus in the upper horizon and the opportunity (time) for plants to recycle complexed nutrients (exchangeable bases) before nutrient-humus complexes are lost to deep layers by leaching. A higher pH could mean a net loss of nutrients to the plant community if microbial activity is increased.

Buffering Capacity: Soil flora and fauna are sensitive to changes in pH. The ability of a soil to resist such changes is called the buffering capacity. Buffering is enhanced by high ionic exchange capacity and high concentrations of weak acids (carbonic, humic), two conditions which are characteristically absent from well drained island soils. Well-drained, acid soils are vulnerable to pH changes. If a markedly acid sandy soil is suddenly brought to a neutral or alkaline condition by an over-application of lime or oyster shells, trace elements can go completely out of solution, causing plants to suffer from, for instance, a lack of available manganese and iron (Buckman and Brady, 1968).

Pleistocene vs. Holocene: According to the available soil surveys (Byrd, *et al.*, 1959; Wilkes, *et al.*, 1974), Holocene island soils are all without a B horizon and exhibit the least quantities of accumulated organics and horizon development. Pleistocene island soils, as a group, exhibit greater variety and development (horizon development, organic accumulation, presence of clay and loam) than Holocene island soils but less development and variety than mainland Pleistocene soils. Differences in soils provide another reason why environmental conditions become more strenuous as one moves from mainland to island and from Pleistocene island deposits to Holocene island deposits.

Values and Vulnerabilities of Island Soils

1. Litter plays a major role in island soils and must be protected. Litter reduces leaching in the upper soil layers by dissipating the force of rain as well as providing most of the ion exchange capacity.

2. Coastal island soil types are closely related to the proximity of the island water table. Changes to the water table (drainage, impoundment, etc.) will affect the type and behavior of the associated soils. Drying soils decrease in pH (Buckman and Brady, 1968).

3. Coastal island soils are characteristically low in nutrients, low in ion exchange capacity, high in permeability, low in buffering capacity, and low in pH. These characteristics make island soils sensitive to a wide variety of manipulative practices such as sewage disposal, agricultural practices, and landscaping.

4. Soils within a single soil association can be very different ecologically. For instance, the Kershaw-Osier-Coastal Beach Association represents soils which have developed on Holocene island deposits (Wilkes, *et al*. 1974). The Kershaw series is excessively drained and droughtly. The Osier series is poorly drained and usually flooded. These two series represent dramatically different selective forces on the island community, yet they are closely intermingled in the dissected terrain of Holocene deposits.

As indicators of ecological conditions, soil maps must employ a scale sufficient to represent soil series.

Nutrient Cycles

Nutrients are chemical elements essential to life. Nutrients tend to circulate through the environment along characteristic pathways known as nutrient cycles (Odum, 1971). The stability of a biological system depends in large part on the ability of the system to balance its nutrient budget, to utilize its resources (turnover) and to compensate for losses with equivalent gains. Coastal islands exhibit characteristic strategies which acheive a balanced nutrient budget.

Nutrients are classified as inorganic (nitrates, phosphates) CO_2, mineral ions, etc) or organic (Vitamin B_{12}). Organic nutrient cycles are important but will not be discussed for lack of data. Inorganic nutrients may be classified according to their primary abiotic source. Thus, gaseous nutrients are available in the atmosphere and include the elements of carbon, nitrogen, oxygen, and sulphur. They enter the system as meterological input (dissolved in rain or mixed with atmospheric gases) and are captured by the stream through such processes as photosynthesis and nitrogen fixation. Sedimentary nutrients include such important elements as calcium, potassium, magnesium, and phosphorus. These are trapped in the earth's crust and are released to the system in ionic form (Ca^{++}, Na^{+}, Po_4^{--}, etc.) by the weathering and ultimate solution of soil rocks and minerals.

Gaseous nutrients are available to islands and adjacent mainland in equal quantities. Mechanisms for photosynthesis and respiration do not differ significantly between islands and mainland. Nitrogen is frequently a limiting nutrient, and its capture by a host of nitrogen-fixing micro-organisms is an important aspect of community productivity. Unfortunately, there is little information on nitrogen cycles pertaining specifically to coastal islands. The fact that excess nitrogen can stimulate growth of dune vegetation while simultaneously lowering resistance to salt toxicity (Boyce, 1954) implies a very delicate role played by nitrogen in coastal ecosystems.

The primary source of sedimentary nutrients is the weathering of rocks and minerals, yet the inorganic fraction of barrier island soils is almost entirely quartz sand which is highly resistant to weathering. Barrier islands evidently maintain levels of productivity equivalent to mainland forests by substituting the meterological input of airborne salts as a source of sedimentary nutrinets (Art, et al., 1973).

Figure 3-4 illustrates a hypothetical scheme for sedimentary nutrient cycling based on values for a Long Island, New York coastal barrier island (Art, et al., 1973). This scheme is probably most pertinent to Georgia Holocene islands with poor soil profiles. A number of observations can be made:

1. Most of the community nutrient reservoir (exchangeable nutrients) is contained in living biomass (leaves, twigs, roots, and stems). The remainder is absorbed to soil

Figure 3-4

Hypothetical Cycling of Sedimentary Nutrients on Coastal Islands

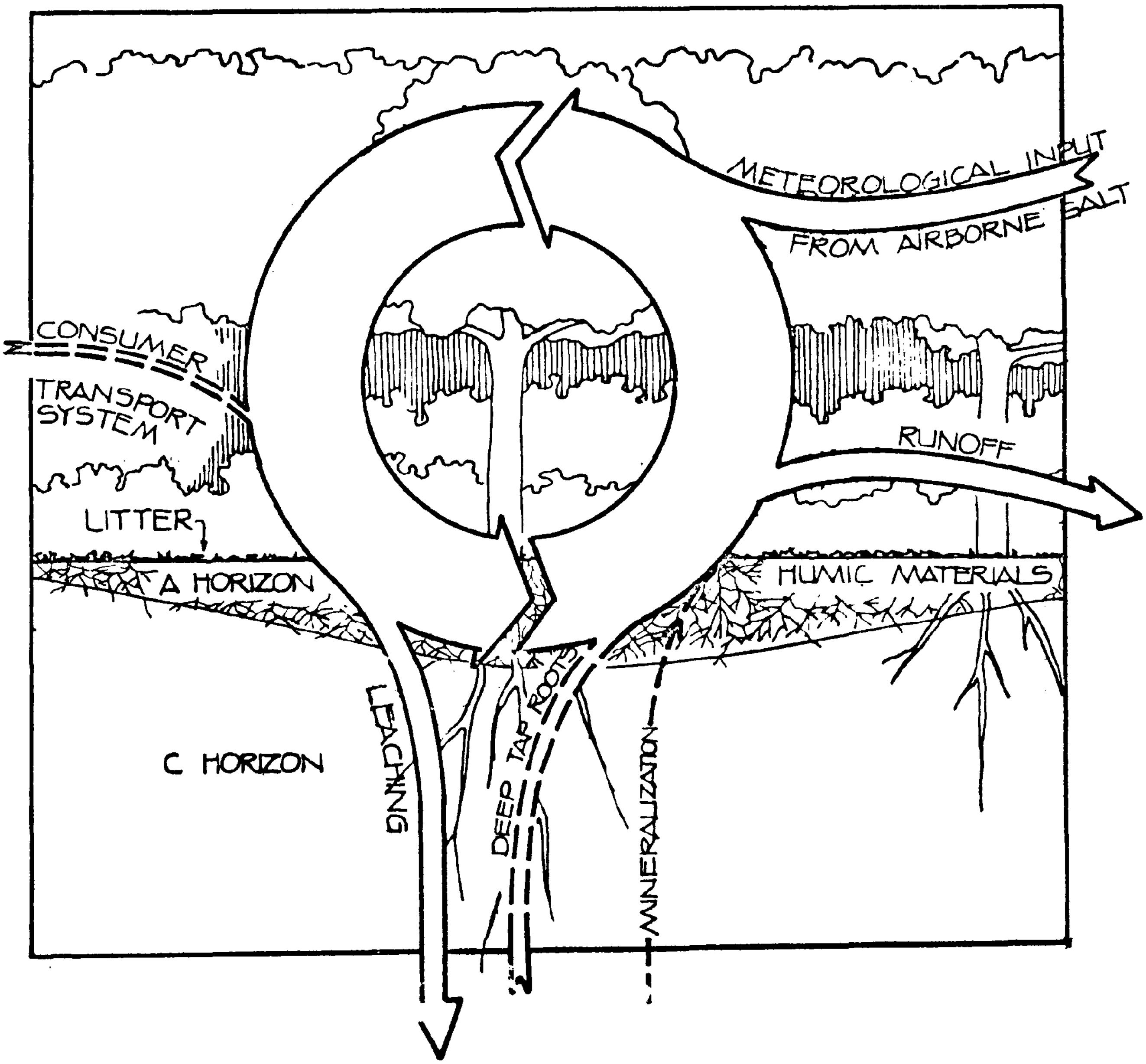


Figure 3-4 represents a hypothetical method of sedimentary nutrient flow on a sandy barrier island. Arrow width represents the proportion of flow relative to other sections of the model. Solid lines represent measurements from a Long Island, New York barrier island (Art, et al.,1973); dotted lines represent hypothetical flows which have not been measured. Until we have actual measurements for a Georgia coastal island, this model cannot be detailed.

organic matter. There are virtually no nutrients attached to the mineral elements of the soil.

2. The major nutrient flow is a tight cycle from leaf production to soil litter and back to leaf production. The magnitude of this flow has been estimated to be four to six times the meterological input (Art, et al., 1973). The percentage of nutrients passing through a grazing food chain (deer, herbivores, insects, etc.) is much less.

3. Litter nutrients not immediately reabsorbed by roots are leached from upper layers of soil and probably lost to the community. The relative proportion lost to ground water and surface runoff, is not known. A certain amount of recycling of deep soil nutrients probably occurs, perhaps by deep tap roots or the pumping action of a fluctuating water level.

4. Art, et al., (1974) believe salt droplets deposited on foliage are the primary source of sedimentary nutrients into their Long Island coastal forest. They did not consider the transport of nutrients into the system by animals to be very important. Such a consumer transport system is probably more important on Georgia islands, but a quantitative study has never been done. Raccoons, deer, and a variety of wading birds represent significant populations of animals which feed in the surrounding marshes and deposit their fecal matter

on the island. A study of energy and nutrient transfer across this marine-terrestrial interface of coastal islands would add significantly to the understanding of coastal island ecology.

There are a number of interesting similarities in nutrient cycling between Holocene formations and moist tropical forests (Art, et al., 1973). Both systems have highly weathered soils which produce very small quantities of sedimentary nutrients. Most of the exchangeable nutrients are bound within living biomass and not the soil. Thus, both systems must quickly recycle nutrients from leaf litter back to living biomass or lose those nutrients to rapid leaching. Because of this similarity, some of the following characteristics of moist tropical forests might be pertinent to Georgia barrier islands.

1. Tropical forests exhibit nutrient conservation mechanisms (Odum, 1971) such as a close approximation of fungal mycorrhyza and tree roots permitting a direct transfer of nutrients from litter to living biomass. Similar mechanisms may exist in the coastal island litter layer.

2. If tropical forest is cleared, the soils rarely support more than a single crop before productivity begins to decline. Soil nutrients are quickly exhausted or leached away. Holocene island soils would be expected to behave similarly. It would be interesting to know how early plantations maintained soil productivity, even on Pleistocene soils with the beginnings of a B horizon.

3. The narrow litter layer is a critical zone of nutrient transfer; its removal short-circuits the nutrient cycle. Fire on coastal islands removes the litter layer and increases the solubility of soil nutrients. Fire would be expected to have its most disruptive effect on nutrient cycles in Holocene areas. It has been shown (Remezov and Pogrebnyak, 1969) for dry, sand soils under pine that the litter contains 20-50% of the total amounts of Ca^{++}, Mg^{++}, P^{+}. and K^{+} involved in the soil's yearly cycle. They demonstrated under these conditions that even one removal of forest litter could impoverish the soil and reduce soil nutrients. The effect may be quite perceptible even several decades later.

Values and Vulnerabilities of Nutrient Cycling

1. With a general lack of a B horizon in coastal island soils, the exchangeable nutrients from decomposition products probably pass from litter and humus directly to the roots of the associated plant community, effectively eliminating the need for a well developed subsoil layer of B horizon. Removing litter could break the nutrient cycle and disrupt community productivity.

2. The artificial application of fertilizers to coastal island soils will probably alter the structure of natural plant communities which have adpated to prevailing winds, salt spray, and nutrient-poor, acidic soils.

Coastal Island Fauna

A considerable amount of faunal life history and distributional data has been collected for the Georgia coastal islands (Hillestad, 1975; Johnson, *et al.*, 1971; Johnson, *et al.*, appendix, 1971). It is evident from this work that the ecology of animal populations on coastal islands is different from what is encountered on the adjacent mainland primarily because of one essential fact: coastal islands are islands and not peninsular extensions of the mainland. This fact manifests itself in a number of ways.

1. When conditions are unfavorable, mainland fauna has the opportunity to move to more favorable areas. When conditions return to normal, a species can return to previously vacated areas. The opportunity for migration on coastal islands is reduced, depending on the mobility of the species. Rattlesnakes and raccoons are excellent swimmers and are widely distributed among the islands. The discontinuous distribution of squirrels, mice, and opossums may indicate periodic extinction in localized areas as well as infrequent recolonization. The distribution of species intolerant to salt water (salamanders) will be discontinuous and localized on a few older Pleistocene areas.
2. The capacity of an island to support species is related to its size (MacArthur and Wilson, 1967). Thus, within a particular geological category, fauna of larger islands should be more diverse than smaller islands. For example, the diversity of Wassaw (2500 acres) fauna should be greater than Little Cumberland (1600 acres) fauna.
3. Insularity isolates some breeding populations and

permits the development of new forms (genetic drift). The indiscriminate introduction of mainland genotypes can obliterate, through interbreeding, unique island forms which may have taken thousands of years to develop. Four taxonomically distinct mammals are currently recognized for the Georgia barrier islands (Johnson, et al., 1971), including the Cumberland Island pocket gopher (Geomys cumberlandius), the Anastasia Island cotton mouse (Peromyscus gossypinus anastasae), the St. Simons Island raccoon (Procyon lotor litoreas), and the Blackbeard Island deer (Odocoileus virginianus nigribarbis). Johnson, et al., (1971) discuss management options for protecting these unique species.

4. Island communities with a reduced number of species develop sensitive equilbria among the existing species. The introduction of new, seemingly innocuous mainland species to island faunas has the potential of setting off significant perturbations within the island community. Introductions are frequently upsetting to communities and should be practived with caution.

5. Native island species (endemics) are less adaptable than mainland species and more prone to extinction when new species (exotics) are added to the community (Carlquist, 1974). Adaptation to island life seems to reduce genetic fitness and with it the ability to compete. The more endemic the organism, the more prone it is to

extinction.

Virtually all populations oscillate in density. However, the more highly organized and mature the community and the more stable the environment, the lower will be the fluctuations in population density with time (Odum, 1971). It has been shown that organization, maturity, and stability decrease as one moves from mainland to island and from Pleistocene island to Holocene island. It should not be surprising, therefore, that dramatic oscillations in the density of animal populations on unmanaged Holocene islands is a characteristic feature of coastal Georgia ecology. Over periods of a few years, densities of mice, deer, and raccoon can reach levels substantially higher than adjacent mainland populations, only to crash in massive dieoffs (personal observation of the authors). Levels higher than normal can probably be associated with periods of abundant food, the inability of excess animals to relieve population pressures by emigrating out of the high-density areas, and the noticeable lack of predators (bobcats, humans, bear, lion) available to harvest the excess animals. Although little data is available, the "boom and bust" characteristic of island populations can probably be extended to insect populations as well, including species of noxious insects (Johnson, _et al._, 1971) which can have such an impact on recreation and development.

Populations without regulatory mechanisms tend to overshoot their food source and crash. While the sudden unavailability of food is a likely candidate for initiating a crash, other causes do exist. For instance, populations develop increased susceptibility to disease at high densities. Raccoon population density may be regulated by disease (Johnson, 1970). A crash by one species is frequently associated by crashes in other species, implying an underlying cause such as island mast production (acorn crop).

It is not necessarily wrong to adopt a laissez-faire attitude toward the regulation of conspicuous island mammals, particularly on islands which are being preserved as natural environments. Coastal island animal populations have undoubtedly undergone periodic, severe oscillations for as long as the islands have been in existence. If so, island communities have almost certainly developed characteristic and unique responses to the oscillations. Several islands are classified as natural but are, in reality, quite mission-oriented (Sapelo, Blackbeard), with management plans which damp natural oscillations while selecting for desireable game species. In a statewide multiple-use program, management of this kind has a worthy cause but should not preclude the existence of other representative islands left to natural conditions.

<u>Values and Vulnerability of Coastal Island Fauna</u>

1. Georgia coastal islands support unique faunal types. Protection of habitat and continued isolation of the species are the essential ingredients of management.

2. Island populations should be expected to fluctuate in numbers more than mainland populations. Controlling

normal population oscillations may alter coastal ecology patterns. Undamped oscillations may, however, result in outbreaks of disease and massive dieoffs. A population response such as this would be undesirable within areas with a high density of people.

3. Mobility is a key to survival when food resources run low. Barriers (fences, roads, developments) impede movement patterns and would increase stress on island populations.

4. When populations are high, food availability will be critical. At such a time, browsing species (deer) may come into conflict with many as they search for alternate food sources such as gardens and landscape plantings.

5. Coastal islands are living laboratories for the study of insularity and its effects on coastal animal populations.

Aquatic Systems

Most references to coastal aquatic systems deal with the extensive Spartina marshes, creeks, and estuaries which separate island from island and island from mainland. There is an additional category of aquatic systems, collectively called island sloughs, which play an important modifying role in terrestrial island ecology. Sloughs are critical as a source of water for island wildlife. As nutrient traps, sloughs represent a step in almost all island food chains. As habitat, sloughs add diversity to islands, support territory for rookeries, and provide resting and feeding areas for a wide variety of resident and transient species.

Because of sedimentation and the accumulation of organic matter, aquatic systems tend to pass through a series of successional stages toward a climax forest condition. A more or less regular but acute physical disruption imposed from outside the system can maintain the system at some intermediate point in the development sequence (Odum, 1971). The principal disruption on coastal islands is a fluctuating water level, although saltwater intrusion and fire represent additional disruptions. Thus, we can consider island sloughs as pulse-stabilized, fluctuating water level ecosystems which respond to outside forces.

1. The Hydrologic Cycle as a Force

The level of the island water table (Figure 3-2) represents the level of exposed water in island sloughs. When it rains, sloughs experience a rapid increase in the water level. This rate of increase provides an important signal for initiating breeding behavior in slough-dependent animals like frogs and toads. There is also a steady loss of water via ground water flow, runoff, and evapotranspiration which results in a gradual decrease in water level. During periods of extended dry weather, a slowly dropping water level stimulates a continual series of successional changes within the slough community. Rapid increases in the water level initiate sudden dieoffs in emergent vegetation, in effect resetting the environmental clock to an earlier, open-water successional stage. Gradual increase and rapid decrease in water levels represent abnormal system responses which probably would disrupt normal behavior patterns.

A fluctuating water level acts as a nutrient pump. When the water level drops, nutrients in bottom muck become available to emergent plants and are transferred to plant biomass. At a very low water level, the slough bottom will dry out, stimulating aerobic decomposition of accumulated organic matter which prepares the system for rapid nutrient release. A sudden rise in water level distributes mobilized nutrients throughout the flooded system. Emergent plants are drowned (harvested), releasing additional nutrients. Production is shifted to submergent and floating vegetation as the system returns to an earlier successional stage.

How a community responds to a fluctuating water level system depends on the frequency and amplitude of the fluctuation. Fluctuations in ground water probably increase in amplitude from mainland to island and from Pleistocene island to Holocene island. Mainland communities have alternate sources of water (rivers and streams) and a water table more resistant to change. The breeding of aquatic species on the mainland does not have to be closely linked with the dynamics of a fluctuating water system. On a Holocene island, however, acceptable conditions for breeding within aquatic systems are highly unpredictable and usually of very short duration. Holocene island communities tend, therefore, to be more responsive than mainland communities to variations in water level.

2. Salinity as a Force

Certain island sloughs are periodically flooded by extreme tides, introducing salinity as an alternate perturbing force. Heavy rains dilute salinities, establishing conditions for salt-sensitive plants such as cat-tail (Typha). Tidal inundations raise salinities, killing salt-sensitive plants while favoring salt-resistant plants. Salinity fluxes interrupt succession, stimulate nutrient turnover, and maintain open-water systems.

Tidal inundations also permit access to island sloughs by several salt marsh species of fish (mollies)(Poecilia latipinna), killifish (Fundulus species), and top minnows (Cyprinodon variegatus) which normally maintain subsistence levels in neighboring tidal creeks. Within the sloughs, populations grow to enormous numbers in the absence of marine predators, feeding on a near limitless supply of rich organic detritus on the slough bottom. Densities in excess of a thousand fish per square meter can be realized. Salinity-pulsed sloughs are particularly important feeding areas for such animals as herons, egrets, grebes, anhingas, and turtles.

Salinities vary widely (0% - 30%) between sloughs and temporally within sloughs depending on the frequency of tidal inundation, rainfall, and evaporation. Temperatures fluctuate widely since water is shallow and exposed to sunlight without the regulatory effect of emergent vegetation. Since saline-pulsed sloughs tend to be rich in rotting organics, dissolved oxygen frequently drops to zero. Fish inhabiting these sloughs can tolerate a broad range of temperatures and salinities (Bacon, *et al.*, 1967; Garside and Jordan, 1968) and even have the ability to gulp air at the surface when dissolved oxygen drops to zero (Odum and Caldwell, 1955).

3. Fire as a Force

Fire reestablishes open water in aquatic systems (Cypert, 1961; Ward, 1942). When conditions are particularly dry, bottom peat can dry out and burn, effectively lowering the bottom of the slough. Such a dramatic disturbance may occur only once in a hundred years and still be an important factor in the pulse stability of an aquatic system. Due to the infrequent nature of this force, its historical role as a disruptive factor on coastal islands is difficult to document, but the potential effects are very real and should always be considered when dealing with coastal island sloughs.

There seems to be a limitless variety of sloughs on the coastal islands, but virtually all are pulse-stabilized. Slough variety is the result of a gradient effect in the intensity of the forces acting upon the sloughs. Water level fluctuations are greater on Holocene formations than on Pleistocene formations. Within a Holocene island, fluctuations will be greater on the newer portions (behind the primary dunes) than on older portions (central forested areas). Deep depressions dry out less frequently than shallow depressions. The impact of salinity depends on the frequency of inundation and the dilution factor (amount of sea water reaching a given quantity of fresh water). The effect of fire depends on the frequency of the burn and the depth to which the bottom of the slough had dried prior to the fire. Limiting nutrients, drainage, soil conditions, soil pH, proximity to airborne salt, and many other factors add to the variety of island sloughs.

Virtually nothing has been done to categorize coastal island sloughs. A tentative classification based on a cursory investigation of Cumberland Island (Pleistocene with Holocene additions) and Little Cumberland Island (Holocene) is as follows:

1. Holocene Freshwater Slough: long and narrow, forming between dune ridges; frequently shaded by overhaning oaks; water levels fluctuate greatly.
    a) Deep Sloughs: flooded for most of the year; usually choked with floating aquatic plants (*Heteranthera*, *Utricularia*, *Limnobium*); fish (*Gambusia*) rarely accumulate to densities that would provide an important food source for herons and egrets.
    b) Moderate to Shallow Sloughs: alternately flooded and dry; willows in the low areas, saw grass (*Cladium*) at moderate levels, annuals (*Pluchea*, *Saururus*) at shallow levels where flooding is occasional. *Gambusia* present but in moderate to low densities.
    c) Primary Dune Depression: very temporary; forming

for short periods of time (several weeks) in the interdunal depressions following heavy rains; vegetation is emergent grasses and shrubs (*Myrica* clumps). Because numbers of predators are reduced, frogs, toads and mosquitoes can breed in enormous numbers in these sloughs.

2. Pleistocene Freshwater Sloughs: variable in size; usually round with gradually sloping edges; forming in broad depressions.

   a) Deep Sloughs: permanently flooded; variable amounts of open water; vegetation can consist of rooted emergent perennials (*Decodon*), floating mats (*Heteranthera*, *Utricularia*, *Limnobium*), or rooted submergents (*Nelumbo*, *Hymphaea*); low numbers of prey fish (*Gambusia*) since these ponds frequently support major predator fish (bass (*Micropterus*), sunfish (*Lepomis*)).

   b) Moderate Sloughs: usually flooded; surface often choked with floating mats (*Heteranthera*, *Utricalaria*, *Limnobium*); very similar to deep Holocene sloughs.

   c) Shallow Sloughs: occasionally flooded; grasses (*Spartina*, *Andropogon*, *Setaria*) where bottom dries out; saw grass (*Cladium*) and various trees (*Acer*, *Salix*, *Nyssa*) where bottom soil remains saturated.

3. Saline-Perturbed Sloughs

a) Sloughs with Frequent Tidal Inundation: usually flooded; open water; vegetation consists of submergents (Ruppia) or surrounding emergent grasses (Spartina, Distichlis, Juncus); high salinities (5-20%); capable of supporting enormous numbers of fish (Gambusia, Fundulus, Cyprinodon, Poecilia).

b) Sloughs with Infrequent Tidal Inundation

1) Deep Sloughs: flooded for long periods of time; open water systems rich in organic detritus; salinities variable but usually low (2%); a wide variety of associated plant species with varying salt tolerances; capable of supporting enormous numbers of fish (Gambusia, Fundulus, Cyprinodon, Poecilia); the most productive of all sloughs as a food source for island wildlife.

2) Shallow Sloughs: flooded briefly; shallow, flat depression with varying percentages of exposed clay, grasses (Spartina), or woody shrubs (Iva, Baccharis); occasionally important for concentrating fish while water levels are receding.

4. Fire-Perturbed Sloughs: this is a speculative category for an observed aquatic system on Cumberland Island; extensive, deep, open water system with a variety of emergent grasses; an almost total absence of woody shrubs and broad-leafed aquatics.

5. Drainage Depressions: Soil usually saturated but rarely flooded; generally forested areas (*Magnolia virginiana*, *Hyssa*, *Acer*) with an understory carpet of mixed grasses, herbs (*Saururus*), and woody shrubs and small trees (*Lyonia*, *Cephalanthus*, *Myrica*, *Ilex*).

Because of their inherent diversity, island sloughs can support a wide variety of plant communities. Sloughs represent perhaps 10% of a total island area but account for the greatest part of the island flora and fauna.

Aquatic systems stimulate faunal diversity in several ways.

1. A variety of plant species and plant communities provide for a greater variety of faunal niches.
2. A greater faunal diversity is associated with an ecotone or edge effect. In other words, a wider variety of species can exist along an interface of two adjoining plant communities than in either community by itself. The perimeter of every slough provides additional edge effect.
3. Coastal islands can be dry islands. Sloughs provide an essential source of fresh water during periods of drought for species which would otherwise not survive.
4. Many animals are specialists, requiring a particular set of conditions (water depth, density of emergent vegetation, availability of food, etc.) for feeding or reproducing. With a wide variety of sloughs, adequate conditions can usually be found at one or another

location on an island at any one time. As conditions change, these animals move from slough to slough, staying within optimum conditions.

Coastal island fauna, particularly those species associated with Holocene formations, have developed so closely with the instability of the island environment that many species require fluctuating water levels for survival. These are called opportunistic species since they coordinate their life cycle with temporary island conditions whenever the opportunity arises. The following are examples of opportunistic species:

1. Treefrogs will go for months without breeding, scattered throughout the island forest and seemingly oblivious to occasional thunder showers. When a torrential rain of significant magnitude occurs, individuals from all over the island will gather in dense breeding congregations at a few selected sites on the island, particularly flooded areas with dense emergent vegetation. This opportunistic behavior insures certain critical conditions:

a) sufficient water to maintain flooded pools for the duration of larval (tadpole) development;

b) habitats low in predators; Grassy sloughs are those which characteristically dry out, depressing resident predator populations such as fish and turtles.

c) irregularly pulsed breeding; Predators are frequently slow to react to surges in prey species.

By massing huge numbers of tadpoles at infrequent localities, a sufficient number of young are sure to survive.

2. The marsh killifish (Fundulus confluentus) is a brackish water species which invades island sloughs with periodic connections to the marine environment. This opportunistic species will breed during the highest water levels and deposit eggs at the very margins of the sloughs (Harrington, 1959). When water levels recede, the eggs may remain stranded on high ground for months but will hatch within fifteen minutes upon being reflooded (Harrington, 1959). The salt marsh mosquito (Aedes solicitans) also deposits its eggs which hatch upon being reflooded, so the marsh killifish achieves at least two results by its unusual opportunistic behavior: 1) protecting its eggs from aquatic predators and 2) coordinating its young with the available food supply (mosquito larvae), being at the right time and the right place when the mosquito eggs hatch.

3. The wood stork (Mycteria americana) is so inefficient at catching fish that it must specialize on sloughs where receding water has concentrated fish to a critical density. The stork nesting cycle in Florida is coordinated with periods of falling water level when fish supplies will be sufficient for rearing young storks (Kahl, 1964). Visiting wood storks on the Georgia

coast exhibit similar feeding behavior.

4. The success of a mosquito hatch in an island slough usually depends on the presence or absence of fish. Some mosquitoes tend to utilize temporary sloughs (grassy) which periodically dry up, eliminating resident fish predators during the dry periods. Several opportunistic species of fish, however, manage to persist in such sloughs during dry periods by taking refuge in alligator burrows (refugia) which extend below water level. When the rains come, water levels rise, mosquito eggs hatch, and the fish are there to utilize the food source for their own breeding cycle.

It is obvious that a drained slough ceases to pump nutrients and provide the variety of food and habitat associated with a normal fluctuating slough. It is not so obvious that a slough with a stabilized water level will behave in the same way. Nutrients will become locked in the bottom, succession will proceed with vegetative growth choking open water, and habitat for opportunistic species will be reduced or eliminated. If a majority of island sloughs were to be stabilized, a major shift in associated fauna could be anticipated.

Values and Vulnerability of Island Sloughs

1. Sloughs are maintained and perpetuated by perturbations in the environment, usually a fluctuating water level but occasionally salt water intrusion or fire. Stabilizing water levels or blocking natural drainage

channels will result in rapid successional changes within the slough, possibly leading to the complete loss of the slough system.

2. Sloughs provide for a major part of the floral and faunal diversity of coastal islands.

3. Sloughs provide food and water for island animals.

4. Sloughs are superb systems for environmental education.

The Strategy of Survival on Coastal Islands

Ecosystems are more easily disturbed by unfamiliar forces (man, introduction of exotic animals, etc.) than by familiar forces (fluctuating water levels, salt, insularity, etc.) (Odum, 1971). Unnatural oscillations in population densities can result in the extinction of some island species. Given sufficient evolutionary time, however, ecosystems adjust to familiar forces. Resistent species and adaptive strategies help to damp oscillations within the system. Although little supporting data currently exists for coastal islands on the Georgia coast, the existence of such uniquely specialized strategies is almost self-evident. If some coastal islands are to be maintained in a natural condition, manipulations to the environment must be carefully considered with respect to their impact on island ecology. A minor manipulation could theoretically initiate irreversible changes in, for instance, the species composition of island forests by interrupting subtle adaptive strategies between interacting species.

Using a hypothetical example, let us assume that Holocene islands have been severely browsed by periodic highs in deer density for the last 5000 years. We can ask the question: What happens if these dominant herbivores are managed at constant, low levels? This would remove not only the periodic impact of intense high-density browsing but also the periodic lack of impact which follows population crashes and reduces browsing pressures to zero! A number of changes could occur:

a) Since different browse plants have different palatability and browsers tend to be specialists, plant species with high palatability would continue to receive heavy browsing pressure, while less palatable species would now be ignored. There would be a shift in forest composition to less palatable species.

b) Some island forest species (Persea, Bumelia) currently have very dispersed distributions. These trees employ a strategy of producing fruit which is highly attractive to browsers (deer). Seeds pass through the gut and are dispersed by random fecal deposits throughout the island. Since the foliage of these two tree species is browsed by deer, survival of seedlings is enhanced by rareness. Thus, the occasional seedling germinating in a thicket will escape notice and survive, particularly if a major die-off in the deer herd has proceeded germination of the seedling.

For purposes of the hypothetical example, we will regulate the deer herd at a constant low density and assume the following results:

1. Fruit from both forest species is now ignored in

favor or more palatable food;

2. Foliage from the first tree is still preferred, but the foliage of the second tree is now ignored by the browsers.

The seeds of both species would cease to be widely distributed, resulting in dense seedling shadows under the parent trees. Because of its localized abundance, the first species would become easier to find and receive increased browse pressure, leading to the loss of all seedlings and the ultimate extinction of the species from the forest community. The second species would remain on the island but change its distributional characteristic from dispersed to clumped.

Although the above is a hypothetical example, it could be tested by monitoring diet selection by coastal island deer at different population densities and noting the response of browse plants to varying intensities of selection (palatability).

The purpose of deriving this example is to draw attention to several ideas:

1. The existence of subtle relationships which might have evolved within the coastal island ecosystems;
2. The effects such relationships might have on the structure of an island community;
3. The vulnerability of island communities to seemingly innocuous manipulations by man.

There must always be a least some examples of totally unmanaged coastal island systems which can be used for testing and comparing the effects of man-induced disturbances.

Island Communities

A hypothetical cross-section of a Georgia coastal island, with a number of characteristic communities, is shown in Figure 3-3. A relatively level forest of Pleistocene origin is bordered by a stabilized dune ridge of Holocene origin. The figure represents a prograding shoreline, with primary dunes, foredunes, and berm developing progressively eastward of the forested secondary dune system.

There are many variations to this cross-section. Holocene islands exhibit an extended series of forested, secondary dune ridges. Islands with a retrograding (receding) shoreline have a reduced or absent primary dune system. In fact, each coastal island is different, representing a unique combination of physical and chemical conditions which impart to it a characteristic behavior and appearance. The complex of beaches, bars, and dunes can be described as a dynamic system involving the interplay between sedimentary processes and sedimentary structures (Oertel, 1974). Nevertheless, island communities, developing under such variable conditions, display fundamental similarities common to all of the Georgia islands.

An island community represents a convenient unit of study because it can be defined as a characteristic assemblage of plants and animals living together under similar physical conditions. A community is also a functional unit. Organisms within a community frequently display common survival strategies, trophic structure, and metabolic patterns (Odum, 1971).

Finally, the behavior of a species within a community is closely interwoven with that of the other species. Changes in the population characteristics of one species can be expected to affect the other members of the community.

1. Beaches

The ocean beach is alternately called a foreshore (Oertel, 1974) by geologists and a coastal beach (Wilkes, *et al.*, 1974) by soil scientists and represents an area which is covered twice daily by tides. Its physical characteristic is fine sand, high salinity, and varying quantities of small shell fragments and sediments.

The ocean beach community is constrained by:

a) the physical pounding of waves and currents on a a shifting substrate (high water); and

b) periodic exposure to dessication (low water).

Most resident members of the community are burrowing animals which move with the sand, extending or retracting their burrows as the shifting sand dictates (Clement and Richardson, 1971). A number of predators (birds and ghost crabs (*Ocypode*) during low water, and fish and rays during high water) visit the beach to feed when conditions are acceptable.

The composition of species within the beach community depends in large part on the amount of silt and clay which is mixed with the sand. The ocean beach fully exposed to surf is a high-energy beach. This type of beach will have a low silt content and support primarily filter-feeding organisms

(Odum, 1971). Beaches on the west side of the islands and beaches protected by sand bars are low-energy beaches which receive varying degrees of protection from turbulence. Low-energy beaches, relative to high-energy beaches, contain more silt and clay, more organic nutrients, and a greater proportion of deposit-feeding organisms.

Producers (plants) perform a minor role within the beach community. Diatom colonies appear as brown patches on the surface of low-energy beaches. These single-celled algal plants are important producers within the estuarine system (Pomeroy, 1959), but total numbers occurring on beaches are probably small relative to the entire estuary. Other species of algae and some cord grass (Spartina alterniflora) may be found in small, scattered patches where turbulence is low.

Consumers, on the other hand, are numerous within the beach community and probably play an important role in coastal ecology. Invertebrates, particularly isopod crustaceans, polychaete worms, and the coquina clam (Donax), provide an abundant source of food for shorebirds. The ubiquitous ghost shrimp (Callianassa major) is a burrowing filter-feeder occurring most abundantly on the high-energy beaches. Fecal pellets released by these animals may be an important source of food for other organisms such as crabs. It has been estimated that the ghost shrimp on approximately five miles of Sapelo Island beach produce a collective total of 280 million pellets per day, equivalent to 26 pounds of organic carbon per day (Frankenberg, *et al.*, 1967).

2. Dunes

Dunes are important to shoreline stability for at least three reasons (Oertel, 1974):

a) barriers which prevent flooding and protect land and structures located directly behind the beach;

b) energy dissipation whereby the energy of a wave surge is absorbed slowly;

c) reservoirs of sand in the erosion and accretion process.

Dunes also support one of the most complex and varied of the island communities. The dune community is a complex system with a number of subsystems (Oertel, 1974):

a) Berm:

The upper or landward edge of the foreshore is an area of sand accumulation called a berm. The berm marks the upper limit to which sand may be transported by wave action. The berm develops seaward as gentle waves add the offshore sand bars to the beach slope.

b) Backshore:

A developing berm broadens to form a low, flat area, or backshore. The extent of the backshore is an indication of how rapidly the shoreline is building.

c) Foredunes:

Periodic spring tides float dead *Spartina* stalks out of the marshes and deposit them on the backshore as "beach straw".

Drifting sand trapped in this litter collects in small mounds or foredunes. Beach straw buried in shallow sand slowly decomposes, thereby satisfying three factors which normally limit the initial colonization of dunes (Ranwell, 1972):

1) development of soil nutrients;
2) stabilization of substrate;
3) retention of soil moisture.

A variety of salt resistant plant species (_Panicum distichum_, _Distichlis spicata_, _Sesuvium portulocastrum_, for example) rapidly colonize the new habitat. Their presence traps more sand and stimulates further dune growth.

d) Primary dunes:

Given sufficient time (perhaps two years), foredunes develop into primary dunes, gaining a half dozen feet of elevation and acquiring a dense cover of sea oats (_Uniola paniculata_) or panic grass (_Panicum amarum_). Plants inhabiting the primary dunes exhibit strategies necessary for survival in a rapidly accreting dune. As parent plants are buried, adventitious roots develop and rhizomes are induced to upward rather than lateral growth (Ranwell, 1972).

e) Secondary dunes:

Given even more time, there is a gradual shift from grasses to shrubs (_Myrica cerifera_, _Yucca sp._) and eventually to trees (_Quercus virginiana_, _Pinus elliotti_, _Bumelia tenax_, _Xanthoxylum clava-herculis_). At some point the successional development of the secondary dune becomes a forest community.

If a high-energy beach is in equilibrium and relatively protected from storm waves, a primary dune system can persist directly behind the berm. Typical primary dune vegetation is not only resistant to heavy concentrations of wind-borne salt but, in the case of sea oats, even requires it (Woodhouse, *et al.*, 1968). A forested secondary dune, on the other hand, usually needs several protective tiers of primary dunes to separate it from excessive salt burn. Slash pine (*Pinus elliotti*) is a transient member of the secondary dune community, quick to colonize and quick to succumb to the occasional heavy storm with its salt-laden winds. When forested secondary dunes are found just behind the berm of a high-energy beach, the shoreline is probably receding rapidly. On the other hand, a low-energy river beach is usually forested to the high-water line.

f) *Strategy of Dune Nutrient Cycling*

The shift from a nutrient-rich foredune habitat to a nutrient-deficient primary dune must present serious nutritional problems for the inhabitants of the open dune community (Art, *et al.*, 1973; Ranwell, 1974), particularly nitrogen which is not available in airborne salt. Studies have shown that the area surrounding the roots of beach grass (*Amophila*) is rich with bacteria relative to the surrounding area. Experimental plants with sterilized roots grew less than controls with normal bacterial flora present. There is also a close spatial relationship between the roots of beach grass (*Amophila*) and mycorrhizal fungi. Both of these strategies help to provide limiting nutrients to the community.

g) Dune Diversity

The diversity of flora within the dune community is high (Ranwell, 1972) for several reasons:

a) nutrients are low, thereby reducing growth rates and competition for space;

b) there is a diversity of habitats, augmented by salt gradients and moisture gradients;

c) there is plenty of available sunlight.

The rate at which woody species naturally colonize a secondary dune community is determined in large part by browsing mammals. Rabbits on British dunes can cause a dramatic reduction in woody species (Ranwell, 1972). There are a number of indications that a similar phenomenon exist for the Georgia coastal islands:

a) deer (*Odocoileus virginianus*) and rabbits (*Sylvilagus palustris*) are common in the dune community;

b) a noticeable browse line may be observed for palatable woody species (*Quercus*, *Bumelia*, *Persea*);

c) there are extensive open areas of uncolonized secondary dunes capable otherwise of supporting woody species;

d) Palatable seedlings are rare to absent, while unpalatable seedlings (*Pinus*, *Myrica*) are present.

This last point indicates that natural colonization by palatable woody species will occur when browser populations are reduced to very low densities or eliminated for periods long enough to allow plants to grow up above the browse line. The fact that mature specimens of palatable trees are found on secondary dunes implies that browser populations have been sufficiently reduced in the past.

h) Ecology of Dune Fauna

A number of visiting species utilize the dunes for feeding and resting, but probably do not require the dunes for survival. In this category are all species of coastal island mammals as well as a variety of wintering birds which utilize the dune area for seeds (finches), prey (hawks) or cover.

Several Georgia birds nest within the dune community. The most critical of these is the gull-billed tern, an exceedingly scarce species which nests in small numbers on the backshore, frequently in association with the least tern (Burleigh, 1958). Other species include the black skimmer (berm), least tern (berm, backshore), Wilson's plover (foredunes), oyster-catcher (backshore, foredunes), and willet (foredune, primary dunes).

Skimmers and least terns have adopted a survival strategy of nesting on the berm, particularly on isolated islets. The advantages of reduced predation in such remote areas outweigh the losses incurred from storms and high waters. However, these colonial nesting species are highly vulnerable to unnatural disturbances, realizing a high mortality of eggs and young from excessive temperatures if adults are flushed from their nests during the day. Every precaution should be taken to locate these colonies and isolate them from unnecessary disturbances by man and feral animals.

Loggerhead turtles are another Georgia species which require natural dunes for successful reproduction (Johnson, et al., 1971; Caldwell, et al., 1959). Loggerheads seem to do best when nesting at the base of a well-developed primary dune ridge (Johnson, et al., 1971) which assures an optimum location for the eggs and the safe return of adult female and young to the water. Other natural conditions are not as favorable. Adults and young can become disoriented among broken primary dunes and perish. A truncated beach may recede before the eggs have time to hatch. A broad backshore with standing water will destroy nests (Ragotzkie, 1959). Nesting success under natural conditions is probably quite low but sufficient for survival of the species, since the loggerhead seems to be a long-lived, prolific breeder. Raccoons, sand crabs, and lethal beach conditions would normally take a considerable toll of eggs, but the occasional year with low predator densities and optimum beach conditions would be sufficient for the survival of the species. Additional pressures, such as predation by man and feral animals, disruptive lights on the beach at night, or the complete loss of a natural dune profile by sediment stabilizing structures, produce more disturbance than the species can tolerate. The loggerhead is all but gone from those Georgia island beaches with a history of development and turtle egg harvesting

The disruption of the dune community by feral animals seems to be a widespread phenomenon (Chabreck, 1968; Cottam, 1970;

Johnson, *et al*., 1971; Ranwell, 1972), although few scientific studies have been done to document the precise effects. Cattle and horses do compete with native browsers, selecting palatable plant species and affecting a shift in the community structure. On the primary dunes, feral animals remove critical vegetative cover needed to stabilize the dunes. The effect of pigs on nesting loggerhead turtles is disastrous (Johnson, *et al*., 1971). The dune community has developed in the absence of man's feral animals and, therefore, can not respond in a controlled manner. Feral animals should be prohibited from the dune community. At present, domestic stock affect the dune communities on Cumberland, Ossabaw, St. Catherines, and Little St. Simons Island.

3. Island Forests

The island forest has been described as a live oak-dominated association with an abundance of sclerophyllous (leather-leaved) broad-leaf evergreens, lianas, epiphytes, and relatively few herbaceous plant (Johnson, *et al*., 1971). Because of differences in environmental conditions, minor species are frequently dominant in localized areas. For example, palmetto (*Serenoa repens*) is a dominant understory species on Holocene formations. An oak-scrub association is recognized for Cumberland Island, and a palm forest (*Sabal palmetto*) is a local feature on St. Catherines Island.

Very little information is available for the maritime forests of Georgia coastal islands (Johnson, *et al*, 1971). Unpublished floral lists exist for a number of islands. Forest associations have been mapped for Cumberland (Hillestad, _et al._, 1975), Little Cumberland (Worthington, 1973), and St. Catherines Island (McCormick, _et al._, 1972). Studies dealing with functional aspects of island forests (succession, climax, response of island forests to physical factors, etc.) are generally lacking and must be borrowed from work done in other coastal areas.

Theories for the existence of a live oak climax on Georgia coastal islands (Johnson, _et al._, 1971) consider the modifying effects of wind, salt, soils, fire (Laessle and Monk, 1961) and the longevity of live oaks, but no single factor seems to dominate. William Bartram on a visit to St. Catherines Island in 1773, described the terrain as a series of forested "ridges and savannahs, [the intermediate spaces being] intersected with plains of dwarf prickly fan-leaved palmetto [_Serenoa repens_] and lawns of grass variegated with stately trees of the great Broom-pine, and the spreading ever-green Water-oak..." (Van Doren, 1955). Bartram has given us a plausible description of a fire-dominated mosaic of burned (grasses, oaks, and large pines) and unburned (scattered clumps of heath (_Vaccinium_) and palmetto) habitat (Clement, 1971).

The historical effects of man on the ecology of coastal island forest must not be overlooked. The islands as we know them today could well be the result of management practices employed centuries ago. There is abundant evidence for the presence of Indians (4000 BP to present) and many of the island were under cultivation from 1733 to 1860 (Clement, 1971). Fire, cultivation practices, and the presence of range animals have all affected the coastal islands in one way or another. At this moment, a precise chronical of historical events and practices for each island would be a valuable aid to our understanding of island ecology.

Unique Forest Associations

There exist a number of unique forest associations for the coastal islands. Some examples, familiar to the authors, will illustrate this point.

a) Associations which are rare or unique to Coastal Georgia:

1) several hundred acres of myrtle oak (*Quercus myrtifolia*) on Little Cumberland Island appear to be an unusually large size for this rare association. (Wilbur Duncan, *pers. comm.*)

2) Carolina laurel-cherry (*Lycium carolinianum*), growing on a tiny island in the Cumberland salt marsh, is presently the only known specimen for the state as well as the most northerly representative of the species.

3) Florida privet (*Forrestiera porulosa*), growing on a narrow shell bar near Little Cumberland Island and on the south end of Cumberland represents examples of this little known species in the state.

b) Associations common to the mainland, but rare on the coastal islands:

1) Tupelo swamp (*Nyssa biflora*) occurs as small stands

in wet drainage areas. Large trees and swampy terrain make these areas valuable for aesthetic appeal and environment interpretation.

2) A nearly homogeneous palm forest on St. Catherines Island is unusual for a coastal island, but may be found on the mainland.

There is a great need to define and catalog the unique forest associations on the Georgia coastal islands. The total area of an individual association can be less than an acre in extent. Small parcels of the environment are particularly vulnerable to residential development, roads, and powerline rights-of-way. Unique forest associations are part of the diversity of coastal islands. Development plans must consider these areas if only because the associations are there and are part of the island ecosystem. Vegetation maps must recognize these small associations.

If proper protection is afforded unusual forest associations, island forests can be ecologically tolerant of controlled human use (Clement, 1971). Clearings in the oak forest, sufficiently distant from the zone of airborne salt, should not adversely affect the forest community. Deer, turkey, and resident song birds would probably benefit from clearings in the forest (lawns, fairways, and grassy rights-of-way) as long as forested buffer zones are interspersed with the clearings. Deer and turkey are edge species, finding optimum food and shelter along transitional environments.

4. Island-Marsh Interface

One of the most interesting communities of the Georgia coastal islands is the island-marsh interface. A unique soil series has developed with it (Wilkes, *et al.*, 1974) because spring tides flood low-lying sand soil with suspended clay and silt. The community consists of a gradual continuum of subcommunities between terrestrial forests and salt marsh. As such, the community represents a zone of gradual change at the marine-terrestrial interface. A number of marine organisms (crabs) and terrestrial organisms (birds, mammals, reptiles, insects) are able to cross such a gradual boundary and have acquired the ability to utilize resources from both marine and terrestrial habitats.

The island-marsh interface is a dramatic example of plant zonation. The critical factor is elevation, affecting frequency and duration of tidal flooding, evaporation rates, soil texture, salinities and temperature. The island-marsh interface community provides a fascinating opportunity for studying the ecology of limiting factors and plant distribution. For instance, the upper extent to which cord grass (*Spartina alterniflora*) can grow in the interface community seems to be limited by an iron deficiency. Salt grass (*Distichlis spicata*) and black rush (*Juncus roemerianus*) are not limited by iron, grow higher in the community, and are ultimately limited by other factors (Adams, 1963).

Values and Vulnerabilities of Island Communities

1. The high-enery beach community is naturally resistant to the physical pounding of surf. Such a community will also be unaffected by a similar impact of heavy pedestrian traffic. The beach is intolerant to chemical disturbance, however, and would be expected to react adversely to chemical pollution.

2. Low-energy beaches are high in organic sediments, high in diversity and abundance of beach fauna, but low in desirability as a recreational beach. These beaches should receive priority as wildlife habitat.

3. Dune communities are resistant to salt and wind but not to the disturbing effects of pedestrian traffic on vegetative cover.

4. The colonization of secondary dunes by woody plants is affected by browsing mammals. The exclusion of deer and rabbits from secondary dunes would be expected to stimulate colonization by oaks and other palatable tree species.

5. Colonial nesting birds are particularly vulnerable to human disturbance. Successful colonies will be those which are protected by a wide buffer zone.

6. Dunes and beaches are dynamic systems which cannot be stabilized without loss of the community. Nesting habitat for loggerhead turtles and sea birds has been lost on islands with stabilized beaches.

7. The forest community seems to be resistant to the impact of low-density residential housing and many forms of outdoor recreation.

Summary

One very important theme occurs throughout this paper: The understanding of coastal terrestrial ecology depends on an awareness of differences (Table 3-2); differences in physical conditions, differences in community response, differences in survival strategy. Coastal island differ from the mainland. Holocene islands differ from Pleistocene islands. To a lesser extent, one Pleistocene island will differ from another.

The adjacent mainland, the Pleistocene island, and the Holocene island represent an environmental continuum from old and mature to young and rigorous. "Old", "young", "mature", and "rigorous" are relative terms which derive from the predominant geological age of the formation being considered. Added to the geological effect is the rather abstract concept of insularity and the tendency for the unit land mass to decrease in size from mainland to Pleistocene island and from Pleistocene island to Holocene island. Both insularity and decreasing size add to the ecological rigorousness of the enrivonment.

Items 1 through 4 (Table 3-2) represent physical characteristics of the system which are primarily regulated by the geology and climate of the coast. These factors intensify along the physical gradient from mainland to Holocene island. The predictability of available water and fluctuations in the water table are physical characteristics which are related to volume and texture of the subsoil, rainfall, and drainage. Similarly, the diversity and maturity of soils relates to the manner in which the subsoil layers were depositied and the age of the deposits.

The concept of an abiotic continuum, varying from "receptive" (mainland) to "resistent" (Holocene island), refers to the facility with which the biotic community can adjust to the physical environment. It is on this abiotic continuum that the community response is superimposed.

Item 6 is a descriptive fact, while items 7 through 11 are functional responses of the community to the abiotic environment, including vulnerability to damaging fires, stability of nutrient cycles, impact of insularity, response of animal populations to changes in the community. In all of these examples, a community will respond according to its location on the continuum. In other words, Holocene communities would be expected to react most violently and be most damaged by unnatural disturbances in the environment, while Pleistocene communities will be damaged to a lesser degree, and mainland communities least of all.

Differences between Pleistocene islands or between Holocene islands tend to be descriptive and not functional. A prograding beach on Blackbeard Island may look strikingly different from a receding beach on Wassaw Island, and the species composition of the two communities may be very different. The manner in which

Table 3-2

Physical Factors and Functional Responses of Selected Coastal Communities

	FACTOR	ADJACENT MAINLAND	PLEISTOCENE ISLANDS WITH HOLOCENE DEPOSITS	HOLOCENE ISLANDS
1.	Predictability of available groundwater	HIGH ◄	------------	► LOW
2.	Oscillations in the water table	MODERATE ◄	------------	► EXTREME
3.	Diversity of soils	HIGH ◄	------------	► LOW
4.	Maturity of soils	OLD ◄	------------	► YOUNG
5.	Abiotic conditions	RECEPTIVE TO BIOTIC DEVELOPMENT ◄	------------	► RESISTENT TO BIOTIC DEVELOPMENT
6.	Vulnerability to damaging fires	LESS ◄	------------	► MORE
7.	Stability of nutrient cycles	HIGH ◄	------------	► LOW
8.	Impact of insularity	NONE ◄	------------	► SEVERE
9.	Species diversity of flora & fauna	HIGH ◄	------------	► LOW
10.	Response of animal populations to changes in the community	MODERATE ◄	------------	► SEVERE
11.	Probability of irreversible changes to the community	LOW ◄	------------	► HIGH

the two communities respond, however, to the physical changes in the beaches should be functionally similar. We should be able to predict the community response of one island based on our knowledge of the other island, in spite of initial differences in the species composition of the two islands. We should also predict that descriptive differences could disappear if physical conditions between the two islands become similar.

Given this overview of the functional aspects of island ecology, however cursory or incomplete, we are in a position to improve our understanding of the ecology of Georgia barrier islands. A number of suggestions can be made:

1. An inventory of natural resources:

The application of ecological principles to specific island conditions requires facts. A comprehensive analysis of Georgia island ecology will require more data than is presently available. There is a need for additional soil maps, nutrient maps, vegetation maps, a catalog of forest associations, faunal descriptions, and measurements of the intensity and duration of a number of physical forces acting on the community. An historical review of man's activities on the coastal islands would be an important part of this inventory.

2. Sample size:

One very important project is to determine the minimal portion of the ecosystem needed to describe an environmental attribute. For example, the description of nutrient cycling on twenty linear feet of primary dune ridge may provide all the information needed to extrapolate to the remainder of the primary dune system. The study of a deer population would require as the minimal study unit an area equal to the size of the island. Some highly mobile species may have to be considered at the coastal ecosystem level. In preparing maps, the scale of resolution of the map must be adequate to represent the minimal unit of the subject being studied.

3. <u>Develop functional understanding</u>:

An improved data base would provide needed information for increasing our understanding of basic ecological functions on Georgia coastal islands. Some of the strategies discussed in this paper are conceived for communities quite different from the Georgia coastal islands. The predictive value of these strategies is limited by the lack of substantiating studies and local data from the Georgia coast.

4. <u>Update ecological surveys</u>:

As the understanding of Georgia island ecology develops, evaluations such as this report should be continuously re-examined and refocused on critical issues. This, in turn, would initiate a form of positive feedback for defining further ecological studies.

5. <u>Predictive models</u>:

A major step in environmental analysis of the Georgia islands would be the development of predictive models. Models require a rigorous understanding of community function as well as a complete resource inventory. Predictive models would permit a better understanding of old questions. For instance: How much disturbance should an island be allowed to absorb before disturbances reach damaging levels? How natural are the coastal islands? How changed are they by the effects of man, historically and at the present?

6. Management guidelines:

Answers to questions like the above provide a strong platform for establishing management procedures. Ultimately, ecological priorities can be integrated into all levels of the coastal land use plan.

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CHAPTER 4

the Value and Vulnerability of Fresh Water Ecosystems

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Introduction

The major sources of fresh water in the coastal counties of Georgia are five river systems; the Savannah, the Ogeechee, the Altamaha, the Satilla and the St. Marys. Other fresh waters include small streams arising in the coastal counties, direct precipitation and ground water. This report is primarily concerned with the major river systems, since these are ecologically most important in the area. These rivers fall into two types; those that rise in the coastal plain and those that rise in the piedmont. The former, which include the St. Marys and Satilla, are blackwater streams which are acidic and contain large amounts of humic acids and other dissolved organic matter, and are very low in other dissolved and soluble solids. The other rivers, which derive at least part of their flow from the piedmont, tend to be higher in dissolved solids, and are better buffered, thus much less acid. All, however, flow through extensive swampy areas and tend to be high in organic matter. Although these streams differ in some respects, they share many characteristics, and the values and vulnerabilities of their ecosystems are common to all.

Some of the values of fresh water ecosystems are clear and economically obvious while others are more subtle and are difficult to evaluate in terms that are clear to laymen. Some of these values are directly assessible in terms of the fresh water ecosystems, while others may be assessed only by indirect effects on other systems. Direct values include human uses of water such as domestic, agricultural and industrial consumption, as well as recreational, aesthetic and educational values. Included in the latter group are the production of fish and wildlife; the production of aquatic plants and invertebrates, which serve as food for fish and other animals; boating, including floating and canoeing; and the uses of the river for research, teaching and other educational needs. Less obvious, but at least equally important, is the function of the fresh water ecosystems in purifying and reaerating waters which have been subjected to human use and contamination. Indirect values include the effect of the rivers on the surrounding water tables, and the effects which occur at the fresh water - salt water interface in coastal estuaries. The latter include the transport of sand and nutrients by the rivers, and the flushing action of high fresh water flows on the estuarine systems. Not only total flows, but the regime, or periodicity and pattern of flow, appear to be important in this respect.

All of these values are vulnerable to disturbances brought about by natural changes or by the unwise or poorly planned activities of man. The major human disturbances, all of which have already occurred to some extent or other in coastal streams, include pollution from agricultural, domestic and industrial sources, cutting of river swamps and flood plain forests, damming, and channelization of the streams. Further disturbances of these types must be kept to a minimum, and, where further disturbance is absolutely necessary, the burden of proof should be placed upon those advocating disturbance. Coastal Georgia is fortunate in having abundant and, as yet, relatively clean and unpolluted sources of fresh water. To permit the profligate destruction of this source would be a tragedy.

Direct Values: Stream Channels

The channels of the major streams are important sources of water for domestic, supply, industry and agriculture, including waste disposal. These channels and the ecosystems which they support also provide important recreational, aesthetic, and educational values. In spite of their obvious and growing importance, or perhaps partially because of it, these stream channel ecosystems are especially vulnerable to disturbance. Those uses of water which create major disturbances, such as pollution, the construction of dams, and channelization, are primarily concentrated in the stream channels, although these disturbances inevitably affect the flood plain and river swamp ecosystems to an equal or greater extent. Ecological destruction is thus likely to be greatest upon this part of the system which is most used and appreciated by the human population.

Sport fishing is a pastime which is enjoyed by hundreds of thousands of Georgians and many visitors to the State every year. The economic value of sport fishing, which supports a multi-million dollar industry, is clear, and the value to the participants in terms of recreation and aesthetics may be even more important. Georgia's coastal rivers support many species of sport fishes, both resident fresh water species and anadromous species which enter brackish or fresh waters to spawn (Dahlberg and Scott, 1971). The relative importance of the marine, fresh water and anadromous species in the catch of residents and visitors in the coastal counties is not entirely clear, but the concentration of fishermen along the stream channels is certainly significant. Fresh water residents which are important sport fish include pickerel, several species of catfish, several sunfishes, crappie and, the most sought after of Georgia fresh water fishes, large mouth bass. These fishes live and feed in the river channels, and many spawn there as well. In addition, there are many smaller forage fish which also live in the rivers, and which are important as food for the larger game species (Dahlberg and Scott, 1971). Several species of salt water fishes enter the river channels to spawn, and some of these anadromous forms are important in sport and commercial fisheries (Carley and Frisbie; Smith, 1968). Striped bass are an especially important sport fish, and American shad and hickory shad are seasonally important as sport and commercial fishes. In addition, the blueback herring may be of some importance commercially.

In addition to the true anadromous fishes, many salt water species penetrate the river mouths to a greater or lesser distance to feed. These include red drum, spot, mullet, southern flounder, hogchoker, spotted trout, pipefish, and needle fish (Dahlberg and Scott, 1971; Georgia Game and Fish Commission, 1968). There are probably other species which penetrate into the river channels at some time or other, as well as many which depend upon the brackish waters maintained by fresh water flows.

It is clear that disruption of the habitat adversely influences the movement and production of fishes in streams. The placements of dams, or other structures which act as barriers to fish migration can disrupt the life cycles of fishes, increase mortality rates and destroy the clues and signals which fishes depend upon to guide them in their movements (Northcote, 1967). It is also clear that channelization of streams reduces cover and habitat diversity, and thus results in decimation of fish populations (Bayless and Smith, 1965; Wharton, 1970). In addition, stream channels which have been channelized and straightened tend to resume their former meandering, thus increasing bank erosion and siltation, and further degrading the fish habitat (Russell, 1967; Leopold, et al., 1964). Fish are remarkable resilient creatures, and so the fisheries are seldom completely destroyed, but serious degradation may take place with even relatively minor disturbance.

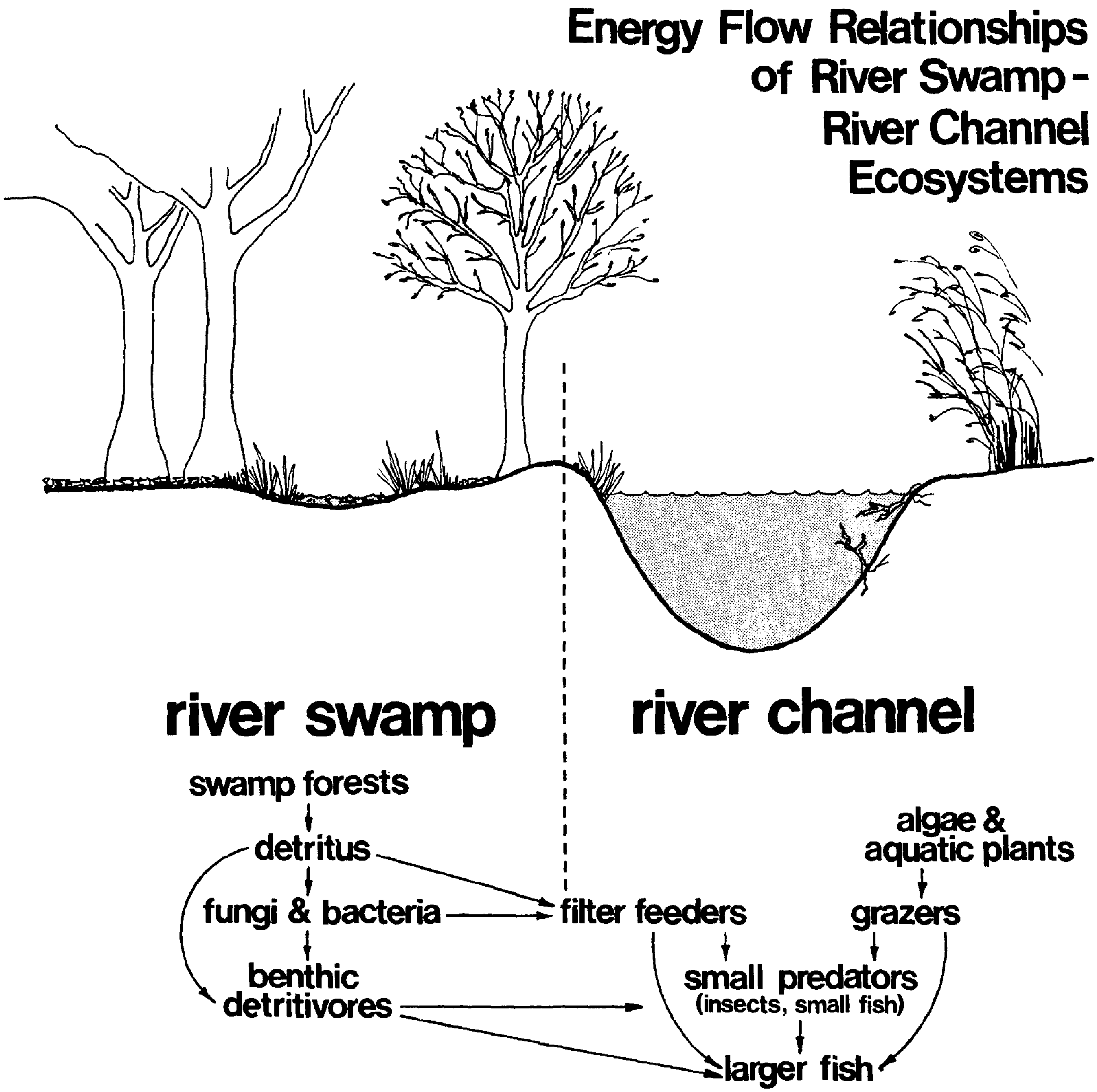
In addition to the fish populations themselves, the stream channel ecosystem of which they are a part includes a great variety of other organisms which interact to form a dynamic stream channel community. This community forms the ultimate biological basis for the production of game and non-game fish species (Gerking, 1967; Hynes, 1970). The important organisms in such communities may include bacteria, many species of algae, higher aquatic plants, a large and diverse insect fauna, fresh water snails and mussels, and numerous other aquatic invertebrates. These inconspicuous, but nonetheless important species may be more vulnerable to pollution and other disturbance than the fishes themselves (Gaufin, 1973). Any change in the aquatic environment results in a corresponding change in the communities of aquatic organisms, and these changes are inevitably transmitted through the food chain to the fish populations. Thus, a degree of disturbance which may seem minor will nevertheless result in a change in numbers and kinds of aquatic organisms. The result of a small disturbance may not be immediately obvious from our point of view, but is nonetheless real, and the cumulative effect of many small disturbances is ultimately expressed as a major change in the populations of fishes and other aquatic organisms. It is important that we be aware of such changes, and that we develop methods of assessing them and determining whether they are of such significance as to negate the beneficial effects of "improvements" which are being imposed upon the stream channel. The flow of energy through the river swamp is schematically shown on Figure 4-1.

It has been suggested that blackwater streams are extremely unproductive (Janzen, 1974), but this does not seem to be the case in the blackwater streams of Georgia. The preliminary results of research now being pursued by Dr. A. C. Benke and me in the Satilla River, as well as a survey by the Environmental Protection Division, Georgia Department of Natural Resources (1973), indicate that the opposite may be true. The Satilla appears to support a fairly good fishery, as established by State Game and Fish Division research (Sandow, et al., 1973; 1974), and the basis for this lies in vast numbers of tiny filter-feeding insects and crustaceans which trap bacteria and detritus carried by the stream. These tiny filter-feeders are fed upon by predacious insects and small fish, and these in their turn are consumed by large fish. Dead trees and branches, which are numerous in undisturbed stream channels, form a major habitat for both filter-feeding and predacious species. These "snags" are often covered with thousands of small vertebrate animals. It is probable that 2/3 - 3/4 of the biomass of stream invertebrates is to be found on dead snags. The ultimate source of energy for this aquatic community appears to be the river swamps which line the banks of much of the Satilla River. Such small filter-feeders are probably of great importance in other streams as well, and in addition to providing food for larger organisms, they are of great significance in the natural purification of waters which have been polluted. The living part of the ecosystem is necessarily an important factor in the use of running water for waste disposal, since pollutants added to water must be broken down by bacteria, and these bacteria, along with remaining detritus, are removed and consumed primarily by small filter-feeding insects and other arthropods (Hynes, 1960, 1970). The maintenance of a rich and diverse community of aquatic invertebrates is thus of great significance to both the productivity of streams and to their ability to absorb and metabolize pollutants.

Other forms of wildlife are also supported by Georgia's coastal rivers. Species such as deer, raccoon, squirrels and many others may derive direct or indirect benefit from the stream channels. Many aquatic birds are directly dependent upon the stream ecosystem for support, including huntable wild fowl as well as many non-game species. Bird watching, or "birding", while not as popular in Georgia as hunting and fishing, is a pastime enjoyed by a large and growing segment of the population. This and other forms of nature study comprise an increasingly important recreational use of our rivers. Such non-destructive use of resources should be encouraged and the increased tendency to introduce grade school, high school and college students to nature study in a more or less formal context will certainly have this effect. The coastal rivers used in this way, are thus an educational resource that can produce profound effects extending far beyond their banks. A few hours spent collecting and studying the living ecosystems of a clear flowing river is an experience that a student may remember for the rest of his life. Perhaps equally important is the use of our rivers as a resource for research. Information gained from study of Georgia's coastal river systems can be extrapolated and extended to apply to other streams and other types of ecosystems, and, perhaps even more significantly, graduate students who receive their research training in the course of such investigations are able to enter society as teachers and scientists and apply the knowledge gained in a broad variety of fields.

The sport of canoeing down rivers is usually associated with the upland streams of northern Georgia, but the coastal rivers also offer many opportunities for this sport. Although they lack the spectacular rapids and falls of the north Georgia streams, they are, in their own way, equally beautiful and fascinating. Drifting gently between banks lined alternately with upland trees and swamp forests, with occasional stretches

Figure 4-1



* Not to scale.

Source: Dr. D. Gillespie, Georgia Institute of Technology.

of somewhat swifter water and occasional detours into swampy backwaters among cypress trees, can be a rich and fascinating experience. The swift excitement of the mountain streams is more than compensated for by the increased opportunities to relax and watch the abundant wildlife along the shores. Some effort has been made to promote canoeing as a sport, particularly on the Satilla River. Efforts include the report by Hanie and Hay (1969) and a set of detailed maps of the river between Waycross and Woodbine. Other coastal streams may be equally attractive, and should see increased utilization in the future if their aesthetic value is not destroyed by other practices.

Direct Values: River Swamps

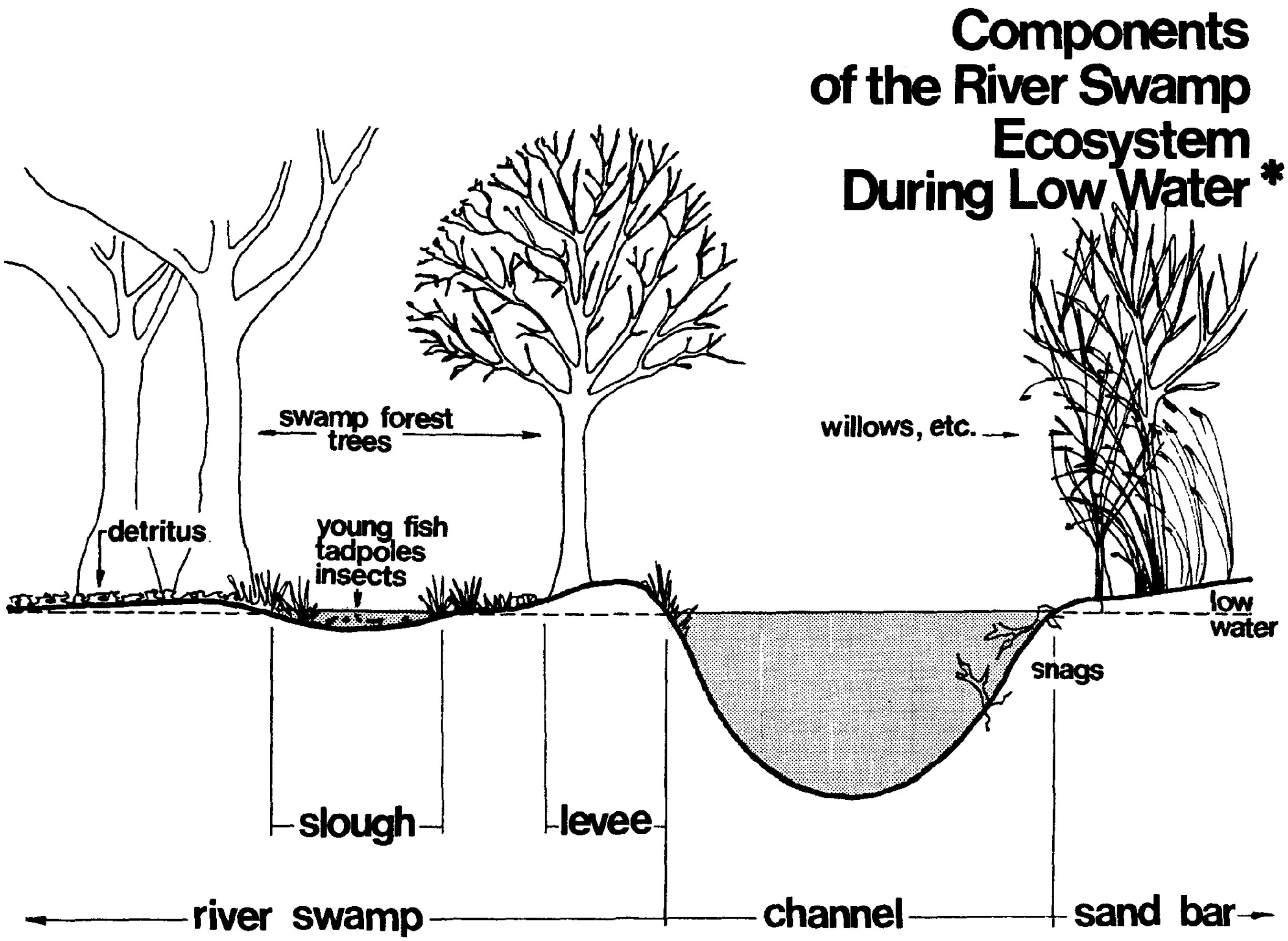
The separation of the flood plains and river swamps from the stream channel is an artificial one, justifiable only as a convenience. They are in reality inseparable, and disturbances which affect one inevitably affect the other. There are, however, many values which can be attributed to the river swamp-flood plain part of the system, as has been ably pointed out by Wharton (1970).

Although swamps have been traditionally regarded by man as unhealthy and unattractive, there is an increasing appreciation of the aesthetic value of river swamps and more extensive swampy areas as well. The swamp as a place of beauty, and as the home of an abundant variety of wild animals and plants, is increasingly appreciated by an urban population disgusted with pavement and smog. On the other hand, there is still plenty of pressure to drain and develop swampland and other flood plain areas for housing and industrial sites and agriculture. Quite apart from the inconvenience of having these developments damaged or even destroyed by floods every few years, such projects are usually ecologically disastrous.

In many streams the major energy source for the ecosystem is allochthonous organic matter, or organic matter produced beyond the immediate confines of the stream, and the coastal river systems are no exception to this (Cummins, 1973). The river swamps are perhaps the most important single source of energy for the aquatic ecosystem. This energy enters the streams in the form of leaves, bark and other particulate matter and as dissolved and colloidal organic matter. This organic detritus accumulates on the forest floor during low water and is picked up and swept into the main channel during floods. It is to some extent replaced by nutrient-rich silt, deposited when swift channel waters, laden with sediment, overflow the banks and drop much of their suspended load as they flow more slowly over the flood plain. The detritus is attacked and broken down by aquatic bacteria and fungi, either on the flood plains or in the river channel. Bacteria, fungi and detritus are in turn consumed by aquatic insects and other invertebrates, either on the bottom or after being filtered from the moving water. These invertebrates are then fed upon by larger animals, as mentioned above (see Figure 4-1). The system is vulnerable to any interference with this detrital food chain and to any interruption of the regular ebb and flow of flood waters. The components of the river swamp ecosystem during low water and during flooding are schematically shown on Figures 4-2 and 4-3.

River swamps and small lakes or sloughs which they often contain can also be productive in other ways. River swamp lakes, trapped when the water goes down, often develop a rich flora and fauna of their own and may supply plankton and other organisms to the river when connected to the main stream during high water (Hynes, 1970). Such lakes and sloughs may also be of great importance as nursery and spawning grounds for many river fishes, and without the periodic flooding, isolation and reflooding of such sites, these species disappear from the streams. There are many species of both fish and invertebrates which are more or less confined to swamps and backwaters and which are eliminated by draining and channelization (Gilbert, 1969; Hynes, 1970). For the river ecosystem, the river swamp is thus an integral part, serving as habitat for some organisms, spawning and nursery grounds for others, and a major food source for all. It is nonsense, therefore, to speak of draining and filling the swamp while preserving the beauty and other values of the river. A stream channel may be preserved, perhaps even with some values retained, but the river ecosystem will have been destroyed.

Figure 4-2

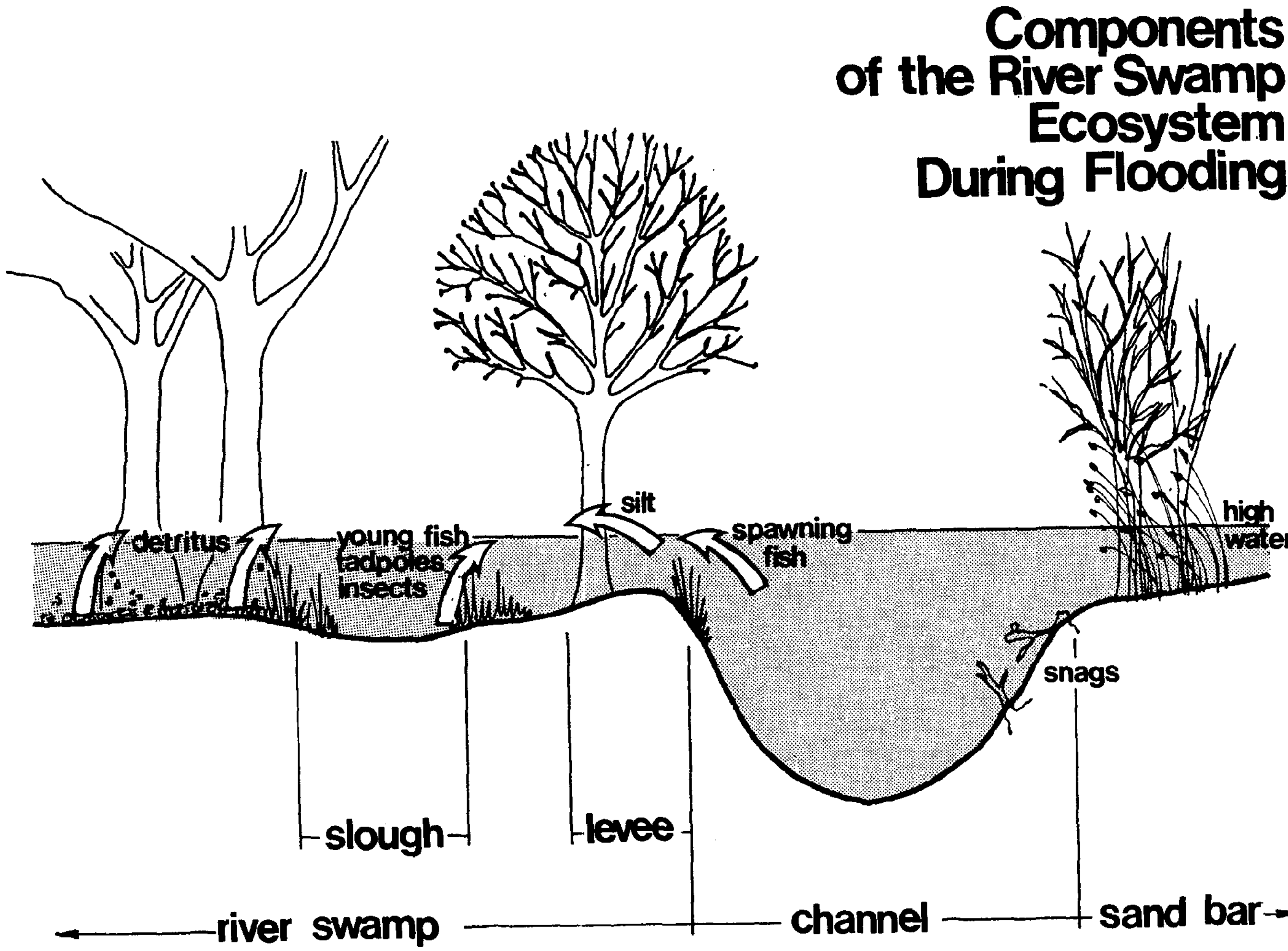


Organic matter accumulates on the forest floor where it is decomposed by bacteria and fungi. Young fish, tadpoles, insects and other organisms mature in sloughs and ponds, which are like protected "nursery" areas. Willows and other vegetation help to stabilize the sand bar. Snags, composed of dead trees and branches, help stabilize the channel and provide a habitat for many small animals.

* Not to scale.

Source: Dr. D. Gillespie, Georgia Institute of Technology.

Figure 4-3



During periods of flooding, the detritus (bacteria, fungi and decomposed organic matter) is washed out of the swamp into the river channel. It is partially replaced by silt from the river. Fish move into the sloughs to spawn in protected waters. Young fish and other animals swim or are washed into the main channel.

* Not to scale.

Source: Dr. D. Gillespie, Georgia Institute of Technology.

Indirect Values

The major indirect values of the fresh water systems of coastal Georgia include those effects which occur at the fresh water-salt water interface in estuaries, involving transport of water, nutrients and other material, and effects on the water tables surrounding the coastal rivers. Estuarine systems are strongly affected by the inflow of water and the dissolved and particulate matter carried with it and also by the periodicity of such inflow. The substrata of the coastal area of Georgia are generally rather porous and as a result the fresh water levels in rivers and swamps may have a significant effect on level and flow of ground water.

Brackish estuarine waters are of great importance as spawning and nursery grounds for many species of marine fish and invertebrates and they are also important as feeding grounds for adults of many species (Remane and Schleiper, 1971). Several species are of major economic importance in coastal Georgia (Carley and Frisbie, 1968). These include blue crabs, oysters, shrimp and several important species of fish. In addition, these estuaries support a great variety of planktonic plants and animals upon which the larger economically important species depend for sustenance. This estuarine ecosystem depends upon a regular, but periodically varying, supply of fresh water from the coastal rivers, and any disturbance of the river system is likely to affect the amount, periodicity and quality of this fresh water supply. Past disturbance has already been felt, both economically and ecologically. Oysters for instance, which were formerly abundant all along the Georgia coast, have been greatly reduced in recent years as a result of pollution, unstable substrate, fouling and other factors (Carley and Frisbie, 1968). There is evidence that other species, including anadromous fishes, have also been adversely affected (Smith, 1968; Adams, 1970). Various distrubances of the fresh water rivers are responsible for these changes. Chemical pollution has adversely affected many species of aquatic animals and plants; changes of land use in watersheds, including deforestation and filling of river swamps, have affected sediment transport and a variety of stream biota; and damming and channelization have affected stream flow regimes, sediment transport and movements of fishes and invertebrates. Further disturbances along these lines can be confidently expected to have additional adverse effects on the coastal ecosystem.

Fresh water rivers are the ultimate source of mineral nutrients for coastal and near shore marine ecosystems although, in general, they do not necessarily provide for the immediate "fertilizer" needs of estuaries (Riley, 1967; Odum, 1971). Estuaries tend to concentrate nutrients and organic matter and to export organic and inorganic nutrients to the waters further offshore. The flushing action of fresh waters flowing through the estuaries, thus fertilizing offshore systems, may be more important than the direct input of nutrients. The near shore accumulation of nutrients, or eutrophication, has become a serious problem in some areas (Ryther and Dunstan, 1971). Both the small but growing input of nutrients from the fresh waters, and their flushing action in moving accumulated nutrients out to sea are thus of great importance.

A factor which has not received enough attention from biologists and engineers is the periodic nature of fresh water flows. Streams vary greatly in discharge during the course of a year, so that a very high percentage of total water and sediment transport may occur within a very short time. There are also variations in flow from year to year, and the time of peak flows is also variable. It is generally assumed in engineering circles that a reduction in this periodicity is beneficial, and this is often incorporated into the design of dams and other structures. While dams may reduce the magnitude of fluctuation in stream regime, channelization is more likely to increase it. A frequently seen pattern is the draining and channelizing of upstream areas, followed later by the construction of dams downstream to control the resulting increase in peak flooding. In Georgia's coastal river systems the river swamps tend to control and slow the downstream travel of flood peaks, reducing the amplitude of the flood stage and spreading it over a longer time. In at least two major river systems, the Altamaha and Savannah, dams have been constructed above the fall line which affect the stream regimes. The coastal ecosystems, both fresh water and salt water, have been adapting for millenia to these natural fluctuations. A major part, in some cases possibly all, of the flushing action of water flows through the coastal estuaries takes place during periods of high water. Reduction of peak flows may result in an accumulation of nutrients and an increase in the already serious eutrophication of estuarine ecosystems. It is reasonable to hypothesize that, in at least some areas, the increased fouling and oversettling which has helped destroy the once abundant oyster beds of the Georgia coast has been the result of decreased peak fresh water flows with their accompanying flushing action. The effects on coastal ecosystems of tampering with the flow of fresh waters is not well understood, and until a great deal of more information is available, additional modifications of this type should be approached cautiously and only after careful study. The life cycles of aquatic organisms involve periodic phenomena that may be closely dependent upon the periodicity of water flows, and these animals may be affected in unpredictable ways (Remane and Schlieper, 1971; Georgia Game and Fish Commission, 1968).

Vulnerabilities

The fresh water ecosystem is a dynamically balanced system maintained by the interactions of physical and chemical environment with the flora and fauna of the biological community. It is vulnerable to any changes which disrupt these interactions. It is, however, a resilient system and capable of resisting and recovering from disturbances.

Physical changes to which the system is vulnerable include those such as dams, channelization and watershed modification. Other physical vulnerabilities involve river swamp filling and dredging and increases in sediment loads in streams. Chemical factors which may be affected include nutrient inputs, changes in water chemistry, release of toxic chemicals, increases of organic load from domestic, agricultural and industrial sources, and, especially in the coastal area, salinity changes. Biological vulnerability may involve interruption of energy flows, as by destruction of swamp forests, disruption of detritus transport, or removal of important parts of the aquatic flora and fauna. There may also be interference with life-history phenomena, such as occur when species are denied access to breeding areas in streams or in ponds and sloughs, when migrations are interrupted, or when feeding grounds and essential cover are disturbed. The communities may also be disrupted by extermination of some species or by the unwise introduction of undesirable exotic species.

It is impossible to identify, with the present state of knowledge, the precise effects of a given level of disturbance. The ecosystem is complex, incorporates many time lags and compensation factors, and is, to some extent, unknown, at least in any quantitative way. Some research has been done or is now proceeding, but unanswered questions abound. The vast areas between the rivers, where swamp forest, fresh water marsh and salt marsh meet and intermingle, are virtually unknown. Even in the relatively well-studied estuaries many problems remain. Basic research is needed into water chemistry, life histories and distribution of organisms, response of populations to gradients of environmental variables, and interactions among populations of organisms in communities. Applied problems include the effects of changing rates and periodicity of water flow, biological effects of chemical changes, and ways of compensating for or correcting changes which have already occurred. The primary need for basic research, along with the development of applications to specific problems, should receive high priority in coastal Georgia.

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CHAPTER 5

a Summary of Ground Water Conditions Coastal Georgia

by

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Introduction

The coastal area of Georgia for many years has been studied by scientists interested in water resources. Probably the principle reason for this interest is the fact that the water of this region is so bountiful; it is also very complex. This is particularly true of ground water. In recent years, numerous studies have been devoted to problems which have developed as a result of the large ground water withdrawals by various industries along the coast.

The reports which have resulted from the various studies are listed in the last section of this report. In general, they are technical reports written for geologists or engineers. This report is an attempt to synthesize and generalize these previous reports so that a person not trained in geology might better understand a very complex subject. No original data was collected for this report.

Basic Concepts

If we examine a section of rock such as that shown in Figure 5-1, we see, that, near the land surface, the earth consists of a mixture of air, rock material and water. This is the zone of aeration. As deeper portions of the rock are examined, we find that gradually the water content increases. Eventually, the mixture no longer contains air but rather the rock material is

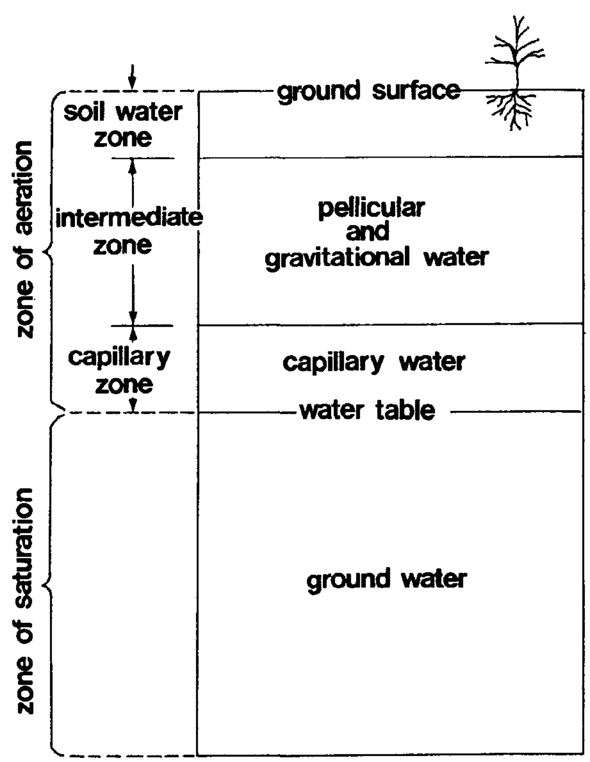


Figure 5-1. Distribution of water in a section of earth.

completely saturated with water. The transition line between the zone of aeration and the zone of water saturation is called the water table. All water below the water table is called ground water. The water above the water table may be called soil water.

The water table, as you might suspect, is in reality a gradational zone. Normally, the water table is a gently undulating surface which is often higher beneath hills and lower beneath valleys. During the periods of little rainfall, the water table falls with the greatest variation in the water table elevation beneath hills.

If we would follow the path of a rain drop as it infiltrates the earth, we would find that it might follow a number of different paths. One of the most important paths allows the water to migrate vertically downward through the zone of aeration under the influence of gravity. Eventually, the water droplet encounters the water table and becomes part of the ground water. The path that it now takes depends upon the point where the ground water is discharging. A simple example is shown in Figure 5-2. Notice that the ground water flows in large arcuate paths. If the point of discharge is distant, the paths will likely be less arcuate. A ground water discharge area can be any surface water body. A water well is also considered to be a ground water discharge point.

An aquifer is a subsurface material which has sufficient porosity and permeability such that it will yield ground water

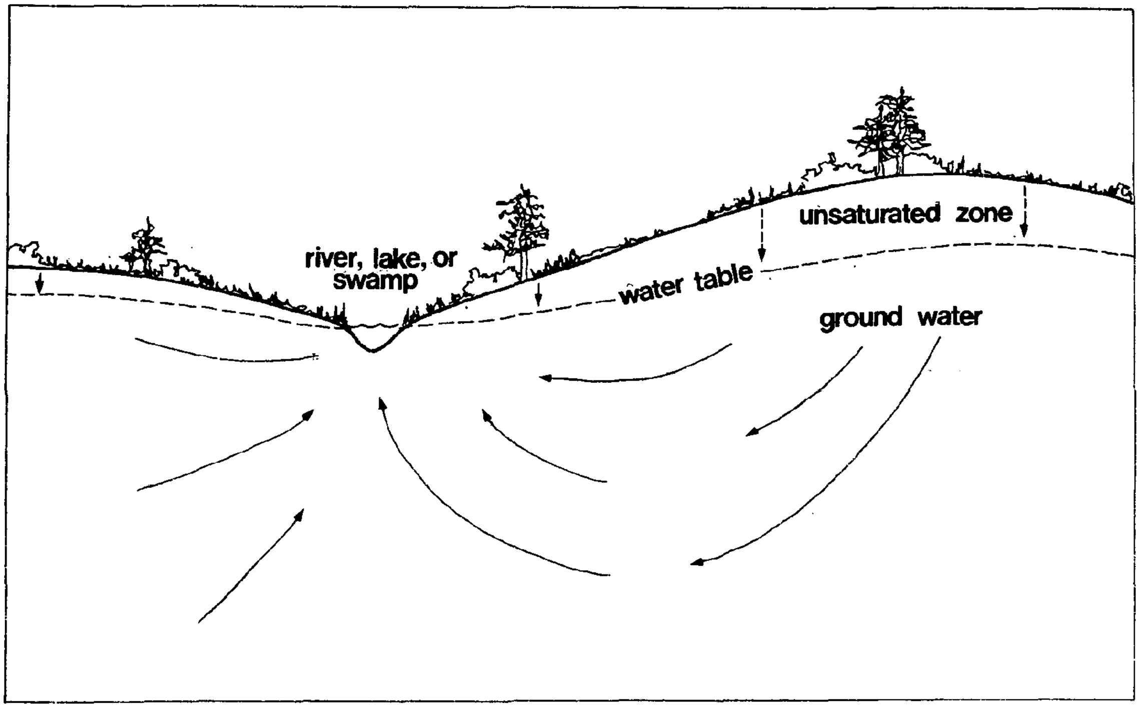


Figure 5-2. Generalized ground water flow in a water table aquifer.

to a water well. The ground water conditions described in the preceding paragraphs would apply to a water table aquifer. Under normal conditions a water table aquifer is an aquifer which is immediately overlain by a zone of aeration. The water level in a well penetrating a water table aquifer usually will not rise above the top of the aquifer.

Artesian aquifers are aquifers which contain water which is under pressure. The requirements of an artesian aquifer system are that the aquifer be inclined and that it be overlain by a bed of material which has a low permeability such as clay. As shown in Figure 5-3, water which enters such an aquifer has difficulty escaping through the upper confining material and

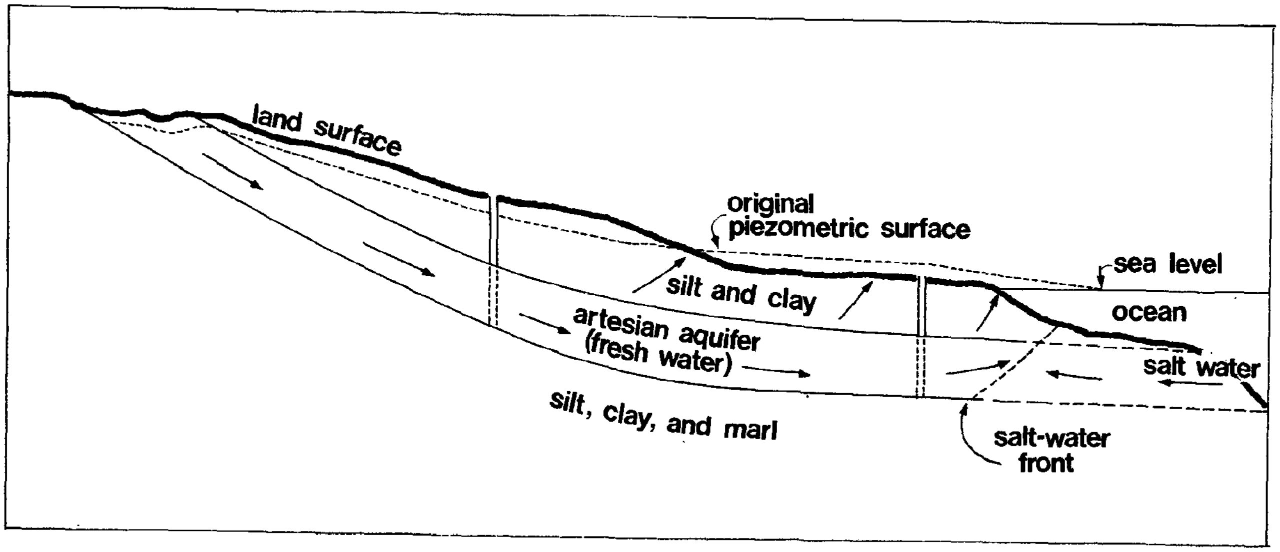


Figure 5-3. General ground water flow in an artesian aquifer.

thus becomes trapped. The amount of pressure which such an aquifer develops depends upon the altitude of the aquifer where it receives water, the permeability of the confining bed, the amount of inclination of the aquifer and the permeability of the aquifer. Since the water is under pressure, the water level in a well drilled into the aquifer will rise above the top of the aquifer. Occasionally there may be sufficient pressure to cause the water level to rise above land surface thus resulting in flowing wells. Not all artesian wells are flowing wells, however. The correlative of the water table for artesian aquifers is the potentiometric level, although potentiometric level is sometimes used to refer to a water table also. The potentiometric level is the level to which water will rise in a water well when the well is not pumped. Maps which depict the potentiometric surface of an artesian aquifer generally show less local "relief" than a map of a water table surface.

As water wells withdraw water they produce a cone of depression. A typical cone is illustrated in Figure 5-4. The size and shape of a cone of depression is dependent upon such factors as the permeability of the aquifer, whether the aquifer is artesian or water table, recharge and discharge factors, and the amount of pumpage. A cone grows in size rapidly at first but enlarges at a decreasing rate as pumpage continues. When the amount of water flowing toward the well from all directions equals the amount of water withdrawn, the cone stabilizes. If the cone does not stabilize, then ground water mining is taking place. In other words, more water is being withdrawn than the aquifer can continuously provide. Ground water mining has not been identified anywhere in southern Georgia.

It is important to recognize the fact that a cone of depression is a necessary and unavoidable aspect of ground water pumpage. Another important concept is that pumpage in an artesian aquifer results in a cone of depression that might better be termed a "cone of pressure relief." Rather than actually dewatering an aquifer as in a water table aquifer, pumpage initially reduces pressure in an artesian aquifer. The reduction of pressure is transmitted very rapidly over a large distance. A cone of depression in a water table aquifer generally grows slowly and affects a small area.

Aquifers in Coastal Georgia

The coastal plain of Georgia covers approximately the

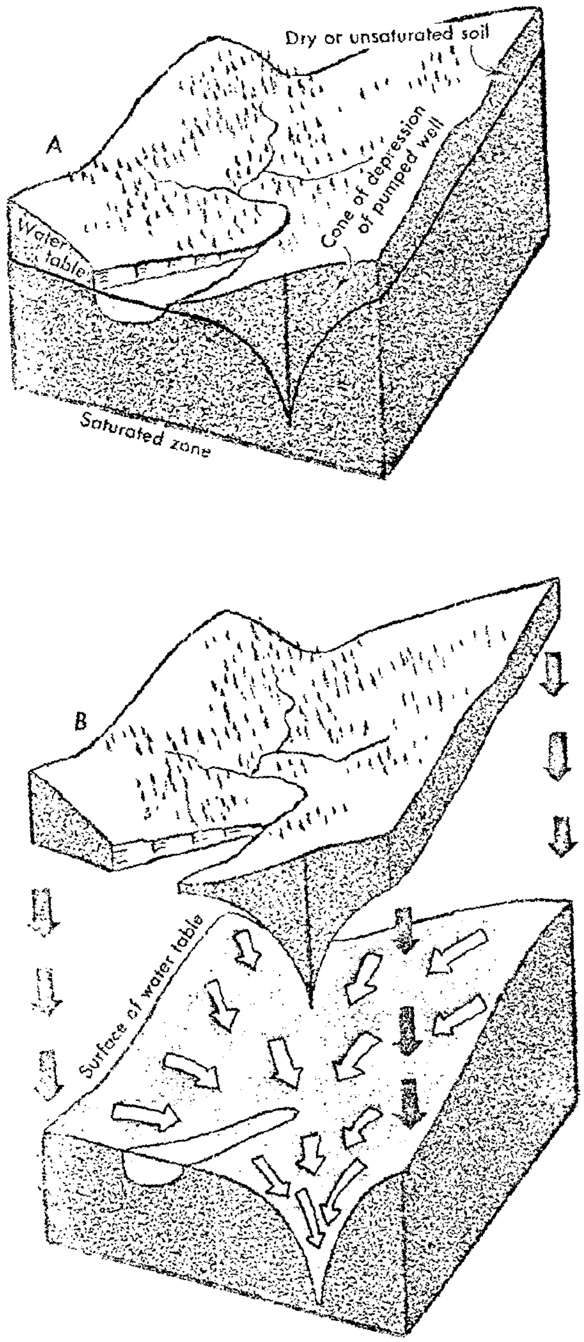


Figure 5-4. Effect on local water table of pumping a well (Leopold and Langbein, 1960).

southern two-thirds of the State. The sediments found in this province were deposited as a result of numerous invasions of ancient seas. The millions of years of sediment deposition resulted in a considerable thickness of sand, clay, limestone and marl. From examination of these sediments in a small area, it would seem that the various beds are horizontal, but in fact, the strata are inclined slightly. With local variations the strata become thicker and deeper southward or southeastward from the fall-line. At Brunswick, for example, the sediment at 5000 feet below the surface is the same age as the sediment at Macon. Figure 5-5 is a cross-section showing this concept.

Notice that in Figure 5-5, the strata looks somewhat like wedges. The portion of each wedge which is near the land surface and not covered by a younger wedge forms that stratum's outcrop. Some strata naturally do not have an outcrop but rather they can only be found by drilling. Ground water in a permeable stratum can most easily be recharged by precipitation falling upon the stratum's outcrop area. Recharge will also occur in other ways which will be described later.

Aquifers

In the coastal area under consideration there are two known aquifers and one potential aquifer which has not been adequately explored. The oldest rock unit which may potentially be an aquifer in the northern coastal area is the Tuscaloosa

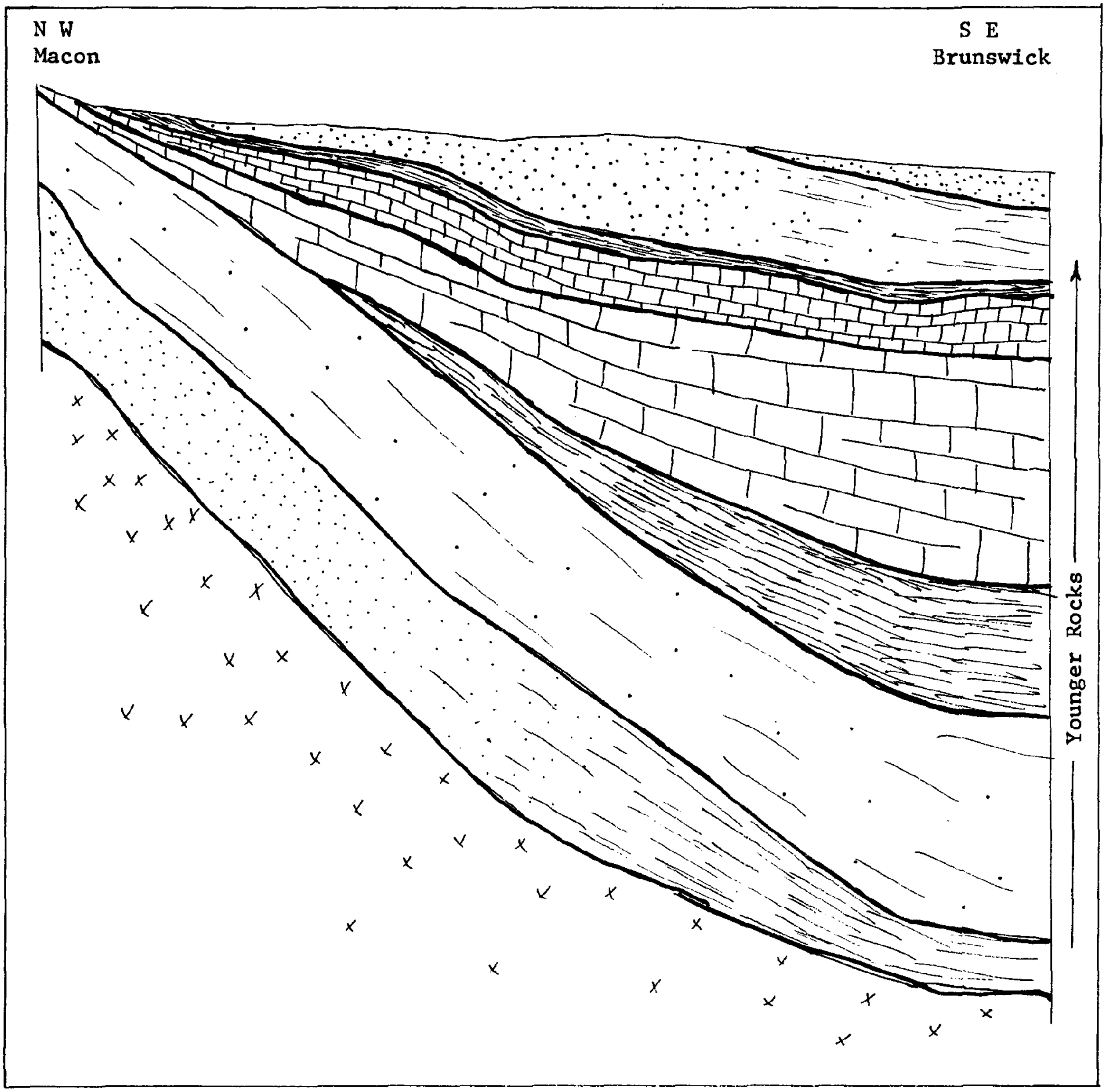


Figure 5-5. Idealized cross section from Macon to Brunswick.

Formation. Several test wells have penetrated the Tuscaloosa Formation in the Savannah area but the goal of these wells was not to determine the water bearing characteristics of this unit. Since the formation consists of sand, one would anticipate that a reasonable quantity of water could be withdrawn from it. At Savannah, however, the formation is found at depths below 2500 feet and will probably contain water having quality problems. Because of its depth the temperature of the water would be higher than normal which might make it useful to catfish farmers.

The youngest aquifer consists of sand and gravel. In general this aquifer is thickest and thus has its greatest potential near the coast. The permeable nature of this aquifer is demonstrated by the stream pattern along the coast. Except for the large rivers which originate outside the region there are few small streams. In other words, most of the precipitation which falls on coastal Georgia immediately infiltrates the surface and recharges this shallow, young aquifer.

The shallow aquifer is used by a few people for domestic purposes and by a few industries for supplemental water. Where the aquifer is thick and composed of coarse material, large quantities of water could be withdrawn. The areal extent of this aquifer is shown in Figure 5-6.

The major aquifer is a thick sequence of limestones which lies between but separated from the two aquifers described above. The limestone is commonly composed almost entirely of of the shells of sea critters. It is honeycombed with numerous small passageways and occasionally has large cavernous zones. The permeability of this rock is very high.

The major limestone aquifer is locally known as the principal artesian aquifer. As shown in Figure 5-7a, this aquifer

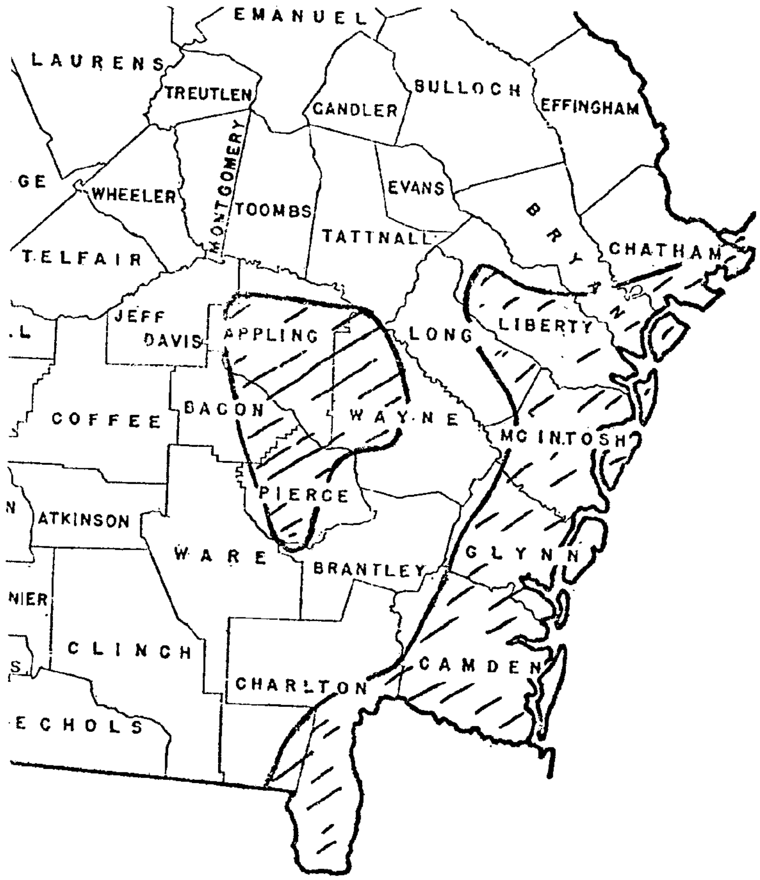


Figure 5-6 Aerial extent of the potential shallow sand and gravel aquifer.

is a usable aquifer throughout much of the coastal plain. Its upper surface is difficult to accurately contour due to the fact that recent and ancient solution of the limestone has created a very rough surface. Figure 5-7b shows the depth to which one must drill before encountering the top of this aquifer. The artesian characteristics of the aquifer are due to the aquifer's gentle dip toward the sea and its covering of clayey material.

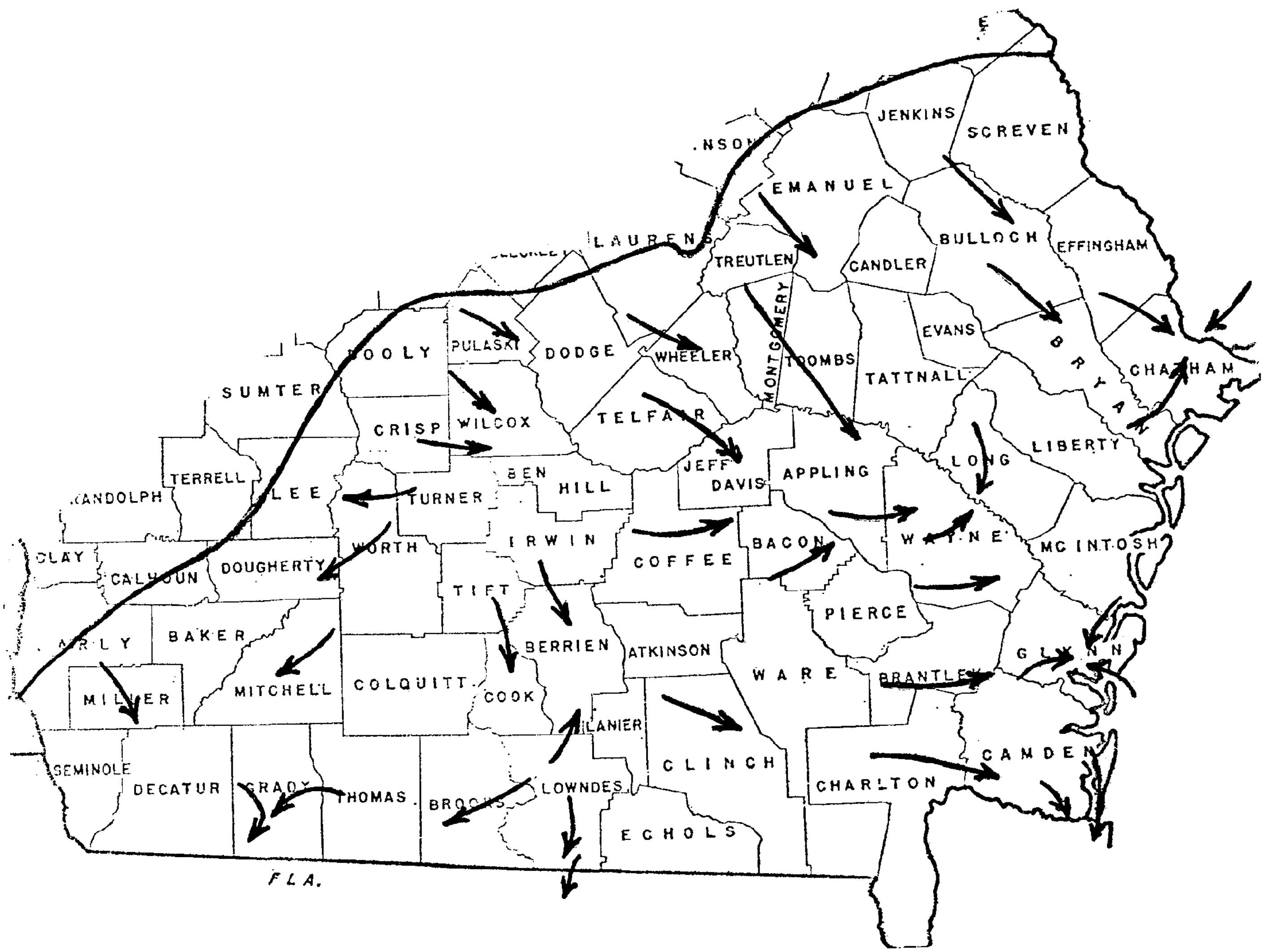


Figure 5-7a. Areal extent of the principal artesian aquifer and direction of ground water movement.

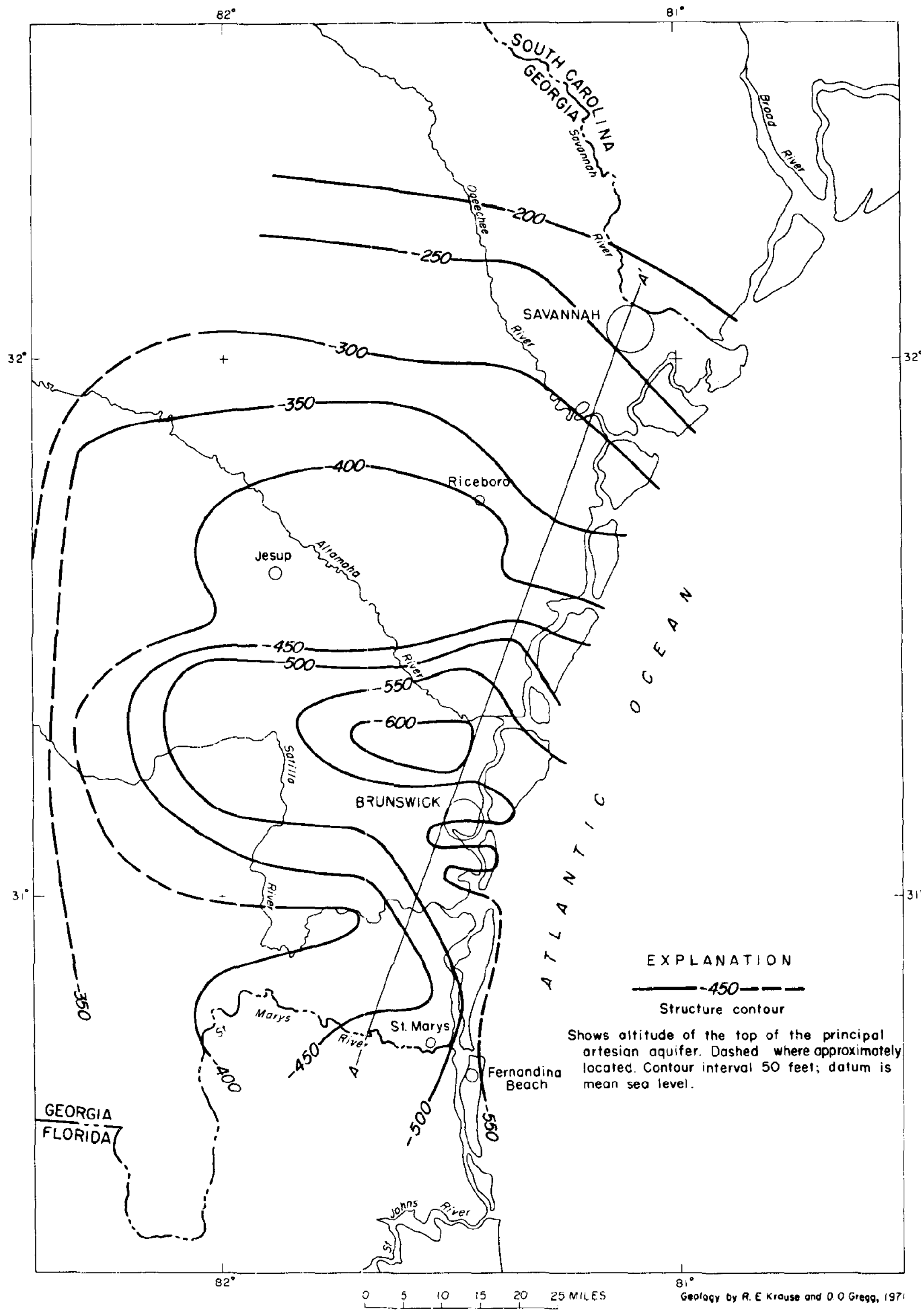


Figure 5-7b. Depth to the top of the principal artesian aquifer in coastal Georgia (Krause and Gregg, 1972).

Principal Artesian Aquifer Recharge and Discharge

As stated earlier a large quantity of water can enter a permeable stratum where that stratum is exposed to the surface. A large quantity of water also enters the principal artesian aquifer even where the aquifer is covered with a clay confining bed. In places, water enters the aquifer from strata lying below the aquifer. Such a transfer of water is due to the fact that water moves from areas of high pressure to areas of low pressure. If the water table, for example, is at an elevation which is higher than the potentiometric level of the principal artesian aquifer, then there is a tendency for water to move downward and into the principal artesian aquifer. In Figure 5-8, water is recharging the aquifer from above at "B" because the

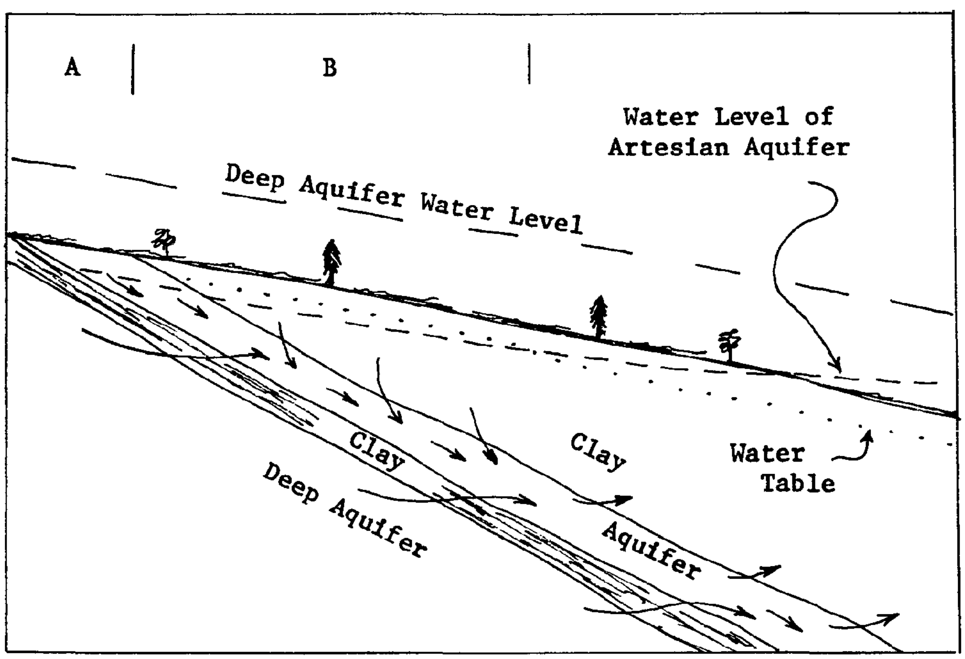
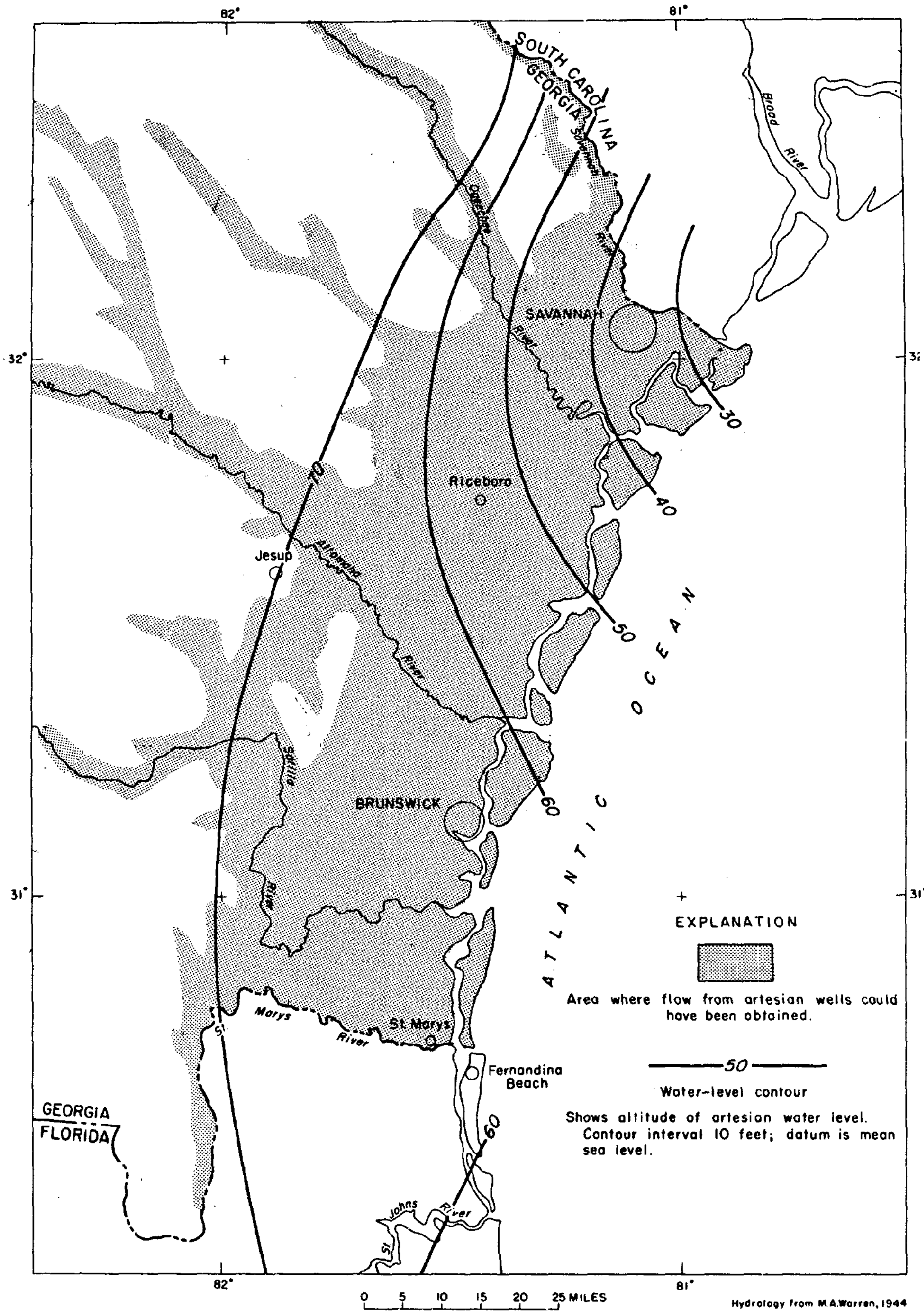


Figure 5-8. Recharge to an artesian aquifer.

water table is higher than the artesian aquifers potentiometric level. Of course, the opposite situation is true also as shown to the right of "B". The deep artesian aquifer in Figure 5-8 is a higher pressure than the shallow artesian aquifer and thus is constantly discharging water. A clay confining bed tends to inhibit such a transfer since the clay has a low permeability. However, when dealing with very large areas such as in south Georgia, the total quantity of water that is able to seep through a clay layer is very large.

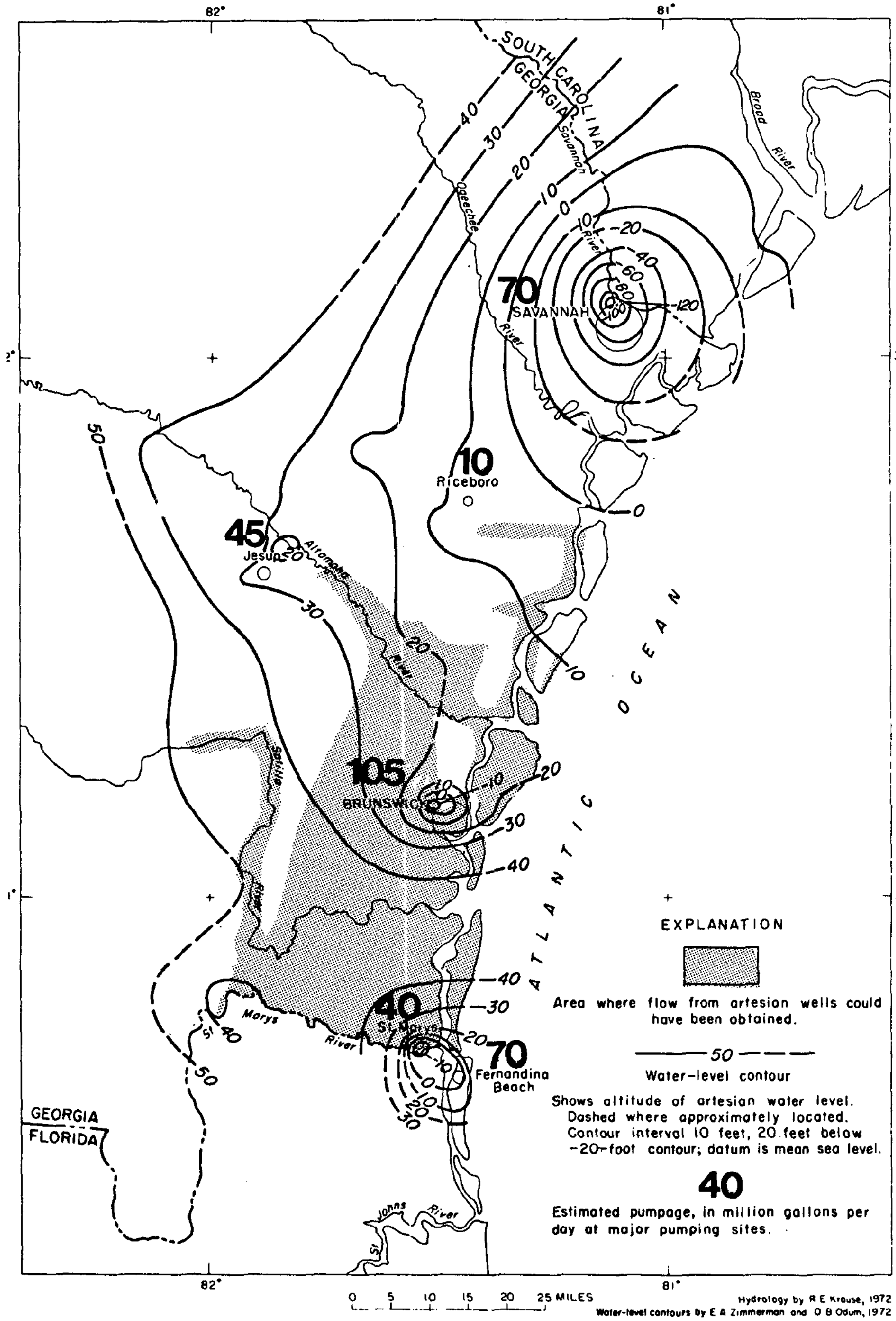
Since water in an aquifer tends to move from areas of high pressure to areas of low pressure, a map showing the potentiometric surface of an aquifer can be used to determine the direction of ground water movement (as in Figure 5-7a). Maps constructed in past years can be used to identify changes that have taken place in the aquifer. The type of change noticed can be attributed to natural effects or man-made effects. Krause and Gregg (1972) illustrated the changes which have taken place in the water levels along the coast. These illustrations are reproduced as Figure 5-9a and 5-9b. Notice that the 1971 map depicts the large cones of depressions which are a result of ground water pumpage.

The natural discharge area of the principal artesian aquifer in eastern Georgia was originally the estuaries in South Carolina and the submarine outcrops of the aquifer off the coast of Georgia and Florida. Most of the water seems to have discharged to the shore area of South Carolina as



1880

Figure 5-9a. Water level in the principal artesian aquifer, 1880 (Krause and Gregg, 1972).



1971

Figure 5-9b. Water level in the principal artesian aquifer, 1971 (Krause and Gregg, 1972).

indicated on the 1880 map in Figure 5-9a. It is difficult to determine where the present natural discharge area is, if indeed it does exist.

Water Use In Coastal Georgia

Background

There are several reasons why ground water use in the coastal area is presently so high. Before the present large-scale development, flowing wells were an important asset. The original potentiometric level was high enough to cause wells to flow thirty to seventy feet above the land surface. Numerous mills used this natural power to operate water wheels which in turn operated grinding wheels and saw. Naturally, as such use expanded, the original pressures decreased thus making the use of pumping equipment necessary.

The cost of treating a water supply is a critical factor for most uses. Most industries require water that will meet certain quality restrictions. The same is also true of municipal and agricultural users. Surface water in the coastal area requires expensive treatment to adjust its chemical and sediment characteristics before it can be used. Ground water, on the other hand, is pure enough for almost any use. The only quality restriction is the natural hardness of the water and occasionally a high sulfate content. Municipalities are required to chlorinate the water before distribution even though the ground water does not naturally contain bacteria.

The cost of a ground water supply as compared to a surface water supply in coastal Georgia is enhanced because of the very large quantities of water that can be pumped from a single well. This allows an engineer to select a plant location based upon factors other than proximity to a river or reservoir. In the Brunswick area, for example, the nearest usable surface water body is a considerable distance from the City. Ground water, on the other hand is of better quality and can be obtained within the confines of a plant's property. In one instance, a withdrawal of 11,000 gallons of water per minute was registered from a very small area.

Accurate comparative costs of surface versus ground water have not been developed. Ground water is probably costing users several cents per thousand gallons whereas surface water probably costs at least ten cents per thousand gallons. A plant which requires 100 million gallons of water per day is obviously going to examine its water cost very closely when selecting a plant site.

Recent Water Use

The importance of ground water to the economy of the coastal area is dramatically illustrated in a recent report "Use of Water in Georgia, 1970, with Projections to 1990" (Carter and Johnson, 1974). Tables 5-1 and 5-2 of that report are reproduced here. Notice that the Coastal Area Planning and Development Commission region withdraw more ground water for public supply, industrial use and thermoelectric plants than any other area in the State.

Table 5-1 - Withdrawal use of water (million gallons per day) by Area Planning and Development Commission region, source, and principal use, 1970.

Area Planning And Development Commission Regions	Public Supply		Rural Use					Self-Supplied Industry		Thermoelectric Power Plants		Total		
			Domestic	Livestock		Irrigation								
	Ground Water	Surface Water	Ground Water	Ground Water	Surface Water	Ground Water	Surface Water	Ground Water	Surface Water	Ground Water	Surface Water	Ground Water	Surface Water	Total
Altamaha-Georgia Southern	10.71	0	3.03	0.81	0.80	0.98	2.35	66.58	0	0	0	82.16	3.15	85.31
Atlanta Region	1.97	192.44	5.48	.22	.47	0	.03	.47	.95	0	601.40	8.14	795.29	803.43
Central Savannah River	6.66	23.25	4.48	.51	1.32	.32	.22	16.31	71.87	0	0	28.28	96.66	124.94
Chattahoochee-Flint	1.85	12.71	2.96	.18	.55	0	.01	.54	4.41	0	657.00	5.53	674.68	680.21
Coastal	38.71	35.00	4.59	.20	.26	.10	.11	255.46	188.75	4.38	513.06	303.44	737.18	1,040.62
Coastal Plain	14.24	0	2.65	.71	1.02	2.60	10.80	19.36	6.80	0	0	39.56	18.62	58.18
Coosa Valley	18.85	19.17	5.67	.50	.97	0	.05	13.20	65.73	0	549.70	30.22	635.62	665.84
Georgia Mountains	2.10	16.71	4.76	1.45	.89	0	.25	2.35	1.07	0	0	10.66	18.92	29.58
Heart of Georgia	7.38	0	2.16	.61	.74	.85	.66	1.47	5.91	0	0	12.47	7.31	19.78
Lower Chattahoochee	2.37	31.95	1.34	.14	.41	.09	.15	0	1.95	0	0	3.94	34.46	38.40
McIntosh Trail	2.30	11.61	3.08	.15	.64	0	.12	.52	5.12	0	0	6.05	17.49	23.54
Middle Flint	5.40	0	1.97	.34	.88	.83	1.98	1.05	0	0	0	9.59	2.86	12.45
Middle Georgia	12.30	21.76	1.86	.12	.47	.02	.08	20.52	26.14	0	241.80	34.82	290.25	325.07
Northeast Georgia	1.50	17.50	3.77	.67	.93	0	.15	1.39	2.72	0	0	7.33	21.30	28.63
North Georgia	.63	16.69	2.98	.48	.43	0	.01	.47	7.13	0	0	4.56	24.26	28.82
Oconee	2.27	7.64	1.70	.21	.57	.02	.04	32.92	4.64	0	1,139.60	37.12	1,152.49	1,189.61
Slash Pine	6.70	0	2.32	.64	.51	.38	3.27	.42	.07	0	0	10.46	3.85	14.31
Southwest Georgia	29.79	0	4.67	1.20	2.54	3.20	9.89	17.17	88.48	0	237.50	55.98	338.41	394.39
Total by Source	157.73	406.43	59.47	9.14	14.40	9.39	30.17	450.20	481.74	4.38	3,940.06	690.31	4,872.80	
Total by Subcategory			59.47	23.54		39.56								5,563.11
Total by Category	564.16		122.57					931.94		3,944.44				

Area Planning And Development Commission Regions	Population Served			Average Water Use (MGD)					Per Capita Use (GPD)	
	By Ground Water	By Surface Water	Total	Ground Water	Surface Water	Residential	Commercial And Industrial	Total	Residential	Total
Altamaha-Georgia Southern	59,300	0	59,300	10.71	0	5.84	4.87	10.71	98	181
Atlanta Region	29,050	1,298,650	1,327,700	1.97	192.44	111.78	82.63	194.41	84	146
Central Savannah River	64,650	146,800	211,450	6.66	23.25	18.10	11.81	29.91	86	141
Chattahoochee-Flint	11,000	76,600	87,600	1.85	12.71	7.72	6.84	14.56	88	166
Coastal	205,600	0	205,600	38.71	35.00	19.90	53.81	73.71	97	359
Coastal Plain	103,900	0	103,900	14.24	0	7.48	6.76	14.24	72	137
Coosa Valley	56,800	132,400	189,200	10.85	19.17	16.06	13.96	30.02	85	159
Georgia Mountains	14,900	82,500	97,400	2.10	16.71	11.09	7.72	18.81	114	193
Heart of Georgia	58,550	0	58,550	7.38	0	5.16	2.22	7.38	88	126
Lower Chattahoochee	17,600	188,000	205,600	2.37	31.95	23.51	10.81	34.32	114	167
McIntosh Trail	12,650	78,850	91,500	2.30	11.61	7.30	6.61	13.91	80	152
Middle Flint	47,500	0	47,500	5.40	0	2.95	2.45	5.40	62	114
Middle Georgia	77,100	145,200	222,300	12.30	21.76	20.94	13.12	34.06	94	153
Northeast Georgia	9,300	101,350	110,650	1.50	17.50	10.64	8.36	19.00	96	172
North Georgia	7,700	63,150	70,850	.63	16.69	6.32	11.00	17.32	89	244
Oconee	17,350	40,650	58,000	2.27	7.64	3.96	5.95	9.91	68	171
Slash Pine	49,450	0	49,450	6.70	0	4.15	2.55	6.70	84	135
Southwest Georgia	192,600	0	192,600	29.79	0	15.34	14.45	29.79	80	155
State	1,035,000	2,354,150	3,389,150	157.73	406.43	298.24	265.92	564.16	88	166

Trends in future water use are very difficult to predict. It is safe to say that ground water will always be the primary source of high quality water in the coastal area but at present, it is desirable to locate new water using industries away from the major pumping centers if possible. Throughout the area shown in Figure 5-7a the principal artesian aquifer can supply large quantities of very high quality water. Many other aquifers are capable of a much larger use also.

Stress to the Aquifer

Natural Stresses

Probably the greatest stress to the ground water supply which nature causes is the minor variations in annual precipitation. Water levels in aquifers respond to variation in precipitation in a manner which depends a great deal upon the physical characteristics of the individual aquifer. Aquifers which are under water table conditions generally have a dramatic and quick response to precipitation variations. The artesian aquifer response is most often difficult to detect. Water table variations can be correlated to specific rainfall events whereas artesian potentiometric levels may be correlated with precipitation variations that range over several years.

Artesian water levels respond quickly to changes in pressure. Such natural changes in pressure are caused by such things as earthquakes, tides, and the wind. Trains and explosions can also affect artesian water levels. Generally, such changes do not disturb the long-term water levels. An interesting discussion of these effects can be found in "Ground Water Designs and Patterns" by J. W. Stewart (1971).

Man-made Stresses

It is a generally accepted fact that man has strained the aquifer system in the coastal area to a much larger degree than nature has. The 1971 water level map shown in Figure 5-9b identifies the "points" where the system is being strained the greatest. The greatest cone of depression is centered at an industrial park near Savannah. St. Marys, Brunswick, Jesup, and Riceboro have cones which are smaller. Notice that in 1971 the cone of depression near Brunswick is smaller than the cone at Savannah even though more water was being withdrawn at Brunswick. This is due to the greater transmissivity (a measure of the water yielding characteristics of an aquifer) at Brunswick than at Savannah.

The 1971 water level map illustrates that the principal artesian aquifer must be managed as a unit since pumpage in one area ultimately affects a very large portion of the aquifer. Interstate cooperation will be needed for management purposes in the near future.

The large cone of depression at Savannah has not resulted in dewatering of the aquifer there. Since this is an artesian aquifer, we are looking at a cone of "pressure relief." Before dewatering of the aquifer and concurrent transition from artesian to water table conditions takes place, the water levels would have to decline another 10 to 20 feet. This is shown diagrammatically in Fig. 5-10. Similarly, dewatering is not taking place anywhere within the coastal area.

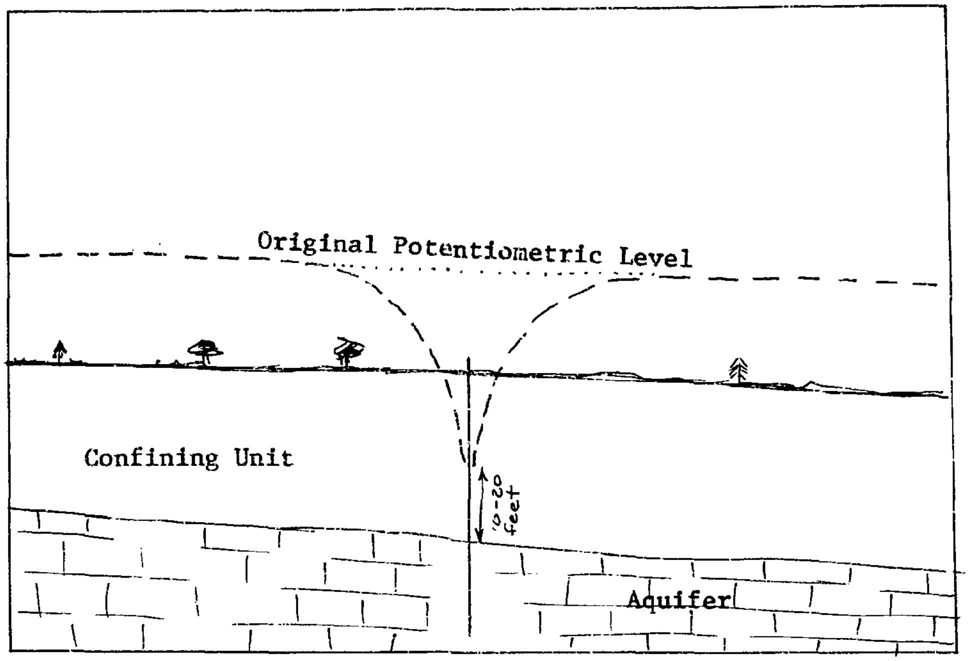


Figure 5-10. Cone of depression in an artesian aquifer.

Effects of the Stress

As mentioned earlier in this report, ground water moves from areas of high pressure to areas of low pressure. This results in a potentially undesirable situation when a higher pressure zone contains water of poor quality and a nearby low pressure zone contains water of good quality. Two problem areas have been documented in coastal Georgia where water of poor quality is presently moving toward pumping centers.

The problem area which has received the most attention in recent years is at Brunswick. The brackish water encroachment can best be explained by the use of Figure 5-11. In very general terms, there are four geologic strata. Confining unit number 1 is found between the depths of 150 feet and 300 feet. This unit is impermeable and creates the artesian conditions. The principal artesian aquifer is found below the confining unit with the best water yielding zones between the depths of 600 feet and 1050 feet. This is the zone from which various users in Brunswick withdraw over 100 million gallons per day (MGD). Confining unit number 2 is found between 1000 feet and 1050 feet. In places, however, this confining

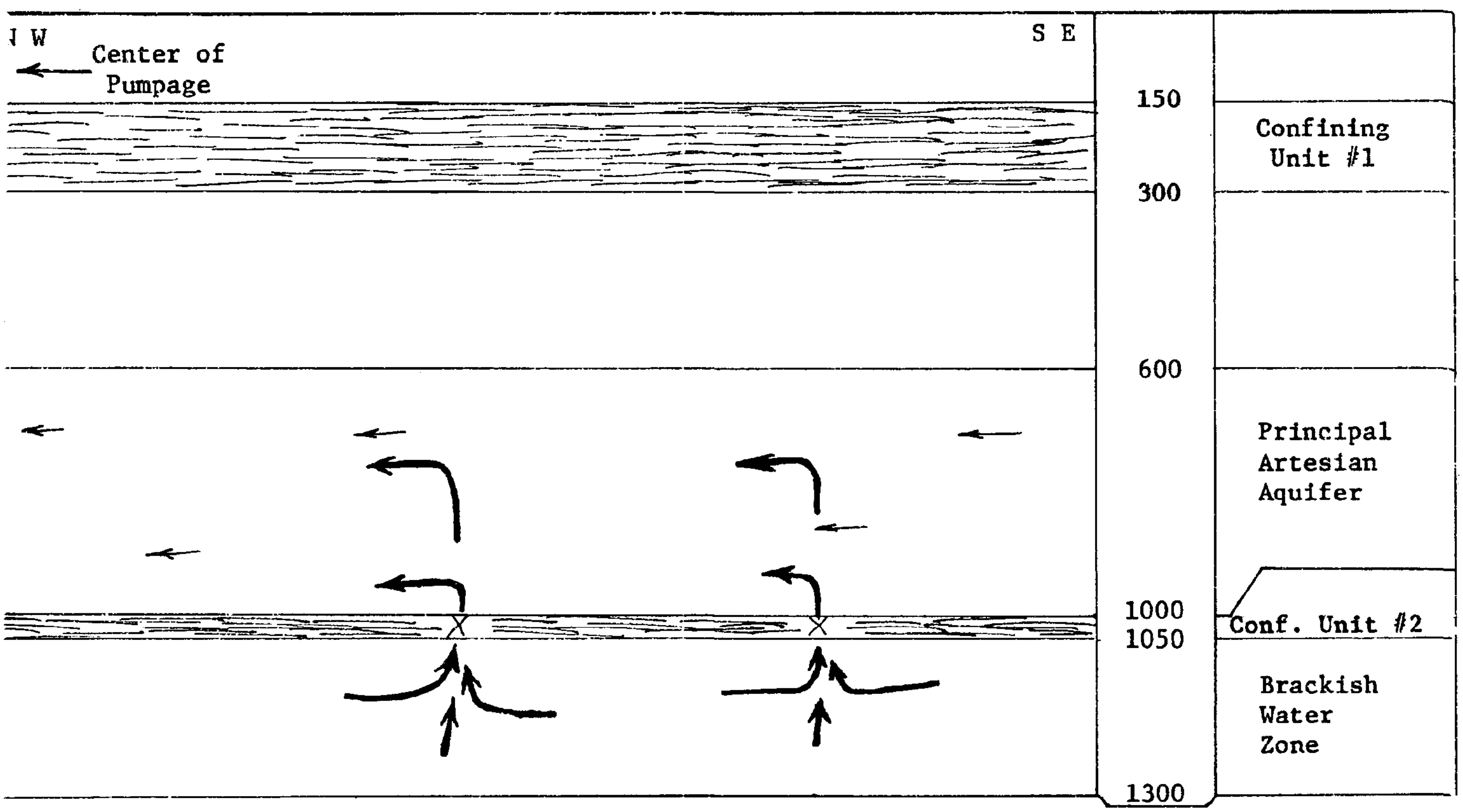


Figure 5-11. Diagram of the Brunswick intrusion problem.

unit has been breached. The reasons for these ineffective zones in the confining unit are not clearly understood. The lowest stratum of concern occupies the interval from 1050 feet to 1300 feet. It is this stratum that provides water that contains chlorides in concentrations of up to 4500 milligrams per liter. This lowest zone now has a potentiometric level which is greater than the potentiometric level of the principal artesian aquifer because of the water withdrawn from the artesian aquifer. The ineffective zones in confining unit number 2 allow brackish water from the lowest stratum to move upward and thus into the fresh water of the principal artesian aquifer. The brackish water then moves with the native water toward the center of pumpage.

Pumpage at Savannah has created a situation which is common to many coastal cities. Referring to Figure 5-12 we can see that

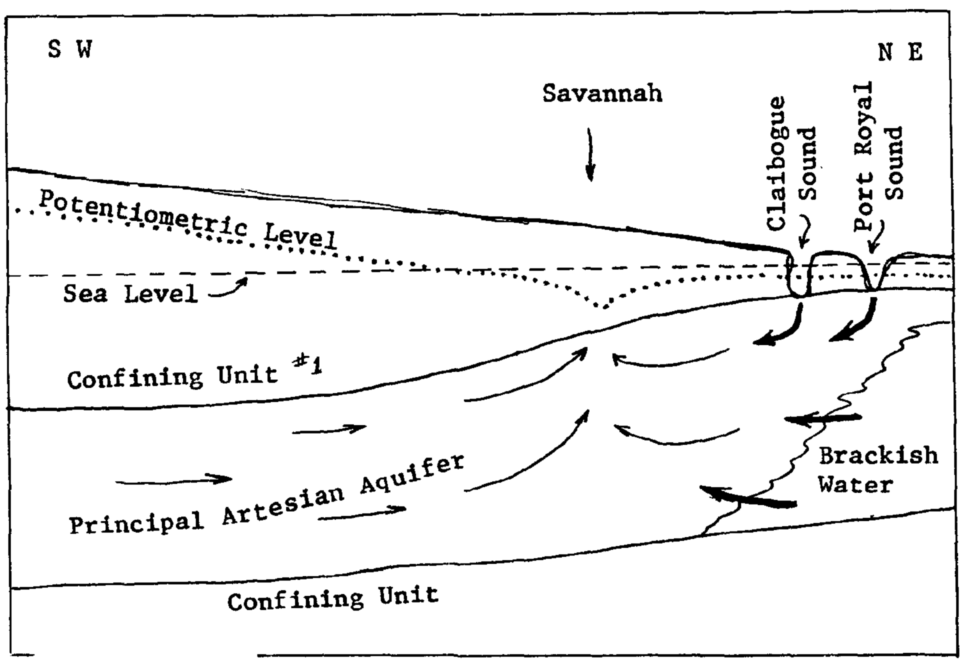


Figure 5-12. Diagram of the salt water intrusion problem at Savannah.

we have basically two subsurface strata of concern. Confining unit number 1 is the unit which results in the artesian conditions at Savannah. It is the same age as the confining unit at Brunswick. Notice how this unit becomes shallower toward the northeast and is breached by the estuaries. Below the confining unit we find the principal artesian aquifer. Again this is the same aquifer which is found in Brunswick. The deeper portions of the principal artesian aquifer north and east of Savannah contain water which is brackish.

Before large ground water withdrawals in Savannah, the potentiometric level was higher than sea-level. Thus, where the principal artesian aquifer is directly exposed to the estuaries, the original water pressure in the aquifer was high enough to keep the denser sea water out of the aquifer. The ground water was actually discharging fresh water to the estuaries. As pumpage increased, the potentiometric levels naturally declined. At present, the potentiometric level is lower than sea level and salt water is slowly recharging the aquifer as shown in Figure 5-12.

Brackish water in the lower portions of the aquifer is likely to be moving toward the pumping center also. Due to the fact that this brackish water is naturally nearer to Savannah, it may move more rapidly toward the pumping center.

Both problem areas discussed above will most likely become worse with time due to the fact that nothing is presently being done to stop the intrusions. If pumpage should increase, the problem will obviously also increase. An increase in pumpage will increase the quantity of brackish water moving toward the pumping center and increase its rate of movement.

As the brackish water approaches the cone of depression, the pressure gradient which is causing the brackish water to move increases. This increase in the pressure gradient causes the brackish water to move at an accelerating rate. As Figure 5-13 illustrates, the velocity is low at distances far away from the center of the cone but increases rapidly as this distance decreases. An increase in pumpage would result in the graph in Figure 13 being shifted upward of toward the left (with an obvious

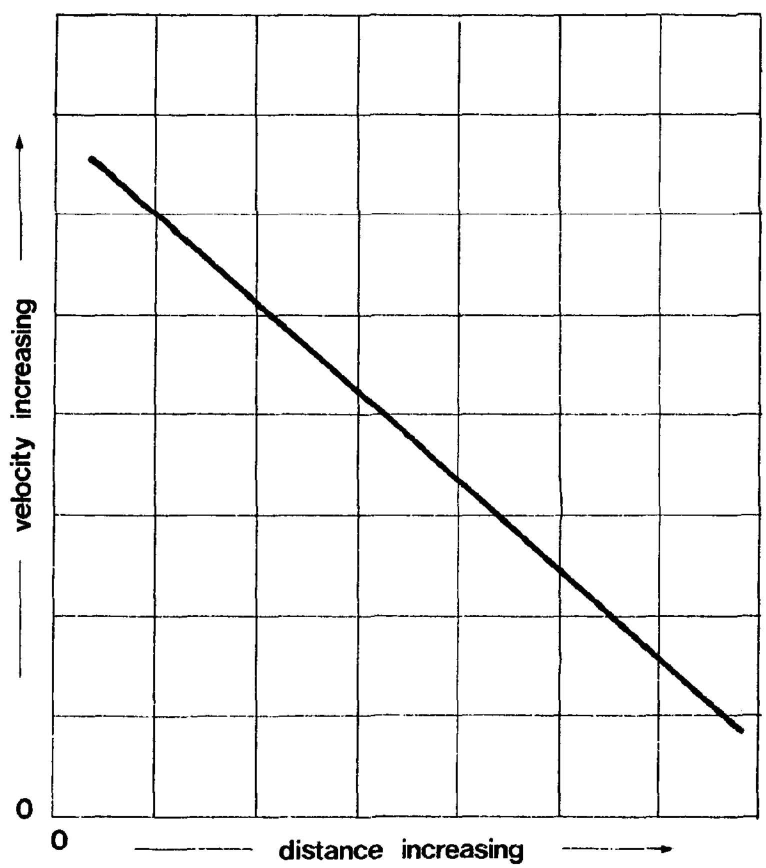


Figure 5-13. Rate of ground water movement toward a cone of depression.

upward limit as to the maximum velocity).

<u>Solutions to the Problems</u>

A number of solutions have been offered that may solve the two intrusion problems. Each solution involves a redistribution of pressure within the aquifer system and thus is extremely expensive. The proposed solutions are briefly generalized below.

A. Reduce the quantity of water withdrawn from the principal artesian aquifer at each pumping center. Additional water needs would have to be met by:

   1. Using wells located far from the pumping center.
   2. By using surface water, or
   3. By using alternate (deeper or shallower) aquifers where they exist.

B. Attempt to reestablish a higher potentiometric level in the aquifer as compared to the brackish water zone without reducing existing pumpage.

   1. Install wells tc inject fresh water into the principal artesian aquifer between the pumpage center and the source of the brackish water intrusion.
   2. Install pumping wells (relief wells) in the brackish water zones to lower the pressure in these zones in relation to the principal artesian aquifer. (This method would not apply to the shallow encroachment experienced at Savannah).

C. Intercept the brackish water before it can reach a pumping center.

1. Similar to B-2 except the wells would withdraw water from the principal artesian aquifer between the pumping center and the zone of brackish water intrusion. The brackish water would move from its point of origin to the interceptor wells and then be withdrawn.

Two primary problems exist with any of the above proposed solutions. First of all, none of the solutions have been tested for conditions unique to the coastal area. Therefore there is no adequate way of accurately determining the cost-benefit ratio of any of the alternatives listed. In fact, there is no guarantee that some of the solutions would even make a significant enough impact on the intrusion problems. Secondly, the aquifer is extremely permeable. The quantity of water that would have to be withdrawn, injected or the amount of pumpage that would have to be reduced to make an impact would be staggering.

The solutions which involve the withdrawal of water (B-2 and C-1) may offer advantages in that the water withdrawn may be used for some industrial or recreational purposes.

Summary

An attempt has been made to explain the ground water resources of the coastal area in very general terms. It would be easy to "write a book" on any one particular aspect of the subject--in fact, this has been done for many subjects as illustrated in the next section. The interested reader can expand from this list to subject matter related to general ground water concepts and not to Georgia specifically. Up-to-date information on the aquifer system is available in unpublished form from both the U. S. Geological Survey and the Earth and Water Division, Department of Natural Resources.

Past studies of ground water in the coastal area have resulted in a fine data base which has allowed parts of the system to be modeled by digital computer. Each past study was completed for a relatively low cost since much of the work involved basic data collection and interpretation. If future studies of the principal artesian aquifer are to be significant studies the costs will be much greater than experienced in the past. This is because of the current need for test wells, computer programming time and more sophisticated tests of model results.

Both the State and federal geological surveys will continue to collect data in this area and study alternate water sources. The future course of action at this point is up to the water managers.

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CHAPTER 6

an Overview of Coastal Georgia Wildlife

by

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* Other papers on coastal resource systems contained in this report highlight the relationship of wildlife with various environmental features. This paper provides an overview of coastal wildlife, drawing upon available printed sources of information. This paper should be considered a general background paper upon which a further synthesis of wildlife information for coastal Georgia can be based.

Introduction

The wildlife community along the Georgia coast is extremely diverse. It contains many forms which are well known and quite spectacular, such as, the Eastern brown pelican (*Pelecanus occidentalis*), the clapper rail (*Rallus longirostris*), and Eastern fox squirrel (*Sciurus niger*), as well as many wildlife forms which are relatively unknown to anyone except research scientists. Although these obscure forms are not well known to the layman, they often occupy an important, if not vital, position in the wildlife community, either as a member of a food chain or as a converter of material required by members of a food chain.

Whenever we speak of wildlife in general, the forms which immediately come to mind are the popular and more spectacular ones. Usually these forms have gained attention because of their value to the sport of hunting or fishing, or because they have been recognized by special interest groups as being endangered for one reason or another. If one made the statement that these popular forms were valuable to at least a segment of our society, there would probably be no pointed disagreement with the statement. However, acknowledgement of the value of those obscure and relatively unknown wildlife forms by a society which is industrially oriented and only beginning to become aware of its total environment will require much effort and much foresight in the planning and implementation of state and federal programs. The public must be educated to the fact that each member of a wildlife community has a functional role to play no matter how obscure or uninteresting nature's design has made it. Seemingly uninteresting forms may be an essential link in the food chain of the larger popular forms, as well as being a vital member of the wildlife community supported by a particular ecosystem. The exact roles of many forms, within the community, large and small, obscure and spectacular, are only beginning to be studied and determined. Some are known and there is considerable evidence that all of nature's wildlife species play important roles within their community (Smith, 1974). Many forms may be relatively unimportant for most of their life and then, reacting to nature's cue, they become the very pulse of the wildlife community (Wharton, 1974).

The role of an individual type of wildlife within a total ecosystem is unknown in many cases. This lack of information is a major reason for protecting wildlife, since accidental elimination of the animals or the habitats may stimulate a chain reaction which may have many adverse effects, or completely eliminate a type of animal. A wide variety of ecological factors must be understood before the value of wildlife and their habitats is understood.

Wildlife has many values associated with hunting and fishing. Hunting is an important recreational activity in coastal Georgia enjoyed by both residents and visitors. Many different habitats, including marshland areas, coastal islands, fresh water river swamps and certain forested areas away from population centers are used for different types of hunting. Fresh and salt water fishing for recreation and commercial purposes is another important activity related to wildlife. In addition to hunting and fishing, Georgia's wildlife has scientific and educational values.

Coastal Habitats and their Animal Dependents

Habitat has been defined as "The place where an animal lives" (Odum, 1963), and it is generally accepted that the habitat selected by a population of animals will be the one which offers the optimum conditions which exist within the limits of its travel. When the habitat of a population is detrimentally modified, the population will be forced to move into new areas if new areas are available. Movement of wildlife from one region to another places stress on the wildlife forms already occupying the new area because habitat which is supporting a wildlife community at its natural carrying capacity cannot support additional animals regardless of their type of numbers (Odum, 1963). Wildlife is absolutely dependent upon suitable habitat and the quality of wildlife in any habitat is directly proportional to the quality and quantity of that habitat.

The Continental Shelf

The Continental Shelf is a relatively shallow region immediately seaward of the bays along the coast. Along the Georgia coast, the water varies in depth from about 60 feet to a maximum of 168 feet (Johnson, et al., 1971); and extends offshore a distance of 70 to 80 miles (Henry and Hoyt, 1968).

Vegetation along the bottom on the Continental Shelf is sparse, yet this habitat harbors a diverse animal community. This wildlife community is localized around the various reefs and the Snapper Banks. It is mainly composed of mature organisms whose larval stages were planktonic and/or whose development largely occurs in an estuarine habitat. Representative bottom organisms include acorn barnacles, oysters, sea cucumbers, and scallops. All of these animals feed on detritus which is continually rained down from the waters above. This detritus consists of small particles that are the dead or decomposed bodies of planktonic plants and animals. The detritus is an essential component of the food chain of the wildlife community of the Continental Shelf since it supports an extremely diverse group of intermediate members of the food chain. These intermediate members, in turn, support such large species as the rock sea bass (*Centropristis philadelphica*), the black sea bass (*C. Striatus*), and the sand perch (*Diplectrum formosum*). In addition to these species of fish, there are a number of birds which utilize those intermediate members of the food chain offshore. These birds include such species as the red-throated loon (*Gavia immer*), and the ganner (*Morus bassanus*) (Johnson, *et al.*, 1971).

The Beach and Dunes

The beaches and dunes along the Georgia coast are composed of fine quartz sands (Greaves, 1966). Johnson, *et al.*, 1971, suggests that the beach and dune habitat is "characterized by the following zones: (1) *shoreline* - the narrow zone seaward from the low tide shore line permanently covered by water over which the beach sands and gravels move with wave action. (2) *foreshore* - the lower shore zone beyond the reach of ordinary low and high water levels. (3) *backshore* - the upper shore zone beyond the reach of ordinary waves and tides extending to the base of the dunes; and (4) *dunes-ridges* - of windblown (eolian) sand."

The diversity of the vegetation - other than aquatic - of this habitat is extremely low, due to the fact that plants growing in this location must be resistant to salt spray, almost constant wind, full light intensity, high evaporation, and relatively high temperatures (Johnson, et al., 1971).

The wildlife community which inhabits the beach is set to a biological clock which is regulated by the tides. At low tide, the beach (foreshore) is exposed and its inhabitants are preyed upon by predators from the land, while at high tide different predators attack from the sea (Johnson, et al., 1971). Among the inhabitants of the foreshore area are such burrowing forms as the ghost shrimp (Callianassa sp.), mole crabs (Lepidopa sp.), and razor clams (Tagelus sp.), (Johnson, et al., 1971) as well as various echinoderms such as sand dollars (Mellita sp.), and brittle stars (Class Ophiruoides), (Frey and Howard, 1969). Included in those species which prey on the foreshore during low tide are birds such as plovers, sandpipers, scavengers such as the fish crow and black vulture, and occasionally mammals such as raccoons, oppossums, and otters. As the tide rises again to cover the foreshore, predators include striped killifish (Fundulus majolis), lizard fish (Synodus foeteus) (Pearse, et al., 1942), common tern (Stern lirunde), and the black skimmer (Rhynlops nigra) (Johnson, et al., 1971) are found.

The upper beach and dunes serve as valuable nesting sites for such bird species as the royal tern (Thadassues maximus), American oyster-catcher (Haematopus pattiatus), and Wilson's plover (Charadrius wilsonia), as well as such other animals as the loggerhead turtle (Caretta caretta), and the Eastern mole (Scalopus aquaticus).

Most of the species of animals found in this habitat depend upon dune and beach stability, especially during their nesting season. This factor critically links the vegetation of the habitat with the preservation of the integrity of the wildlife community, because there is evidence that even minor modification in the plant community can turn stable beach and dune habitat into a shapeless mass of shifting sands (Johnson, *et al.*, 1971).

The Barrier Islands

The major barrier islands along Georgia's coast provide a suitable habitat for a multitude of wildlife species. One of the principal reasons for the diversity of wildlife is the diversity of the plant community, which is dominated by a pine and live oak canopy. Whitetailed deer, wild turkeys, raccoons, feral hogs, snakes such as the diamond back rattler and the cottonmouth water moccasin, and a wide array of songbirds are common on these islands. Species such as foxes, wolves, bobcats, pumas, and bears were present in the past but have been largely exterminated (Johnson, *et al.*, 1971).

Rare or unique species which still inhabit the islands include the loggerhead turtle (*Caretta caretta*), the Cumberland Island pocket gopher (*Geomys cumberlandius*), the St. Simons Island raccoon (*Procyon lotor litoreas*), the Anastasia cotton mouse (*Peromyscus gossypinus anastasae*), and the Blackbeard Island deer (*Odocoileus virginianus nigribarbis*). The isolation of barrier islands separated from the mainland shore has created the environments for the development of unique species.

Fresh and brackish water ponds and sloughs also are important habitats for wildlife. They provide food, shelter and nursery areas for various species, and are a major source of fresh water for island animals and birds.

The problem of habitat loss is compounded on islands isolated from the mainland since there may be very little space into which animals can expand their range in order to adjust for any habitat lost or destroyed. In case of considerable habitat loss, it is quite probable that the wildlife affected will over-use the remaining habitat and, subsequently, be subjected to natural population controls such as starvation and disease. These natural controls are usually devastating to entire populations and the recovery periods are long. There is a need for in depth study and detailed planning for the stable existence of the coastal island wildlife species. Failure to control habitat modifications associated with certain types of development "may seriously reduce or eliminate some populations before their taxonomic position, range, distribution, and ecology can be determined" (Johnson, et al., 1971).

The Marsh and Estuary

The intimate interaction between the coastal marsh and estuary often causes them to be considered as a single ecological unit (Schelske and Odum, 1961; Johnson, et al., 1971). As a unit, this habitat supports vast numbers of wildlife species as well as being an extremely important functional element of the coastal ecosystem. Much of the primary food energy is produced in the tidal marshes and exported to estuarine and open ocean waters by the pulse of the tide and flushing action of fresh water rivers. Many fish and wildlife species are dependent upon the marsh and estuary for support during some phase of their life cycle.

The marsh and estuary habitat serves as the spawning ground and nursery area for many species of fish which spend most of their life in the open ocean. These areas also provide a hiding place from predators. Living conditions here are suitable for wading birds; they provide important winter feeding grounds for many species of migrating waterfowl. Several mammals and various birds of prey are also supported by this habitat, but these animals are usually more closely associated with the ecotone or edge which exists along the dry land periphery of the marsh and estuary.

Georgia's marsh-estuary system supports an abundant sport and commercial fishery. Fish and shellfish of commercial value include shrimp, blue crabs, shad, oysters, and king whiting. Many other species, including snappers, groupers, triggerfish, shark, black sea bass, mackerel and barracuda are popular sport fishing species in offshore waters.

Rivers and Fresh Water River Swamps

Fresh water river swamps are very productive wildlife habitats in coastal Georgia. Species such as deer, raccoon, squirrels and many aquatic birds and fish, among others, depend upon the river environment for life support. In addition, the river swamp provides many functions which are essential for the support of the fish. Young fish, tadpoles, insects and other organisms utilize sloughs and ponds of the river swamp for spawning. These protected areas also serve as protected nurseries and hiding areas for young fish. In addition, organic matter accumulates on the forest floor, is decomposed by bacteria and fungi, and eventually is washed into the river channel during periods of flooding. This decomposed matter (called detritus) is the beginning of the food chain which supports many of the fish and wildlife species of the river. Many of the functions of the fresh water river swamp parallel the salt water marsh and estuarine system, although the particular species are different.

Fresh water rivers in the coastal counties support an abundant fishery. Fish species with importance to sport fishing include catfish, sunfish, crappie, and large mouth bass. Several species of salt water fish, such as striped bass and shad, enter the river channel to spawn in fresh water areas. These fish are termed anadromous. In addition to the true anadromous fish, many salt water species penetrate the river mouths to a greater or lesser distance to feed (such as red drum, spot, mullet, southern flounder, etc.). Hence the fresh water river system is intricately connected with the salt water environments.

The Nature of Existing Information

This brief report has highlighted the importance of coastal Georgia wildlife. There is a great deal of additional information on specific wildlife species available through the Department of Natural Resources and published research reports which this report has not summarized. In addition, further research is needed on wildlife species and wildlife habitats, especially habitats located in dry, upland areas where pressures for urbanization may occur. Future research needs include delineation of habitats for endangered species, and research related to the inter-relationships of habitats and species with each other. Finally, the effects of man's activities on important wildlife habitats should be assessed and integrated into local and State planning programs.

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CHAPTER 7

Coastal Georgia's Cultural Resources

by

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Department of Natural Resources

Coastal Zone Management Act

The Coastal Zone Management Act of 1972 recognizes that "important ecological, cultural, historic, and aesthetic values in the coastal zone which are essential to the well-being of all citizens are being irretrievably damaged or lost. In response to Congressional concern over these losses the Act requires that the states include "an inventory and designation of areas of particular concern in their management programs." (PL 92-583, sections 301 and 305). The effect of this legislation has been to demand that culturally significant sites be properly included in any consideration of the environmental resources of the coastal lands. A Special Task Force Committee at the University of Georgia, in their analysis of the critical needs of the coastal zone in this State, classified "major historic and archaeological sites of natural significance or of special value to the history and culture of Georgia" in their first category of resources. This includes the sand dunes of the barrier islands and endangered species of flora and fauna, which are vital to the integrity of the coastal area and possess a high to very high degree of sensitivity to certain kinds of human use or development. Apart from their intrinsic value, it is the non-renewable nature of cultural resources which makes their conservation so urgent; once destroyed, there can be no recovery of the knowledge of the past which they make available to us, a knowledge which must be seen as part of our common inheritance and a public trust.

An Arena of History

Few places anywhere in America can boast a concentration of historically significant places going back to man's earliest presence equivalent to coastal Georgia's. Because parts of the coast have been spared intensive industrialization and urbanization in this century, sites survive that might otherwise have been lost. Nevertheless, many historical and archaeological sites have been permanently destroyed.

The first people following the river courses across the slope of Georgia to the sea ten thousand years ago settled where the land ends, in a place of teeming life and primal beauty. Since then, civilizations have layered up like the silt of the river delta and have shifted and changed form like the sand bars and the dunes. The Creek Indians, encountered by the Spaniards, did not know what people had built the ancient burial mounds; in our own time, scholars have debated whether certain tabby ruins were mission buildings or the remains of sugar mills on nineteenth century plantations.

History is so dense on the coast that it is difficult at times to separate the strands. The peninsula called Seven-Mile-Bend, on the Ogeechee River in Bryan County, seemed to Governor John Reynolds in 1755 the only suitable location for a capital to replace Savannah, with which he was dissatisfied: "Hardwicke has a charming situation, the winding of the river making it a peninsula and the only fit place for a capitol." He could not have know that the Lamar Indian civilization had occupied the site from approximately 4000 B.C. to 1500 A.D. Nor could be have foreseen that in February of 1863, the C.S.S. "Nashville", refitted with heavy guns and renamed "Rattlesnake", would run aground in Seven Mile Reach while attempting to run the Union blockade and be destroyed by the armored monitor, "Montauk". Such a place typifies, in its layers of history, the entire coastal region.

There are ironies as well as mysteries in these coincidences of place. Governor Reynolds' appraisal of Savannah is a case in point, in that Hardwick, even after repeated attempts at settlement, became one of Georgia's "dead" towns, while Savannah became the mecca for urban designers in our own time who marvel at Oglethorpe's 1733 plan for the city. Or consider how the freedmen and runaways, who burned and sacked the lovely town of Darien in 1863, fulfilled the prophecy of those stout Highland founders of the town who had protested, twenty years before, when the province of Georgia had petitioned for the admission of slavery. "Introduce slaves", they wrote in a counter-petition, "and we cannot but believe they will one day return to be a scourge and a curse upon our children and our children's children". Fitting, too, that Jekyll Island, which served in the seventeenth century as a supply station for pirates and buccaneers, should become at the end of the nineteenth century the resort of the Morgans, Astors, Goulds, and Rockefellers who built sumptuous enclaves there.

"The Debatable Land"

Perhaps the most telling irony, though, is that over and over again in its history the coast of Georgia has been a "debatable land," even into our own day. The number of fort sites on the historic maps is a good indication of the frequent earnestness of the debate. The term "debatable land" was actually the description used in an agreement between England and Spain concerning the contested region below the Altamaha, but it sums up well the whole long history of the struggle to possess the varied riches of island and coastal lowland. The Spanish conquistadors sought literal riches, wresting territory from the Indians and enslaving them even while their missionaries sought, without much success, to win their souls for the white man's God. As early as the middle of the sixteenth century, more than two hundred years before Oglethorpe's arrival, Spain was forced to vigorously press its claim against that of the French, on whose behalf Jean Ribaut had explored the coast, presuming to name the St. Marys River the Seine, and the Altamaha the Loire. Part of England's intention in chartering the colony of Georgia was to provide a defense against the Spanish in Florida, and major fortifications were established at Savannah, Sunbury, Darien, St. Simons, St. Marys, and Cumberland Island. Oglethorpe had achieved good relations with the Indians, who aided him against the Spanish, but there is ample evidence that the Indians eventually realized that they were being driven out of their lands. The half-Indian Mary Musgrove, Oglethorpe's interpreter, who had begun by convincing the Yamacraw chief Tomochichi that he should allow the settlement of Savannah, sixteen years later led an insurrection demanding from the English the return of all the land that had previously belonged to the Creeks.

When the Treaty of Paris (1763) ended Spain's presence in Florida, a new argument over possession of the coastal lands came from the neighboring colony of South Carolina, whose original charter included all the land to the St. Marys River. That claim proved too difficult to make good, however, and in just a few years the Revolution created a new set of friends and enemies on the same ground. The French, whose privateers had plundered the coastal towns in earlier days, sent a large fleet from the West Indies to aid the colonies, and French troops participated in the seige of Savannah. The issue of independence from England had produced divisions in Georgia more bitter than those in other colonies. Many Loyalists fled to Florida, organized a company of Rangers, and made that border once again the scene of sporadic guerilla fighting.

The years after the war have been described as peaceful, and certainly those were prosperous times in coastal Georgia. The early agricultural adventures in silk manufacture, wine-making, and the growing of exotic crops--citrus, olives, dates, etc.--had long since given way to extensive cultivation of rice and indigo, while lumbering, cattle-raising, and naval stores had become important industries. It is interesting to recall, however, that the original impetus for the introduction of slavery into Georgia had been the example of South Carolina's success in growing rice on large plantations, an enterprise that slavery made feasible. So it is fair to say that behind the affluence and genuine grace of the society that emerged in the first half of the nineteenth century, another "debate" went on, a moral one, whose issue would again mean war. Fannie Kemble, the English actress who married Pierce Butler and came to his ancestral home on Georgia's coast only to discover that she could not tolerate the life that slavery made possible there, expressed the dilemma in her famous Journal: "...With shame and grief of heart I say it, by their unpaid labor I live--their nakedness clothes me, and their heavy toil maintains me in luxurious idleness." Journal of a Residence on a Georgian Plantation was not published until 1863, and so stirred sentiment in England against the South that there was no longer a possibility of English support for the Southern cause. If Mrs. Stowe's book, in Lincoln's words, "began the great war", Fannie Kemble's may have been responsible for determining its course.

The plantations were burned, the countryside ravaged, the economy destroyed in the war, and the period of Reconstruction left bitternesses that one hundred years would not erase. Sherman created a short-lived black separatist empire on St. Catherines and Sapelo Islands, and Tunis Campbell, its governor, later took over the ruined town of Darien with an army of freedmen. Yankee carpetbaggers bought land on speculation, and the ancient struggle for control on the coast went on during the long years of recovery. These were the years in which the possibilities of the coast as a vacation-resort area became apparent, and at the end of the century many of the old plantations were being purchased and restored as country estates by millionaire businessmen.

That empire, too, has passed, but the nature of the coastal region as a "debatable land" continues into our own time. Long-time residents and those lately come seeking a livelihood or a second home; investors and developers, ranging from those who use the place-and-family names associated with a plantation site for a subdivision, to the new conquistadors drawing up plans for whole towns; conservationists and university researchers seeking to protect the irreplaceable and complex ecology of the coastal environment; federal and State agencies looking for guidelines for producing growth with the least attendant loss of quality--all of these forces figure in the new struggle. What is most to be hoped for Georgia's coast is that the new order which is bound to emerge from all of this will not be one cut off from the colorful and meaningful past, without deep roots in the communities that have already flourished there. The history of the coastal region of Georgia is absolutely distinctive, and unique solutions will have to be found for preserving that inheritance.

Conservation of Historic and Archaeological Sites

The physical vestiges of that past are as vulnerable as they are vital to our understanding of it. The archaeological site, for example, exists as a hidden repository of evidence, of knowledge essential to the piecing together of man's history and pre-history, giving the problem of its conservation a special character, different from that of an historically significant building. Archaeological sites can be excavated and their store of data retrieved and recorded, so that the land on which they are found may in most cases later serve other functions. But until that investigation is accomplished by competent authorities, a legacy that belongs to every citizen of Georgia is threatened by premature disturbance of the earth where archaeological sites exist.

At the federal level, a battery of legislation exists to protect archaeological and historic sites. The Antiquity Act of 1906 and the Historic Sites Act of 1935 extended assistance and protection to properties of national significance through the National Park Service of the Department of the Interior, an authority broadened by the pivotal National Historic Preservation Act of 1966 to include properties of state, regional, and local significance as well. This Act established the National Register of Historic Places, a "protective inventory" of districts, sites, buildings, structures and objects significant in American history, architecture, archaeology and culture. The criteria for evaluation for a potential nomination to the Register stress integrity of location, design, setting, materials, workmanship, feeling, and association, and the following four characteristics:

(1) Association with events that have made a significant contribution to the broad patterns of our history; or

(2) Association with the lives of persons significant in our past; or

(3) Embodying the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or

(4) That have yielded, or may be likely to yield, information important in prehistory or history.

The procedure for nomination to the Register requires that application be made on behalf of a property by a State

Liaison Officer appointed by the Governor to supervise the program within the State. In Georgia, the Historic Preservation Section of the Department of Natural Resources is the agency responsible for surveys and nominations.

The National Historic Preservation Act also provides a program of matching federal funds, dispersed by a grant to the state, to support the preservation work of public or private agencies and individuals. Perhaps most important for the cause of conservation is the provision that no federally-financed project may cause in any way the demolition or degradation of a National Register listing.

The Department of Transportation Act of 1966 and the National Environmental Policy Act of 1969 both acknowledge that the preservation of historic and cultural resources is a national concern of high priority. They prohibit, except in extreme circumstances, any actions on the part of a federal agency that would impair protected sites, recognizing that preservation is an environmental activity and not just the concern of architects and historians. NEPA requires that federal agencies prepare in advance a detailed description of what adverse environmental consequences, if any, may result from a proposed project.

Executive Order 11593, "Protection and Enhancement of the Cultural Environment", of May 1971, further assures that the federal government will take the lead in "preserving, restoring, and maintaining the historic and cultural environment of the nation" by adequate care for the cultural resources under federal ownership, nominating suitable sites, structures, and objects to the National Register. The order also makes mandatory the institution by federal agencies of procedures which would guarantee that their own plans and programs contribute to the "preservation and enhancement of non-federally owned sites, structures, and objects of historical significance."

Most recently, Public Law 93-291 (the Moss-Bennett Act of 1974) provides that whenever a federally funded or licensed activity threatens the loss of significant data, an appropriate historical or archaeological authority may petition the Secretary of the Interior to undertake whatever surveys or reports are needed to assure the recovery and protection of the data, or to require that up to one percent of the project's funds be used for that purpose. In January of 1975, the Housing and Community Development Act of 1974 began providing block grants to local governments through the Department of Housing and Urban Development, allowing them to undertake historic preservation projects as part of their urban renewal programs.

Action at the State and Local Level

The importance of this legislative support for the conservation of cultural resources is that standards of concern are established by which state, regional, and local agencies and interested groups may judge their own priorities; what the federal government is saying, in effect, is that no action of theirs shall do harm to any portion of our national heritage.

To the extent that they can impose this judgment on non-federal agencies or individuals, by withholding funding or licensing, they intend to do so. Developers who ignore these strictures may find themselves subject to work stoppages, court injunctions, and other time-consuming and costly delays. Potential as well as actual historic or archaeological sites are protected, and anyone considering alteration of such property should seek the advice of the Historic Preservation Section of the Department of Natural Resources in Atlanta before disturbing the property in any way.

Georgia has willingly cooperated with the national effort to develop programs for the conservation of cultural resources. In 1972, Governor Jimmy Carter established the Georgia Heritage Trust, whose task it is to discover, assess, acquire and protect those properties which ought to be enjoyed by all Georgians. Under this program, Wormsloe and Hofwyl-Broadfield Plantations, for example, have been acquired for the enjoyment of all Georgians.

The State effort has always depended for its effectiveness on the valuable support and competency of local groups and individuals interested in historic conservation. The newly-revised edition of the State's Historic Preservation Handbook addresses itself to these groups and seeks to provide them with a working tool for "preservation, restoration, reconstruction, and rehabilitation" within their own communities. The emphasis in the handbook is one with which coastal planners and citizens need to be familiar:

> In the 60's and 70's historic preservation has become more concerned with community planning and less with pure history. No longer mainly saving a few super historical sites, historic preservation now concerns itself with all manmade evidences of the past--individually and collectively--that by age or character contribute to the total environment. Thus, an old building or group of buildings, or public square that lends dignity and stability to a community, is given a priority to be saved for its association with earlier generations and the foundations of the community. Preservation of historic structures, objects, and sites is fundamentally tied... with continued use and function...Whole districts become a focus of attention as opposed to single structures. (Historic Preservation Handbook, pg. 54.)

This concern with the larger environment should appeal especially to those interested in the future of the coast, because it suggests the possibility of new and more positive approaches to the work of preserving the past, especially in rural areas. An example of this new awareness of the cultural significance of regions is furnished by the recent purchase of Drayton Hall, South Carolina, by the National Trust for Historic Preservation and the Charleston Foundation. Drayton Hall is in the Carolina low country twelve miles from Charleston, a property of 625 acres of land and marsh on the Ashley River, in a landscape punctuated by plantations, old rice fields, a church and a fort--the analogy with parts of coastal Georgia is quite clear. An article in the quarterly Historic Preservation describes what the expectations are for this area:

> In the region surrounding Drayton Hall are elements of different activities from the area's history--from rice growing to phosphate mining, from an old fort to an old church. In addition to Drayton Hall there are two other major plantations...With coordinated planning by public and private landowners along the Ashley, with adequate land protection,

easements and buffering on the other side of the river, with carefully designed public park land, the cultural, commercial and social history of the Ashley River region can come alive again not as a packaged restoration, but as a blending of diverse elements into a dynamic historic and cultural landscape region. At the same time, the river would be environmentally protected. (Ann Satterthwaite, "A New Meaning for Landscape", Historic Preservation, July, 1973.)

Another interesting precedent may be seen in the plans for a unique historic trail system in western Montgomery County, Maryland. Developed under grants from the National Endowment for the Arts, the county planning board, and a private foundation, the plan calls for a system of hiking, biking, canoeing, and horseback-riding trails in a 100-square mile area, to be integrated with natural sites and about 250 historic sites from Indian times to the present. Historic themes, such as nineteenth-century agriculture, railroading, and vernacular architecture will be included. One trail, for example, will run from a sandstone quarry on the side of Sugarloaf Mountain following an old railroad line to the Monocacy Aqueduct, built of stone from the quarry. ("Historic Trail System Planned in Maryland", Preservation News, September, 1974, pg. 3.)

The more familiar notion of "shunpikes"--scenic roads designed to attract travelers away from the interstates and into the towns and countryside through which they are passing--are going to work only if there is something really worth seeing and experiencing; here again, isolated sites provide much less incentive than an entire region that offers a unique and pleasant landscape, rich in a history and culture that has been made accessible to resident and visitor alike. No one needs to argue the economic asset that tourism can provide for a community, but the effort to attract tourists is often short-sighted and opportunistic. When a community determines to expend every effort to save itself from the universal sameness that afflicts so many American towns and rural landscapes, when it takes bold steps to see that part of what it has been in the past shapes the look and feel of life there today, then other Americans will want a chance to come, and see, and learn, and appreciate the unique achievement it represents.

But such towns and countrysides do not just happen, and the "bold steps" require the commitment of all those persons who care about the future of the coast. The State of Georgia and the federal government are clearly sympathetic to the need for affirmative action to prevent continued loss of cultural resources, but the initiative for determining what is needed ought to come from the communities themselves. Existing State and federal legislation needs the reinforcement of local ordinances measured to the specific needs of individual communities. Individuals, local government and community organizations must themselves contribute to on-going surveys of their own resources that will continue to reveal possibilities for the enhancement of their environment. Some kind of statement of their philosophy and goals in the conservation of historic and archaeological sites is needed, in order to determine what legal controls will best effectuate the community's intentions. Officials and citizen groups must also keep themselves informed about current thinking in preservation and planning studies, such as the movement to encourage local governments to establish a "revolving fund" for the temporary acquisition of threatened sites or structures, or to grant reasonable tax exemptions to those who undertake the restoration of buildings in whose welfare the whole community has an interest. Legislation can also make possible scenic and facade easements as devices for preserving the character of a site without actual purchase. The possibilities are endless for communities with a will to see their vision become a reality.

Federal guidelines for the development of Coastal Zone Management programs specifically state that "there is room to exercise strengthened design and management imagination and creativity under this program...While past research and planning efforts have often been limited by existing law, policy, and practices, the Act encourages creative approaches to action, programs for orderly development, and preservation or restoration of areas within the coastal zone for their conservation, recreational, ecological, or esthetic values..." (<u>Federal Register</u> Vol. XXXVIII, no. 229, pg. 33047.) This is a challenge which all those who love the coast, islanders and inlanders alike, hope will be adequately met--and in time.

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CHAPTER 8

Soils Information for Coastal Georgia

by

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Soil Characteristics and Mapping

Soil is a natural resource and is one of the most important components of a natural resource inventory. Soil forms the upper layer of the ground and results from the combined geologic, hydrologic, biologic, and meteorologic processes. It is composed of mineral matter, dead organic material, living organisms, gases, water and dissolved substances which are the products of climatic influences, geologic parent material, relief, vegetation, animal activity and time.

Much that is important to man takes place in the soil, and soil is, directly or indirectly, the foothold for much of the life-supporting activities on earth. It and the associated living organisms are the natural medium for the growth of plants; its properties and living organisms serve man by consuming wastes and purifying water; its surface and mantle serve as a foundation for buildings, roads, and most man-made structures. Thus, the understanding of the dynamic, biophysical soil system is of great assistance in determining the location of land uses in order to sustain the uses with minimum deleterious effects. Conversely, the ability of soils to sustain use is a function of the type and amount of impact that natural processes and man's activities have upon them.

The soils of the coastal region of Georgia have been or are in the process of being mapped at two different levels of detail; the general soil map and the detailed soil map. Through the Resource Assessment Program of the Georgia Department of Natural Resources, general soil maps (also called soil association maps) prepared by the Soil Conservation Service, U. S. Department of Agriculture, are being made available at a scale of 1" equals 1 mile (1:63,360) and 1" equals approximately 4 miles (1:250,000) for every county in the State. The nature of the information is similar on both scales of maps.

A soil association is defined by the Soil Conservation Service as:

> ...a landscape that has distinctive proportional pattern of soils. It normally consists of one or more major soils and at least one minor soil, and it is named for the major soils. The soils in one association may occur in another, but in a different pattern. (Wilkes, et al., 1974).

As a result of different uses, anticipated changing needs, and the preparation of different county maps by different individuals, there are some discontinuities in data along county boundaries. This is not a significant problem at this level of generalization.

The more detailed soil survey, in which phases of soil series form the mapping units, has not been completed for all of the coastal region. Published reports have been completed for Bryan and Chatham counties (Wilkes, et al., 1974) and McIntosh County (Byrd, et al., 1961), although the 1961 report is not completely consistent with the 1974 report due to the implementation of the National Cooperative Survey, resulting in certain changes in definition of soil series and in procedure during the period between the surveys. In addition, field mapping has been completed for Glynn County, and is in progress for Camden and Liberty Counties. SCS defines soil series as being made up of soils that have profiles (the sequence of natural layers, or horizons, in a soil, extending from the surface down into the parent material) almost alike. The soils in a series are then divided and mapped as phases on the basis of differences in the surface texture, slope, stoniness, or other characteristics since these affect the use of the soils by man (Wilkes, et al., 1974). The mapping is usually done at scales of 1:15,840 or 1:20,000.

The two levels of mapping and description must be applied in different ways in land use planning. The soil association maps are useful for obtaining a general idea of the soils in a region (a county, for example), comparing different parts of a region, or locating large tracts that are suitable for a certain kind of land use. They are not suitable for planning the management of farms or fields, or for selecting the exact location of a road or building because of the variability in characteristics of the soils which may make up an association (Wilkes, et al., 1974). For the latter purposes, the use of the detailed soil surveys is necessary, since they can provide reliable information for sites as small as three acres. Even with the detailed surveys, further investigation in the form of field work will be necessary for such things as checking the specific site for a septic tank location or for completing the final design and installation of engineering structures.

The major soils of the coastal region of Georgia (Bryan and Chatham Counties being generally representative of the region) are described by Wilkes, et al., (1974) as chiefly having

> ...a sandy surface layer over a loamy or sandy subsoil or underlying layers. These soils are mainly nearly level or gently sloping and occur as broad, smooth areas drained by wet depressions. They generally are seasonally wet or almost always wet, except for the better drained soils on the slight ridges and dune like relief.

The factors that have led to the formation of this basic pattern of soils are also described by Wilkes, et al.,(1974), and their material follows.

Parent Material

Parent material is the unconsolidated mass from which soil forms. It largely determines the chemical and mineralogical composition of a soil. The soils in Bryan and Chatham Counties formed from transported materials.

The area shows evidence that the land was submerged by the ocean in stages. This is especially true for those areas less than 40 feet above sea level. The formation of barrier islands, tidal marshes, and lagoons during each stage promoted the sorting and mixing of the sediments. As the ocean retreated to its present position, soil-forming processes developed the soils as we know them today. Barrier islands of sand were formed by tides and winds, and these islands were left as the sea level dropped. The sandy Lakeland, Chipley, Osier, and Kershaw soils developed in these sandy materials. Because of their sandy origin, these soils have faintly developed horizons. Lagoonal-tidal marsh sediments are characterized by mixed sand, silt, and clay. Capers soils developed from clay in present tidal marshes, and Pooler, Meggett, Ogeechee, and Cape Fear soils developed from clayey deposits in relics of lagoons and tidal marshes. Albany, Craven, Ellabelle, Pelham, Wahee, and Olustee soils developed from mixed sand and clay sediments that were affected by tidal streams and estuaries.

The older areas more than 40 feet above sea level have been somewhat eroded, and the land features showing marine influences are not so distinct as in the lower areas. The soils at the higher elevation are similar in both chemical and mineralogical composition to those of lower areas, and geological erosion has exposed older deposits to the soil-forming processes. Lucy and Dothan soils developed from older exposed sediments.

The Angelina, Bibb, and Johnson soils formed in recent alluvium that washed from the Coastal Plain and was deposited by the larger streams. These materials are mixed sand and clay and are within the stream flood plain.

A series of sand ridges are on the northeast side of the Ogeechee and Canoochee Rivers and on the present barrier islands. These ridges are quartz sand probably deposited by wind. Kershaw soils formed in this sand.

Climate

Climate affects the formation of soils through its influence on the rate of weathering of rocks and on the decomposition of minerals and organic matter. It also affects biological activity in the soils and the leaching and movement of weathered materials through the soils.

Bryan and Chatham Counties have a warm, moist climate. The average annual temperature is about 66°F. The temperature averages about 51° in January and about 81° in July. The average rainfall is between 45 and 50 inches. The warm, moist climate promotes decomposition of organic matter almost the year round, and only where the soils are waterlogged do appreciable amounts of organic matter accumulate. The abundant rainfall removes calcium, magnesium, and other basic elements and replaces these cations with hydrogen. As a result, hydrogen is the dominant cation and makes most of the soils highly acid in reaction. Also, the movement of water through the soil translocates other soluble material and colloidal matter into the lower layers. The result is that the soils in Bryan and Chatham Counties have chiefly a sandy surface layer over clay-enriched layers. Exceptions are the Kershaw, Lakeland, and Chipley soils, which formed in quartz sand.

Relief

Relief, or the differences in elevation, influences soil formation through its effect on drainage, runoff, erosion, and percolation of both water and air through the soils.

Precipitation is not absorbed by the soil where the rainfall rate is faster than the infiltration rate or where the soil is already saturated with free water. Low-lying areas stay wet for extended periods. When a soil is wet, decomposition of plant tissue is retarded. Consequently, more organic matter accumulates in the surface layer of poorly drained and very poorly drained soils than in better drained soils. Because relief is low througnout most of the survey area, the soils in about 60 percent of the acreage are poorly drained or very poorly drained.

The greatest differences in relief in the survey area occur in Bryan County west of the Ogeechee River and north of the Canoochee River. Elevation increases from about 30 feet to about 80 feet above sea level within a mile. The gradient is such that geological erosion has lowered the streams to well below the general land surface. Most of the well-drained soils occur in this part of the survev area.

In wet or ponded soils, movement of air is restricted and the oxygen content is lower than in well-drained soils. Oxygen is removed from some of the iron and aluminum compounds of the subsoil, causing gray mottles or dominant gray colors in the B horizon. This explains why the Pelham, Ellabelle, and other poorly drained and very poorly drained soils have dominant gray colors just below the surface layer, why the Ocilla and other somewhat poorly drained soils have gray mottles in the upper part of the B horizon, and why the Fuquay and other well-drained soils have uniform yellow to red colors free of gray mottles to a depth of at least 3 to 4 feet.

Plants and Animals

Various plants, animals, and bacteria are active in the soil-forming processes. The changes they bring about depend mainly on the kinds of life processes peculiar to each. Plants furnish most of the organic matter available to the soil. Grass-type vegetation returns to the soil most of the plant tissue produced each year. Forest vegetation, however, returns only part of the tissue in the form of leaves. Organic matter accumulates mainly in the surface layer.

In about 75 percent of the acreage of the survey area, the soils formed under forest vegetation. The organic matter produced under forest vegetation is enough to give the surface layer a dark color and an organic-matter content of about 1 to 3 percent. It is not enough to add appreciable amounts of organic matter to the surface layer except where excess water slows decomposition. If waterlogged the surface layer has higher organic-matter content and is darker and thicker than it is in drier areas. The uprooting of trees by wind also affects the formation of soils through the mixing of soil layers.

About 25 percent of the survey area has marsh or grass-type vegetation, and the surface layer is higher in organic-matter content than in forested areas. The surface layer of some marsh soils contain as much as 15 percent organic matter.

Small animals, earthworms, insects, and micro-organisms influence the formation of soils by mixing organic matter into the soil by helping to break down plant residue. Small animals burrow into the soil and mix the layers. Earthworms and other small invertebrates feed on the organic matter in the upper few inches. They slowly but continually mix the soil material and may alter it chemically. Bacteria, fungi, and other micro-organisms hasten the decomposition of organic matter and the weathering of minerals.

Time

The alteration of soil materials so that deep, distinct layers develop in the soil requires time. The length of time that geologic materials have remained in place is commonly reflected in the distinctness and thickness of the horizons in the soil profile.

Craven soils are formed in parent material that is less than 35 feet above sea level and has distinct layers. Dothan soils formed from geologically older parent material that is more than about 70 feet above sea level. They have had more time to form and their clay-enriched layers are thicker than those in the Craven soils. Also, Dothan soils have concentrations of oxides in the form of nodules of ironstone and soft plinthite.

The sand soils that formed in homogeneous deposits of quartz sand typically lack distinct genetic layers because quartz sand resists alteration by the soil-forming processes.

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CHAPTER 9

Vegetation Information for Coastal Georgia

by

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Department of Natural Resources

The Importance and Use of Vegetation Information *

Vegetation is the basic biotic component of an ecological system. It is the immediate source of almost all of the necessary minerals used by the animal components of an ecosystem, it plays a fundamental role in the cycling of oxygen and carbon through the processes of photosynthesis and respiration, it functions as the energy-fixer for an ecosystem, and it acts as a modifier of climate, pollution, and landscape form.

Much of the documented evidence concerning vegetation's role in noise and air pollution abatement, climatology, runoff control, and landscape form is given in terms of vegetation

* General introductory material is taken from Chaney, *et al.*, 1974.

structure (the density and distribution of leaf structures vertically, laterally, and horizontally) rather than species present (floristics). Of course, the types of species present determine the structure of the vegetation at any particular point in time, but the structural changes that occur over time can influence the floristics by various means and therefore control, to a certain extent, the future structures.

For land use planning, consideration must be given to the present structures, the longevity of those structures, the uses being made of the structures, and the probable succeeding structure. In addition, the effects of such events as fire, cutting, cultivation, abandonment, and development on the structure, and the probability of the spatial occurrence and extent of the events must be considered. To make an analysis of the extent to which such effects as soil erosion, runoff and peak flow will increase as a result of various changes, the vegetation structure must be described in a meaningful way.

Plant species generally do not occur singularly, but in association with many other species of plants and animals. A wide variety of factors interact to produce patterns of individuals and associations of species. These associations are interacting organizations that utilize energy and raw materials in such a way they form distinct living systems (communities) with their own composition, structure, and functional characteristics. As a result, vegetation is a delicate integration of environmental conditions and can, to a certain extent, be used as an indicator of such conditions. Species of plants are seldom restricted only to certain areas, however. The occurrence of a single species is not usually considered definitive proof of environmental conditions or plant species relationships. The ratio of different species to another often provides more useful clues. Billings (1965) describes the advantages and disadvantages of using vegetation as an indicator of environmental conditions (Table 9-1).

Classifying and mapping vegetation classes is not an easy task. Each species has a range of tolerance for each of many individual environmental factors, and its distribution depends on its tolerance for and the distribution of those environmental factors. Bozeman (1975) lists the principal factors which affect the distribution of plant and animal species (Table 9-2). The interaction of all these factors adds up to a mosaic of different species of different ages occurring in different places at different times.

Regardless of the system of mapping used, delineating the vegetation boundaries is a problem, and the ultimate problem lies in the nature of the vegetation. When plant communities merge gradually, as they do in nature, the person preparing maps is faced with the problem of establishing boundaries based almost entirely on arbitrary decisions (Kuchler, 1973). The basic principle of systems for synthesizing data from similar stands is the repeated occurrence of groups of species or structure. Often, characteristic or key species may be

Table 9-1

Vegetation As An Environmental Indicator

Disadvantages:

1) Because of the time necessary for growth, vegetation usually lags somewhat behind the actual conditions that allow it to be established. Trees, being slow growing, may indicate conditions that occurred a long time ago; many trees can tell us the date and extent of prehistoric forest fires. Thus, there are also some advantages to this lag.

2) It is difficult to express the environmental indications of vegetation in physical terms. Every vegetational stand is a reflection of its past and present total environment, but it is difficult to transpose this information into physical units that can be used quantitatively in equations.

Advantages:

1) Vegetation can indicate past environmental conditions and events such as forest fires or past climatic cycles. No physical instrument can do this.

2) Vegetation can tell us much about soil conditions: salts, available nutrients, physical structure, capacity for crop or timber yield. Once the original correlation is established, the vegetation can be used as a soil indicator without digging a hole or taking soil samples.

3) Because of the difference in palatability of various plant species to animals, vegetation is a very delicate indicator of the kinds and numbers of animals present and the grazing history of the land. Range ecologists can often tell at a glance whether a given area is overgrazed or can profitably carry more stock.

Source: Billings, W. D., 1965, Plants and the Ecosystem.

Table 9-2

Principal Factors Determining Plant - Animal Distribution

1. Climatic Factors (Primary Importance)
   a) temperatures
      mean annual, maximum and minimum
   b) precipitation
      distribution, amount, form
   c) atmospheric humidity
   d) light
      intensity, duration, quality
   e) wind
   f) potential evapotranspiration (an integrated expression)
   g) water chemistry

2. Edaphic (Soil) Factors
   a) available soil water
   b) soil aeration, oxygen
   c) soil temperature
   d) quantity and nature of soil solutes
   e) pH
   f) soil texture

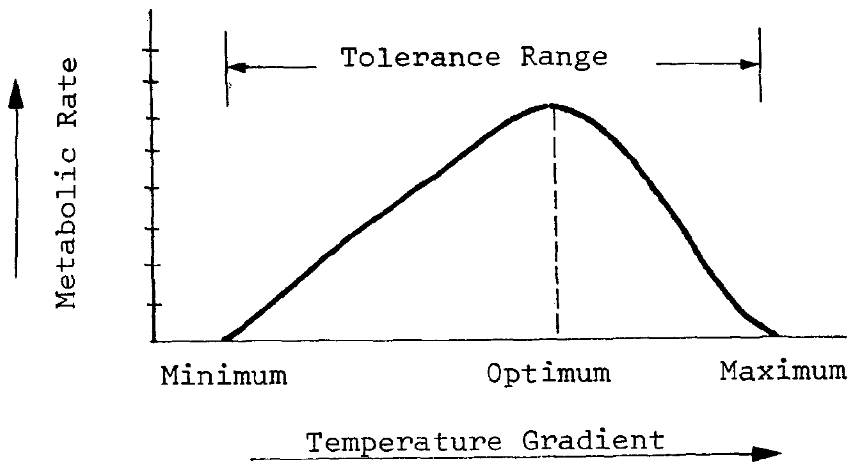
3. Biotic Factors
   a) intra-and interspecific competition, food availability
   b) grazing and predation pressures
   c) parasitism (animal, fungal, bacterial, viral)
   d) mutualistic relationships
   e) man

4. Other Factors
   a) fire, intensity and frequency
   b) altitude and latitude
   c) topographic effects of slope, exposure
   d) pollution
      pesticides
      agrichemical run-off
      industrial wastes
      biologic - human wastes
                 animal wastes
   e) geologic
      biological history of organism
      physical barriers to dispersal
      geologic catastrophy and processes
   f) chance distribution or dispersal

(Table continued on following page.)

Table 9-2

Principal Factors Determining Plant - Animal Distribution (Cont'd)



Temperature response curve for a typical animal, showing maximum and minimum temperature tolerance, tolerance range, and optimum.

Source: John R. Bozeman, Department of Biology, Georgia Southern College.

designated on the basis of their restriction to a particular community. The problem again is that some areas are representative and some are not.

In addition to the problems mentioned, there lies a larger argument which centers on the definition of vegetation types and the definition and desired accuracy of the boundaries considering variations in substratum (water, soil, rock) and the amount of disturbance affecting the vegetation. Some authors argue that plant species distributions shift along environmental gradients, the resulting situation being not one of clusters of similar species, but rather one of the species of one area imperceptibly blending with those of contiguous areas - a continuum of populations. Of late, Whittaker (1970), a strong supporter of the continuum theory, has stated that communities or associations are not mutually exclusive of continuum, and that the existence of both must be accepted. Monk (1968) supports this view in his discussion of the successional relationships of the vegetation of north-central Florida, an area whose vegetation patterns are very similar to those of mainland Georgia. Kuchler (1973) points out that it is difficult to distinguish between transitions (ecotones) between communities and the continuum. This is particularly true in coastal Georgia where there are slight variations in such factors as relief, slope, and water table level. Thus, the boundaries between the community types are often broad transition zones (Bozeman, 1975; Monk, 1968). The problem then circles back to the original consideration of boundaries.

Classifying vegetation means identifying "communities" with natural or arbitrary boundaries (stands). No two stands will be exactly alike, but various stands will resemble one another more than other stands. Stands that resemble one another more than other stands collectively make up a vegetational type.

Vegetation Information Available for Coastal Georgia

The vegetation of the coastal region of Georgia has been classified and mapped as a scale of 1" = 1 mile as a part of the statewide Georgia Resource Assessment Program. The method by which the categories were defined and mapped (largely based on difference in physiographic location and physiognomic characteristics observable on 1" = 1 mile aerial photo mosaics) means that the mapping units are more appropriately designated as vegetative cover types than as true community types. Monk (1968) has defined community types for an area of north-central Florida which are very similar to those found on the mainland of coastal Georgia (Bozeman, 1975). The vegetation cover types are generally analagous to the community types, but there are differences due to the aggregation of elements of different community types into a vegetation cover type because of (1) the difficulty of distinguishing subtle difference in the mixture of species between two closely related community types from the 1" = 1 mile aerial photo mosaics, and (2) the difficulty of mapping at the 1" = 1 mile scale small areas of distinguishable vegetation types.

In addition to the work done for the Georgia Resource Assessment Program, there have been several other descriptions and mapping of selected areas of the coastal region. Johnson, et al, (1971) provides a good overview of the natural history and ecology of the marshes, islands, and estuarine waters. They do not, however, discuss the mainland conditions. Detailed vegetational analysis and mapping has been done for Cumberland Island (Bozeman, 1975), St. Catherine's Island (McCormick, Ashbaugh, 1972), and the marshes of McIntosh County (by Dr. Robert Reimold and Richard Linthurst, Sapelo Island Marine Institute, University of Georgia). These studies go well beyond the level of detail of the mapping available for the entire coastal region, and are more appropriate for site specific, operational planning analyses. In that sense, these latter studies are analogous to the soil series and phase mapping while the vegetation mapping for the entire coast is roughly comparable to the soil association mapping. Generally speaking, stronger correlations exist between the vegetation types identified in the individual detailed studies and the soil series and phases than between the soil associations and the vegetation types identified through the Georgia Resource Assessment Program (Bozeman, 1975).

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CHAPTER 10

This chapter is excerpted from An Ecological Survey of the Coastal Region of Georgia, A Report to the National Park Service, by A.S. Johnson, H.O. Hillestad, S.A. Fanning, and G.F. Shanholtzer, August, 1971. This material has been reproduced with the permission of Dr. A.S. Johnson and the National Park Service.

THE MARSHES

A 4- to 6-mile band of marshland comprising about 393,000 acres (Spinner 1969) lies behind the barrier islands. Nearly 286,000 acres of this is covered by a single species of marsh grass, known as saltmarsh or smooth cordgrass. (See Table 12 for scientific names of marsh plants not given in the text.) The remaining 106,000 acres consists of several other types of salt, brackish and freshwater marshes.

Formation and Sediment Characteristics

Tidal marshes are formed in conjunction with barrier island development. When sea levels rise, dune and beach ridges become partially submerged. Water filling the trough between these structures and the mainland or other barrier islands is subject to relatively less energy perturbation than open waters, and clay and silt sediments suspended in the water are deposited, leaving a mud type substrate. In time, salt tolerant marsh plants such as cordgrass stabilize the area.

Deposition continually occurs on the tidal marsh, but at a very slow rate. The added weight of the sediment contributes to submergence and the accumulation of additional sediments (Hoyt 1968d). As flood tides rise above creek banks and inundate the marsh floor with a shallow layer of water, the energy maintaining the sediments in a suspended state is reduced, and the sediments drop out of suspension. As the tides recede, some sediments are resuspended, but this amount averages less than that of flood tides. The receding tide waters form an extensive drainage system of tidal creeks and rivers. (Figure 26), not included. Some tidal channels erode deeply enough to expose Pleistocene sands and frequently penetrate barrier island deposits (Hoyt et al. 1966).

Four sources contribute to the suspended material that is deposited in the marsh: (1) continental shelf, (2) mainland rivers, (3) the marsh itself, and (4) organic deposits (Levy 1968). Continental rivers are the principal source of this material which is distributed and sorted by longshore currents, waves and tidal currents (Neiheisel and Weaver 1967).

Superficial deposits are up to six feet deep. Cross-bedding related to channeling is common (Henry and Hoyt 1968). Total depths of recent marshes range from 30 to 50 feet (Hoyt et al. 1964).

Grain size of sediments in the marsh range from clay to fine sand. Large amounts of sand from reworked sandy sediments are locally common. Teal and Kanwisher (1961) have analyzed the salt marsh substratum for per cent sand, silt, clay, organic matter, and roots. Their results show that higher marsh sites have more sand and less organic matter than lower marsh sites. When saturated on high tides, the upper layers of marsh mud contain 50 to 70 per cent (wet weight) water (ibid.).

Two distinct layers of salt marsh sediments are revealed in cross-section. The aerated and leached sediments of the upper few centimeters are brown. The sediments below are black and rich in reduced organic end products including hydrogen, sulfide, methane, and ferrous compounds.

Although marsh soils are normally neutral or slightly alkaline, some of them have the potential to become extremely acid under certain conditions. When marsh soils containing large amounts of organic matter are regularly flooded and anaerobic conditions exist, the sulfates in sea water are reduced and precipitated as sulfides. These conditions occur most commonly at the mouths of larger rivers, in brackish water marshes thickly vegetated with species such as big cordgrass and reed cane. So long as anaerobic conditions prevail, soil pH remains high. But when the soils are exposed to prolonged aeration (as in drained areas, dikes or spoil areas), the sulfides are oxidized, and one of the products is sulfuric acid. The soil becomes extremely acid (pH may drop to as low as 2.0) and no plant growth can occur. Such soils are then called "cat clays." The acidity is so severe that it is not feasible to correct the condition by liming and the area may remain barren for many years (Edelman and Staveren 1958, Fleming and Alexander 1961).

Vegetation

The U. S. Fish and Wildlife Service has classified the wetlands of the United States into 20 types (Shaw and Fredine 1956). Six of these are coastal marshes occurring in Georgia. These are characterized in Table 10. The extent of these types of marsh on the Georgia coast is as follows (Spinner 1969):

Types 12 and 13	31,700 acres
Types 15 and 16	650 acres
Type 17	74,850 acres
Type 18	285,650 acres

More specific marsh types may be recognized according to plant associations. Many factors contribute to the determination of plant composition of coastal marshes. These include water levels and fluctuations, salinity, type of substratum, acidity, available nutrients, and fire, among others. Salinity and inundation are most important, and gradients or zonations of vegetation related to these factors are commonly evident. Intolerance for salinity and inundation prevent most species from occupying tidal salt marshes (Table 11), and species diversity is greatest in shallow. freshwater marshes. The harsh combination of critical limiting factors in the marsh produces conditions allowing a few tolerant species such a competitive advantage that they develop pure stands. On the Georgia coast, the most extensive of these monospecific marshes are smooth

TABLE 10. COASTAL WETLAND TYPES OCCURRING ON THE GEORGIA COAST*

Type	Water levels	Characteristic species
12 Coastal shallow fresh marshes	6 inches or less	reedcane, big cordgrass, cat-tail, arrowhead, smartweed
13 Coastal deep fresh marshes	6 inches to 3 feet	cat-tail, wild rice, pickerelweed, giant cutgrass, pondweeds
15 Coastal salt flats	Always wet, but rarely inundated	glasswort, saltgrass
16 Coastal salt meadow	Always wet, but rarely inundated	saltmeadow cordgrass, saltgrass
17 Irregular flooded salt marsh	Flooded irregularly	needlerush
18 Regularly flooded	6 inches or more at high tide	smooth cordgrass

*From Shaw and Fredine 1956.

TABLE 11. RELATIVE SALT TOLERANCE OF SOME PLANTS IMPORTANT IN THE COASTAL MARSHES OF GEORGIA*

Species	Per cent salt
sawgrass	0.00-0.20
cat-tail	0.00-1.68
giant cutgrass	0.00-0.89
reedcane	0.00-2.04
southern bulrush	0.00-1.13
Olney's three-square bulrush	0.55-1.68
salt marsh bulrush	0.64-3.91
needlerush	0.12-4.43
big cordgrass	0.55-2.04
salt meadow cordgrass	0.12-3.91
smooth cordgrass	0.55-4.97
saltgrass	0.45-4.97

*Data from Penfound and Hathaway 1938.

cordgrass, needlerush and giant cutgrass.

Freshwater and brackish marshes

Freshwater marshes occur primarily near the mouths of larger mainland streams and are most extensive at the mouth of the Altamaha River. They may extend for some distance up the rivers before being replaced by cypress-gum or hardwood swamps. Much of the area now covered by freshwater marsh was cypress swamp before it was cleared and diked for rice culture. Shallow freshwater marshes contain a variety of species including cat-tails, several bulrushes, smartweeds, aneilema, arrowhead, arrow arum, and others. The deeper freshwater marshes are more extensive, occupying about 25,000 acres along the Georgia coast. In many areas this marsh type is comprised almost exclusively of giant cutgrass. Stands of sawgrass occur intermittently. Around the deeper margins of the marsh, stands of cat-tail are common and wild rice occurs in sporadic stands. In the deeper creeks and potholes, submersed and floating-leaved plants are dominant.

As salinities increase to brackish conditions (about 0.5 to 2.0 per cent), giant cutgrass is replaced primarily by big cordgrass and, to a lesser extent, salt marsh bulrush.

Salt marsh

Most indigenous plants cannot survive salinities approaching sea strength; they are replaced in the salt marsh by a few species with high salinity tolerances. Included in this group are smooth cordgrass, needle rush, saltgrass, glasswort, salt meadow cordgrass, and sea oxeye (*Borrichia frutescens*).

The salt marshes of the southeastern states have been the subject of much study. Studies of plant associations in the salt marshes of North Carolina have been reported by Wells (1928), Reed (1947), Bourdeau and Adams (1956), and Adams (1963). Kurz and Wagner (1951) reported on salt marsh vegetation in Florida and at Charleston, South Carolina. General treatments of salt marshes include those of Townsend (1925), Ragotzkie et al. (1959), Chapman (1960), and Teal and Teal (1969).

Of the local marsh plants only smooth cordgrass is adapted to both the salinities and the tidal fluctuations of the low tidal marsh. Teal and Teal (1969) describe the adaptive mechanisms in smooth cordgrass that enable it to exist in the marsh. Root membranes prevent the entry of much salt into the plant, and the cells selectively absorb sodium chloride to maintain osmotic pressure and prevent plasmolysis. Special glands on the leaves excrete excess salt.

Ducts in the stems carry oxygen to the roots of the plant, where it is used in the oxidation of iron sulfides to soluble iron compounds that are used by the plant. The high iron requirement of smooth cordgrass is one of the factors that restrict it to the salt marsh (Adams 1963).

Smooth cordgrass and most other salt marsh plants grow best in fresh water, at least under laboratory conditions (Taylor 1939). But they do not commonly occur in freshwater marshes, partly because they are unable to compete with more vigorous species. Their tolerance to salt stress enables them to persist in the salt marsh free of competition. Thus, zonation in the salt marsh is primarily related to elevation as it determines frequency, depth and duration of inundation, and soil salinity.

The zones of the salt marshes of the southeastern United States have been classified in various ways (Wells 1928, Penfound 1952, Adams 1963, Teal 1958, Stalter and Batson 1969, and others). Following is a description of the usual gradient in vegetation in Georgia salt marshes, proceeding generally from the tidal creek landward (see Figure 27). Unless otherwise indicated, _Spartina_ used hereafter refers to smooth cordgrass.

A portion of the creek banks exposed at every low tide is devoid of vegetation. These banks are composed of sand, mud or oyster shells. Slumping occurs along some banks and results in relatively large deposits being exposed directly to tidal currents. The upper slopes of the banks are vegetated with smooth cordgrass. The cordgrass grows tallest here (3 to 10 feet), and Teal (1958) designated this zone the "tall _Spartina_ edge marsh." The cordgrass grows to about 3 feet on top of the levees. Teal (ibid.) called this zone the "medium _Spartina_ levee marsh."

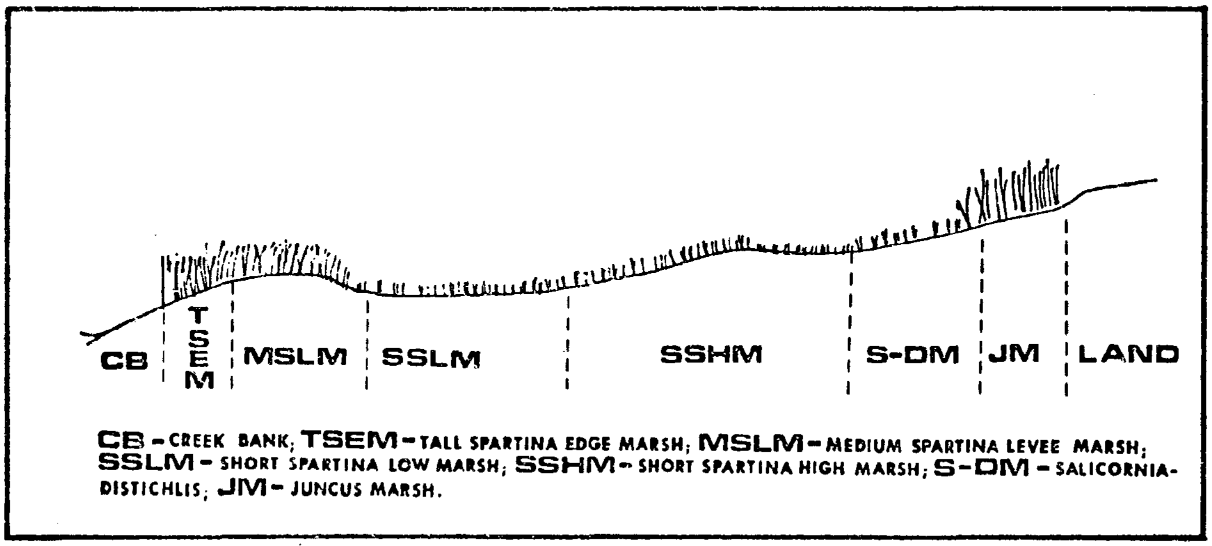

Figure 27. Typical profile of a salt marsh showing the marsh types described by Teal 1958. (Adapted and redrawn from Teal 1958.)

Behind the levees the marsh is thickly vegetated with smooth cordgrass and is covered by every tide for several hours each day. Sand content is 0 to 10 per cent (Teal 1958). Teal (ibid.) called this area the "short *Spartina* low marsh." Stalter and Batson (1969) designated this zone together with the creek banks and levees as the "low low marsh."

With increasing elevation toward the edge of the marsh, inundation is to a lesser depth and is for a shorter period of time. Sand content is from 10 to 70 per cent (Teal 1958), and salinity of the soil beneath the cordgrass progressively increases (Penfound and Hathaway 1938, Bourdeau and Adams 1956, and Stalter and Batson 1969). A dwarf form of smooth cordgrass occurs in this zone that is probably a genetic variant, environmental conditions reinforcing the differences between the two forms (Broughton and Webb 1963, Stalter and Batson 1969). Teal (1958) termed this zone the "short *Spartina* high marsh," and Stalter and Batson (1969) called it the "high low marsh."

At elevations where the marsh is flooded for only about one hour each day, the dwarf *Spartina* gives way to other species: notably glasswort, saltgrass, sea oxeye, and sea lavender (*Linomium carolinianum*). Sand content is 85 to 95 per cent in this zone (Teal 1958). This zone is called the "*Salicornia*-*Distichlis* marsh" (Teal 1958) or the "low high marsh" (Stalter and Batson 1969).

Sandy, unvegetated areas are locally common in the higher portions of the marsh. These areas are commonly called salt barrens or salt pans. Subject to infrequent flooding and rapid evaporation, the barrens are too saline to support vegetation. Glasswort occurs around the margins and grades into saltgrass.

Salt meadow cordgrass (which, farther north on the Atlantic coast, forms extensive meadows that are harvested for hay, straw and upholstery stuffing) occurs on the Georgia coast only at the rim of the marsh in a zone that is flooded only a few times each week. Salinity decreases abruptly in this zone (Bourdeau and Adams 1956). Salt meadow cordgrass occurs only where relatively low salinities prevail. Other plants that characterize this zone are high tide bush (*Iva frutescens*), groundsel tree (*Baccharis halimifolia*), and salt myrtle (*Baccharis glomerulifolia*).

Needlerush marsh occurs at slightly higher elevations that are rarely flooded, especially where salinity is lower. It occurs as a narrow zone around the salt marsh on the islands, and forms extensive pure stands in many areas adjacent to the mainland.

Marsh Fauna

Animals that complete their life cylces in the salt marsh have morphological, physiological and behavioral adaptations for coping with extremes of salinity, inundation and exposure in the marsh, and the activity cycles of most species are keyed to the tides.

Following is a discussion of some of the animal forms occurring in the salt marsh: their distribution, abundance and ecological relationships. This information was obtained from published material and from field observations by the authors. The discussion is extended to include rails and waterfowl in the freshwater marshes; otherwise, it is restricted to animals of the salt marsh.

Vertebrates

Mammals.--The harshness of the salt marsh restricts the numbers of resident mammals to a few species. Raccoons are one of the most abundant mammals. Marsh rabbits are common along the edges of the marsh adjacent to high ground. Mink are more common than otter, but both of these carnivores are seen infrequently. The rice rat is common along the levees of tidal creeks.

Mammals that have adapted to living or feeding in the marsh are highly mobile. Raccoons feed in the marsh at low tide and are inactive at high tide regardless of whether it is night or day. They retreat to the higher ground on the mainland or islands at high tide or construct a bed of cordgrass above the high tide level. In freshwater marshes nearby, their activity is mostly nocturnal (Ivey 1948). Mink and otter are well adapted to feeding in the aquatic environment of the marsh, but they often retire to higher ground for nesting and denning purposes. Kale (1965) stated that mink may spend much of their life in the marsh. He observed that they constructed beds of dead cordgrass on the high ground of the marshes or used hollow tree trunks washed into the marsh. The rice rat is well adapted to spend a 24-hour day in the salt marsh. The rat constructs its own nest in the tall Spartina or occupies an abandoned nest of the long-billed marsh wren (Sharp 1967).

Food for marsh mammals is abundant but is of limited diversity. Raccoons are known to feed heavily upon fiddler and squareback crabs (Uca spp. and Sesarma spp.), two of the most abundant animals in the marshes. They also prey on the eggs of diamondback terrapins (Coker 1906), clapper rails (Oney 1954), and marsh wrens (Kale 1965). They are not considered a limiting factor on wren populations (ibid.). The food habits of marsh mink are not known for the coastal region of Georgia. Teal and Teal (1969) state that clams and crabs are the principal foods of marsh mink in autumn, and Wilson (1954) reported that fish occurred in 61 per cent of the digestive tracts of mink from marshes of northeastern North Carolina. Oney (1954) listed the mink as a predator on clapper rail eggs. Otters feed mostly on fish. Wilson (ibid.) found fish in over 90 per cent of otter digestive tracts and fecal samples from northeastern North Carolina.

The rice rat is preferentially carnivorous. Studies on Sapelo Island (Sharp 1962, 1967) reveal that during the summer the rats feed primarily on fiddler and squareback crabs and the larvae of the rice borer, with other insects occurring as incidental food items. In the fall, crabs were the major food items, but small amounts of seed and fibrous portions of smooth cordgrass also were used. Kale (1965) attributed considerable egg loss and nestling mortality of the long-billed marsh wren to predation by rice rats. Sharp (1967), however, found no remains of wrens in 22 rats examined, and he suggested that the wren is only an incidental food item during the summer.

Marsh rabbits are characteristic of high marsh and normally do not occur in tidal salt marsh (Tomkins 1955, Teal 1962). Marsh rabbits are strictly herbivorous, but their exact food habits are unknown.

Harvest of marsh furbearers such as raccoon, mink and otter generally is low in the coastal area because of the low market value of pelts, especially from this area. There are an estimated 300 fur trappers (Spinner 1969). Raccoons are taken for food by a small number of hunters; there is no closed season. The only management for mink and otter is the regulation of harvest by an established trapping season.

Birds.--Kale (1965) stated that three species of birds were intimately associated with the salt marsh community in coastal Georgia. These are the long-billed marsh wren, the clapper rail or marsh hen and the seaside sparrow. Kale (ibid.) studied the ecology and bioenergetics of the marsh wren, and Oney (1954) studied the biology, distribution and limiting factors of the clapper rail in Georgia. The seaside sparrow has not been intensively studied in Georgia.

The following discussion of the long-billed marsh wren is based primarily on Kale's (1965) study in the vicinity of Sapelo Island. During the breeding season, the marsh wren establishes territories averaging 100 square meters in the tall *Spartina* edge marsh. Singing males establish breeding territories, and nesting and brood rearing takes place within the territory. The peak of the breeding season is May to July. Predation is the primary cause of mortality of eggs and young. Major predators are rice rats, raccoons and mink. However, mortality factors are minor limiting factors on marsh wren populations; Kale concluded that the highly developed territorial and colonial behavior of the marsh wren was the principal factor limiting population size. A discussion of food habits and bioenergetics of the wren is included in the section on food webs and energy flow.

The clapper rail is a common game bird in coastal salt marshes. Clapper rails begin nesting in the medium *Spartina* marsh early in April. Oney (1954) found that some nests were inundated by as much as 19 inches of water during high tides and hatched successfully. Teal and Teal (1969) also reported that the eggs of the marsh hen can withstand tidal inundation. The major nest predators probably are raccoons, mink and crows. The major food is the squareback crab, which occurs in the soft mud areas of the tidal streambanks. Other foods include fiddler crabs and periwinkle snails (*Littorina* *irrorata*). During the winter months when the crabs become inactive, clapper rails shift to other foods. Richard Heard (personal communication) observed that rails feed on snails (*Melampus* sp.) during cold weather.

The clapper rail is hunted by a small number of hunters (5000 in 1968--Spinner 1969) during the high tides of September-November. Prior to 1948 the rail harvest approached 86,000 birds (Oney 1954). However, the use of outboard motors in rail hunting was prohibited by federal law beginning in 1948 and rail hunting declined sharply. Oney (1954) recommended that outboard motors be allowed in rail hunting.

The king rail, a close relative of the clapper rail, occurs in the freshwater and brackish marshes. Meanley (1969) reported that king rails nested in giant cutgrass and softstem bulrush along tidal canals on the Savannah National Wildlife Refuge. The fiddler crab (*Uca minax*) of the latter habitat is a preferred food of the rail. King rails feed on freshwater insects, fish, crustaceans, and amphibians that are abundant in mats of alligator-weed in the canals and ditches (Meanley 1969).

The willet, although common on beaches, is more common in the salt marsh. It feeds on fiddler and squareback crabs and periwinkle snails in the short *Spartina* low marsh (Tomkins 1965b).

The seaside sparrow has not been studied in coastal

Georgia. Kale (1965) observed that in his study area the seaside sparrow fed primarily on the ground. Howell (1932) listed small crabs, pelecypods, gastropods, dragonflies, grasshoppers, spiders, and beetles as foods.

Wading birds use the marsh as a feeding and nesting area. Five species frequent the marsh in large numbers throughout the year. Other species occur seasonally in the marsh, especially during the summer. Several large rookeries are located on some of the marsh islands. (Figure 34, Appendix 4). not included.

Great blue herons, little blue herons, common egrets, snowy egrets, and Louisiana herons are common residents of the salt marshes. During high tides, they feed in shallowly flooded marsh grass. Snowy and common egrets are most frequently encountered in the marsh at low tide. Cattle egrets have been observed feeding on fiddler crabs near tidal creeks; they feed more commonly near agricultural areas inland.

During the summer of 1970, a large wading bird rookery was discovered on a marsh island in the Altamaha River (Figure 34). This rookery contained, in addition to large numbers of white ibis, 75 to 100 nesting pairs of glossy ibis. Hebard (1950) reported glossy ibis nesting in Georgia, but Burleigh (1958) did not acknowledge his record, and Sciple (1963) considered it too "tenuous" to accept. The observation of glossy ibis nesting in Georgia in 1970 fills the hiatus in the breeding distribution for this species as noted by Teal (1959).

Georgia is within the Atlantic Flyway of migratory waterfowl, and the coastal region is on the southern portion of the flyway. The major species of ducks occurring in this flyway include mallard, black, pintail, gadwall, baldpate, shoveler, green-winged teal, scaup, ring-necked, and canvasback. All of these species occur in varying numbers along the Georgia coast. The number of waterfowl wintering on the Georgia coast has been affected by refuges farther north where many waterfowl spend the winter instead of migrating farther south to their natural wintering areas. For example, very few Canada geese now winter on the Georgia coast, and populations of wintering mallards are significantly reduced by northern refuges.

Most waterfowl management on the Georgia coast is on lands owned by state and federal wildlife agencies. Despite the fact that several areas in private ownership offer excellent opportunities for attracting waterfowl, little private management is practiced as compared with South Carolina, for example. There are a few marsh areas near the Satilla River that are under the management of private hunting clubs, but the management programs of these clubs are minimal.

Freshwater marshes have greater variety of aquatic plants (Table 12) and are most heavily used by waterfowl.

TABLE 12. SOME NATURALLY-OCCURRING PLANTS OF SIGNIFICANCE IN WATERFOWL MANAGEMENT

Species		Growth habit[1]	Habitat[2]
Generally desirable			
Muskgrass	*Chara* spp.	Sb	Fr, B
Spikerushes	*Eleocharis* spp.	E	Fr, B
Soft-stem bulrush	*Scirpus validus*	E	Fr
American 3-square bulrush	*Scirpus americanus*	E	Fr
Olney's 3-square bulrush	*Scirpus olneyi*	E	Fr, B
Salt marsh bulrush	*Scirpus robustus*	E	B
Southern bulrush	*Scirpus californicus*	E	Fr
Dwarf spikerush	*Eleocharis parvula*	E	B
Giant foxtail grass	*Setaria magna*	E	Fr
Wild rice	*Zizania aquatica*	E	Fr
Wild millet	*Echinochloa crusgalli*	E	Fr
Red-root sedge	*Lachnanthes caroliniana*	E	Fr
Pondweed	*Potamogeton* spp.	Sb, Fl	Fr, B
Bushy-pondweed	*Najas* spp.	Sb, Fl	Fr, B
Wild celery	*Vallisneria americana*	Sb	Fr, B
Widgeon-grass	*Ruppia maritima*	Sb	Sa
Aneilema	*Aneilema keisak*	E	Fr
Water-shield	*Brasenia schreberi*	Fl	Fr
Banana water-lily	*Nymphaea mexicana*	Fl	Fr
Smartweed	*Polygonum* spp.	E	Fr
Generally undesirable			
Needlerush	*Juncus roemerianus*	E	B, Sa
Sawgrass	*Cladium* spp.	E	Fr, B
Giant cutgrass	*Zizaniopsis miliacea*	E	Fr, B
Smooth cordgrass	*Spartina alterniflora*	E	B, Sa
Salt meadow cordgrass	*Spartina patens*	E	Sa
Big cordgrass	*Spartina cynosuroides*	E	B
Reedcane	*Phragmites communis*	E	Fr
Saltgrass	*Distichlis spicata*	E	B, Sa
Pickerelweed	*Pontederia cordata*	E	Fr
Golden club	*Orontium aquaticum*	E	Fr
Arrow arum	*Peltandra virginica*	E	Fr
Glasswort	*Salicornia* spp.	E	Sa
Alligator-weed	*Alternanthera philoxeroides*	E	Fr
Yellow cow-lily	*Nuphar luteum*	Fl	Fr
White water-lily	*Nymphaea odorata*	Fl	Fr
Lotus	*Nelumbo* spp.	Fl, E	Fr
Fanwort	*Cabomba* caroliniana	Sb, Fl	Fr
Cat-tail	*Typha* spp.	E	Fr
Arrowhead	*Sagittaria latifolia*	E	Fr
Waterweed	*Elodea canadensis*	Sb	Fr
Bladderwort	*Utricularia* spp.	Sb, Fl	Fr
Parrot's-feather	*Myriophyllum* spp.	Sb	Fr
Coontail	*Ceratophyllum* spp.	Sb	Fr

[1] Sb = submersed, E = emergent, Fl = floating leaved

[2] Fr = freshwater, B = brackish, Sa = saline

Except on Blackbeard Island, most coastal waterfowl management is in old rice field impoundments and newly diked marsh in brackish water areas. Water contol devices are strategically placed in the dikes, and water levels are manipulated to favor plants used by waterfowl. These include in brackish impoundments submersed plants such as widgeon-grass, muskgrass, and pondweed, and emergent plants such as dwarf spikerush and salt marsh bulrush, and in freshwater impoundments smartweeds, aneilema and panic grasses.

The salt marshes (not including potholes and tidal streams) have limited appeal as feeding areas for most species of waterfowl. Lynch (1968) stated that the "true worth of the southern tidal marsh lies not so much in its direct appeal to waterfowl, but rather in its subtle contributions to waterfowl food chains of adjacent environments." Foods available to waterfowl in salt marshes are mainly animal forms. In tidal creeks and potholes widgeon-grass, a submersed aquatic, is the most important duck food. Most dabbling and diving ducks utilize this plant. The black duck, the most common duck using the salt marsh, feeds primarily on snails. Many species of waterfowl use areas within the salt marsh as resting and loafing areas (Teal and Teal 1969).

The open waters of the tidal creeks are especially attractive to diving ducks and other birds preferring animal foods. Pied-billed grebes, red-breasted and hooded mergansers, and large numbers of scaup commonly feed in the tidal creeks.

At low tide the exposed mud flats of the tidal creeks and marshes are preferred feeding areas for many species of shorebirds such as willets and greater yellowlegs.

Species and preferred habitats of birds occurring on the coast of Georgia are tabulated in Appendix 3. not included

Reptiles.--The diamondback terrapin is the only reptile inhabiting the salt marsh throughout the year; it is very common there. Formerly the diamondback was a "gourmet's delight" and commanded high prices in northern markets; about 1900, marketable females commonly sold for 30 to 36 dollars per dozen (Coker 1906). Only the females reach a marketable size of about six inches; males seldom exceed 4 1/2 inches in length. Experimental rearing studies were conducted by state and federal agencies (Coker 1906; Hildebrand 1929, 1932; Barney 1922), and although artificial production was successful, it did not prove to be commercially profitable. Small numbers of terrapins are currently taken from Georgia marshes for personal use, and a few turtles are still sold commercially.

The terrapin feeds mainly on periwinkles in the short Spartina marsh during periods of high tides. Martof (1963) reported that the peak in egg-laying in the marshes near Sapelo Island occurred late in May and early in June. Female terrapins dig nests and lay their eggs slightly above the high tide line. Raccoons are their main predators.

Alligators sometimes are observed in the tidal creeks and sounds when they move to and from freshwater and brackish marshes. A few alligators feed in the salt marsh.

Invertebrates

Approximately fifty species of insects occur in the salt marshes (Teal and Teal 1969). Some of these complete their life cycle in the marsh, others only breed or spend a portion of their life cycle there. The salt marsh grasshopper (*Orchelimum fidieinium*) is restricted to the salt marsh and is one of the few marsh insects that have been studied intensively. Smalley (1960) found this species to be the primary grazer of smooth cordgrass in Georgia. It is more fully discussed in the section on food webs and energy flow. The plant hopper, *Prokelisia marginata*, very common in the marshes, sucks the juices of smooth cordgrass (Teal and Teal 1969).

An ant, *Crematogaster clara*, feeds on the surface of the cordgrass but lives within the stem of the plant. During high tides, a specially adapted individual blocks the entrance to the nest with its head and thus prevents the colony from being flooded (Teal and Teal 1964).

Two species of salt marsh mosquitoes occur on the coast, *Aedes taeniorhynchus* and *A. sollicitans*. *Aedes taeniorhynchus* is the more common species, but *A. sollicitans* is more aggressive in attacking humans (Bidlingmayer and

Schoof 1957). Both species breed above the intertidal zone and lay their eggs in potholes and depressions that are covered only by excessive amounts of rainfall or above-normal high tides (King et al. 1960). Oviposition occurs on moist soil or grassy areas within the zone (ibid.). Saltgrass is a good indicator of these zones. However, it is not essential to the breeding of either species as both commonly breed in the cracks that occur in silt dredged from coastal rivers (H. F. Schoof personal communication). The eggs can withstand droughts of 4 to 6 months, and eggs may hatch within hours following flooding. The detritus-feeding larvae live in the tidal pools before transforming into adults.

The salt marsh mosquito is a vector of the dog heartworm (*Dirofilaria immitis*). Although certain arboviruses have been isolated from these mosquitoes, diseases of public health significance, such as encephalitis, have not been traced to *A. taeniorhynchus* or *A. sollicitans* (H. F. Schoof personal communication).

Three blood-sucking midges, *Culicoides furens*, *C. hollensis*, and *C. melleus*, occur in the coastal area of Georgia. These noxious insects breed in the marsh and are very abundant during the summer.

Deer flies (*Chrysops* spp.) are extremely common in the coastal region. During the peak emergence in mid-May (Snoddy 1970), they are a severe annoyance to inhabitants of the area. Breeding takes place in habitat similar to the breeding sites of salt marsh mosquitoes. However, the larvae of deerflies are semiaquatic; they are seldom found in areas which are covered with tides.

Several species of crabs are common in the marsh. The brown squareback crab (Sesarma cinereum) occurs on the landward side of the marsh, and the purple squareback crab (S. reticulatum) and mud crab (Eurytium limosum) occupy the soft mud area on the levees of tidal creeks in the dense cordgrass Oney 1954, Teal 1958).

Teal (1958) studied the factors responsible for the distribution of the three species of fiddler crabs in the Georgia marsh. He determined that Uca pugnax and U. minax select sites with a muddy substratum suitable for digging burrows that do not collapse when flooded by tides. Uca minax, the largest species, prefers marsh habitat in brackish water and has the highest tolerance to fresh water. Uca pugilator, commonly called the sand fiddler, selects sandy marsh areas for its burrows. Teal noted that this crab is excluded from some sandy marsh habitat by competition from the other two crabs. Uca pugilator plugs its burrow before tidal inundation and, although the burrow is in sandy marsh, it does not collapse because of air trapped within the burrow (Teal and Teal 1969). All of the fiddlers feed on organic detritus, and food is not a limiting factor in their distribution (Teal 1958). All of the fiddler crabs reach the adult stage in one year.

Two species of snails, the periwinkle and *Melampus lineatus*, are common in the salt marshes. The shell of the periwinkle is sealed by a horny, protective shield (operculum) attached to the foot, an adaptive protection against dessication. *Melampus* is susceptible to dessication because it has no operculum and therefore must remain near damp sites. It moves up and down the cordgrass stalks with the tides and feeds on detritus deposits on the plant. Experiments with *Melampus* indicate that it has a biological clock timed to tidal movements and begins to climb the *Spartina* stalks before the tidal water arrives (Teal and Teal 1969).

Primary Production

Primary productivity is the rate at which energy is fixed or carbon is stored by the photosynthetic and chemosynthetic activities of producer (autotrophic) organisms. The fixed energy becomes available for consumption by consumer (heterotrophic) organisms within the system. Therefore, any analysis of total productivity is really an analysis of the rate of plant growth (Schelske and Odum 1961).

Research at the University of Georgia's Marine Institute reveals that the marsh-estuaries of Georgia are highly productive ecosystems. Schelske and Odum (1961) list five factors that are responsible for this high productivity. These are (1) three types of primary production units, (2) tidal ebb and flow, (3) abundant supplies of nutrients,

(4) rapid regeneration and conservation of nutrients, and (5) year-round production with successive crops.

Primary production units are smooth cordgrass (Smalley 1959), benthic algae (Pomeroy 1959) and phytoplankton (Ragotzkie 1959). Each producer unit occupies a different "production niche." Spartina thrives in the intertidal zone and produces two-thirds to three-fourths of the total primary production. Net Spartina production is about 6580 kcal/m^2/year (Teal 1962). Maximum production occurs during the summer months. Mud algae contributes one-third to one-fourth of the total primary productivity (Schelske and Odum 1961). Pomeroy (1959) determined gross productivity to be approximately 1800 kcal/m^2/year and net production to be 1620 kcal/m^2/year. Thus the mud algae are the most efficient producer systems in that only 180 kcal/m^2/year is lost to respiration. Production rates were approximately the same throughout the year. During the summer, production was high when marshes were flooded and light intensity was reduced. However, in winter, when insolation was less, maximum productivity occurred when the marsh was exposed. Phytoplankton production is greater than previously thought (Schelske and Odum 1961), but exact production figures are not available. Schelske (1962) has determined that nutrients are not a limiting factor on phytoplankton production. However, high turbidity in estuarine waters limits light penetration and phytoplankton production below a depth of about six feet. Phytoplankton production increases when the marsh is flooded because the surface area is four to five times greater at high tide than at low tide (Ragotzkie and Bryson 1955).

Tidal action is perhaps the most important factor influencing primary production. Twice daily, tides of approximately seven feet carry essential nutrients into the marshes, export detritus and nutrients back into estuaries, and provide a large surface area for phytoplankton production. Tidal flushing maintains a desirable vertical distribution of nutrients and detritus.

Nutrients are abundant and probably are not a limiting factor in estuarine production (Schelske and Odum 1961). The nutrients of the fertile estuarine waters are contributed by the marshes and not directly by inflowing rivers (Schelske and Odum 1961, Thomas 1966).

A significant factor relating to primary production is the rapid turnover of nutrients within the system. Such is the case in Georgia estuaries where nutrients are not "tied up" but move rapidly through the system (Pomeroy 1960). Fewer nutrients are needed for production if they are continually available to organisms (Schelske and Odum 1961).

Nutrients are conserved in the system by recycling; they are repeatedly reused with little loss to the system. The horse mussel, for example, is an important biological agent in the recycling of phosphorus (Kuenzler 1961), an essential element in estuarine production.

The three primary producers sustain production on a year-round basis (Schelske and Odum 1961). *Spartina* produces two crops per year, mud algae produce at a fairly constant rate, and phytoplankton contribute to production throughout the year (ibid.).

The combined effect of these factors produces one of the most naturally fertile areas of the world. The net production of the marshes and estuaries amounts to approximately 2000 gm/m^2/year or 10 tons (dry weight) per acre of organic material (Odum 1961).

Energy Flow and Food Webs

The most comprehensive studies of energy flow in the salt marsh have been conducted at the University of Georgia's Marine Institute. These studies have revealed that energy stored by the primary producers follows two pathways through the ecosystem (Figure 28): the grazer food chain and the detritus food chain (Odum 1961, 1963). The grazer food chain has four primary consumers: *Orchelimum fidieinium* (Smalley 1960), *Prokelisia marginata*, *Trigonotylus* sp., and *Ischnodemus badius* (Marples 1966). Smalley (1960) found that during a period of about 100 days, salt marsh grasshoppers consumed approximately 2 per cent of the total *Spartina* crop. The utilization efficiency of salt marsh grasshoppers (.57 per cent) was low because *Spartina* grows throughout the year at varying rates and because the

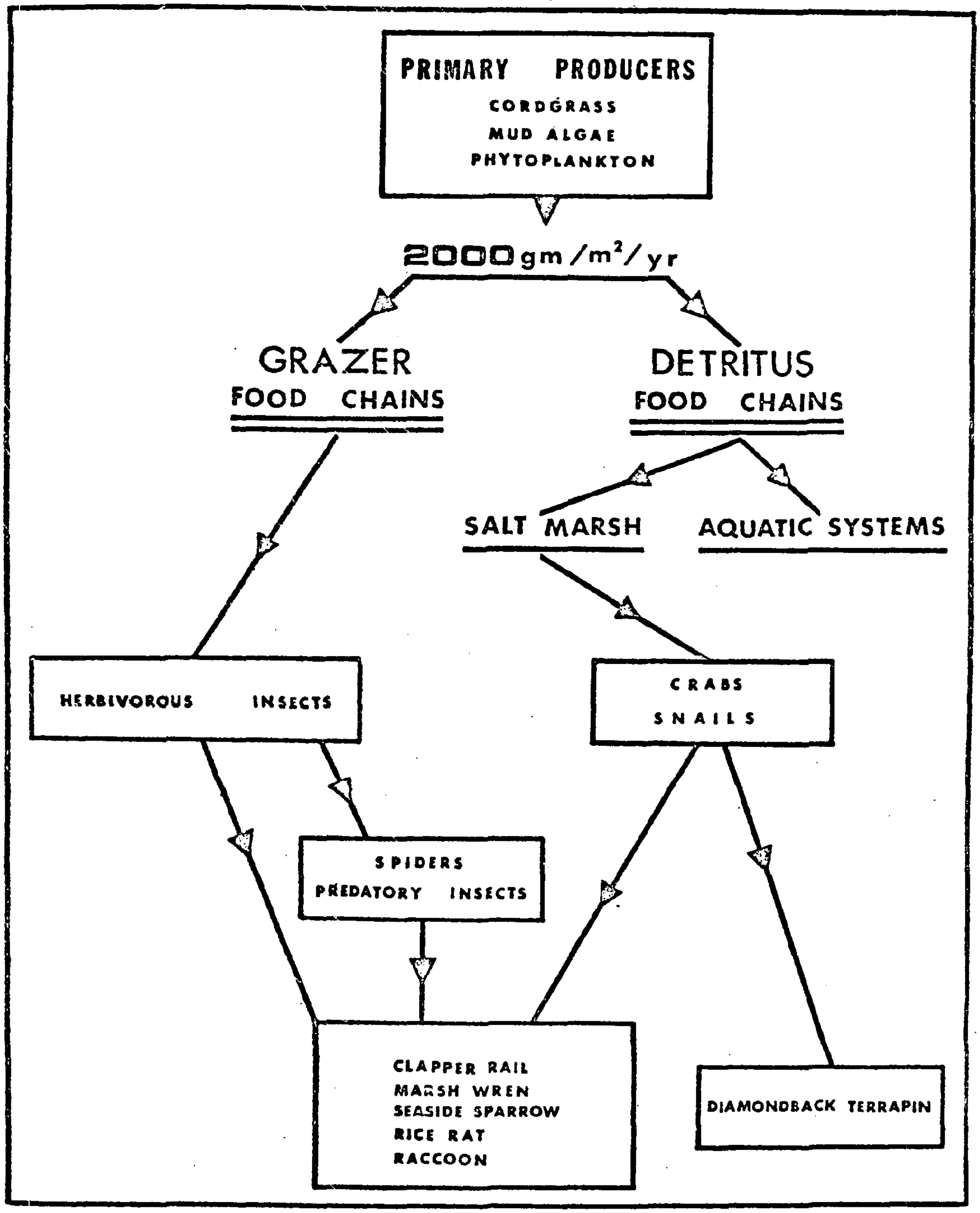

Figure 28. Very generalized diagram of production and utilization of organic matter in the salt marsh. Approximately 5 per cent of the primary production is utilized by the grazer food chain and 95 per cent by the detritus food chain. Approximately 55 per cent of the primary production is accounted for by the salt marsh ecosystem, leaving 45 per cent available for export into the aquatic system.

grasshopper has a short life span (4 months) and ingests only leaves (Smalley 1960). Total energy flow for the grasshoppers and planthoppers is summarized in Table 13. Odum (1961) reported that only 5 per cent of the total *Spartina* production is utilized by the herbivores *Orchelimum* and *Prokelisia*; therefore, most of the marsh production is available to detritus-algae consumers.

The base of the detritus food chain is dead *Spartina* which is attacked by microorganisms. Odum and de la Cruz (1967) stated that "organic detritus is the chief link between primary and secondary productivity" (autotrophic and heterotrophic levels). It has been suggested by several workers that bacteria may be an important link in the food chain, making some of the hard-to-digest materials available as well as serving as food themselves. They colonize the detritus particle and, upon ingestion, may be stripped off and utilized as food (Burkholder and Bornside 1957; Teal 1958, 1962; and Pomeroy et al. 1969). Burkholder and Bornside (1957) estimated that the standing crop of bacteria in the marsh is 10^7 bacteria per gm wet mud.

Teal (1962) considered the important detritus-algae feeders to be fiddler crabs, oligochaetes, periwinkle snails, and nematodes among the deposit feeders, and *Modiolus demissus* and *Mamayunkia aestuarina*, among the suspension feeders. Marples (1966) reported that the periwinkle snail and fiddler and squareback crabs were the most important

TABLE 13. SUMMARY OF ENERGY FLOW IN THE SALT MARSH*

Organism	Gross production	Respiration	Net production
I. Producers			
smooth cordgrass	34,580**	28,000	6,580
mud algae	1,800	180	1,620
phytoplankton	- - - no comparable data - - - -		
II. Consumers			
A. Primary			
salt marsh grasshopper	29.4	18.6	10.8
plant hopper	275.0	205.0	70.0
crab	206.0	171.0	35.0
annelid	35.0	26.0	9.0
nematode	85.0	64.0	21.0
mussel	56.0	39.0	17.0
snail	80.0	72.0	8.0
Total	766.4	595.6	170.8
B. Secondary			
mud crab	27.2	21.9	5.3
clapper rail	1.7	1.6	0.1
raccoon	1.7	1.6	0.1
Total	30.6	25.1	5.5

*Modified from Teal (1962).
**Values in kcal/m^2/yr.).

detritus feeders. Several investigators have determined rates of energy flow for some of these forms. Teal (1962) presents some of his own data and summarizes the data of others relating to these detritus feeders. This information is summarized in Table 13.

Predaceous insects (secondary consumers) feed on the herbivorous insects and in turn are fed upon by marsh wrens and rice rats (tertiary consumers). The marsh wren was shown by Kale (1965) to be also a secondary consumer on the grazer food chain since it also fed on herbivorous insects. Predators of the detritus feeders include mud crabs, raccoons, clapper rails (Teal 1962), and the diamondback terrapin. Additional predators which have been observed to prey upon fiddler crabs (detritus feeders) are red drum, willet, white ibis, herring gull, gull-billed tern, boat-tailed grackle, whimbrel, snowy egret, cattle egret, and little blue heron. Table 13 summarizes the energy flow data presented by Teal (ibid.) for the mud crab, raccoon and clapper rail.

The utilization of organic matter in the salt marsh (Figure 28) accounts for approximately 55 per cent of the total primary productivity. Therefore, roughly 45 per cent (4.5 tons per acre) of the production is available for utilization by and support of an abundance of estuarine animals (Teal 1962), including numerous finfish and shrimp which sustain an important industry.

In summary, 6.1 per cent of incident light energy is utilized by the salt marsh in gross production and 1.4 per cent of light energy becomes net production (2000 $gm/m^2/yr$). Fifty-five per cent of the net production is consumed by the marsh inhabitants and 45 per cent is available for export into the estuarine system (Odum 1961, Teal 1962).

(bibliography contained at the end of section on "Open Marine and Estuarine Waters")

CHAPTER 11

This chapter is excerpted from An Ecological Survey of the Coastal Region of Georgia, A Report to the National Park Service, by A.S. Johnson, H.O. Hillestad, S.A. Fanning, and G.F. Shanholtzer, August, 1971. This material has been reproduced with the permission of Dr. A.S. Johnson and the National Park Service.

THE OPEN MARINE AND ESTUARINE WATERS

The marshes, being protected by the barrier islands from frontal assault by the ocean, interact with the ocean indirectly, through systems of tidal streams and estuaries (Figure 26, not included). Estuaries are semi-enclosed bodies of water having free connections with the open sea and having sea water measurably diluted with fresh water derived from land drainage (Pritchard 1967a). The estuaries of Georgia connect with the sea through the sounds that separate the barrier islands. These are north to south from the Savannah River Entrance to the St. Marys River Entrance: Wassaw Sound, Ossabaw Sound, St. Catherines Sound, Sapelo Sound, Doboy Sound, Altamaha Sound, St. Simons Sound, and St. Andrews Sound. Salt water is diluted by fresh water from the Savannah, Ogeechee, Altamaha, Satilla, and St. Marys rivers. The coastal or inshore waters extend from the mouths of the sounds and from the barrier beaches to a depth of about 60 feet. The offshore waters of the continental shelf lie beyond.

The continental shelf along the Georgia coast is 70 to 80 miles wide with a gentle slope of about two feet per mile (Henry and Hoyt 1968). It is covered by sediments deposited during low stands of the sea. The topography of the continental shelf off the Georgia coast is shown in

Figure 29. The poorly defined valley in the shelf east of Sapelo Island is thought to be a filled valley once occupied by the Altamaha River (Pilkey and Giles 1965). An abrupt increase in slope of descent occurs at 50 to 80 meters (ibid.). This break marks the edge of the continental shelf and the beginning of the upper continental slope. Seaward of the continental shelf is the Blake Plateau, an intermediate plateau between the continental shelf and the ocean basin. The Blake Plateau averages 700 to 1000 meters depth (Pilkey and Terlecky 1966).

The coastal (inshore) waters are somewhat diluted with fresh water; they are turbid, and they are most productive. Beyond the continental slope, ocean waters are clear and relatively unproductive. The waters of the continental shelf are of intermediate fertility.

Physical Characteristics

Patterns of circulation

The waters of the Georgia coast are subject to many interacting forces that produce complicated patterns of circulation that to a large extent determine the distribution of sediments, nutrients, oxygen, temperature, salinity, food, and planktonic forms of larval and adult organisms.

Ocean currents are produced by wind, gravity and differences in density of water strata. Surface currents commonly are caused by the stress that winds exert on the

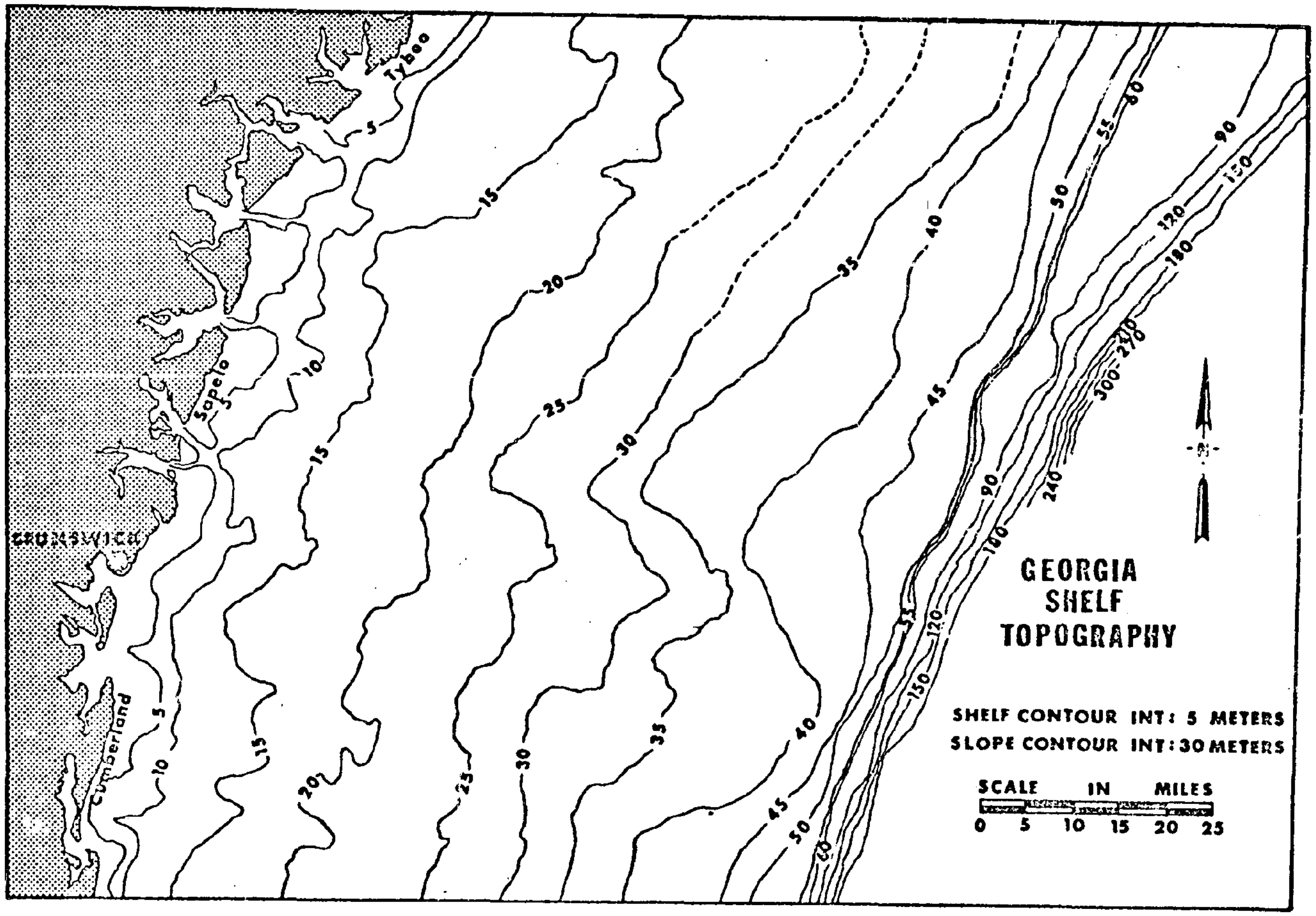

Figure 29. Bottom topography of the continental shelf off Georgia. Contour interval changes at continental shelf. (Adapted and redrawn from Pilkey and Giles 1965.)

water surface; tidal currents are caused by the interacting forces of gravity of the earth, the moon and the sun; and density currents are related to differences in density that result from variations in temperature and salinity within a body of water.

The Gulf Stream, a northerly flowing current of warm, saline water beyond the continental slope, is a density current. It results from warm, tropical waters spreading northward over the more dense polar waters which sink and flow toward the equator. The currents are deflected from direct poleward flow by wind friction, earth rotation and land masses. Eddies form inshore from the Gulf Stream and may be responsible, in part, for the southward transport of sediment along the Georgia coast.

The movement of the waters inshore from the Gulf Stream has not been studied systematically and must be assumed from a limited number of observations. Bumpus and Lauzier (1965) summarized data from drift bottles on seasonal direction of surface currents of the continental shelf from Newfoundland to Florida. The data from Georgia, admittedly inadequate, indicate currents flowing as follows: winter--southerly; spring--northerly; summer--southerly and northerly; fall--southerly. Bellinger (1968) reports that flow is southward during the summer, fall, and winter, extending out 20-30 miles during the summer and about 45 miles during the other seasons. Rates of surface flow vary densities of the water masses is less. As temperatures begin to rise in the spring, inshore waters warm faster and the temperature gradient gradually disappears, but the salinity gradient is steeper than at any other time of the year because of heavy freshwater discharge. The lessening temperature gradient and steepening salinity gradient compensate to produce water of similar densities inshore and offshore. These shifts in densities probably result in slow, seasonal water movements. They could be responsible for setting up the inshore-offshore components mentioned by Bellinger (1968).

Tidal currents are the horizontal movements of water which, unlike the currents caused by wind and density differences, are periodic. The tidal component is most pronounced in narrows such as entrances to bays and constricted parts of rivers. Tidal currents for the Georgia estuaries were given by Haight (1938).

The Georgia coast is subject twice daily to tides approximately the same height. The height of the tide increases from about 5 1/2 feet at Nassau Sound, Florida, to about 7 feet near Savannah. The tidal movement of saline waters into the estuaries and the drainage of rivers into them cause the complicated hydrologic patterns characteristic of estuaries.

Pritchard (1967b) described four hypothetical circulation patterns for estuaries, two of which may be applicable to Georgia estuaries. <u>The moderately stratified estuary</u> is one in which tidal action serves as the dominant force mixing fresh and salt waters. The Savannah River exhibits this type of circulation. In an estuary with no tide or friction, undiluted sea water would extend upstream along the bottom to a point where the river surface was approximately at sea level. The less dense fresh water would flow seaward on top of the salt water. When there is tidal action, as in the moderately stratified estuary, turbulence carries fresh water downward and salt water upward. The salt content of both layers increases toward the sea, but at any given point the bottom layer is more saline than the top. <u>Vertically homogeneous estuaries</u> occur where tidal mixing is vigorous and freshwater input is low. In this case vertical salinity stratification breaks down.

The circulation patterns and physical characteristics of only a few Georgia estuaries have been studied. The Savannah River, a moderately stratified estuary, has been studied by the U. S. Corps of Engineers. It has a drainage area of approximately 9850 square miles and an average discharge of 11,290 cfs (U. S. Geological Survey 1960). It is tidal for approximately 50 miles upstream. A physical model of the river has been designed in order to study shoaling (U. S. Army Corps of Engineers 1949). Figure 30 shows the tidal currents at ebb and flood tides as predicted by the model.

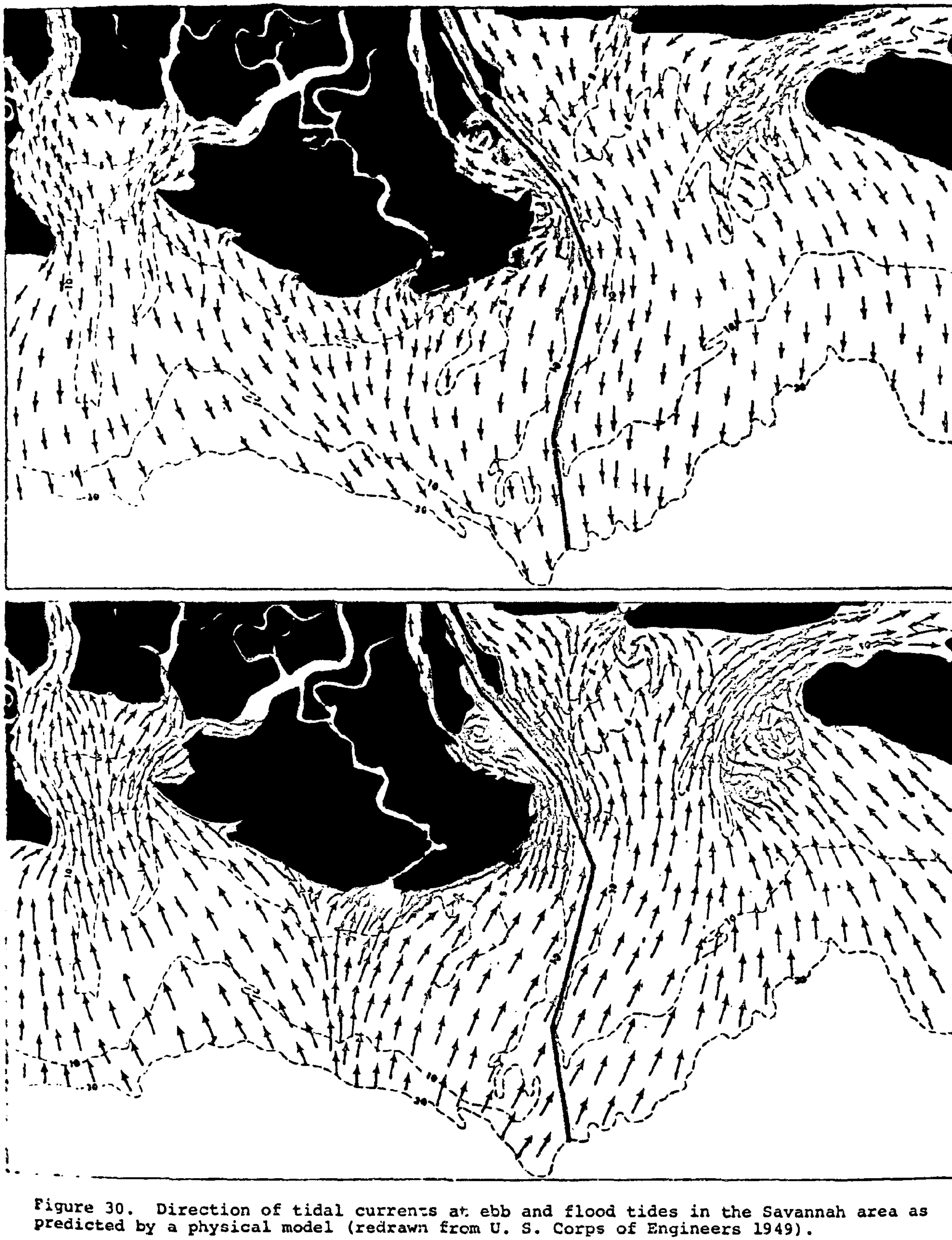

Figure 30. Direction of tidal currents at ebb and flood tides in the Savannah area as predicted by a physical model (redrawn from U. S. Corps of Engineers 1949).

The Altamaha River has the greatest discharge along the Georgia coast. It has a drainage area of approximately 13,600 square miles and an average discharge of 12,600 cfs (U. S. Geological Survey 1959). Several miles from the ocean it divides into a number of distributaries (Darien, Butler, Champney, and South Altamaha) which empty into Altamaha Sound and to a lesser extent into Doboy and St. Simons sounds. The hydrography of this river has been studied to only a limited extent. Neiheisel (1965), in a study of the causes of shoaling in Brunswick Harbor, presents information on the mixing and flow of water in Brunswick Harbor as influenced by the Altamaha River. Discharge into Brunswick Harbor, a well-mixed estuary, by the Turtle River is negligible. However, during maximum peaks of discharge, fresher water from the Altamaha enters the Harbor through the Mackay and Frederica rivers. The water discharged through the Altamaha Sound into the ocean is moved along the shore and enters Brunswick Harbor through the sound entrance. Salinity measurements in the Mackay and Frederica rivers show that they are partially mixed estuaries with some density stratification during a period of low discharge. During higher discharge it is assumed that the interface would become sharper and move toward the harbor. Salinities were approximately 5 parts per thousand in the Mackay River near Altamaha Sound and approximately 20 parts per thousand near St. Simons Sound (Neiheisel 1965).

The hydrography of Doboy Sound, recently studied by Levy (1969), is also affected by the Altamaha River. During ebb tide fresh water from the Altamaha flows seaward through the Darien-Rockdedundy complex into Doboy Sound through the Black, South, and North rivers. During mid-ebb this water flows out the mouth of Doboy Sound along the south shore while water from the sounds leaves by the north shore. Because of the limited fresh water flow, Doboy Sound is a mixed estuary (at least during the summer months) with no recognizable salt wedge and little vertical stratification. A salt wedge is present just seaward of the inlet, where less saline, highly turbid waters of the longshore drift overlie more saline oceanic waters. This moves shoreward on flood tide.

Ragotzkie and Bryson (1955) studied the Duplin River, a tidal river located near Sapelo Island and opening into Doboy Sound. Having no significant fresh water source, it is an elongated tidal bay about 5.9 miles long with a tidal excursion, of about 3 miles. At mean low water the river has a relatively small horizontal area; however, at 6 feet above mean low water the water flows over the banks and onto the salt marsh. The area of marsh flooded increases rapidly as the level of water rises. From one-third to two-thirds of the volume of water entering the Duplin River on a rising tide leaves the river to flood the marsh. The volume of water involved is greatly increased with relatively small

Quaternary sediments consisting of coarse-grained particles are less than 100 feet thick and are mostly of Pleistocene origin (ibid.).

Carbonate contents of shelf sediments are discussed by Gorsline (1963), Pilkey (1964) and Pilkey et al. (1969). Carbonates average less than 25 per cent over most of the shelf and consist mostly of mollusks. Carbonate content increases seaward to about 50 per cent on the shelf edge and nearly 100 per cent on the upper slope where foraminifera are the major components (Pilkey 1964). This increase toward the shelf edge probably results from the diminishing contribution of terrigenous materials.

The presence of oolites off the Georgia coast is indicative of pre-existing shoreline conditions and low sedimentation rates, and the abrasive history of the carbonate fraction indicates that former shorelines in this area, like those of the present, were subject to relatively low wave energies (Pilkey et al. 1969).

Phosphorite averages about 1.1 per cent of shelf sediments (Henry and Hoyt 1968). Present day rivers apparently lack phosphorite in their sediment loads, yet all shelf samples and most estuarine sands contain these grains in varying amounts (Pilkey and Terlecky 1966). Pevear and Pilkey (1966) and Pilkey and Terlecky (1966) concluded that much of the sands and nearshore fine sediments originate from landward transport from outer portions of the shelf and increases in tidal height. The waterways are subject to high turbulence as this large volume of water enters and leaves. Mixing is rapid and no stratification long can be maintained under these conditions.

Sediments

Coastal sediments have been the subject of considerable study since 1960. Much of this work was done by the University of Georgia Marine Institute. Papers dealing with sediments of the continental shelf (shelf sediments) and of the shallow waters near shore (paralic sediments) are reviewed by Henry and Hoyt (1968).

Previous sections of this report have described origins, composition, depositional patterns, and migrations of sediments of offshore bars, beaches, and dunes, and marshes. The following summary is restricted to some ecologically important aspects of shelf and inshore sediments not previously discussed.

Nearshore, a narrow band of fine sands is considered to be of Recent origin (Pilkey and Frankenberg 1964). Minerals of mainland (terrigenous) origin (mainly quartz) are the dominant constituents (Henry and Hoyt 1968).

A relatively sharp boundary between Pleistocene and Recent sediments occurs quite consistently at about 6 fathoms, generally about 12 miles offshore (Pilkey and Frankenberg 1964). Cenozoic deposits on the continental shelf range from 2000 to 2500 feet deep (Henry and Hoyt 1968).

not from mainland rivers. Shelf phosphorite has evidently been derived from either Pleistocene rivers or from ancient phosphatic sediment outcrops on the shelf.

The heavy mineral fraction of shelf sediments averages less than 0.5 per cent (Henry and Hoyt 1968). The heavy mineral suite includes staurolite, kyanite, garnet, zircon, epidote, pyroxenes, amphiboles, rutile, and tourmaline (Pilkey 1963). Heavy mineral distributions are frequently useful aids in the determination of sediment origins, but heavy minerals in shelf sediments off the Georgia coast show minimal variation because of their common origin in Piedmont rivers (Pilkey 1963).

Fauna of Estuaries and Inshore Waters

Vertebrates

Fishes.--The waters off the coast of Georgia support a variety of fishes related to the diversity of habitat. Some estuarine species enter fresh water to spawn and a few freshwater species enter the brackish estuaries. Some species are restricted to the estuaries and inshore waters and some are restricted to the waters of the continental shelf. But many species migrate between these habitats at various stages in their life cycles, and the estuaries are vitally important as nursery grounds and spawning grounds for many commercially important species harvested on the continental shelf. Stroud (1971) listed the species that are dependent upon the estuaries during some stage in their lives and reported that they comprised 63 per cent of the Atlantic catch. He calculated that, for the Atlantic coast generally, each acre of estuarine habitat produces a yield of 535 pounds on the continental shelf.

The continental shelf off Georgia generally is composed of shifting sediments and does not provide good fish habitat. However, a coral reef, or live bottom, recently has been discovered 16 miles due east of Cabretta Inlet on Sapelo Island. Such reefs provide a stable surface for the attachment of organisms important in the food chain. Artificial reefs also are being established by the Georgia Game and Fish Commission.

There has been relatively little work on the ecology of fishes of the Atlantic coast of the southeastern United States. Tagatz and Dudley (1961) studied the seasonality of fishes in four coastal habitats near Beaufort, North Carolina, and Tagatz (1968) and McLane (1955) surveyed the fishes of the St. Johns River, Florida.

Some pertinent work has been done off the Georgia coast. Anderson (1968) surveyed the fishes caught by shrimp trawling from South Carolina to northeastern Florida from 1931 to 1935. Miller and Jorgenson (1969) studied the seasonal abundance and length frequencies of fishes collected in two habitats and presented a list of fishes collected at a freshwater station in the Altamaha River. They made thorough surveys by seining at a beach habitat on St. Simons Island and two high marsh stations, one near Jekyll Island and one near Meridian, Georgia. Dahlberg and Heard (1969) surveyed the common inshore elasmobranchs of the Georgia coast. Dahlberg and Odum (1970) sampled fish populations in St. Catherines and Sapelo sounds by trawling at three-week intervals for 13 months. Struhsaker (1969) presented a list of fishes taken during five years of exploratory trawling on the continental shelf off Georgia and other southeastern states.

A list of fishes that may be encountered in Georgia's coastal waters is included (Appendix 1). not included.

Reptiles.--The loggerhead turtle, previously discussed, is the only marine reptile that is common on the Georgia coast. Green and Ridley's turtles have been reported from coastal Georgia (see Appendix 2). not included.

Marine mammals.--Information on marine mammals of Georgia coastal waters is restricted mainly to stranding records and associated data. Only six species of whales, all toothed (Odontoceti), are recorded as having stranded on the island beaches, although sight observations and strandings from adjacent states indicate that about 23 species are probably components of Georgia's offshore fauna.

Atlantic bottle-nosed dolphins are probably the most common whales in the waters immediately adjacent to the coast. They are observed, frequently in pairs, swimming off the beaches and tidal rivers. Stranding dates are confined to the last half of the year, although the dolphin is commonly sighted throughout the year.

The pilot whale, also common, occasionally strands in large numbers on the island beaches. Between 15 and 25 stranded on St. Simons Island in 1962, and 53 stranded on Little St. Simons in 1968 (Caldwell et al. 1971). There is, as yet, no satisfactory explanation for these mass strandings.

Occasionally other whales such as the rare goose-beaked whale (with less than 20 known specimens from the western North Atlantic--Moore 1963) strand on the coast or are observed in the offshore waters. To date no baleen whales (Mysticeti) have stranded in Georgia.

The manatee occasionally is sighted or collected on the coast (Tomkins 1956, 1958), but its status as a permanent resident is doubtful.

Man inadvertently has introduced the California sea lion into the coastal waters of the southeastern United States, and sight observations (Caldwell et al. 1971) confirm the presence of the species off Sapelo Island.

Specific records of marine mammals in Georgia are given in Appendix 5.

Invertebrates

Most studies of estuarine invertebrates have dealt with those forms relating in a basic way to the estuarine food chain (plankton) and with species having commercial

TABLE 14. EPIFAUNA COLLECTED FROM DOCKS AT COLONELS ISLAND (NORTH NEWPORT RIVER, ST. CATHERINES SOUND)*

Phylum Cnidaria
- Unidentified anemone
- Unidentified hydroid

Phylum Ectoprocta
- _Anguinella palmata_
- _Alcyonidium_ sp.
- _Amathia distans_
- _Conopium tenuissimum_

Phylum Annelida
- Class Polychaeta
  - _Nereis (Neanthes) succenea_
  - _Polydora_ sp.

Phylum Arthropoda
- Class Pycnogonida
  - _Tanystylum orbiculare_
- Class Crustacea
  - Subclass Copepoda
    - _Doropygus laticonis_
  - Order Thoracica
    - _Balanus eberneus_
  - Order Amphipoda
    - _Amphithoe valida_
    - _Corophium simile_
    - _Gammarus mucronatus_
    - _Lumbos websteri_
    - _Mellita appendiculata_
    - _Paracaprella tenuis_
    - _Parapleustes_ n. sp.
  - Order Decapoda
    - _Paleomonetas vulgaris_
    - _Paleomonetas pugio_
    - _Eurypanopeus depressus_
    - _Panopeus herbstii_

Phylum Chordata
- Subphylum Urochordata
  - _Molgula manhattensis_

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*Heard and Heard 1970.

a listing of those species that were considered common or abundant by the investigators in at least one monthly sample. Benthic epifauna and infauna were sampled within the sounds using a 20-foot otter trawl and a bucket dredge. One hundred and eighty-five genera or forms were reported. Of these, 79 were considered common by the authors in at least one sample. These species are listed in Table 15. Classification or higher taxa have been changed in Tables 14 and 15 to agree with those of Meglitsch (1967). The restricted sample area and the selection by the collecting devices for certain invertebrates contributed some bias to the lists.

Most invertebrates of commercial importance (e.g. crabs, oysters and shrimp) have been extensively studied. Following is a brief discussion of blue crabs, oysters and brown and white shrimp.

Studies by Durant (1970) indicate that in Georgia oysters (Crassostrea virginica) begin to spawn when the temperature is about 73°F. Spawning was observed to begin in May and to continue until October, with peak periods in July, August and September (ibid.). Larval stages last for 2 to 3 weeks (Wallace 1966), after which the young attach to some substrate. Galtsoff (1964) states that only soft mud and shifting sand are totally unsuitable. However, oysters may convert a mud bottom to a more suitable habitat if a few settle on a hard object and themselves become objects of

TABLE 15. INVERTEBRATE FAUNA OF SAPELO AND ST. CATHERINES SOUNDS*

Phylum Porifera
- *Halichondria* sp.
- *Microciona prolifera*

Phylum Cnidaria
- *Leptogorgia virgulata*
- *Renilla reniformis*

Phylum Nemertina
- Bicolored form

Phylum Phoronida
- Unidentified species

Phylum Ectoprocta
- *Aeverrillia setigera*
- *Alcyonidium verrilli*
- *Amathia distans*
- *Anguinella palmata*
- *Bowerbankia gracilis*
- *Bugula neritina*
- *Membranipora arborescens*
- *Membranipora tenuis*
- *Schizoporella unicornis*

Phylum Mollusca
Class Gastropoda
- *Anachis avara*
- *Busycon canaliculatum*
- *Busycon carica*
- *Cerithiopsis emersoni* (*C. subulata*)
- *Crepidula plana*
- *Doridella burchi*
- *Eupleura caudata*
- *Mitrella lunata*
- *Nassarius vibex*
- *Polinices duplicatus*
- *Pyrogocythana* (*Mangelia*) *plicosa*
- *Terebra dislocata*
- *Turbonilla* (*Pyrgiscus*) *interrupta*

TABLE 15. (Continued)

Class Pelecypoda
- *Abra aequalis*
- *Amygdalum papyria*
- *Barnea truncata*
- *Ensis directus*
- *Lyonsia hyalina*
- *Mulinia lateralis*
- *Musculus lateralis*
- *Mya arenaria*
- *Solan viridus*
- *Spisula solidissima*
- *Tagelus divisus*
- *Tellina agilis*

Class Cephalopoda
- *Lolliguncula brevis*

Phylum Annelida

Class Polychaeta
- *Arabella iricolor*
- *Clymenella torquata*
- *Diopatra cuprea*
- *Glycera americana*
- *Harmothoe-Lepidonotus* spp.
- *Heteromastis* sp.
- *Hydroides dianthus*
- *Lumbrineris tenuis*
- *Marphysa sanguinea*
- *Nereis* (*Neanthes*) *succinea*
- *Notomastis* sp. (spp.?)
- *Parapironospio pinnata*
- *Pectinaria* sp. (*gouldii*?)
- *Sabella microphthalma*
- *Sabellaria vulgaris*
- *Sabellaria* sp. (*floridensis*)
- *Sabellides* sp. (*oculatus*?)
- *Scoloplos-Orbinia* spp.
- *Spiochaetopterus oculatus*
- *Sthenelais boa*

Phylum Arthropoda

Class Pycnogonida
- *Anoplodactylus* sp.

Class Decapoda
- *Acetes americanus carolinae*
- *Alpheus normanni*
- *Eurceramus praelongus*

TABLE 15. (Continued)

Latreutes parvulus
Lysmata wurdemanni
Pagurus longicarpus
Pagurus pollicaris
Palaemonetas pugio
Palaemonetas vulgaris
Penaeus aztecus
Penaeus setiferus
Periclimenes longicaudatus
Trachypenaeus constrictus
Upogobia affinis
Phylum Echinodermata
Class Asteroidea
Asterias forbesi
Luidia clathrata
Class Ophiuroidea
Hemipholis elongata
Ophiothrix angulata
Phylum Chordata
Subphylum Urochordata
Mogula manhattensis

*Heard and Heard 1970.

attachment. Galtsoff describes the soft mud bottom of the South Atlantic as being only marginally suitable for oysters. He further states that oysters need a free exchange of water, salinities of 5 to 30 per cent and temperatures from 34°F to 86°F. Conditions are ideal for feeding when the water, free of pollution and containing a low concentration of small diatoms and dinoflagellates, moves over the bottom in a nonturbulent flow.

The negative factors influencing oyster production are described by Wallace (1966) as "pollution, predators, and people." He reports that oyster production is inversely proportional to human population growth in New England and the mid-Atlantic states. Only in the southeastern and Gulf states does oyster production even approach that of twenty years ago. Wallace (1966) concludes that pollution is the primary cause of the decline of the oyster industry. Sewage is detrimental because it covers the bottom with sludge that smothers oysters and reduces oxygen (Galtsoff 1964). When Escherichia coli, bacteria associated with fecal matter and used as an index for pollution, reach certain numbers, the oyster grounds are closed for health reasons. Figures 35a-h (Appendix 6) not included show areas closed to oyster gathering by the Georgia Department of Public Health as of 1970. Industrial wastes also affect oysters. Galtsoff (1964) reports that red liquor and black liquor, both wastes from pulp mills, reduce the length of time the oyster shell remains open, thereby reducing the time available for feeding. Butler (1966) found that shell deposition is decreased in the presence of chlorinated hydrocarbon insecticides (e.g. DDT) at concentrations as low as 10 parts per billion. Oysters are especially susceptible to pollution because of their stationary mode of existence and their ability to concentrate pollutants in their tissues. Predators include flatworms, mollusks, echinoderms, crustaceans, fish, birds, and mammals (Galtsoff 1964).

The predominant species of marine shrimp occurring in Georgia waters are the white shrimp (*Penaeus setiferus*) and the brown shrimp (*P. aztecus*), both of which are important commercially. The life cycles of white and brown shrimp are basically similar. The bottom-dwelling (benthic) adults release their eggs freely into the waters offshore. Within a short time, the eggs hatch into planktonic larvae. After passing through several intermediate stages, the young shrimp (postlarvae) move into the estuary and adopt a benthic existence (Anderson 1955). After very rapid growth, they assume the adult form. Marking studies indicate that after migrating offshore the shrimp do not move into deep water but make seasonal migrations parallel to the shoreline (Anderson 1955). White shrimp penetrate the estuary to a greater degree, arrive later and stay for a longer period of time than the browns.

Salinity optima for young penaeid shrimp is in the range of 5 to 20 per cent, although they can tolerate salinities from 1 to 60 per cent (Kutkuhn 1966). A complex interaction of factors including circulation, temperature, salinity, and fertility of waters, and type of vegetation and substratum determines distribution, survival and growth of young shrimp (ibid.). Optimum conditions are approached in the nursery grounds of the marsh-estuary complex.

Nichols and Keney (1963) report that the identity and distribution of crabs of the genus *Callinectes* on the southeastern coast of the United States is uncertain. Rathbun (1930) reported two species, *C. sapidus* and *C. ornatus*, occurring between New Jersey and Indian River Inlet, Florida. Lunz (1958) found that only 30 per cent of the crabs caught by trawlers in South Carolina were *C. sapidus*. The two species are not recognized as such by fishermen and are combined as blue crabs in catch data reported for coastal Georgia.

Van Engel (1958) reports that in the Chesapeake Bay area *Callinectes sapidus* begins mating early in May and continues into October. Females probably mate only once, at the time of the last molt. Sperm live in the female receptacles for at least a year and may be used as often as the female spawns (two or more times). The females migrate to saltier waters after mating, some passing out of the bay and into the ocean. Spawning is delayed at least two months after mating. When laid, the eggs are attached to the abdomen of the female where they remain about two weeks until hatching. Van Engle (1958) reports that there are two larval stages, four or five zoeal stages, and the megalops. These stages are passed through in about one month, after which the first crab stage is reached. Costlow and Bookout (1959) observed seven zoeal stages in laboratory-reared animals. Nichols and Keney (1963), based on the occurrence of early stage larvae, believe that spawning occurs throughout the year. Peak numbers of first stage larvae were found in Georgia waters during July, August and September, and large numbers of first and second stage zoeae were found near the beaches with progression to advanced stage zoeae 20 to 40 miles offshore. Van Engle (1958) reported that early in August many crabs reach the "first crab" stage and begin migrating into waters of lower salinity. Male crabs remain in less saline waters year round.

Thus blue crabs are a part of both the benthic and planktonic communities, and they use both inshore and offshore waters.

Fishery Resources of Estuaries and Inshore Waters

The estuarine and inshore waters of Georgia support a moderate-sized commercial fishery. The commercial harvest of fish and shellfish for the period 1960-65 averaged 21.4 million pounds valued at approximately $3.4 million (Carley 1968). The catch accounted for about 15 per cent by weight and 17.6 per cent by value of the harvest of the South

Atlantic states. The commercial harvest of fish and shellfish has fluctuated considerably over a period of years, but total monetary value of the catch has been relatively stable because of increasing prices.

The shrimp fishery is the most important commercial fishery in Georgia, accounting for 83 per cent of the harvest value (Carley 1968). Blue crabs account for one-half to three-fifths of the pounds of the annual harvest but account for less than 10 per cent of the harvest value (ibid.). Oysters average about one per cent of the total catch. Shad are the most important fish in the catch and, with other fish species, make up approximately five per cent of the total catch (ibid.).

Shrimp are harvested on the Georgia coast by trawling during the six-month season from June 1 - December 31. The area open to harvest extends from the mouth of the sounds to 3 miles offshore. Shrimping outside the 3-mile limit is legal throughout the year. White shrimp dominate the catch until late in July when they are replaced by the brown shrimp. The browns then dominate the catch until they are again replaced by white shrimp late in August. The catch of white shrimp increases until it peaks in October. The total catch normally consists of two-thirds white shrimp and one-third brown shrimp (Carley and Frisbie 1968a).

Trawling is legal in Georgia during the daytime only. This regulation is a significant factor influencing the composition of the total catch. The white shrimp feeds during the day and burrows into the mud at night. Conversely, the brown shrimp is nocturnal, burrowing into the mud during the day.

The pink shrimp (Penaeus duorarum), also commercially important in some areas, occurs infrequently in the catch in Georgia. This shrimp has habitat requirements (relatively clear, shallow waters with a firm bottom) that are met in relatively few areas in Georgia waters.

Linton (1970) conducted a survey of the distribution and abundance of oyster beds in 1966 and 1967 and found about 10,180 acres of oyster beds, almost all of them intertidal and landward of the barrier islands. Oyster beds are better developed in the northern portion of the state where they occur in a band 7 to 8 miles wide (see Figures not included 35a-h, Appendix 6). All oysters in Georgia are taken from privately held areas through leasing arrangements (Carley and Frisbie 1968b). The most important factors limiting production are pollution, unsuitable substrate, and predation (ibid.). Between one-third and one-half of the estuarine area suitable for oyster growth is polluted (Figures not included 27a-h), and the oyster beds are closed to harvest for public health reasons (ibid.). Little effort has been made to manage oyster beds on a long-term basis. Assuming effective pollution control were possible, oyster production could be significantly increased. Oyster shells and other material suitable for spat-setting could be deposited in many areas, and raft or line culture would be feasible in many areas (Shaw 1967).

A relatively small hard clam fishery existed in coastal Georgia until about 1932. A recent study by Godwin (1967) revealed in the Altamaha Sound a population of brackish water clams (Rangia cuneata) that could support a commercial fishery, but the area is closed for shellfish harvest because of pollution. The hard clam or quahog (Mercenaria mercenaria) does not occur in harvestable numbers in Georgia (ibid.).

Blue crabs are taken in greater numbers than any other commercial species but, due to a low unit price, they represent a small portion of the monetary value of the catch (Carley 1968). Crabs are harvested with pots and traps and are taken in otter trawls incidental to shrimp trawling.

Finfish have averaged about 5 per cent of the total quantity and value of all fish and shellfish in Georgia. Harvest by species is shown in Table 16. The greatest proportion of the catch of finfish in 1967, thirty-six per cent of the poundage and 45 per cent of the total economic value, was American shad (Lyles 1969). Shad are anadromous fish, spawning in fresh water and moving into the ocean to mature. The adults move up the rivers from January until April. Many shrimp and crab fishermen supplement their income by fishing for shad during this time. Young shad

TABLE 16. FISH WITH TOTAL LANDINGS IN GEORGIA OF MORE THAN 1000 POUNDS PER YEAR*

Species	Pounds	
	1966	1967
croaker	5,100	6,000
flounder	33,500	22,000
whiting	145,400	186,700
sea bass	2,700	1,700
black drum		2,400
red drum		5,600
grouper		92,300
red snapper		54,900
weakfish	1,300	
spotted sea trout	1,200	6,900
Spanish mackerel	1,300	2,000
spot	5,200	10,500
bait and animal food	127,600	203,400
hickory shad	2,000	1,300
American shad	385,900	334,100
mullet	2,000	

*Lyles 1968, 1969.

begin to move down the rivers in July and are found in the Atlantic by October (Godwin and Adams 1969).

Whiting made up 20 per cent of the finfish poundage and 15 per cent of the dollar value in 1967 (Lyles 1969). They usually are caught while trawling for shrimp. Carley (1968) reports that there has been a downward trend in the abundance and catch of whiting. There are three species of whiting inhabiting the coast of Georgia (*Menticirrhus americanus*, *M. saxatilis*, and *M. littoralis*), but they are not distinguished in commercial records. *Menticirrhus littoralis* prefers shallows and surf, so it is not often caught in trawls. Both *M. americanus* and *M. saxatilis* spawn in spring and early summer. The young of the former occur in both offshore and inside waters, whereas those of the latter species live in the surf. The adults of both species are found in both inside and outside waters (Hildebrand and Cable 1934).

Red snapper accounted for 6 per cent of the poundage and 17 per cent of the cash value of the 1967 catch, and grouper accounted for 12 per cent and 10 per cent, respectively. These are by far the largest catches reported for these two species since 1957 (Power 1959; Power and Lyles 1964; Lyles 1965, 1966, 1968, 1969). Both species are caught with hand lines off the live bottom and shelf edge habitats. Red snapper are also caught in trawls (Lyles 1965, 1969; Struhsaker 1969).

The total value of the commercial fishery is probably underestimated. Carley (1968) reported that in many cases fish caught while shrimping were given to the crew of the vessel and were not reported. Menhaden form the base of the largest fishery in the United States by volume. The larvae and juveniles spend their first summer in the estuaries where they grow rapidly and serve as an important food item for many carnivorous species. They move into deeper waters in the fall where they are caught in large purse seines (June 1961). Approximately 2000 purse-seine sets were made in Georgia in 1959, each averaging 20-25 tons of fish (June 1961): a total of 40,000 tons. Because there are no menhaden processing plants in Georgia, these fish were landed outside the state, probably at Fernandina Beach, Florida, and are not listed in the Georgia landings.

Sport fishing is also an important element in the coastal economy. Expenditures by an estimated 281,400 salt water sport fishermen on the Georgia coast totaled $22,523,280 in 1968 (Cheatum et al. 1968). Table 17 lists the sport fish most commonly caught on the Georgia coast. Harvest figures are not available for salt water fish taken by sport fishermen in Georgia.

Productivity and Energy Flow

Nutrients

The waters comprising the coastal region are actually a solution of many inorganic and organic compounds and

TABLE 17. COMMON SALT WATER SPORT FISHES OF GEORGIA

Inshore species	Offshore species
spotted sea trout	king mackerel
red drum (channel bass)	dolphin
Spanish mackerel	little tuna
tarpon	great barracuda
bluefish	Atlantic bonita
cobia	pompano
sheepshead	crevalle jack
striped bass	greater amberjack
American shad	red grouper
southern kingfish	red snapper
triple tail	black sea bass
southern flounder	sailfish
weakfish	
Atlantic croaker	
spot	

other materials in suspension. The movements and concentrations of these substances are important aspects of the ecology of the area. Elements such as carbon, nitrogen and phosphorus are necessary for primary production and often prove to be limiting factors. Of these, phosphorus and zinc have been studied in the Georgia coastal waters.

Phosphorus is often limiting in oceanic waters (Raymont 1963). Pomeroy et al. (1965) found phosphorus concentrations of 1 micromole per liter (μM/L) in Doboy Sound. At this high concentration phosphorus was not considered to be a factor limiting primary production. Estuarine water of the Altamaha River contains phosphorus in concentrations ranging from 0.05 to 4.0μM/L, whereas the river water has a phosphate concentration of 0.1μM/L. Pomeroy et al. (1969) concluded that the estuary acts as a "sink" since it accumulates sediments that contain organic matter as well as many minerals. Experiments have been conducted in which ^{32}P was released in the headwaters of the Duplin River (Pomeroy et al. 1969). From this work it was determined that the sediments play an important role in the phosphorus cycle. Phosphorus from the surface sediments, which are in equilibrium with the water, moves into a number of deposit feeders and from them, via excretion, back into the water. Subsurface sediments, not in equilibrium with the water, are the source of phosphorus for smooth cord-grass. Bacteria within the sediments are probably accumulating phosphorus, which is released by the bacterial feeders (Johannes 1965). Thus, there is a separation between pathways within the salt marsh. Phosphorus in subsurface sediments is incorporated into the cordgrass which serves as the principal source for insects and spiders. Most of the cordgrass, however, dies and enters the detritus food chain. Thomas (1966) showed that the estuarine waters, rich in phosphorus, are flushed out into the offshore waters and serve as a nutrient source for phytoplankton.

Zinc is a trace element required by some organisms and often is concentrated by them. Tracer studies with ^{65}Zn indicate that the cycle of zinc, like that of phorphorus, is dominated by the sediments which act as a mixed-bed ion exchanger (Pomeroy et al. 1969). Organisms, except fiddler crabs and oysters, take up zinc and phosphorus at much the same rates. Oysters demonstrate a preferential retention of zinc, and fiddler crabs show high initial values of zinc activity, falling off rapidly and becoming erratic, suggesting movements in and out of the area. Bioelimination of zinc seems to be slow. Concentrations of zinc are, like phosphorus, high in the Duplin River as compared to sea water, and the same processes that concentrate phosphorus may concentrate zinc (ibid.).

Vitamin B_{12} is a nutrient essential for growth by many organisms such as bacteria, algae and protozoa. It is synthesized mainly by bacteria and fungi (Burkholder and

Burkholder 1956) and is found in large quantities in marine invertebrates and fish. Starr (1956) and Burkholder and Burkholder (1956) studied the distribution of this vitamin in suspended solids and marsh muds from the Georgia coast. Burkholder and Burkholder (1956) found that the dark-water rivers contained high concentrations of B_{12} per unit of suspended particles. Both studies showed a progressive increase in B_{12} from offshore stations to the head of a tidal creek. However, Starr (1956) reports that ocean waters contain detritus richer in B_{12} than the more turbid sound waters. The highest concentration of B_{12} is contained in the detritus at the headwaters of the tidal rivers. Starr (1956) also established that detritus entering the marsh at high tide was not as rich in B_{12} as that leaving on the ebb tide. Sediment samples taken from areas devoid of marsh were much lower in B_{12} than those taken from marsh areas; however, both were lower in B_{12} than water leaving the marsh. Starr (1956) concluded that the muds did not add appreciable quantities of vitamin-rich detritus to the waters. Burkholder and Burkholder, however, report that muds treated with sulfite yield values 3.8 times higher than untreated samples, and Starr did not mention this technique which could have changed his conclusion. More work is needed to clarify this problem as well as the role of B_{12} in productivity of the sea.

Most of the turbidity of coastal waters is caused by suspended sediments, but a significant portion (18 per cent) is caused by organic material (Odum and de la Cruz 1967). A standing crop of 2 to 20 micrograms ash-free, dry organic matter per liter is reported for the Georgia estuaries, a value much greater than reported for open sea water or other sounds and bays (ibid.). These measurements were taken at the mouth of a small tidal creek draining a salt marsh. Samples taken at mid-ebb tide always produced more organic detritus than did samples taken at mid-flood tide. This suggested that organic material is being exported from the marsh. Teal (1962) also calculated a net flow of organic material from the marsh to the estuary and beyond.

The waters of the coastal region appear to be rich in organic materials, the two inorganic nutrients phosphorus and zinc, and vitamin B_{12}. All of these are found in higher concentrations in the salt marsh-estuary system than in the open ocean.

Food Webs

Food webs of the estuary are not nearly as well understood as those of the salt-marsh. Many of the conclusions concerning the food webs of the Georgia estuaries must be inferred from work done in other regions. The estuarine environment is more complex than the marsh system, and many estuarine species migrate seasonally. Estuarine inhabitants can be categorized as plankton, benthic infauna, epifauna or fouling organisms, and nekton. Some are deposit feeders, some suspension feeders, and some are carnivores.

Specific food habits studies have been conducted on commercially important invertebrates such as crabs, shrimp and oysters. Shrimp are deposit feeders; Darnell (1958) reports that detritus and fine organic material composed 58 per cent of the food of shrimp examined, and mollusks 12 per cent. He suggested that both young and mature white shrimp are omnivorous, feeding largely on detritus. Oysters are suspension feeders. Galtsoff (1964) studied ciliary currents produced by oysters and concluded that the food-sorting mechanism is designed for continuous feeding in low concentrations and that food selection, except on the basis of size, is open to question. The blue crab is both a scavenger and a predator; foods include mollusks, detritus, crabs (Callinectes, Rithropanopeus, and unidentified species), vegetation, and fish remains (Darnell 1958).

Data from published studies of the stomach contents of fish (Table 18) are summarized in Table 19 to show generalized feeding habits of estuarine fishes. Food items are divided into the following general types: detritus, algae, zooplankton, microbenthic invertebrates, macrobenthic invertebrates, shrimp, and fish. The majority of fish consume more than one type of food and are not confined to one trophic level. Ninety-two per cent of the fish fed to some extent on benthic invertebrates. These percentages are based only on those common species which have been studied,

TABLE 18. SOME FOOD HABITS STUDIES OF COMMON ESTUARINE FISHES

Species	Reference
Sphyrna tiburo (bonnethead)	Gunter 1945
Lepisosteus osseus (longnose gar)	Goodyear 1967
Megalops atlantica (tarpon)	Rickards 1968
Bevoortia sp. (menhaden)	June 1961
Anchoa mitchilli (anchovy)	Darnell 1958
Galeichthys felis (sea catfish)	Darnell 1958
Opsanus tau (oyster toadfish)	Schwartz and Ducher 1963
Pomatomus saltatrix (bluefish)	Grant 1962
Orthopristis chrysopterus (pigfish)	Hildebrand and Cable 1934
Archosargus probatocephalus (sheepshead)	Gunter 1945
Lagodon rhomboides (pinfish)	Darnell 1958
Bairdiella chrysura (silver perch)	Darnell 1958
Cynoscion nebulosus (spotted sea trout)	Darnell 1958
Cynoscion regalis (weakfish)	Hildebrand and Cable 1934
Leiostomus xanthurus (spot)	Darnell 1958
Menticirrhus americanus (southern kingfish)	Gunter 1945
Menticirrhus littoralis (Gulf kingfish)	Gunter 1945
Menticirrhus saxatilis (northern kingfish)	Welsh and Breder 1923
Micropogon undulatus (Atlantic croaker)	Darnell 1958
Pogonias cromis (black drum)	Welsh and Breder 1923

TABLE 18. (Continued)

Sciaenops ocellata (red drum)	Darnell 1958
Stellifer lanceolatus (star drum)	Welsh and Breder 1923
Mugil cephalus (striped mullet)	Darnell 1958
Paralichthys lethostigma (southern flounder)	Darnell 1958
Chilomycterus schoepfi (striped burrfish)	Gunter 1945

TABLE 19. FEEDING HABITS OF ESTUARINE FISHES*

Type feeder	Per cent of species studied
Planktonic feeders only	4
Benthic feeders only	32
Fish feeders exclusively	8
Detritus feeders only	0
Plankton feeders	44
Benthic feeders	92
Fish feeders	52
Detritus feeders	16
Strict herbivores	0
Strict carnivores	34
Shrimp feeders	52
Limited to one type food	28
Eat more than one type food	72
Eat more than two types of food	52
Eat more than three types of food	32
Eat more than four types of food	12

*Summarized from data reported from studies listed in Table 18.

and the data were collected with varying degrees of precision from widely scattered areas. Some of the studies took the age of the fish into account; others did not. However, in every case where stomach analyses were done for individual size classes, a change of food habits was correlated with a change in size. For example, croaker less than 25 mm in length eat principally zooplankton; those 25-50 mm feed mostly on microbenthic invertebrates. Detritus, shrimp and macrobenthic invertebrates are the main food items of fish 50-200 mm. Large croaker (greater than 200 mm) eat macrobenthic invertebrates, shrimp and fish (Darnell 1958).

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GEORGIA'S COAST