COASTAL AND MARINE PROCESSES

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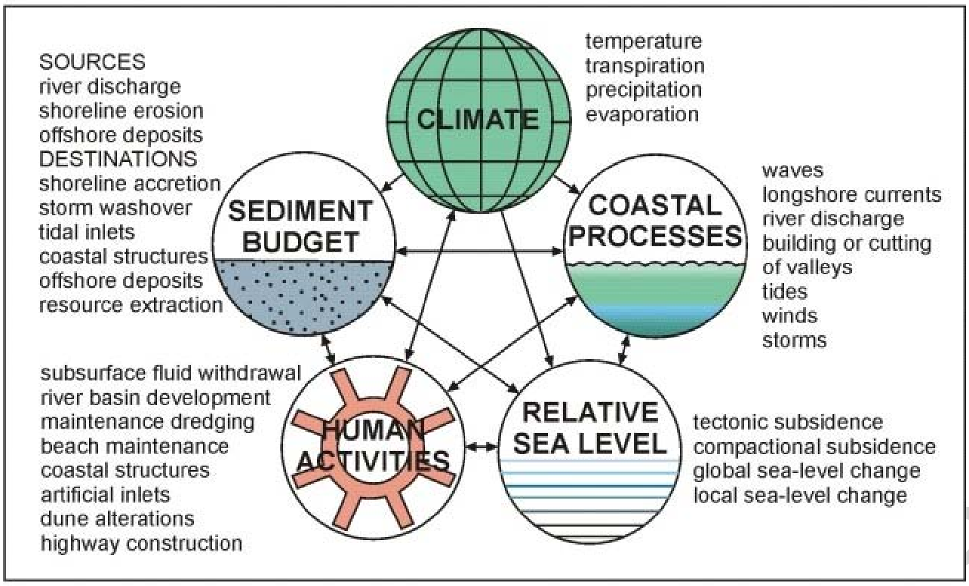

Figure 1. Coastal environments are affected by a variety of factors in a complex web of interactions.

Coasts, as boundaries between land and water, are characterized by the geologic nature of the land, which is unstable and often fragile, and the dynamic power of wind and sea. As a result, coastal environments are constantly changing as they seek to achieve and maintain equilibrium among the many opposing natural forces. The vibrant beauty of shore areas is attracting a growing population; however, the ever-changing character of coasts makes them hazardous for people and, in the long term, for buildings and structures. The risks associated with living along a coast are comparable to those experienced by people living on a river flood plain, near an earthquake fault, or close to a volcano—all carry the possibility of eventual catastrophe. Because coastal regions have wide public appeal as places to live, population growth continues to accelerate along the world's coastline. This population explosion superimposed on the dynamic forces acting on coasts is leading to a coastal crisis marked by the following concerns:

- Coastal erosion at widely varying rates affects about 90% of the world's coasts and is likely to increase due to rising sea levels and increased storm activity.
- During the past 200 years, more than half of the wetlands in the United States have been lost due to a combination of natural processes and human engineering. Such loss of valuable wetlands is occurring worldwide, especially in deltaic regions.
- Pollution of coastal areas has forced the closing of one-third of the shellfish beds around the United States, has restricted beach use, and has seriously contaminated ground water in some coastal communities. Coastal pollution is widespread around the globe, especially near urban centers where sewage treatment is inadequate and ocean dumping of wastes still occurs.
- In many coastal urban areas, hard-mineral resources such as sand and gravel for construction aggregate and beach nourishment are no longer readily available onshore. Mining of beach sand accelerates coastal erosion. Offshore marine sand deposits may provide alternative sand resources, but pose environmental and

> economic dilemmas. The crisis in the coastal zone is growing worldwide but is especially serious in the United States and many other developed countries in Europe and Asia, where an expanding and more affluent population combined with a variety of government programs over the past 50 years have enabled widespread and often unwise development to take place. If present demographic trends of population growth and expanded development continue, and if sea-level rise and increased storm intensity brought on by climate change global warming also occurs as predicted, stress on the world's coastal environments will increase substantially over the next 50 years. Intelligent and planned stewardship of the world's coastal resources requires balancing human needs and expectations with coastal realities. Earth-science information that is based on sound scientific research on the coasts, the way they change position and shape, and the factors influencing their development is critical in any attempt to lessen the conflicts and ease the tensions brought on by competing human goals and natural processes.

Ignorance and continued disregard of the geologic and other physical processes that constantly reshape our coasts are intensifying the collisions between people and nature. Despite historical precedents, catastrophes like hurricanes and tropical cyclones too often catch us unaware and unprepared. As powerful as some recent storms were, they will be surpassed by more powerful storms in the future; population growth and increased development along the coasts suggest that these future storms may cause even more damage and loss of life.

Well-coordinated multidisciplinary scientific efforts are needed to improve our understanding of how coasts form and evolve. A clear understanding of how coastal environments have formed and what natural changes they have undergone in the recent geologic and historic past is critical in predicting with confidence their future character. Many different scientific disciplines must be involved. Many different scientific groups can provide critical expertise in specific fields of research. Cooperation between Federal and State agency as well as academic scientists will ensure that this scientific expertise is applied in site-specific studies to solve the individual problems that make up the coastal crisis. Concerted efforts focused on understanding our coasts require efficient coordination to get maximum return from the limited resources available.

As important as increasing our basic scientific understanding of the earth-science processes affecting coasts is, it is equally important to make this information available to coastal-zone planners, managers, and engineers in forms that they understand and can use. These groups must have adequate, accurate information on coastal processes in order to make decisions, assess risks, and solve problems in an efficient and cost-effective manner.

Some engineering practices and human activities that are incompatible with natural processes and that cause long-term harm to the coast can be modified to lessen their effect. In other cases, erosion mitigation techniques that closely replicate natural processes, such as beach nourishment, sand dune creation, and shoreline restoration, can be used to provide temporary protection. In extreme circumstances of high rates of erosion, abandonment and relocation of communities might be the best long-term alternative for many coastal regions around the world. Dealing effectively with the present coastal crisis and resolving future conflicts along our coasts will require a combination of solutions that must be based on long-term societal needs and on sound scientific and technical knowledge, rather than emotional responses to meet short-term needs. Results of scientific investigations must be clearly communicated to coastal planners, engineers, and managers; and, most importantly, to political decision-makers and the public. Only when these diverse groups understand the range of choices available and the costs (social, financial, and environmental) and risks associated with each choice, can prudent and enlightened decisions be made.

1. Introduction

Coastal zone regions worldwide are reaching a crisis. Threats to coasts and to coastal communities are growing as development, recreation, and waste disposal activities increase, often in conflict with long-term natural processes. Other threats to the world's coasts such as sea-level rise, storm effects, and reductions in sediment transport from the land to the coast result from climate change, global warming, and the damming of rivers. Many of these threats to coastal regions are likely to increase in the near future.

The impending crisis of our coasts stems from misconceptions about what coasts are and how they function and from increasing human actions based on those misconceptions. Differences between our perceptions and the reality of coasts intensify the conflicts between people and nature. These conflicts will worsen as the coastal population expands and competing uses of the recreational, wildlife, shipping, and mineral resources of coasts increase. See article Chapter ***Shelf Seas***. See ***Coastal Zone***.

1.1. Perception and Reality

We think of land as stable and treat it as a permanent asset. For most land, this premise is reasonable because land generally changes very slowly in human terms. Although tectonic and geologic processes, such as plate tectonics and erosion, are always at work, they usually result in very gradual changes that are often barely noticeable during a human lifetime. Coasts, however, are not static; they are dynamic landforms. They can change shape and location quickly in response to natural forces and human activities. These forces and activities continually act on and influence coasts—sometimes in the same direction, but often in opposite directions. As a result, the shape and position of the coastline changes. Sand and other sedimentary materials are moved onto and off of beaches by currents, winds, and waves. Seasonal movement of littoral sands creates broad summer beaches followed by narrow winter beaches in an annual cycle. During major storms, huge waves and storm surges can move large amounts of coastal sediments and can flood vast areas in a matter of hours. On a larger scale, the coast itself moves as it tries to achieve equilibrium with the forces acting on it. Barrier islands and offshore sandbars move landward and along the coast, driven by longshore currents and sea-level rise. Headlands are eroded, moving the coast landward. Sediment is deposited on river deltas, extending the coast seaward. Coastlines also move in response to changes in sea level; even if the land remains stationary, a rise in sea level will move the coastline inland over decades and centuries by inundation and erosion. See ***Coast Flooding***.

1.2. People vs. Nature

Because humans too often treat the coast like other parts of the landscape—as a stable platform on which to safely and easily build—some of our actions conflict directly with the dynamic nature of coasts. Other human activities, such as the increasing buildup of atmospheric greenhouse gases, may indirectly affect the coasts through global warming, causing worldwide sea-level rise as glaciers and grounded ice sheets melt. Still other actions, such as the damming of rivers for flood control and water management, may affect the stability of coastlines by restricting the supply of new sediments being carried to the coasts.

Conflicts between people and nature have always existed along the coasts. The increasing desirability and accessibility of coasts as places to work and live have intensified these conflicts greatly over the past 50 years. These conflicts are especially evident in the United States and other developed countries, but are becoming more common worldwide. For example in the U.S., the 1990 census shows that 25 of the 30 coastal States have had dramatic population increases in the past two decades. Coastal areas across the United States now have population densities five times the national average. Currently, 50% of the U.S. population lives within 75 km of a coast; this number is projected to increase to 75% by the year 2010. These population figures are similar for other regions of the world. As the coastal population grows, so does the need for additional facilities for housing, transportation, recreation, potable water, and waste disposal. Pollution is already severe near some large coastal urban areas and has hurt the fishing industry and caused serious environmental problems. See ***Human Impact on Coastal Areas***. Wetlands and marshes worldwide are now widely recognized as important but fragile parts of the coastal environment. In the United States, Louisiana, which contains more than 40% of the tidal wetlands in the 48 conterminous United States, is losing as much as 100 km^2 of wetlands each year due to a complex combination of natural and human-engineered processes. These marshes are one of the world's most productive ecosystems. Their continued demise seriously affects migratory waterfowl, bird populations, and fish and shellfish resources, as well as the coastal culture of Louisiana. Similar loss of wetlands is occurring in many other deltaic regions of the world. See ***Marshes*** in Chapter ***Coastal and Tidal Systems***.

1.3. The Key: Earth-Science Information

How should we deal with these competing needs? How can we manage the coastal crisis? The first step is to understand our coasts better, to build a solid foundation of earth-science data on coastal processes and evolution, and to identify what factors are important in quantitatively determining the location and movement of coasts. Only after thorough research and interpretation can the critical scientific results be translated into practical terms and be incorporated into sound coastal management policies.

2. Types of Coasts

Coasts are the dynamic junctions of water, air, and land. Winds and waves, tides and currents, migrating sand dunes and mud flats, a variety of plant and animal life—all combine to form our ever-changing coasts. Their dynamic nature results in their great diversity. Most of us envision a coast as a broad stretch of sand with frothy surf breaking along the shore; in fact, many types of coasts are found, ranging from sandy beaches to rocky shores to coral reefs to coastal wetlands. Some examples from are described below.

2.1. Rocky Shores

Rocky shores form on high-energy coasts where mountains meet the sea and at the base of sea cliffs. Active tectonic environments, such as California and the Pacific coast of South America, produce rocky coasts as a result of mountain-building processes, faulting, and earthquakes. Rocky coasts also form where ice and strong waves have effectively removed fine-grained sediment. In Alaska and parts of Scandinavia, glaciers have scoured most of the sediment cover from the shore. In the Arctic, ice gouging and rafting have removed sand-sized particles from some beaches, leaving cobbles, and boulders.

2.2. Sandy Shores and Barrier Beaches

Sandy beaches can be categorized into three types: mainland, pocket, and barrier beaches. Mainland beaches stretch unbroken for many miles along the edges of major landmasses. Some are low standing and prone to flooding; others are backed by steep headlands. They receive sediment from nearby rivers and eroding bluffs. Examples of mainland beaches include coasts of eastern Australia, the Great Lakes, northern New Jersey, and southern California. Pocket beaches form in small bays surrounded by rocky cliffs or headlands. The headlands protect the sandy alcoves from erosion by winter storms and strong currents. Pocket beaches are common in the Mediterranean, New England, and the Pacific Northwest. Barrier beaches are found along the Gulf of Mexico, the US east coast, and parts of the North Sea. They are part of complex integrated systems of beaches, dunes, marshes, bays, tidal flats, and inlets. The barrier islands and beaches are constantly migrating, eroding, and building in response to natural processes and human activities.

2.3. Coastal Wetlands

Coastal wetlands include swamps and tidal flats, coastal marshes, and bayous. They form in sheltered coastal environments often in conjunction with river deltas, barrier islands, and estuaries. They are rich in wildlife resources and provide nesting grounds and important stopovers for waterfowl and migratory birds as well as spawning areas and valuable habitats for commercial and recreational fish. Most of the coastal wetlands of the U.S. are in Louisiana, along the Mississippi River and its active and ancient deltas, and in Alaska, at the mouths of the Yukon and Kuskokwim Rivers. The Great Lakes and the southeastern seaboard are fringed by other important wetlands, such as Florida's Everglades. Coastal wetlands can be dominated by salt water, as along the gulf coast of Louisiana, or they can contain a complex and changing mixture of salt and fresh water, like the estuaries of the Chesapeake, Galveston, and San Francisco Bays. See ***Estuaries*** in Chapter ***Coastal and Tidal Systems***.

2.4. Coral Reefs

Coral reefs abound along the southern coast of Florida and around the Hawaiian Islands, Puerto Rico, the Virgin Islands, and most of the Pacific Islands. In the shallow waters off tropical isles, living coral organisms build reefs that provide important wildlife habitats and protect coasts from waves and storms. Healthy coral reefs are also an important source of carbonate sediment for tropical beaches. Raised coral platforms no longer inhabited by living coral provide coastal materials and form islands such as the Florida Keys. See Chapter ***Evolution and Function of Coral Reef Ecosystems***.

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the United States and the social issues and implications of exploding populations and coastal development.]

Biographical Sketch

Jeff Williams is a marine geologist specializing in coastal, estuarine, and inner shelf geologic framework and processes with over 30 years of experience in researching the geologic origins and evolution of coastal and estuarine systems, late Quaternary sea-level change, and modern shelf sand bodies. He has participated in more than 80 field studies, managed many large and complex field projects nationwide in the U.S., published more than 200 papers and reports, and been a member on more than a dozen high-level U.S. national science committees including the National Ocean Partnership Program, the National Oceans Conference, and the Coral Reef Task Force. He served as Coordinator of the Coastal and Marine Geology Program, managing and directing 250 staff and a budget of $US38 million, from 1996 to 2000. He returned to a research position in July 2000. Education: BS degree in Geology, Allegheny College, 1967; MS degree in Geology/Oceanography, Lehigh University, 1969.