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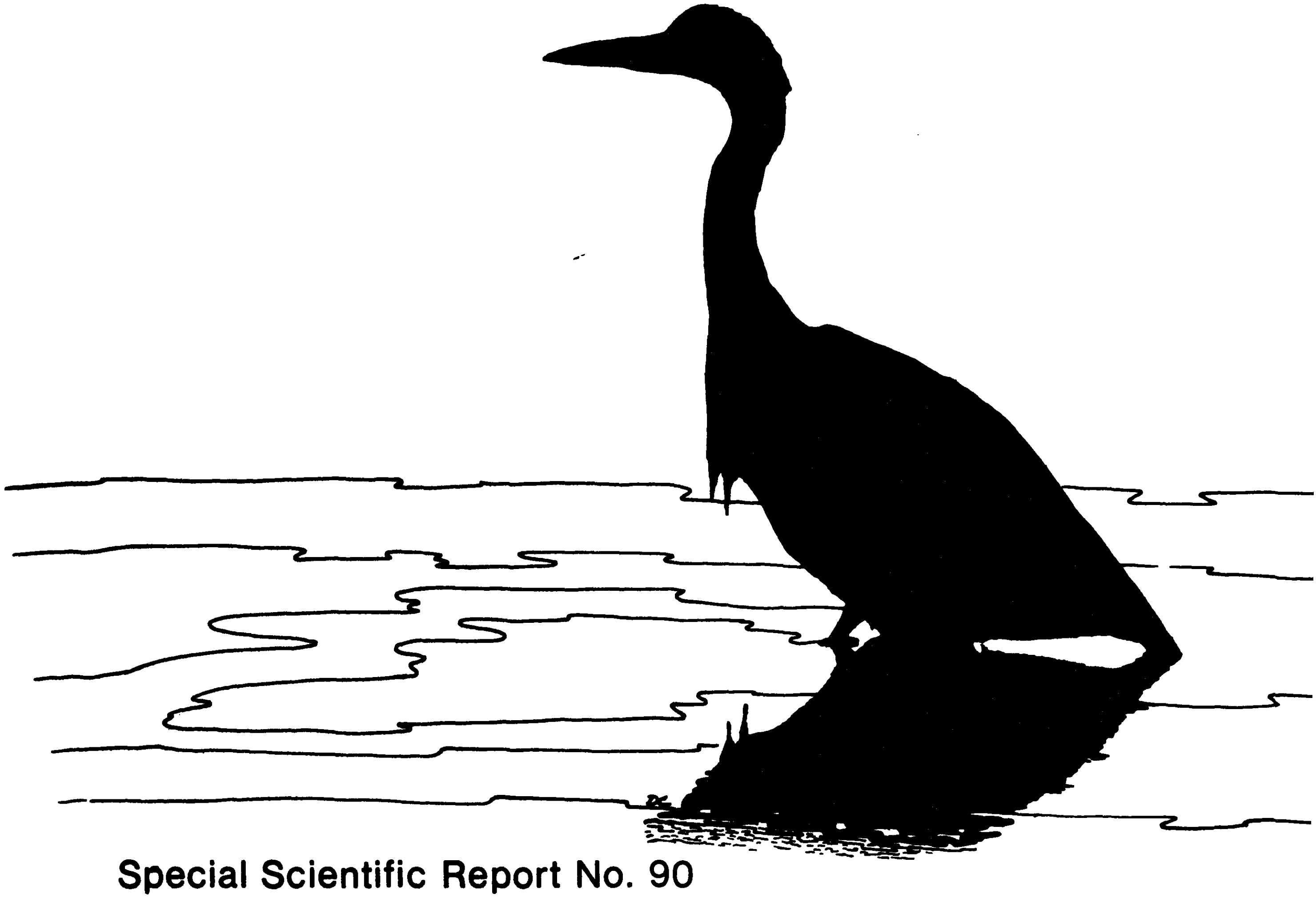

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VALUES AND MANAGEMENT STRATEGIES FOR NONVEGETATED TIDAL WETLANDS

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PREFACE

The Legislature of the Commonwealth of Virginia enacted the Wetlands Act of 1972, in the spring of that year, after six years of review and study of wetlands. The Wetlands Act, however, only addressed that portion of wetlands where vegetation is growing.

Much more has been learned about our marine environment in recent years. While it became apparent that the Wetlands Act was effective in protecting vegetated areas, it also became apparent that development was shifting to nonvegetated wetlands. It also became apparent that the general public, while learning about vegetated wetlands, was not aware of the ecological values of the total wetlands system and some of the real value of intertidal flats, beaches and bars.

The Commonwealth commenced planning for more comprehensive coastal resources management in 1974. The values of nonvegetated wetlands were recognized as these areas were designated as geographical areas of particular concern. Subsequently, management proposals for these areas were inserted into draft legislation.

A major purpose of this contribution is to assist legislators, understand the reasons behind a management proposal which will be considered by the General Assembly early in 1978.

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Part I.

Values and Management Strategies for Nonvegetated Tidal Wetlands: A Summary

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Nonvegetated tidal wetlands are those coastal environments between mean higher high water (MHHW) and mean lower low water (MLLW) in which no vascular plants grow. These environments largely fall within the 1972 Virginia Wetlands Act definition of wetlands as "all land lying between and contiguous to mean low water and an elevation above mean low water equal to 1.5 times the mean tide range" except for their lack of vascular vegetation.

Nonvegetated wetlands mainly occur adjacent to tidal marshes, beaches, and other shorelines. In Virginia, intertidal flats are not as extensive as in areas with greater tidal range, but nonetheless constitute a moderately extensive and widespread habitat in the Commonwealth. The seaside Eastern Shore because of its greater tidal range contains nonvegetated intertidal flats at least as extensive as its tidal marshes.

Values

Nonvegetated wetlands are among the most valuable of coastal environments in supporting coastal resources. They share some valuable attributes with both tidal marshes and subaqueous estaurine habitats. Primary productivity in intertidal areas is larger than in open waters because of the greater supply of light and nutrients available in very shallow areas. This primary productivity is the result of nonvascular plants (bottom-dwelling macro- and microalgae and phytoplankton) which inhabit the intertidal zone. This productivity is typically less than that of tidal marshes, but a greater proportion of it is passed to the estuarine food chain. Also, primary production goes on year round, whereas vascular plant production ceases in winter.

Nutrient storage and cycling constitutes another valuable function of nonvegetated wetlands. This is facilitated because the intertidal zone provides direct interfaces between water, sediments, atmosphere, and biota. The sediments may serve as both a source and a sink for particular nutrients, enabling an intertidal area to maintain high productivity even when nutrients in the water are critically low.

Intertidal areas are widely recognized as important nursery and feeding grounds for commercially important fishes and crustaceans and for the prey which support them. Intertidal and shallow water habitats provide abundant food and a critical refuge from predators for sensitive life stages of these animals (e.g. juvenile fishes, shedding blue crabs, etc.). In addition shellfish such as oysters, hard clams, and soft clams inhabiting nonvegetated wetlands constitute a resource of notable commercial (especially on the Eastern Shore) and recreational importance.

Shoreline protection is provided to varying degrees by intertidal beaches, flats, and bars because they dissipate wave energy which erodes fast land. Waves crossing a broad flat or beach will decrease in velocity and energy before reaching the shore. Sand bars cause waves to shoal and break and, thus, lose energy well offshore. The importance of nonvegetated wetlands in shoreline protection will depend on their exposure, extent, morphology, sediment type and even the biota inhabiting the flat.

Nonvegetated wetlands constitute the principal feeding ground of shorebirds and many waterfowl which exploit benthic animal prey. Some birds specialize in protected mud flats, while others forage only on exposed sandy beaches.

Nonvegetated tidal wetlands provide multifaceted recreational and aesthetic resources. They provide access to bathing, boating, recreational fishing and simply provide gratification to human senses. Commercial functions are also served by access across the intertidal zone. The great potential for conflict in the multiple uses - recreation, aesthetics, commerce, and living resources - underscores the necessity for sound management for nonvegetated wetlands.

Rigorously quantitative statements about the resource values of the various nonvegetated and vegetated wetland habitats are not yet permitted by the state of knowledge. Even qualitative or relative valuations are made difficult by the fact that environmental attributes vary greatly in quality as well as quantity., Primary productivity varies widely in nonvegetated wetlands. On clean dynamic sand beaches primary productivity is low due to substrate instability and low levels of nutrients. On stable mud or muddy sand flats, mats of algae may form and nutrients are actively regenerated. The value of primary productivity in such nonvegetated wetlands may rival or exceed that associated with tidal marsh production.

The value as a habitat or feeding grounds for fish and shellfish is particularly difficult to quantify. Habitat utilization may be seasonal and standing crop of sedentary prey may not accurately reflect the food resources of the habitat. Low prey densities have, in fact, been found to be attributable to intensive fish and crab predation in the Chesapeake Bay. These heavily cropped prey must turn-over rapidly to survive and their sparse biomass belies their productivity. In general, however, nonvegetated wetlands, are more valuable than vegetated wetlands, themselves, as feeding or nursery grounds or permanent habitats for fish and shellfish. Intertidal zones which are extensive, adjacent to marshes or submerged aquatic vegetation or in low salinity nursery zones are the most valuable habitats. For foraging shorebirds or waterfowl, nonvegetated wetlands are of equal or greater value than vegetated wetlands. Again, those flats near marshes, which provide cover, are of particular value.

Nonvegetated wetlands present a less formidable buffer against shoreline erosion than do tidal marshes. However, wave dissipation by adjacent flats is often required for marsh formation and growth.

Obviously, the broader and shoaler the intertidal zone the more effective it will be in preventing shoreline erosion.

Nonvegetated wetlands are more often encountered and used by humans than vegetated wetlands. Intertidal beaches are perhaps the most accessible, used and resistant to use of coastal environments. Mudflats, although generally less attractive to the general populace, are the preferred sites of bird watchers.

Impacts of Human Activities

Man's uses and the unwitting impact of other human activities constitute a threat to nonvegetated wetlands.

Dredging activities may result in the direct alteration by dredging or filling of intertidal areas. Dredging or filling is accomplished for navigation, materials acquisition, shoreline stabilization, beach replenishment or land "reclamation". Dredging or filling also cause indirect alterations to intertidal areas removed from the direct activity by changing wave, current, sediment deposition and erosion patterns. Eliminating or effectively deepening the nonvegetated wetland will result in reduced primary productivity, possible elimination of fish and wildlife feeding grounds, the deposition of fine sediments and resultant risk of oxygen depletion. Filling intertidal areas effectively removes them from the aquatic system.

Shoreline modification through construction of bulkheads, groins, breakwaters, docks and piers has important effects on nonvegetated wetlands by causing scour or sedimentation. For example, an improperly designed bulkhead may cause erosion of sediment at the base of the bulkhead, resulting in alteration of the extent and elevation of the intertidal habitat.

In the coastal zone, land use patterns may effect alterations of intertidal habitats through alteration of natural surface drainage, increased deposition of sediment and the introduction of nutrients and toxicants. Soil erosion exacerbated by poor practices in road building, land clearing, construction, forestry and agriculture may increase intertidal sediment deposition.

Impacts on nonvegetated wetlands from boating stem from two sources. The first is the development of marinas, docks, piers, and associated dredged channels. Secondly, disturbances are created by boats motoring through shoal areas, disturbing the substrate, and erosion of intertidal bottoms created by wakes of boats.

Increased recreational utilization of the coastal zone places nonvegetated wetlands under heavy pressure. Shoreline inhabitation and access increases the demand for bulkheads, groins and piers. Beach utilization and recreational fishing and shellfishing may also impact intertidal habitats.

An index of the magnitude of direct development pressures on nonvegetated wetlands may be gained by comparing the number of permits issued by the U. S. Army Corps of Engineers for projects which affect nonvegetated wetlands to that reviewed by local wetlands boards. The latter activities affect vegetated wetlands and come under the jurisdiction of the Virginia Wetlands Act of 1972, while the former at present do not. According to figures compiled by the Virginia Marine Resources Commission for 1974-1976, over one and a half times as many activities which involved vegetated wetlands either involved only nonvegetated wetlands or certain private open-pile structures, which are excluded or exempted, respectively, from the Wetlands Act. Thus, conservatively at least as many construction or other alteration activities affected nonvegetated wetlands alone as affected vegetated wetlands. Also most of those activities affecting vegetated wetlands also impact adjacent nonvegetated wetlands. The extent of these activities makes clear the need for the development of effective management strategies for nonvegetated wetlands.

Management

If nonvegetated wetlands are to be included together with vegetated wetlands under the Virginia Wetlands Act, a comprehensive management program must be developed and implemented which is based on the resource values, desired uses and associated impacts of nonvegetated wetlands. A fundamental requirement will be an evaluation scheme through which the resources and sensitivities of nonvegetated wetlands may be judged. A comprehensive inventory of all nonvegetated intertidal areas in Virginia such as undertaken for vegetated wetlands would be both costly and time consuming. Compared to tidal marshes nonvegetated wetlands do not have obvious or easily measured features such as vegetation type on which to base an evaluation scheme. Thus it does not seem feasible or particularly effective to conduct broad, in depth inventories of nonvegetated wetlands as have been conducted for tidal marshes and swamps.

Background inventories of nonvegetated wetlands, should they be needed, may be sufficient if based on existing charts, maps, and aerial photographs supplemented by rather casual broad inspection or spot checking. In practice, the main mechanism for evaluation will be site visitation for the purpose of making standard observations. These field observations will then be evaluated based on a priori guidelines developed as part of the management plan. Unfortunately, the level of understanding of the relative values of different nonvegetated wetlands habitats and, therefore, of the criteria which can be best used in their evaluation, falls far short of that for vegetated wetlands. Research in progress focusing on the ecology of intertidal and shallow water habitats in the Commonwealth will hopefully increase this understanding. In reality, though, initial evaluation criteria will be relatively qualitative and general. As new research results are brought to bear on evaluation and as more experience is gained by field inspection of proposed activities, the criteria will evolve, mature and increase in specificity. As a start, however we envision very simple field question questionnaires (Attachment 1) may be used to record simple observations required for observations.

Attachment 1

Nonvegetated Wetland Evaluation Report

Location (supply map if possible)

County:

Water Body:

Specific Location:

Date and Time of Inspection(s)

Tidal Height During Inspection:

High Low
Spring Neap

Description of Nonvegetated Wetland

Estimated width (MHW-MLW):

Estimated long shore extent:

General category: e.g.:
- Bar (disconnected from shoreline)
- Tidal flat (>5 m width)
- Fringing intertidal zone (<5 m width)
- Periphery of vegetated wetland
- Creek banks
- Beach

Sediment characteristics: (standard descriptors to be provided)

collection of sediment samples recommended

Biotic Characteristics

Plants: (e.g. interspersed marsh plants; submerged aquatic vegetation, macroalgae, microalgae mats, microalgal suggested by brown or green coloration of substrate, etc.)

Shellfish: (oysters, soft clams, hard clams, others)

Obvious marine animal life:

Observed or presumed bird utilization:

Human Uses:

Observed or apparent direct utilization: (e.g. recreational crabbing, public beach, private access beach, boat docks, etc.).

Adjacent land use: (e.g. undeveloped woodland, high density residential, low density residential, agricultural, industrial, etc.).

Part II.

The Resource Ecology of Nonvegetated Wetlands: A Review

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I. INTRODUCTION

Despite their dubious value to the casual observer, nonvegetated intertidal areas contain a wealth of both tangible and intangible products desired by society. One of their most obvious values, for man's developmental activities, is exemplified by the number of shoreline permits granted by the Army Corps of Engineers each year.[1] Other equally important values include the roles these habitats have in maintaining ecosystem food chains, prevention of shoreline erosion, harboring shellfish resources and providing public recreation. A better understanding of the resources available in Virginia's nonvegetated wetlands is of major importance to the management of these valuable coastal areas and, therefore, the aim of this review.

In this report, past and recent literature is reviewed to help clarify the nature and values of nonvegetated wetlands. Boundary limits as well as various physical, biological and chemical parameters are reviewed to facilitate a better understanding of these environments. In addition, the tangible and intangible values are described, clarifying their importance relative to one another.

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[1] From January 1973 to April 1976 permits were granted for 35,364 ft. of piers, 58,468 ft. of bulkheading, 7,928,875 cubic yards of dredge material, 1,019,858 cubic yards of depositor fill, 25,050 ft. of jetty construction and 1,978,607 cubic yards of spoil disposal in intertidal areas.

Wetlands, as defined by the Virginia Wetlands Act of 1972, encompass only that portion of the vegetated intertidal zone which meets specific vegetative and elevational restrictions. Cowardin (1977) defined "wetlands" inclusively as:

> "land where the water table is at, near or above, the land surface long enough to promote the formation of hydric soils or to support the growth of hydrophytes. In certain types of wetlands, vegetation is lacking and soils are poorly developed or absent as a result of frequent or drastic fluctuations of surface water levels, wave action, water flow, turbidity or high concentrations of salts or other substances in the water or substrate. Such wetlands can be recognized by the presence of surface water or saturated substrate at sometime during each year and their locations within, or adjacent to, vegetated wetlands or deep water habitats."

Under this definition, nonvegetated intertidal areas are included as wetlands. Therefore, sand and mud flats, bars and beaches, as well as the more traditional vegetated wetlands, are all encompassed in the broad definition.

II. NONVEGETATED WETLAND TYPES

A. Intertidal Flats

Sand and mud flats are generally defined as areas of unconsolidated sediments that are flat, irregularly shaped and usually continuous with the shoreline. These intertidal areas are divided into the categories listed below according to sedimentary composition (Cowardin, 1977):

1. Cobble-Gravel: predominantly cobble and gravel with shell fragments and finer sediments intermixed
2. Sand: predominant component is sand, other particles may be mixed in
3. Mud: predominantly silts and clays, usually high in organic content, tends to be anaerobic below the surface
4. Organic: exposed soils of formerly vegetated wetlands.

These intertidal flats are created and controlled by the combined effects of currents, tides, wave action and available sediment type (Postma, 1967; Groen, 1967; Bartburger, 1976; Reineck, 1967; Orth, 1978; Anderson, 1972). The wave component is created by incoming oceanic or bay wave action or locally wind-generated waves. Wind waves passing over intertidal flats create turbulence which can increase particle size as depth shoals (Postma, 1967). In addition, waves of amplitudes <0.5 m may be sufficient to resuspend some silts and clays on intertidal flats (Anderson, 1972).

Tides and currents usually combine to create the next hydrographic parameter in the tidal flat. Maximum flood is reached at the beginning of each tidal cycle as the water moves through the channels with the current flood velocity decreasing as the water spreads out over the flats. Maximum ebb tide is reached near low water when the majority of the water movement is through the channels (Orth, 1978; Postma, 1967; Groen, 1967). During one tidal cycle in the estuary the magnitudes of ebb and flood are either symmetrical or asymmetrical. In the case of an asymmetrical system, like the Chesapeake Bay, the flood tide is the larger of the two constituents resulting in a net particle movement landward in an estuary (Postma, 1967). This landward movement of particles is further facilitated by two processes referred to as "scouring lag" and "settling lag"[2]. These "lags" cause finer particles to move farther landward than would be expected if current velocities were the only contributing factor. Once the ebb tides begins, the currents in the more landward areas on the intertidal flat may be too feeble to resuspend these particles (Postma, 1967; Groen, 1967).

In addition to particle movement, the sediment sources in these areas are extremely important in the maintenance of the intertidal flat. The most obvious sources of sediment are shoreline erosion and the watersheds, which empty into the estuarine system. These reservoirs, known to contribute significant amounts of sediment to the estuarine system, are not the sole sources however. Two other processes, eolian[3] transport and overwash, have been shown to be important sediment sources in several systems. According to Bartburger (1976), sand fencing for dune stabilization (which might reduce eolian transport and overwash) can be detrimental to the total ecology of a barrier island system. Through investigations of

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[2] "Settling lag" occurs when current velocity drops below the level necessary to maintain a particle in suspension. As particles settle, they continue their landward movement. "Scouring lag" describes the need for more current velocity to resuspend a particle from the sediment than is needed to maintain that same particle in suspension (Groen, 1967).

[3] Eolian transport refers to the movement of sand by wind and the term "overwash" is applied to sand carried over beach dunes by waves or storm surges.

available sediment sources and historical erosion and run-off data, he found approximately one half of the sand present in the system was unaccounted for if one considered only river born sediments and shoreline erosion. Further investigation demonstrated that eolian transport and overwash were contributing the missing portion of the sediment load to the island interior, marsh, and tidal flat systems.[4]

In all estuarine systems, the hydrographical and meteorological forces cannot independently maintain a tidal flat area if sedimentation rates are low. Biologically important forces, such as dense populations of molluscs, filter the finer seidments returning to the surface pseudofeces and fecal pellets[5] which are more difficult to

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[4] An example of disrupting these processes to the detriment of an area can be found at Cape Hatteras, North Carolina. According to Dolan (1972, 1973) and Godfrey and Godfrey (1973) massive dune ridges were constructed which concentrated the wave energy on the beach face and artificially created dune line creating severe bach and dune erosion. In addition, sediment nourishment to the interior of the island, lagoonal shores and marshes was small or totally lacking. Instead of the sand being overwashed on to the island to keep the land abreast of sea level rise, the sands are now being eroded and carried out to deep water. According to Dolan (1972, 1973) the cost of maintenance of these barrier island systems may exceed the economic and psychological value attached to their existence. Barrier islands in their natural states are not being destroyed by nature but are responsing to the natural sea level rise by retreating landward. Thus, Dolan (1972, 1973) believes the states should carefully consider their plans for future development (or lack of development) in the new shoreline areas now in their possession.

[5] Fecal pellets are bodily wastes excreted after ingested material has been subjected to digestive processes while pseudofeces are materials that are captured but do not pass through an organism's digestive system.

suspend (Postma, 1967; Waneless, 1975)[6]. In addition, resuspension of these sediments may be further decreased by the presence of mucilaginous films[7] from diatom communities and algal mats (Waneless, 1975).

B. Beach and Bar Systems

There are several definitions for beach and bar systems. According to Bascom (1951), "a beach is a deposit of material which is in transit either along shore or on and off shore". It is charactered by the following three elements:

(1) Quantity of rocky material

(2) Shoreline area in which material moves

(3) Energy supply which moves it.

Cowardin (1977) defines a beach as "an unconsolidated sloping landform composed of sand, gravel, or cobbles which is generated by wave and current action." The beach is continuous with the shore and extends landward to a distinct break in landform or substrate type (i.e. foredunes, cliff bank, or zones of vegetation). Bars are described as elongate ridges, banks, or mounds, bordered on at least two sides by

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[6] Postma (1967), summarizing Verwey (1952), stated that within a few days to a few weeks a filter feeding assemblage of organisms could filter the complete water mass located over a tidal flat.

[7] Mucilaginous films are adhesive, slimy masses of a gelatinous substances, similar to plant gums and usually containing proteins and sugars, which are secreted by diatoms and other plant-like organisms.

water. Both of these areas may be irregularly flooded and exposed to very regular cyclic tidal inundation.

In general, the slope of the beaches, the wave character and the average particle size are related, i.e., the greater the slope the larger the particle size (Hedgpeth, 1957; Bascom, 1951). The majority of beach material movement consists of an exchange between offshore (underwater) bars (ridges) and the berm[8]. These offshore bars may be considered products of erosion appearing when violent wave action cuts back the berm and deposits the beach material in ridges offshore. These bars modify the waves approaching the shore. The outer slope of the bar is relatively steep causing the larger waves to break and reduce their wave energy (Bascom, 1951). This decreased wave energy has less erosive ability as it approaches the beach face. Both areas, bar and beach, have high surface permeability, variable surface moisture and relatively low organic content (Cowardin, 1977).

The major constraint on the sand conservation and maintenance of these systems is not the seasonal offshore movement, but the longshore movement of sand. Waves which strike the shore at an angle transport millions of tons of sand. If the prevailing waves arrive in this

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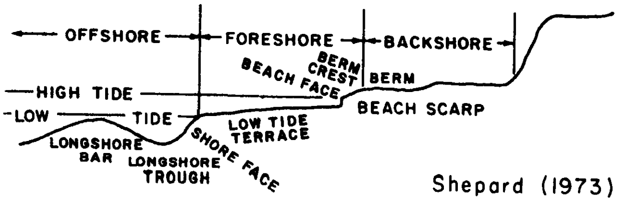
[8] As shown in this classic diagram of beach subdivisions, the berm is the nearly horizontal portion of the beach (commonly used for sunbathing).



Shepard (1973)

manner, littoral currents often flow constantly (Hedgepeth, 1957; Bascom, 1951). Although these currents are not sufficient to move the sand on their own, turbulence in the surf zone suspends the particles enabling a relatively weak current to move a large amount of sand (Bascom, 1951).

III. BIOLOGY OF NONVEGETATED WETLANDS

Biological systems in all nonvegetated intertidal areas are subjected to rigorous biological, chemical and physical stresses. These stresses involve principally: 1) duration of exposure or inudation, 2) magnitude of wave or tidal action, 3) nature of substratum, 4) topography of the shore, 5) physio-chemical parameters, e.g. dissolved oxygen, temperature and salinity, and 6) inter- or intra-specific competition (Gray, 1974; Orth, 1978). The location and number of individual species varies from habitat to habitat with 80% of the species present being found in the top 15 cm of the sediment.

Macrofauna[9] is defined as those organisms retained on a 0.5 mm mesh screen, meiofauna as those passing through 0.5 mm mesh screen but retained on a 64 mesh screen and microfauna as those organisms capable of passing through a 62 mesh screen. These size class delineations are also used to describe the flora of an environment.

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[9] Macrofauna are organisms like worms and molluscs, that are usually large enough to be seen with the naked eye. Microfauna, in contrast, are animals too small to be seen without magnification. This term is usually applied to soil dwelling organisms. The term meiofauna commonly refers to minute animals adapted for living in the spaces between sand grains (Barnes, 1974).

Through the literature it has been shown that the fauna and flora are dependent upon each other in the overall maintenance and economy of an area. From the smallest pennate diatoms to the largest deposit feeding polychaetes, each plays an important role in the community and the ecological food chain.

A. Macrofauna

In the intertidal habitat, the macrofauna utilize the resources available within the environment through a division of feeding types. Below are listed the five main feeding types, food resources, and characterizing organism.

(1)	Deposit feeders	feed on sediment deposits and associated with fauna and flora, e.g. polychaete worms
(2)	Suspension feeders	feed on particles filtered from the water column, e.g. barnacles, oysters
(3)	Scavengers	feed on carion present in habitat e.g. blue crab
(4)	Carnivores	feed on living fauna - predator - e.g. oyster drill
(5)	Omnivores	feed on living flora & fauna - predator, e.g. periwinkles

An understanding of these feeding types prevalent in an area is necessary to understand the ecology of a given intertidal zone.

Although these areas are under severe physiological and biological stresses, the inhabitants have adapted to these conditions. Characterisitically, there are a large number of small organisms present which are important to the general overall economy of the intertidal area than the larger, more commercially important species. One gram of substrate may contain as many as 500,000 bacteria, thousands of diatoms, algae, nematodes, copepods, ostracods, amphipods, etc. The predominant macrofauna in the intertidal zones are the polychaetes, molluscs and crustaceans. Many of these organisms can retreat into the lower levels of the sediment where the environment is more protected and the organisms experience a less rigorous physical environment. The water content in this region is higher while the temperature is more stable.[10] Mud flats tend to drain more slowly than those composed of sand and are therefore exposed to environmental extremes for a shorter period of time during a tidal cycle. Sand flats do, however, retain a surprising amount of water because of their slight elevation above sea level and capillary action (Gray, 1974).

The organisms present in depositional, low energy environments are predominantly deposit feeders which constantly rework the sediments. Reworking of bottom sediments is a product of intense

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[10] An example of temperature modification in the infauna is found in tube dwelling polychaetes Chaetopterus. Ambient temperature at the surface was found to be 35°C during the study. The maximum temperature found in the 12 Chaetopterus tubes was 29°C illustrating the modification of environment through retreat to lower levels (Gray, 1974).

activities of deposit feeders[11]. These organisms cause extensive changes in their environment through the creation of a pelletized surface and decrease in surface sediment compaction (with a resultant increase in sediment water content). Constant reworking can decrease the ability of suspension feeding organisms to survive due to the lack of suitable substrate and increased turbidity in the water column (Rhoads, 1974). Such extremely unstable bottoms are limited mainly to the deep subtidal areas. Intertidal and shallow subtidal areas tend to be stabilized by populations of benthic diatoms, grasses, and algal mats (Rhoads and Young, 1970).

Bioturbation and reworking of sediments is a normal estuarine process. It aids in reducing anaerobic[12] conditions, facilitates the entry of aerobic bacteria and oxygen into the sediments, accelerates decomposition and returns nutrients like phosphates, carbon dioxide (CO_2), and ammonia to the sediment - water interface to be utilized again (Gray, 1974). This ability to rework sediments is an important characteristic of deposit feeders. Where these organisms are abundant, they may rework the sediments and thereby cycle nutrients several times before the nutrients are isolated from further

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[11] One organism, Balanoglossus auranticus, can rework up to 500 gms of substrate and is common to much of the southeastern U.S. (Gray, 1974). Gordon (1966) studied Pectinaria gouldi and found it could rework up to 600 gms of sediment per year. Amphitrite ornata reworked 23 gms/daily while Leptosynapta inhaerans reworked sediments at rates similar to Pectinaria gouldi.

[12] Sedimentary organisms may function in an aerobic (oxygen containing) or anaerobic (oxygen deficient) environement. Dependence on either of these environmental conditions maybe partial (facultative) or complete (obligate). Hence, an obligate anaerobe can only exist in the absence of oxygen.

biological activity by long term sedimentation[13] (Gordon, 1966).

The dominance of specific organisms found in intertidal areas varies with the environment they inhabit. In the tidal flats, polychaetes, crustaceans, and molluscs usually predominate. Various studies indicate that particle size is the determining factor in the development of the faunal distribution zones (Orth, 1978; Howard and Dorjes, 1972).

In contrast, the more exposed beach and bar habitats are inhabited by a strikingly less diverse fauna predominated by rapidly burrowing filter feeder molluscs and crustaceans, scavenging crustaceans, and a few large burrowing polychaetes. Individual species are highly specialized for the rigorous environment and populations are often very dense. Zones of distribution are nearly as pronounced as in the more stable tidal flats. It is also a habitat where landward invasions of species have historically occurred. One of the better known samples of landward migrations is Ocypode or the ghost crab commonly found along Virginia's beaches (Hedgepeth, 1957).

The influence of these organisms have on the intertidal systems depends on the energy requirements and amount of organic matter

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[13] Sedimentation in an estuarine system is a continuous process of building up the intertidal area thereby keeping pace with sea level rise. This continuous process slowly buries detrital material (potential nutrients) unless retrieved and returned to the surface through bioturbation and sediment reworking. Like its land counterpart, there is a continual loss of chemical nutrients to the marine sediment system once these elements reach a depth below the level affected by reworking.

utilized by the macrofauna, and varies with each individual. According to George (1964) Cirriformia tentaculata (on a mud flat) only digested 7.9% of the matter actually ingested, only one half of the organic matter actually available, with the rest being voided as feces and pseudofeces. Hibbert (1977a) completed a more indepth study actually placing caloric values on the amount of food ingested. He found a Mercenaria mercenaria population ingested 1292 Kcal $m^{-2}yr^{-1}$. From this amount the following breakdown was given:

	Amt. Kcal $m^{-2}yr^{-1}$
Resipiration	241
Flesh production	72
Gamete production	61
Feces and Pseudofeces production	759
Excretion	160

He found only a small portion of the nutrients available was actually used for biomass products like flesh and gamete production. Most of the nutrients, as suggested by George (1964), were returned to the system as fecal pellets or pseudofeces to continue cycling in the food chain.

B. Meiofauna, Bacteria and Fungi

The intertidal habitat support a varied population of meiofauna. In the past these organisms have been considered only a minor link in the food chain. More recent investigations, however, demonstrate their true importance as primary consumers and potential high energy food sources (Platt, 1977; Sikora *et al.*, 1977). Nematodes are usually the dominant organisms in a meiofauna community. They may represent from 67% to 97% of a community's inhabitants (Sikora *et al.*, 1977). Platt (1977) found nematodes in densities of $171/cm^2$, $87/cm^2$, $131/cm^2$ in fine sand flats. These values were lower than those usually obtained in a muddier intertidal habitat but higher than values obtained in coarser beach habitats which retain less organic matter. This information supports the hypothesis that meiofaunal populations are distributed according to sediment type and food availability.

As a major component of the meiofaunal community, nematodes may be an important high energy food source for higher trophic levels.[14] By compiling diffuse substrate resources into a compact "package", nematodes may lower the foraging effort expended by detritivores because of the high energy content per unit area. Even though bacteria have a higher turnover rate than nematodes, organisms on a higher trophic level can only utilize the biomass present at the

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[14] Ecologists use the phrase "trophic levels" to refer to the successive levels of nourishment in a food chain. A simple food chain, which designates the sequence of energy movement through organisms, would proceed from producers (plants) to primary consumers (herbivores like rabbits) to succeeding levels of consumers (including carnivores, like foxes) and always ending with decomposers (usually bacteria and fungi) (Keeton, 1967).

time of foraging. Therefore, Sikora et al. (1977) indicate that the energy lost through moving up one more trophic level on the ecological food chain is outweighed by the low effort, high energy packaging obtained by detritivores utilizing nematodes.

Bacteria and fungi, some of the smallest components of the intertidal community, exert influence over both the sediments and overlying waters. The large numbers, rapid reproduction, and intense biochemical activity of these organisms have decided effects on the physical, chemical, and biological properties of the area they inhabit. Intertidal habitats usually exhibit both anaerobic and aerobic conditions with the extent of each zone depending on oxygen penetration into the sediments. Tidal flats in particular, are regions of relatively stable sediments causing strong reducing (low oxygen) layers to form below the surface. In these anaerobic areas, facultative anaerobes[15] (bacteria and fungi) decompose materials at a lower energy level and slower rate than aerobic bacteria. This anaerobic decomposition, though slow, is essential to recycling vital nutrients, such as carbon, nitrogen and phosphorus, in tidal flats (Orth, 1978).

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[15] Sedimentary organisms may function in an aerobic (oxygen containing) or anaerobic (oxygen deficient) environment. Dependence on either of these environmental conditions may be partial (facultative) or complete (obligate). Hence an obligate anaerobe can only exist in the absence of oxygen.

Microbial communities may compete with sediment detritivores for some resources but are responsible for the conversion of nutritive materials into forms which may be utilized by many species in higher trophic levels. Distributions of Hydrobia sp. and Macoma balthica significantly correlated with finer particle size which support higher concentrations of microorganisms (Orth, 1978).

In many intertidal areas, in particular tidal flats, shallow water chemical activities by bacteria and fungi can have profound effects in the overlying waters. The dissolved oxygen content of these waters may be depleted by the respiration of large bacterial populations in areas of high organic content. In addition, a nocturnal decrease in oxygen occurs with the cessation of photosynthesis by the flora. The hydrogen ion concentration may be slightly higher (therefore the pH lower) in these areas with high bacterial biochemical activity. Reactions such as ammonifixation, denitrification, and sulfate reduction tend to decrease the overall hydrogen ion concentration, while respiration, nitrification and fermentation create an increase. These biochemical effects created by bacteria and fungi may affect the distribution of other organisms. By establishing aerobic conditions, and restricting the oxygen availability to the upper most layers of the sediment, bacteria and fungi may indirectly influence the distribution of infauna (Orth, 1978).[16]

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[16] Many organisms are extremely sensitive to changes in the acidity or alkalinity (pH) of the surrounding environment. Changes, however slight, in the pH of overlying waters can be detrimental to organisms whose vital metabolic processes can only occur within a narrow range of hydrogen ion concentration.

C. Flora

Although classified as nonvegetative, these areas contain various nonvascular plants capable of significant productivity. The various types of plants found in intertidal areas are phytoplankton, benthic macroalgae and benthic microalgae. With the exception of the macroalgal plants, major components of these populations are pennate diatoms and dinoflagellates (Gray, 1974). Most living benthic algae are found in the top few centimeters of sediment although only those algae in the top several millimeters are photosynthetically active (Orth, 1978).

The wider range of physical environments makes the productivity of intertidal areas more valuable than marshes. In some areas gross primary productivity of a tidal flate adjacent to a saltmarsh cordgrass (Spartina alterniflora) marshes showed productivity levels equal to that of the marsh algal community. Tidal flats not associated with marshes showed even greater variability, ranging from 0-1100 mg C $m^{-2}h^{-1}$ (Orth, 1978). Cade and Hegeman. (1977), in a study of organic carbon sources in a tidal flat, found that primary productivity was related to tidal levels. At the lowest (least exposed) intertidal station, productivity was only 29 gm C m^{-2} while at the highest (most exposed) intertidal flat productivity was recorded to be 188 gms C m^{-2}. Cade and Hegeman. (1977) also found the primary productivity of benthic algae and phytoplankton were unable to account for the large amounts of organic carbon deposited on the tidal flat in the Wadden Sea from the winter low to the summer peak. This variation in organic carbon production and actual productivity was accounted for through allochthonous food sources stranded on the intertidal flats.

The benthic flow present in the intertidal regions is of substantial importance to the primary productivity of the area. In addition to the rapid turnover of algae (therefore rapid recycling of nutrients), algae are consumed directly by herbivores and are present during winter months when food is scarce. Paralleling its use for primary consumption is its contribution to the detrital pool consumed by blue crabs, oysters, copepods, fiddler crabs, mussels, mollusc larvae, chironomid midge larvae, ostracods, snails, cumaceans, mysid shrimp, amphipods and fish[17] (Orth, 1978). This idea is supported by Gray (1974) who found that when microscopic plants were abundant in the sediment, deposit feeders tended to predominate.

Tidal resuspension of benthic microflora, in areas of expansive tidal flats, is important to the total primary productivity in the water column. During periods of low phytoplankton biomass (late spring and summer) productivity in the resuspended zone contributes the major percentage of primary productivity in the water column. In Buzzards Bay, yearly cycles of particulate carbon and chlorophyll _a_ concentrations are found. These seasonal changes in food resources

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[17] Wetzel (1977) illustrated how _Nassarius obsoletus_ obtained 60%-70% of its carbon requirement from benthic algae. A large portion of the detritus _Nassarius_ consumed was structural carbohydrates which could not be assimilated. Therefore, _Nassarius_ utilized the algae associated with the detritus.

available to zooplankton may be the result of tidal resuspension (Roman and Tenore, 1977). Cade and Hegema. (1974) found large amounts of functional chlorophyll a in sediments to a depth of 10 cm in the West Wadden Sea which photosynthesized when placed in light. This buried flora represents a standing stock of primary producers activated when the area was disturbed by storms. Thus in areas with extensive intertidal zones (tidal flats compose 40-50% of the Wadden Sea) the benthic microflora was as important as the phytoplankton in primary productivity[18].

In addition to the primary production of nutritive elements contributed, benthic diatom communities are important in the stabilization of some marine sediments. In a study of 7 diatom species, Holland *et al*. (1974) found that four which secreted mucilagenous films signficantly retarded resuspensions of fine sediments. In addition, these diatoms appeared to retard the laminar flow of sand. Migration of this benthic flora away from the surface of the sediment increased the diatoms stabilizing effect. This

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[18] In addition to measurements of carbon production, the dynamics of community plant productivity can be assessed by quantifying the levels of chlorophyll a. A constant measure of productivity with any parameter is difficult to obtain due to differing site selections, varying sampling and analytical techniques, and the clustering of algal patches. Some comparative measurements of chlorophyll a have been made, however. Orth (1978) found that salt marsh values range from <10-200 mg/m^2 while tidal flats showed variations between 4-1000 mg/m^2. Another study from the Barnstable Harbor flats to the Continental Shelf showed the following variations between stations; 420 mg/m^2 in the tidal flats, 14 mg/m^2 in the open bay system and 2.5 mg/m^2 in the continental shelf waters (Gray, 1974). Wide variations within a particular habitat create difficulties in detecting any significant seasonal variations in chlorophyll a values.

sediments stabilization by benthic diatoms creates a selective advantage for autotrophic[19] plants by stabilizing the light intensity.

Species of macroalgae, the more visible forms of the benthic algae, occur in some intertidal regions. Two species of macroalgae were found to colonize sandy tidal flat areas. One, Enteromorpha prolifera subsp. radiata, exists almost exclusively on sand flats and in marshes. Enteromorpha flexuosa tends to develop best on the sandier parts of the flats either attached to solid substrata or anchored in the sand in the Wadden Sea (Nienhuis, 1970). Woodin (1977) reported two polychaetes Nereis vexillosa and Platynereis bicanliculata which attached drifting macroalgae to their tubes and utilized them as food. Under such conditions it was found the algae reduce stresses like desiccation, salinity and temperature (2°C cooler) of the polychaete. This "gardening" behavior, as it was termed, enabled the macroalgae Ulvacea to expand its habitat and colonize new areas during non-reproductive periods.

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[19] Organisms can be divided into two groups on the basis of their methods of nutrition. Fully autotrophic ones (the majority of which are photosynthetic plants) manufacture the organic nutrients they need from simple, inorganic elements. Heterotrophs (most animals and plants that lack chlorophyll), on the other hand, must obtain prefabricated organic nutrients from the environment (Keeton, 1967).

IV. RESOURCE VALUES OF THE INTERTIDAL AREAS

Delineating the nature and relative importance of resource values for specific properties of a habitat is an extremely difficult task. Natural biological systems are not easily described by universal or rigid value guidelines. Therefore, value assessments must be flexible enough to apply to even the most complex habitats.

The following section will discuss several important values associated with the nonvegetated wetlands described previously.

A. Primary Productivity

As mentioned above, benthic algae in intertidal flats are important to the primary productivity of the surrounding ecosystem. Their importance, and therefore value, varies from one intertidal area to another and is affected by the following variables.

Variable	Effect
The proximity of the intertidal area to a highly productive marsh i.e. *Spartina alterniflora*	Lessens the relative importance of primary productivity in the intertidal zone
The total expanse of the nonvegetated intertidal habitat within a particular area	The more intertidal habitat per unit area, the more important its primary productivity
The time of the year	Intertidal benthic algae productivity is more important during periods of low phytoplankton activity
The physical characteristics of the area	The more dynamic the physical regime, the less benthic algae present, and therefore lower primary productivity.

To determine the relative productivity value for any given intertidal area, these variables should be evaluated individually. Two examples of this concept are cited below.

> (1) An intertidal beach is not as valuable a site of primary productivity as a tidal flat located in a fairly quiescent environment due to the more dynamic nature of the beach environment, which would preclude the colonization of any substantial numbers of benthic algae.
>
> (2) Tidal flats of similar sediment composition, size and physical regimes may vary in relative value in relation to their surrounding ecosystem. If tidal flat #1 is located adjacent to a large and highly productive marsh while tidal flat #2 is adjacent to a marsh in productivity, tidal flat #2 will be of a higher value to its particular area in terms of primary productivity.

B. Nutrient Cycling

Nutrient cycling is a continuous transfer process between air, water, sediments and biota of an environment. The nutrients cycling within these systems are in a state of dynamic equilibrium between concentrations present in the water column and concentrations present in the sediment. In this environment, decomposers break down complex organic substances into simpler elemental forms. Without these vital decomposers, nutrient recycling would become seriously disrupted. Imbalances in the food chain would occur as nutrients necessary to plant and animal growth become unavailable (Orth, 1978).

In many tidal flat areas, decompositional demands for oxygen exceeds the supply, creating anaerobic environments or reducing zones.[20]

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[20] Reducing zones are characertized by chemical reactions that remove oxygen (or add hydrogen).

The sediment depth at which these zones are found varies with the porosity of the sediments and vertical mixing of the water in the sediments. The boundary of this environment occurs where oxidizing processes are replaced by reducing conditions. This boundary, called the redox-potential discontinuity or RPD layer, is known to enhance the cycling of other nutrients through the sulfur cycle (Wood, 1965).

Within the sulfur cycle, the reduction of sulfates leads to free sulfides which then follow one of two paths. In the first, the sulfur forms insoluble precipitates with iron found in the sediments. To facilitate the second pathway the rate of free sulfide production must exceed the rates of removal of free sulfides as complexes or precipitates. Therefore, excess sulfides may diffuse up, through the anaerobic zone into the water column where they are oxidized to form sulfates, sulfites, thiosulfates or insoluble sulfur. Through this method significant amounts of hydrogen sulfide are released from marsh and tidal flat soils each year (Wood, 1965).

Cycling of nutrients other than sulfur occurs via anaerobic decomposition. Complex plant or animal tissue is broken down into simpler organic compounds like alcohols and fatty acids. This decomposition occurs in the reducing zone with organic compounds being used as hydrogen acceptors instead of oxygen. These processes result in the formation of essential organic and inorganic compounds like H_2S, NH_3, CH_4, and H_2 (Fenchel and Riedl 1970).

Another important nutrient, phosphorus, may exhibit significant exchanges between upper sediment layers and overlying waters, particularly in sediments with high silt, clay and organic content. Pomeroy _et al_. (1972) and Gessner (1960) observed that the flux in phosphorus levels was a result of absorption and a _biologically_ controlled exchange between various microorganisms and water. A relatively constant phosphorus concentration is maintained in the overlying water column with the sediments serving as both sink and source. Orth (1978) summarized the characteristics which determined the effectiveness of the processes:

(1) exchange capacity of the sediments
(2) exchange rate at sediment-water interface
(3) amount of local biological activity
(4) relative tidal cycle
(5) flushing rate of the body of water

Due to the absorption quality of the sediments, there is a relatively high availability of phosphorus in intertidal areas. Pomeroy _et al_. (1972) postulated that 10 cm of sediments in Doby Sound, Ga. contained enough exchangeable phosphate to replace that contained in the overlying water column 25 times (Orth, 1978). This reservoir-like nature enables an intertidal area to maintain high levels of productivity even when nutrient availability from external sources appears critically low.

A thorough understanding of nitrogen cycling in wetlands is still pending further scientific investigations. In general, in anaerobic tidal flats, mineralization of organic nitrogen ends at ammonia. This ammonia will tend to accumulate unless reduced in the anaerobic zone by various heterotrophic bacteria utilizing the nitrogen as an energy source. This denitrification in the intertidal environment is accomplished primarily by blue-green algae (_Nostroc_ and _Anabaena_ etc.) and occasionally by nitrogen fixing photosynthetic bacteria in the uppermost layers of sediment. Although cycling dynamics in these areas are not clearly understood, the demonstrated importance of nitrogen as a nutrient mandates its consideration with other nutrients in terms of productivity and water quality.

In summary, nutrient cycles in nonvegetated intertidal areas are important in maintaining a dynamic balance in the food chain. In addition, tidal flats, in conjunction with marshes, may be able to assimilate high nutrient loads through absorption in the sediments and biological activity. This ability to treat high nutrient loads could be of monetary importance to man as a less expensive alternative for treating his waste materials (Gosselink _et al_., 1974).

C. Fisheries

Fish and Crustaceans

Intertidal areas are recognized as important feeding grounds for many commercially important fish and crustaceans (Gray, 1974). Zijlstra (1972) illustrated the importance of the rich intertidal area of the Wadden Sea as a nursery and feeding ground for demersal fish[21]. According to Talbott (1966) striped bass and other small fish utilized intertidal flats as nursery and feeding grounds with the polychaetes, mollusc, and crustaceans serving as prey (Gray, 1974). In summarizing information on feeding of fish in intertidal areas, Orth (1978) reports predation on polychaetes and bivalves in mud and sand flats. These predators, he found, tended to crop mainly siphons and other feeding structures, leaving the remainder of the organism intact.

Commercially important species which utilize the intertidal flat at some point during their life history include striped bass, croaker, spot, seatrout and flouder. The blue crab, Callinectes sapidus, another important species to fisheries, utilizes the tidal flat when young because of its abundant food availability and protection from predators. The penaid shrimp, which spawns offshore, also migrates to the flats for food and protection during its early stages of rapid growth (Odum, 1971).

The intertidal beach zone is also an important habitat for fish of several species. Lipton and Travelstead (unpublished) listed the following species known to utilize the James River intertidal area as a nursery ground:

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[21] He found 64% of the sole and 80% of the plaice first year stock to occur in the Wadden Sea which is 50% tidal flats. Beukema (1976) supported the idea of the Wadden Sea tidal flats as feeding grounds. His study showed that the predation by the fish was centered mainly on the zoobenthos.

alewife (*Alosa pseudoharengus*)
blueback herring (*A. aestivalis*)
shad (*A. sapidissima*)
striped bass (*Morone saxitilis*)
croaker (*Micropogon undulatus*
menhaden (*Brevoortia tyrannus*
hogchoker (*Trinectes maculatus*)

Peak abundances were found in August and September, when juveniles of several species utilized the near shore area for feeding.

Large scale destruction of intertidal flats and beach areas would, of course, have an immediate effect upon the benthic populations present. Secondarily, there would be large-scale impacts upon the estuarine dependent fisheries which utilize these areas for nursery and feeding grounds. The potential economic cost associated with the loss of these species was documented earlier in this paper.

Molluscs

The oyster (*Crassostrea virginica*) and the hard clam (*Mercenaria mercenaria*) are two commercially important species which inhabit the intertidal zone in Virignia. In most low saline environments, the oysters may be found in tidal and subtidal habitats. It is important to note that in high saline environments *Crassostrea virginica* is found only in intertidal areas due to high predation and disease pressures. *Mercenaria mercenaria* is characterized by an extensive geographic range and inhabits the sheltered bays and inlets. This species is important to the recreational clammer as well as supporting the largest commercial clam industry in the U. S. It has accounted for approximately 17% of the total volume and 53% of the total exvessel (i.e. dock side) value in the past ten years (Ritchie, 1977). Unfortunately, productive bottoms for both these species are being irreversibly damaged through dredging and fill operations in coastal states. It has been projected by Chestnut (1974) that continued industrial and population growth will damage additional coastal areas.

D. Recreation and Aesthetics

Recreation in the non-vegetated intertidal zone is an ever increasing industry of developing economic importance for states located in the coastal zone. Ducsik (1974) states that the Bureau of Outdoor Recreation projected an annual increase of 10% to 12% in public use of coastal recreational areas. The annual revenues from these areas make them increasingly important. In 1968, it was estimated that some 112 million people spent $14 billion pursuing recreational activities in the coastal zone (Ketchum, 1972)[22].

The projected increase of coastal zone use already presents problems which will increase in magnitude in the years to come. One serious problem is that most recreational facilities are fairly fixed and already filled to capacity. Coastal areas not only attract large numbers of recreational visitors but also have a large residential population of their own to accommodate (Ducsik, 1974).

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[22] The greatest demands for facilities are placed on these areas by the daily and weekend user. The populations exerting the greatest pressures on coastal recreation are those from large metropolitan areas located within a 125 mile radius (Ducsik, 1974).

The suitability of coastal areas for recreational activities depends on several factors summarized below from Ketchum (1972) and Ducsik (1974).

(1) Climate - plays an important role in population explosion of the southern coastal states.

(2) Proximity - plays an important role in the over burdening of coastal areas near large metropolitan areas

(3) Competition - recreationalist competing with commercial and shipping interest, industrial plants and private ownership for coastal areas

(4) Shoreline Erosion - 25% of total shoreline (U.S.) exposed to wave and current action has significant erosion problems exacerbated by man

(5) Pollution - poor water quality from sewge, oil spills, pesticides, and industrial effluents - creates problems around every major coastal city

(6) Living Resources - sports such as hunting, fishing, and wildlife observation depend on natural fauna and flora

Within nonvegetated wetlands, the beach is described as supporting the widest variety of recreational uses. As a result, beaches are subject to the most use by the largest number of people at the lowest cost. Tidal flats, on the other hand, were considered to be in less overall demand recreationally than the beaches (Ducsik, 1974). Any member of the Audubon Society would, however, vouch for the importance of tidal flats as bird-watching havens[23].

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[23] The availibility of these shoreline areas for public use is already restricted for the throngs of recreationalists. Within the 28 contiguous coastal states there are 60,000 miles of shoreline. Of this 60,000 miles, only 21,900 miles are suitable for recreation with 4,350 as beach and 6,214 miles as other wetlands. Within the Atlantic Coast alone, only 3% of the recreational shoreline is public. In the more densely settled North Atlantic and Middle Atlantic regions there are 5,912 miles of recreational shoreline of which 5,654 miles are under private control (Ducsik, 1974). Obviously, there is a lack of public recreational facilities for use by the public.

In considering man's influence on intertidal areas, recreational use by the beachgoer rank low on the scale of serious impacts to the environment. This should not imply that there are no problems involved with recreational usage. Dune vegetation adjacent to beaches may be destroyed and adverse effects may develop with the secondary invasion of irresponsible development, pollution, dredging or filling of areas for residential and commercial use (Ducsik, 1974).

Although difficult to quantify, the recreational and aesthetic values of "natural" areas is of increasing importance to our society. Pressures for more areas to which the public can retreat, including coastal regimes like beaches, are growing with little increase in the amount of land available. With these pressures and the problems they create, more attention should be given to conservation (i.e. reasonable use) of those intertidal areas within Virginia's jurisdiction.

E. Shoreline Protection and Stabilization

The intertidal flats, bars and beaches are all valuable to some degree in shoreline protection and stabilization. Both sand and mud flats are important in decreasing the velocity (erosive potential) of waves as they approach the shoreline. The tidal flat area causes the waves to spread out as they pass over the flat, decreasing their velocity and lowering their energy before the waves strike the shoreline. These areas further stabilize the sediment from resuspension by supporting mucilaginous producing algae which bind the sediments and retard the waves and currents ability to resuspend sediment particles.

The primary value of a sand bar is its ability to shoal and break offshore waves (thereby decreasing their wave energy as they approach shore) during periods of stormy weather. Occasionally these bars are removed during periods of severe storms, but will reform during periods of calmer weather.

Intertidal beaches are also dynamic shoreline defense structures. Beaches are created as a product of energy dissipation of oncoming waves. The beach slope is also related to the sediment particle size, and they are not considered ephemeral features. Some natural erosion does occur through processes like long-shore transport, with the concomitant accretion of this material on other shores. Once man begins tampering with these dynamic systems (through groins and jetties or beach stabilization programs to prevent overwash) shoreline erosion can become a problem of enormous consequences with domino-like effects that are often difficult to terminate or reverse.

F. Feeding Grounds for Birds

Several studies have shown the intertidal zone to be of paramount importance as feeding grounds for certain bird species (Goss-Custard *et al*., 1977a; Goss-Custard *et al*., 1977b; Goss-Custard, 1977; Bengston & Bo Svensson, 1968; Reading and McGrorty, 1978). This dependence on the intertidal zone varies from a faculative to obligate response[24]. Exposed mudflats support a wide population of feeding birds because of their large macrobenthic populations. The benthic organisms found in these finer grained sediments tend to be small, thin-shelled, and usually restricted to the upper 5 cm of the sediment (oxidized layer) (Orth, 1978). The large collective biomass and near-surface location of these animals enable the birds to forage with little expenditures of time and energy.

Two major species of obligate shorebirds are the osytercatcher (Haematopus ostralagus) and the ringed plover (Charadrius hiaticula) (Eltringham, 1971). Oystercatchers feed mainly upon small cockles and a few types of polychaete worms. In areas where cockles are in low abundance the oystercatcher may create severe predatory pressure on the cockle population. When its preferred prey is not present, the oystercatcher will shift to other organisms. This food preference makes oystercatchers characteristic of depositional environments which normally harbor large numbers of shellfish (Heppleston, 1971; Reading and McGrorty, 1978).

In addition to obligate species which obtain their regular food from the itertidal area, many species utilize intertidal areas as habitats on a more seasonal basis. The knot, Calidris sp., breeds in the tundra region and overwinters in areas such as Morecomb Bay,

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[24] Facultative: those birds which visit the area but do not depend solely upon it for their livelihood. Obligate: those birds which depend on the area for a vital resource-usually food.

Lancashire. The black bellied plover (Plurialis squatarota) undergoes two seasonal migrations during which they rely heavily on intertidal mudflats for their main food sources (Orth, 1978). A local study conducted at the Windmill Point dredge spoil island on the James River was found to attract a large number of avian migrants from groups especially associated with intertidal environments. Its unique drawing power comes from the large tidal flats and basin, a sand beach perimeter and openness relative to the surrounding woodland community. Of these habitats, the mudflat tended to support the largest number of shorebird species. Such species as the pectoral sandpiper (Calidris melanotos) and common snipe (Capella gallinago) were found to concentrate at the interior of the marsh. The killdeer (Charadrius vociferus), western sandpiper (Calidris mauri), and semipalmated sandpiper (Calidris pusillus) were observed to use the exterior beaches and mudflats extensively (Wass and Wilkins, 1977). For a complete list of shorebirds and waterfowl which may utilize the intertidal region for feeding grounds refer to Wass et al. (1972).

Whether facultative or obligate, each type of waterfowl depends on varying degrees on the intertidal area for a portion of its livelihood. Large scale destruction or alterations of these areas important to particular species may have severe ecological effects on the birds which utilize them.

G. Effects of Intertidal Areas on Water Quality

Microbial processes which occur in the sediments of intertidal areas determine the reducing conditions which may affect water quality. Specifically free sulfides (H_2S) concentrations formed in the anaerobic layers may create some water quality problems[25] (Bella _et al_., 1972). Free sulfides in the water are considered a major contributor to the chemical oxygen demand (COD), a measure of water quality. In addition, if released in sufficient quantities to the overlying waters, free sulfides have a demonstrably toxic effect on fish, crustaceans and a variety of microinvertebrates. The continued presence of significant concentrations of free sulfides in waters containing dissolved oxygen has been considered to be highly improbable. Yet, in one study conducted by Bella _et al_. (1972), the free sulfide concentrations were measured at 1 mg/l with a 4 mg/l dissolved oxygen content in the overlying tidal flat waters. This level of sulfide, according to the literature, could be quite toxic to a wide variety of species. Bella _et al_. (1972) stated that the conditions prompting such sulfide concentrations were probable when the following conditions were prevalent:

Presence of silt and clay particles
Presence of organics contained within shallow water deposits
Shallow water depths
Presence of available sulfates

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[25] Hydrogen sulfide is normally present in intertidal areas as part of the pH dependent systems. ($HS \quad H^+ + HS^- \quad 2H^+ + S^=$). Under aerobic conditions, biological and chemical reactions utilize oxygen as an hydrogen ion acceptor. Under anaerobic conditions, when oxygen is unavailable, sulfides take on that role for some elements.

Presence of low concentrations of available iron in deposits

Poor drainage

Low water velocities

In view of this information, the water quality in high energy intertidal areas with, sandier sediments, good drainage, and low oragnic content, are less likely to have water quality problems associated with free sulfides than mudflats. It should be noted, however, that the existence of any (or any combination) of these characteristics does not imply that an area will necessarily have this type of problem.

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