MODULE 2

NATURE OF THE MARINE ENVIRONMENT

OBJECTIVE

1. To describe the biochemical nature of the marine environment, and explain the inter-linkages between coastal and marine ecosystems.

2. To develop an awareness that the Caribbean Sea functions as a single ecosystem.

THEMES

2.1 The Heterogeneous Nature of the Sea
2.2 Coastal Ecosystems
2.3 The Caribbean Sea as a Bioregion
2.4 The Marine Environment: Source and Sink

DELIVERY TIME

3 Hours

MODULE 2	NATURE OF THE MARINE ENVIRONMENT
THEME 1	The Heterogeneous Nature of the Sea
OBJECTIVE	To demonstrate that the marine environment is composed of a series of distinct ecosystems.
SIGNIFICANCE	Biological complexity and interaction are determined by biophysical factors. Successful management of marine resources therefore requires an appreciation of the spatial differentiation of the physical factors, and its related impact on biological diversity and function
PRESENTATION	Lecture, participant discussion
EQUIPMENT / MATERIALS	Overhead projector
EXERCISE	NA
TIME	1.5 Hours

INTRODUCTION

Though seawater covers approximately 71% of the earth's surface (Tait, 1981), the marine environment is not a homogenous body of water, encompassing as it does many different sub-environments. These range from the cold, dark ocean depths to the well-lit surfaces that are well-mixed through wave action, and from the open ocean to the highly variable transition zone between land and sea. The variables that determine biotic composition and ecological characteristics of the different zones are:

- Light;
- Depth;
- Temperature;
- Currents;
- Wave action;
- Nutrient/chemical composition; and
- Proximity to land mass.

LIGHT AND DEPTH

Light changes in intensity and wavelength as it passes downward through the sea. Assuming consistency of incident illumination, the amount of light that penetrates the surface depends on:

- Surface conditions (a turbulent surface reflects more light than a calm surface);
- Absorption and refraction by the water column; and
- Turbidity of the water.

The more turbid the water, the less light that penetrates, and even in clear ocean waters, approximately 80% of the light is absorbed within the top 10m. Given that trenches on the ocean floor reach as deep as 11km, the light (and associated heat) is confined to a very thin surface layer of the ocean.

A second issue of relevance is that water refracts (breaks up) light, and the different wavelengths are absorbed at different rates. Infrared and ultra-violet wavelengths are usually absorbed first, with the blue-green part of the spectrum having the greatest penetration in clear water. Other factors, such as turbidity and the concentration of plankton, also affect the rate of absorption and the differing rates of attenuation of the different wavelengths.

The important issue is that due to the limited penetration of light, primary production in the marine environment takes place primarily in the upper layers, where there is sufficient light to support photosynthesis. Though different organisms congregate at different levels in the water column, marine fauna is most abundant in the surface layers (less than 50m, extending as deep as 100m under clear conditions, close to the equator in summer) (Tait, 1981).

TEMPERATURE

Temperature affects the ecological processes in the ocean in two main ways:
- By affecting photosynthesis; and
- By affecting the mixing of the water column.

The photosynthetic rate increases as temperature increases, up to a particular maximum. Temperature increases past this maximum result in a rapid reduction in photosynthetic rate. It has been suggested that the efficiency of photosynthetic activity is probably equivalent in both temperate and tropical climes, due to the adaptive features of the associated phytoplankton (Tait, 1981).

The mixing of the water column caused by temperature-generated density gradients facilitates the movement of nutrients into the deeper levels of the ocean (Cooler water is denser, and therefore sinks. See also the information on the effect of temperature on density gradients under the sub-section on currents. P. 2.5).

One of the main contributing factors to temperature gradients in the sea is latitude. In low latitudes, such as in the Caribbean, heat is absorbed at the surface of the sea, producing a thin warm layer with temperatures between 26-30^{0}C. This thin warm layer is separated from the deeper, colder water by a discontinuity layer or thermocline, which typically is to be found between 100-500m. The permanence of this thermocline (in contrast to temperate waters) is the main reason that tropical seas (including the Caribbean) are considered the best option for the utilisation of ocean thermal energy conversion (OTEC) technology.

Water temperature exerts a powerful control over the distribution and behavior of marine organisms. Coupled with the concentration of productivity in the uppermost layers of the tropical seas, the Caribbean fisheries resources can be expected to be fairly much concentrated in a thin upper layer of the Caribbean sea. In fact, much of Caribbean finfish production takes place on shallow ocean banks and coral reefs.

CURRENTS

"*The major currents of the oceans are caused by the combined effects of wind action and barometric pressures on the surface, and density differences between different parts of the sea*" (Tait, 1981). A major factor affecting wind action and the currents themselves is the rotation of the planet. The density differences are due to differences of temperature and salinity, the former resulting from the cooling (and sinking) of water masses at the northern and southern poles.

The sinking of water masses at the two poles produce outflows that are manifested as "deep" currents, which act to take nutrients and oxygen to the deeper layers of the oceans. The higher-density water that sinks at the poles is continuously replaced by warmer surface water from the equatorial region, resulting in the "surface" currents.

Surface ocean water enters the Caribbean through a number of passages between the islands in the eastern Caribbean chain, with such flows being derived primarily from the North Equatorial Current and the Guiana Current. Deep-water inflow to the Caribbean is fairly small, and takes place primarily as part of the Upper Atlantic Deep Water, entering through the Virgin Islands Basin (Watlington & Donoso, 1996). These currents flow through the Caribbean and Gulf of Mexico, before exiting into the North Atlantic as the Gulf Stream. This current pattern has major impacts on critical elements of Caribbean resources and their management, particularly in relation to issues such as fishery recruitment and movement of pollution and diseases (see also section on bioregionalism).

Due to the fact that inflow of deep water into the Caribbean basin is relatively small, it is thought that replenishment of the deep/bottom layers of the Caribbean Sea takes place slowly over long time periods.

NUTRIENT/CHEMICAL COMPOSITION

Seawater is a complex mixture of dissolved inorganic material and dissolved gases (ignoring the many inorganic and organic materials and organisms that are merely in suspension). The amount of dissolved inorganic materials is what gives seawater its salinity. Because this amount is typically 35g/Kg, the salinity of seawater is typically $35^{0}/_{00}$. However, factors such as low or high rainfall regimes, high or low evaporation, melting of glaciers, high surface drainage from landmasses, etc., influence salinity levels in localised situations.

Table 2.1 shows the major inorganic constituents of seawater.

Table 2.1: Major Constituents of Ocean Water (S = $35.00^{0}/_{00}$)	
Constituent	**g/Kg**
Sodium	10.770
Magnesium	1.300
Calcium	0.412
Potassium	0.399
Strontium	0.008
Chloride	19.340
Sulphate (as SO_4)	2.710
Bromide	0.067
Carbon (present as bicarbonate, carbonate, and molecular carbon dioxide)	0.023 at pH 8.4 to 0.027 at pH 7.8
Source: Tait, 1981	

All the atmospheric gases are present in solution in seawater. Oxygen typically varies between 0-8.5 ml/L, with the higher values close to the surface, where some equilibrium with atmospheric oxygen is achieved. Carbon dioxide is present primarily as bicarbonate ions, and is the major factor controlling the pH of seawater (normally within the range 7.5-8.4).

A number of minor constituents of seawater can be considered as essential nutrients for plant growth. These nutrients include nitrogen (as nitrate), phosphorus (as phosphate), silicon (as silicate), iron, and manganese. Of these, nitrate and phosphate are considered the controlling nutrients, with the nitrate:phosphate ratio remaining fairly constant at 7:1 by weight and 15:1 by ions (Tait, 1981). Due to the fact that these minor elements are essential for plant growth, they are considered to be Limiting Nutrients, and the plants selectively absorb these limiting nutrients. As such, inputs of nutrients to the marine environment stimulate rapid growth of plant species, especially algae.

Nitrogen is present in seawater in several forms, nitrate (1-600µg/L), nitrite (0-15µg/L), ammonium ions (0.4-50µg/L), and traces of nitrogen-containing organic compounds (30-200µg/L). Concentration is usually lowest at the surface (1-120 µg/L NO_3-N), because of uptake by plants.

Phosphorus is present mainly as orthophosphate ions (<1-100µg/L), with traces of organic phosphorus (<1-30 µg/L). Like nitrogen, phosphorus concentrations are low and variable at the surface (0-20 µg/L phosphate-P), increasing with depth, with maximum concentrations occurring between 500-1,500m.

MARINE BENTHIC COMMUNITIES

Marine benthic communities are classified based on substrate, depth, temperature, and salinity (Tait, 1981). These include:

1. **Shallow Water and Brackish Communities**
   Typically have upper limits of distribution extending to the shore. Temperature range based on latitude, but normally eurythermal within wide limits. Salinity varing widely 7-34$^{0}/_{00}$), and normally euryhaline.

2. **Offshore Communities**
   Typically having upper limits of distribution below extreme low-water spring tidal level. Normally eurythermal and euryhaline, but within narrower limits than the shallow water communities (salinity 23-35.5$^{0}/_{00}$).

3. **Deep Communities**
   Typically having upper limits of distribution not above 70m in depth. Normally stenothermal and stenohaline, with salinity ranges of 34-35.5$^{0}/_{00}$).

Factors affecting the distribution of marine organisms, and therefore the types and distribution of benthic communities, include the following:

- Temperature;
- Water composition;
- Current speed;
- Depth/Pressure;
- Illumination;
- Salinity;
- Turbidity;
- Substrate material;
- Availability of food; and
- Biological competition.

As expected, some factors (such as current speed) have a dominant influence over others (such as oxygen concentration), and several inter-related factors therefore operate to determine the structure and functioning of benthic communities.

COASTAL INFLUENCES

That area of the land-sea interface commonly referred to as the coastal zone encompasses three divisions; land, the littoral or inter-tidal zone (that is periodically inundated), and the sub-littoral zone (extending from the inter-tidal zone to the edge of the continental shelf).

The quality of the water, distribution and types of periodically submerged lands, types and distribution of benthic communities, availability and status of fish and other marine resources vary greatly. Not only is there variation in space, but even at one location, the conditions may change significantly over different time intervals. This great variability is influenced by the following factors:

- Absence or presence of a coastal shelf, and the bathymetric variability leading to the shoreline;
- Season (winter vs. summer);
- Drainage (dry vs. rainy);
- Topography (absence or presence of wide plains);
- Type of shoreline (rocky, beach, etc.);
- Configuration/complexity of the coastline (open, bay, etc.);
- Variation in the tidal changes; and
- Rainfall pattern.

These factors determine the physical conditions of a locale, and therefore the suitability of an area for colonisation by particular assemblages of plants and animals. Physical and chemical parameters that would change based on the mix of the above "forcing functions" include:

- Periodicity of exposure of inter-tidal areas;
- Temperature;
- Current speed;
- Wave action;
- Concentrations of oxygen, organic materials, nutrients, inorganic materials, and food;
- Salinity; and
- Freshwater inputs, turbidity, and illumination.

Superimposed on this natural variation are the inputs to the nearshore environment resulting from human activities. Human activities not only exacerbate the effects of a number of the forcing functions, they add new factors, such as chemical and solid waste pollutants and sewage and agricultural nutrients. In addition to changing the variability of the nearshore environment, human activities also directly affect the natural functions of these coastal ecosystems (Module 3).

MODULE 2	NATURE OF THE MARINE ENVIRONMENT
THEME 2	Coastal Ecosystems
OBJECTIVE	To demonstrate that coastal ecosystems provide a range of goods and services, and that such ecosystems are linked.
SIGNIFICANCE	The linkages between coastal ecosystems are not always recognised or appreciated. As such, in making decisions about the spatial distribution of economic activity, critical ecosystem processes are often disrupted. The maintenance of ecosystem integrity therefore requires an understanding of the ecosystems and their linkages.
PRESENTATION	Lecture
EQUIPMENT / MATERIALS	Overhead projector
EXERCISE	NA
TIME	0.5 Hours

INTRODUCTION

When renewable natural resources commonly occur together to form characteristic groupings, such assemblages are referred to as ecosystems. An ecosystem can be defined simply as a biological community of interacting organisms and their physical environment. Typical ecosystems occurring in the coastal zone include:

- Coastal forests
- Coastal scrub communities
- Beaches
- Wetlands (freshwater & saltwater)
- Rocky shorelines
- Seagrass beds
- Coral reefs
- Benthic communities
- The open ocean.

These ecosystems are all connected (except forests and scrub communities) by the movement of water, land to sea (terrestrial influence) and open ocean to land (oceanic influence). The linkages between these ecosystems can also be determined from some of their ecological functions (Table 2.2); including:

- Wetlands and seagrass beds providing a nursery function for species of marine fauna;
- Coastal wetlands trapping sediments and reducing concentrations of nutrients and pollutants before these reach the marine environment;
- Export of organic materials from wetland communities and seagrass beds to nearby coral reefs;
- Protection of some nearshore communities by coral reef systems; and
- Recruitment of certain marine fauna (corals, fish, etc.) from upstream areas (some occurring hundreds of miles away.

Table 2.2: Natural & Economic Functions of Selected Ecosystem	
Ecosystem	**Function**
Forests	• Flood protection • Provides resins, oils, medicines • Ensures water availability • Provides food and drink • Erosion prevention • Provides fuelwood and charcoal • Provides lumber/timber • Habitats for wildlife species • Supports tourism
Wetlands	• Flood control • Fish, shrimp, and lobster nursery • Sediment trap (improved surface runoff to the sea) • Land building (sediment trap) • Protects the shorelines from wave energy and storms • Acts as habitat for birds, crocodiles, and other species of wildlife • Provides a source of food material for nearby coral reefs • Provides materials for construction, fishing, and craft • Tourism and other forms of recreation
Coral Reefs	• Provides habitat and food for fish and other marine organisms • Protects coastline from wave action • Provides material for sandy beaches • Tourism and other forms of recreation
Seagrass Beds	• Function as nurseries for juvenile fish and shellfish • Prevent shoreline erosion by reducing wave energy, and binding the sand together. This also results in improving water clarity • Functions as feeding grounds for turtles, manatees, and some fish species and urchins • Export food materials to nearby coral reefs

MODULE 2	NATURE OF THE MARINE ENVIRONMENT
THEME 3	The Caribbean Sea as a Bioregion
OBJECTIVE	To demonstrate that the Caribbean Sea is a single biogeographical unit
SIGNIFICANCE	The resources of the Caribbean Sea are often viewed as belonging to particular nations, and garnering multi-national cooperation for the management of those resources is very difficult. However, tidal movement and larval dispersal patterns suggest that the Caribbean Sea is one system, and resource management successes and failures in one part of the system will affect the resources in other parts.
PRESENTATION	Lecture
EQUIPMENT / MATERIALS	Overhead projector
EXERCISE	NA
TIME	0.5 Hours

INTRODUCTION

Although Theme 1 stressed the point that the sea is not a homogenous environment, the currents operating in the Caribbean Sea, supported by the bathymetry, ensures more connectivity throughout the Caribbean (including the Gulf of Mexico) than between the Caribbean Sea and adjacent oceans.

This connectivity is suggested by patterns such as pelagic larval transport throughout the Caribbean. The pattern of recruitment and dispersal for pelagic larvae suggests that areas within the region (including reef areas) are linked (Roberts, 1997).

Miller (1996) defines a bioregion as "…*a geographical space that contains one whole or several nested ecosystems*". This implies that bioregions can be of differing scales (Table 2.3). Examples of programmes to manage, or at least protect, marine resources at a supra-national level in the Wider Caribbean Region include the following:

1. The Caribbean Environment Programme (Module 3, Appendix 3.1);

2. The Fisheries Resources Assessment and Management Program (CFRAMP) of the Caribbean Community (CARICOM).

3. The natural resources management programme of the Organization of Eastern Caribbean States (OECS), that is managed by the Natural Resources Management Unit of OECS.

4. The initiative by CARICOM to have the Caribbean Sea designated a Special Area in the context of Sustainable Development.

Table 2.3: Hierarchies of Bioregional Management

Ecological Levels of Organisation	Levels of Bioregional Organisation and Management	Indicative Activities and Capacities for Each Level
♦ Global ecosystems: air, water, nutrients, geo-chemical, migration	♦ Global/Intergovernmental programmes - Conventions on: Biological Diversity, Climate, Wetlands, Migratory species, Forest and Germplasm Agreements, etc.	♦ Intergovernmental negotiation ♦ Diplomacy ♦ Supported by science, information, and management
♦ Regional ecosystems: - Bioregional province level - Landscape level - Plant/animal communities - Migration	♦ Bioregional Programmes: - Multi-country Level: Mediterranean Action Plan, Wadden Sea, La Amistad Biosphere Reserve - Country Level: Great Barrier Reef Marine Park, Yellowstone National Park, North York Moors National Park, CAMPFIRE community wildlife management, Hill Resource Management Program	♦ Sciences ♦ Information gathering, development, and delivery ♦ Regional Planning, inter-country planning and cooperation ♦ Protected area planning and management ♦ Cooperative mechanisms for private, public, and communal land owners ♦ Policy and technology development to encourage sustainable practices in forestry, agriculture, fisheries, wildlife, tourism, and water management ♦ Monitoring and reporting
♦ Local ecosystems ♦ Habitats - Structure - Species composition - Genetic variation - Local migration - Patch dynamics	♦ Local site level: - Community protection of spawning areas, local watershed management plans, and forest rehabilitation efforts	♦ Develop and use skills and knowledge (traditional and technological) to protect, restore, inventory, research, and sustainably harvest natural resources
Source: Miller, 1996		

MODULE 2	NATURE OF THE MARINE ENVIRONMENT
THEME 4	The Marine Environment: Source and Sink
OBJECTIVE	To reaffirm the productive and assimilative capacities of the seas
SIGNIFICANCE	Though the marine environment provides a range of goods and services, the integrity of the system is impaired because the by-products of land-based activities are routinely transported to the marine environment.
PRESENTATION	Group discussion
EQUIPMENT / MATERIALS	NA
EXERCISE	Itemise the Source and Sink functions of the marine environment
TIME	0.5 Hours

INTRODUCTION

The marine environment provides a range of goods and services that are used by human beings for a variety of purposes (Module 3). The marine environment can therefore be said to be a **Source** of benefits. The goods and services provided by the marine environment include:

1. **Goods for direct consumption and for use as raw materials**
    a. Primary consumption - water, foods, etc.;
    b. Raw materials - jewelry, construction materials, medicines, etc.

2. **Provision of services**
   Transportation, recreation, education, dispersal of marine fauna, etc.

3. **Maintenance of life-support systems**
   Maintenance of atmospheric balance, etc.

Conversely, human beings use the marine environment as a means for disposal of its wastes; sewage, industrial effluents, and even (in the recent past) hazardous materials.

Additionally, substantial amounts of inorganic, organic, and man-made materials that are found naturally on land, or deposited by humans, eventually finds its way to the marine environment. Even gaseous byproducts that are emitted to the atmosphere are eventually deposited in the marine environment, directly or indirectly through streams and rivers.

In addition to the direct human inputs and the inputs from drainage from land, the marine environment naturally functions as a **Sink**. One such function is the regulation of the amount of carbon dioxide in the atmosphere. In this regard, it has been suggested that coral reefs function as global sinks for carbon dioxide, and their management should be accorded the same level of importance as tropical forests.

Bibliography

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