Intergovernmental
Oceanographic
Commission

Manuals and Guides No. **32**

Oceanographic Survey Techniques and Living Resources Assessment Methods

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For bibliographic purposes this document should be cited as follows :

Oceanographic Survey Techniques and
Living Resources Assessment Methods
IOC Manuals and Guides No. 32. UNESCO 1996
(English)

Published in 1996
by the United Nations Educational,
Scientific and Cultural Organization,
7, place de Fontenoy, 75700 Paris

Printed in UNESCO's Workshops

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PART 1 : INTRODUCTION

1.1 THE EASTERN AFRICAN ACTION PLAN

More than 25% of the population of the Eastern African Region today lives along its coastal areas or not far inland. Most seek employment around the coast as well as unrestricted access to and from the foreshore, the freedom of navigation on any waters, the right to anchor and seek shelter, the right to fish and gather shellfish and other living resources for their livelihood or sustenance and the right to seek their leisure and recreation. In addition, coastal areas provide the landfall or take off point for imports and exports respectively, they are often the focus for industrial development and, increasingly, they are promoted as the sites for tourism developments which have become the chief foreign currency earner in many of these countries.

These multiple demands on coastal resources require the best management strategies to ensure sustainability.

The Governments of the Eastern African Region (Somalia, Kenya, Tanzania, Mozambique, Comoros, Madagascar, Mauritius, Seychelles and France (Reunion)), recognizing the importance of their marine and coastal areas and, at the same time, the environmental threats that they face, adopted the Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region. Through the Plan they seek regional solutions to region-wide problems.

The governments are assisted with the implementation of the Action Plan by a number of multilateral aid agencies. These include UN, UNDP, ECA, FAO, UNESCO, IOC, WHO, WMO, IMO, UNIDO, IAEA, IUCN, EU, and UNEP.

The protection and management of the marine and coastal areas in the Eastern African Region (EAF/5) is a key component of the Action Plan and it was under this component that FAO/PAP-RAC/IUCN/IOC/UNEP Regional Workshop on the Development of Coastal Area Management Plans, Surveying Techiniques and Marine Resources Assessment, was held in Mombasa, Kenya, in 1993.

1.2 INTEGRATED COASTAL AREA MANAGEMENT

It is the task of administrators and managers to seek a wise balance between the many conflicting demands being made on the coastal environment, ensuring that its limits of tolerance and its capacity for sustainability are not exceeded. In order to do this successfully they need a comprehensive management approach giving them a holistic view of the resources, the demands, and the various direct and indirect physical interrelationships.

Integrated coastal area management is an approach that allows such a comprehensive and holistic view to be taken of the multiple, often conflicting, demands that are made on coastal resources. It provides decision-makers, planners and managers with a practical methodology for resolving conflicts and assigning priorities and for balancing protection and development.

The Regional Workshop on the Development of Coastal Area Management Plans, Surveying Techiniques and Marine Resources Assessment, brought together a number of participants from throughout the Eastern African Region with planning, management and related responsibilities for coastal and marine resources. The participation of the Intergovernmental Oceanographic Commission (IOC) of UNESCO comprised sessions on oceanographic and ecological survey techniques for coastal area planning and management.

This manual arises from those sessions and it is being published in the belief that the methodologies and techniques provided to the Workshop participants, are of much broader interest and can be applied successfully beyond the Eastern African region in order to achieve a wiser use of coastal resources, to reduce wastage of non-renewable resources, to avoid conflicts and to ensure sustainability for future generations.

The section on oceanographic survey techniques is the work of Dr Larry Awosika of the Nigerian Institute of Oceanography and Marine Research, Lagos, Nigeria, while the section on living resources assessment methods was contributed by Dr Philip Tortell of Environmental Management

Limited, Wellington, New Zealand. Dr Tortell was also responsible for overall editing of the manual and preparing it for publication.

1.3 PRINCIPLES AND DEFINITIONS

Survey, monitoring, assessment and similar measurements are only a means to an end. They achieve little in themselves except, maybe add a quantum of knowledge and some understanding. What is even more important, is the use of the results of survey and monitoring - how and when to use the information and knowledge obtained through survey and monitoring.

Since survey and monitoring can consume a great deal of time, staff and funds, it is essential to establish clear objectives before survey and focus on those objectives throughout. Survey, monitoring, assessments and measurement can turn into an expensive "black hole" into which resources are poured at ever increasing amounts. It is often the view that more data are needed and that there is not enough information - in effect, there are never "enough" data and the important thing is to make the judgement as to how much data and information are "essential" in order to meet the objectives.

Some Definitions *"Coastal area"* is the area or zone which spans the interface between land and water; it includes both land and water and it extends inland as far as the expected influences on that interface; it extends seaward as far as one can meaningfully manage.

"Management" means planned, rational and wise use of land and water and all their resources and values in a sustainable, long-term manner so as to obtain the maximum benefits with the minimum of impacts which are kept within tolerable limits.

"Integrated" is a management approach which takes a comprehensive view and does not sacrifice unknowingly some resources for the sake of others; if such sacrifices have to be made, they are not made in ignorance, but only after careful consideration and after clear objectives have been set in order of priority, and after careful assessment of the comparative values and impacts.

"Integrated coastal area management" is a shift from the reactionary, problem-oriented approach to a planned, pre-emptive, management-based approach; it is a comprehensive and holistic approach which addresses the multiple demands on both terrestrial and marine resources; it provides the conceptual framework within which the cumulative, multisectoral environmental consequences of development can be managed to remain within assessed, pre-determined, tolerable limits.

1.4 ACKNOWLEDGEMENTS

The authors first presented this material to participants at the Regional Workshop on the Development of Coastal Area Management Plans, Surveying Techniques and Marine Resources Assessment. The excellent discussions and questioning generated by participants during the Workshop have helped us to focus better and improve our material for this manual.

We are grateful to the Secretariat of the Intergovernmental Oceanographic Commission (IOC) of UNESCO for encouraging us to present our material for publication and for their support during the preparation of this manual.

A number of the techniques and methodologies described in the manual were taken from a variety of other works. We wish to record our appreciation to the authors and publishers of these other works which are listed in the references at the end of each section.

PART 2 : OCEANOGRAPHIC SURVEY TECHNIQUES

2.1 NAVIGATIONAL SYSTEMS

Collection and monitoring of oceanographic data most often takes place on board research vessels or other craft. The accuracy of such information depends on the ability of the vessel to locate its exact position either to repeat previous stations where data collection has already taken place in the past, or to undertake new investigations. To meet this objective, special navigational systems have been developed and the more important ones are described below.

Conventional methods can be used to fix positions rather simply but the level of accuracy is very low. Radar, compass and sextant angles can be related to land based known positions or features to give rather rough positions. Such land based features can be hills, steep headlands, bays, identifiable outstanding buildings or other marked features on existing maps.

2.1.1 Shore based radio navigation system

In coastal areas, shore-based transmitter stations can be used for more accurate positioning. The receiver onboard determines the distance difference between the vessel and two pairs of trisponders onshore. An example of this system is the Decca chain which provides good positioning information over distances of a few hundred kilometres. The Omega navigation system, with very long wavelengths, is another type of shore based radio navigation system but this type is best suited for submarines down to 20m below the surface.

Trisponder navigation systems are widely used for local work in small areas in the open sea. They are usually deployed at three or more suitable points in the working area. Acoustic interrogator pulses are sent from onboard to the shore stations and these are answered by trisponders with pulses at different frequencies. The system on the ship computes the distance to all trisponders and the exact position of the vessel can hence be fixed. Trisponder systems can also be used for the positioning of deep-towed sampling or surveying devices and submersibles.

2.1.2 Transit satellite navigation system

Transit satellites circle the earth at an altitude of 1100km corresponding to a revolution time of about 108 minutes. They transmit electromagnetic waves with approximate frequencies of 150mHz and 400mHz. Every two minutes, the satellites also transmit accurate time signals and phased modulated waves with orbital parameters of their path and elevation. From these, the satellite itself provides the information necessary for the precise determination of its path. The satellite receiver on the ship decodes this information and computes the position of the ship.

2.1.3 Global Positioning System (GPS)

This satellite navigation project developed by the US Department of Defence was originally conceived as a target control for weapon systems. Its use has however been extended to civilian land, marine and air navigation, providing incredibly accurate, world-wide navigational capabilities. The GPS overcomes the limitations of other navigational systems such as the frequent problems of electronic signal interference due to weather storms experienced by Loran-C and Decca. The GPS consist of 21 active satellites and three spares, each orbiting the earth twice a day. Each GPS satellite transmits precise time and position data. Land based control stations constantly monitor the GPS satellites to ensure accuracy of information. GPS operates 24 hours a day without delays between fixes that are commonplace with transit satellite navigation.

2.1.4 Speed logging system

This system utilises Doppler sonar and inertial aids. For modest accuracy, the standard ship speed log, in combination with the gyro compass, can be used for positioning. The Doppler sonar system is a sonar transducer containing four crystals which generate supersonic sonar beams in the fore, aft, port and starboard directions. After transmission of a pulse train, the crystals receive the back scatter and part of the signal. The observed frequency shift serves to determine the velocity vector of the ship in relation to the sea bed or, in water deeper than about 400m, relative to a layer in the water column which scatters a sufficient percentage of the wave.

2.1.5 Integrated navigation systems

An integrated navigation system (INS) combines the output of several systems. The main advantage of this is that it combines sensors with different navigational characteristics, with the weak points of one subsystem as the strong parts of another. For example the Transit system can be used in conjunction with Doppler sonar. The Transit satellite provides accurate fixes every few hours while the Doppler sonar enables dead reckoning between fixes.

2.2 MARINE PROCESSES

The marine environment is a dynamic environment and this dynamism must be taken into account when undertaking coastal and marine survey work.

2.2.1 Tides

The term "tide" describes the periodic and regular variations in sea level which have a coherent amplitude and phase relationship to some periodic geophysical forces. The moon and, to a lesser extent, the sun, create ocean tides by gravitational forces. These forces of attraction and the fact that the sun, the moon and the earth are in motion in relation to each other, cause water masses to be set in motion. These tidal motions of water masses are a form of very long period wave motion, resulting in a rise and fall of the water surface giving rise to episodes of high tide and low tide. The change in level occurs twice each day in the case of diurnal tides such that there are two "high waters" and two "low waters" in each lunar day (about 24.8 hours). Where there is a long bay or a river mouth, the rise in water level is accompanied by an inward flow of water termed the “flood” while the subsequent outward flow is termed the “ebb”. The state where the sea water is at the lowest level is termed “low water” while the state where the sea water is at its maximum level is termed “high water”. The difference between the low and high water is termed the “tidal range”.

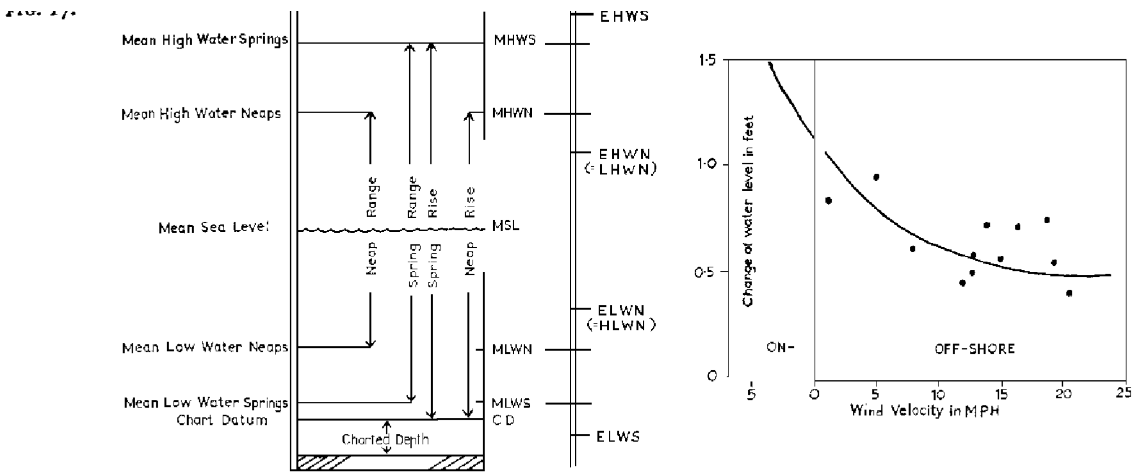


Figure 1. (A) *Left* - The nomenclature of tidal levels for mean springs and neaps, showing the extent of the range and c
the rise as related to ‘Chart Datum’. Extreme levels for springs and neaps are shown in the separate column.
(B) *Right* - The effect of onshore and offshore winds in raising and lowering the water level of predicted tides.

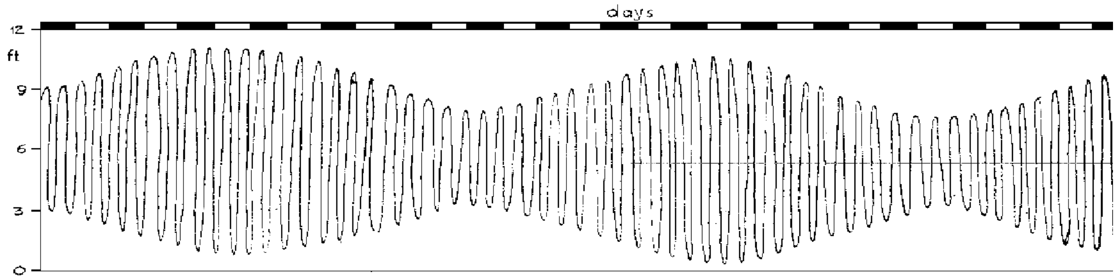


Figure 2. The tidal curve for semidiurnal tides with two sets of springs and two of neaps, over a period of one month.

Tides of highest magnitude occur at new moon and again during full moon when the positions of the moon, sun and earth are aligned. This means that the gravitational forces of the sun and moon come into phase and the range of the tide increases to a maximum. These are known as “spring tides”.

Minimal tides occur during the first and third lunar quarters when the sun and moon are acting in opposition to each other or are aligned at right angles. These are known as ”neap tides”. Successive spring and neap tides occur at intervals of about 15 days.

In localities subjected to semi-diurnal tides there are two high and two low waters in each lunar day. For semi-diurnal tides in some regions, two successive high waters will have nearly the same height and two successive low waters will have nearly the same (lower) height. In other regions successive high and low waters will each have different height. In some areas a predominantly semi-diurnal tide becomes diurnal for a short time each month during neap tides.

The tidal oscillations generate currents termed “tidal currents”. Tidal currents are generally in phase with tidal direction and are stronger during ebb tides than during flood tides.

2.2.2 Waves

Waves involve water motions which are largely (but not exclusively) confined to the surface and may be described as the surface disturbance of a fluid medium. There are also waves that form below the surface.

Waves are typified by an up and down bobbing periodic motion which is particularly apparent at the surface. The observed alternate elevations and depressions of the surface above and below its mean position is merely indicative of the passage of energy. In wave motion, the medium through which the wave passes does not move along with the wave. If a cork was left on the surface, the cork bobs up and down but does not travel horizontally even though the ripples are propagated horizontally across the surface. The horizontal movement of the wave results from the vertical oscillations of the water column with the same frequency but with a progressively increasing phase lag the further the waves are from the source.

The generation and subsequent propagation of waves can result from changes in air pressure caused for example by wind acting directly on, and putting some stress on, the water surface. Another possible cause is any significant disturbance of the basin *(i.e.* the earth's crust) holding sea water such as during an earthquake with the resulting tsunami. Most waves are caused by the former.

Wave parameters of importance and which may need to be recorded during a survey include:

- Wave Height: The wave height (H) is the vertical distance between a crest and an adjacent trough.
- Amplitude: This is a measure of the intensity of oscillation. It is defined as $H/_2$.
- Wavelength: The wavelength (L) is the horizontal distance between neighbouring crests or troughs in the direction of wave travel.
- Wave Period: The wave period (T) is the time interval between the occurrence of successive

troughs or crests at a fixed position.

- Wave frequency: This is the number of crests passing a given point per second, *i.e.* oscillation per second. It is the reciprocal of the wave period, *i.e* I/T.
- Wave velocity: The distance a given crest appears to travel in a second.

Internal waves can be caused by a wide variety of phenomena including storms, tidal action, travelling ships or a combination of factors. They usually occur at density interfaces in the ocean. The surface that separates the water masses of differing densities may be set in motion in a manner similar to that previously described for the ocean surface. Below the density interface, there is orbital motion in the direction of propagation while above it, there is movement in the opposite direction. In comparison with surface waves, internal waves are slow moving and are generally sinusoidal in shape. This results largely from the fact that the density interface is easily distorted because the difference in density across this interface is small.

Wind generated waves can be categorised into three types:

- Sea: Refers to most wind generated waves and includes waves under the direct influence of the wind. The wave patterns are complex and the shape is trochoidal (*i.e.* peaked crests and rounded troughs). The type of "sea" can be used as an estimate of wind speed and corresponding sea characteristics. This is the basis of the Beaufort Scale.
- Swell: This term describes waves which, at the time of observation, are not under the direct influence of wind. This may arise because the wind causing the waves has ceased or the waves may have moved away from the area of active wind. The patterns are simpler than those of "sea" and they approach the ideal sinusoidal pattern. They are characterised by a smooth undulating surface and may occur simultaneously with a sea-type wave pattern.
- Surf: Unlike the first two categories, surf is restricted to shallow waters. It marks the steepening and eventual breaking of the wave form.

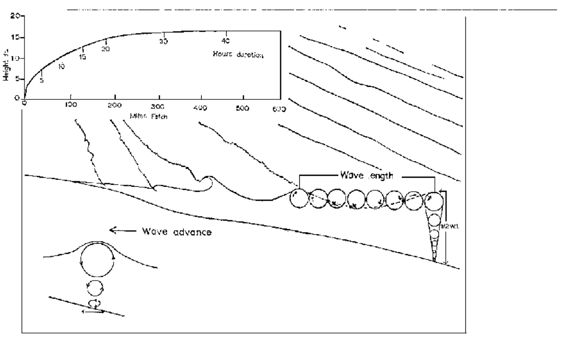


Figure 3. Marine Waves. Orbits shown at intervals in the propagation of a wave with the simultaneous position of water particles and the profile of the water surface.
Left below : Motion of water particles on reaching shallow water.
Left above : Relation between wave height and length of fetch. Maximum height of waves raised by 30mph wind.

There are various ways in which the breaking of the waveforms can be described. In a "spilling breaker", the break is gradual over some distance and the water appears to be spilling over the side of a container - hence the nomenclature. In a "plunging breaker", the wave form steepens, curls over and eventually breaks with a crash of water. In a "surging breaker", the wave form also steepens. However, rather than spilling or plunging, it rushes up the beach face.

The three categories just described belong to the category of so called running waves because the wave form is moving across the water surface hence distinguishing them from standing waves.

The breaking point of a wave is the position along the beach profile where the wave height is at its maximum. Associated wave breaking point parameters include the following:

- The breaker height H_b.
- The breaker depth, d_b, which is related to the still water level. An alternative definition is h_b, the breaker depth related to mean water level.
- The breaker distance B_b, which is the distance from the shoreline to the breaking point measured perpendicularly to the coast, along the x-axis.

2.2.3 Wave reflection, refraction and diffraction

A simple way of appreciating these terms is to draw an analogy with light rays. As waves enter shallow water, the part of the wave in deeper water moves more rapidly than the part in shallow water. This causes the wave crests to turn to be more parallel to the bottom topography. Wave refraction is due to the decrease in wave velocity as waves move into shallow water and is analogous to refraction of light. Refraction can also be observed in deep waters. When a wave crosses a current, if it has a component of motion against the current, it tends to be refracted into a stream. If it has a component of motion with the current, there is a tendency for it to be turned aside.

Waves can also be reflected and diffracted in shallow water. For example, waves moving against a vertical sea wall or a steep cliff will be reflected back towards sea. Wave diffraction causes energy to be transferred along a wave crest. Wave diffraction can cause waves to effect water far to the lee of the interfering structure. Diffraction may however be complicated by refraction depending on the topography of the bottom surrounding the barrier.

2.2.4. Currents

The main types of currents responsible for transport in the ocean are tidal currents, wave generated longshore currents, rip currents and oceanic currents.

Tidal currents: The rise and fall in sea level generate currents which are called tidal currents. When currents and tides are both semi-diurnal, there is a definite relationship between times of current and the times of high and low water in the locality. Tidal currents that attain maximum velocity during the time from low water to high water are called flood currents and those that attain their maximum velocity during the time from high water to low water are called ebb currents. The variation in the speed of the tidal current from place to place is not necessarily consistent with the range of the tide.

In general, the current turns earlier near shore than in midstream, where the speed is greater. The speed of the current also varies across a channel, being usually greater in midstream or midchannel than nearshore. In winding rivers or channels the strongest currents occur near the concave shore and are weak or may eddy near the opposite (convex) shore.

Tidal currents also vary with depth. In a tidal estuary, particularly in the lower reaches where there is considerable difference in density from top to bottom, flood usually begins earlier near the bottom than at the surface. The difference may be as much as one or two hours or as little as a few minutes, depending on the estuary, the location in the estuary and the freshwater conditions. Even when the freshwater flow becomes so great as to prevent the surface marine current from flooding, it may still flood below the surface. The ebb speed and strength usually decrease gradually from top to bottom, but the speed of flood tide is often stronger at subsurface depths than at the surface.

Wave generated currents: When waves break obliquely to the shoreline, they generate currents in the direction of the wave opening. These currents are called longshore currents which move parallel to the general orientation of the shoreline. Longshore currents are mainly responsible for moving sediments as well as other suspended matter along the shore. Longshore movement takes place primarily in two zones. Beach drifting occurs along the upper limit of the wave action and is related to the swash and backwash of the waves. The other zone is the surf zone where the largest quantity of material is in suspension and which can be carried by relatively weak longshore currents.

Rip currents: Rip currents flow seawards (though not too far seawards) perpendicular to the shoreline, when waves break. Rip currents are responsible for transporting sediments out to sea particularly in the surf zone.

2.2.5 Oceanic circulation

The totality of the systems of water movement is a very complex one. This is probably so because the factors which govern these various movements in both the vertical and horizontal directions are themselves subject to considerable variations. Besides, describing the motion of a fluid which is itself in a basin that is rotating as well as being in orbit and which is at the same time influenced by the wind is bound to be complicated. These motions are perhaps best described in terms of their complex mathematics some of which can be found in any standard text on dynamic physical oceanography.

Oceanic circulation can be considered from two angles - wind driven (mostly surface) circulation and thermohaline (mostly intermediate and deep) circulation. These divisions are very useful for descriptive purposes.

Wind driven circulation : Wind driven circulation is directly influenced by atmospheric circulation. Atmospheric circulation has solar radiation as its driving force and so radiation from the sun can be regarded as the ultimate driving force of oceanic circulation. Surface currents generally have a horizontal component.

When the wind blows over the water surface, there is friction between moving air and motionless water. Apart from causing ripples and waves, the stress of the wind results in the transfer of energy which causes water motion (currents). They may be turbulent or laminar depending on the velocity of the causative wind. Because these currents are generated at the air-water interphase, their strength decreases with depth.

The direct influence of atmospheric parameters on surface ocean circulation is apparent if one examines the relationship between the major gyres in the northern and southern hemispheres. The currents, although following the wind pattern closely, are at an angle to it (45º) to the right and left of the wind directions in the northern and southern hemispheres respectively. This is due to the Coriolis or geostrophic effect. Other peculiarities include the tendency for westward current intensification. This is due to the latitudinal variation in the magnitude of acceleration associated with a solid rotating earth under liquid oceans irrespective of hemisphere.

Thermohaline circulation: This type of circulation is associated with deep waters below the major wind driven currents and as the name implies, it is due to temperature and salinity differences. These differences result in density variations which set up movement akin to a convection current. Thermohaline forcing can also be achieved by freshwater runoff from land which sets up a salinity gradient normal to the coast.

Upwelling: Upwelling may be defined as the upward transport of sub-surface (often nutrient rich) cold water to the sea surface. It is caused by a variety of factors and varies in duration and extent.

In some coastal areas, the vertical temperature profile sometimes appears to be anomalous and reflects a breakdown in thermal stratification. This apparent anomaly can be caused by movement of water in response to the Coriolis effect according to the Ekman Spiral during which surface winds result in the net horizontal transport of surface water, causing deeper, colder water to rise (upwell) to the surface. In the northern hemisphere for example, where surface winds blow in a north-south direction on the western side of a land mass, the wind results in the net transport of surface water westwards making way for the deeper colder water to upwell. This setting is particularly true of coastal inshore upwelling.

Upwelling and the associated phenomenon of downwelling can also result from surface wind stress causing divergence or convergence. The term upwelling sometimes leads people into thinking that water is upwelled from the bottom. This is rarely the case and characterization of water masses in upwelling areas in terms of their physical, chemical and biological characteristics has revealed that water is upwelled from depths that rarely exceed 400m.

Upwelling is very important in fisheries since cool upwelled water usually contains relatively high concentrations of nutrients especially nitrate and phosphate. Upwelling areas are therefore usually fertile and may support rich fisheries. Examples of some rich fishing grounds based on upwelling include the Pacific coasts of California and Peru and the Atlantic coast of southern Africa and off the coast of Ghana.

2.3 OCEANOGRAPHIC TECHNIQUES

Instruments for oceanographic measurements and data gathering must have certain qualities -

- High sensitivity and good reproducibility so that even small fluctuations in thermodynamic variables can be identified.
- Salt resistance.
- Ability to withstand hydrostatic pressure and supply data not affected by pressure effects.
- Sufficiently robust to cope with rough field conditions.

2.3.1 Bathymetry

Bathymetry is the distance (water depth) between the water surface and the sea bottom. Methods that are used to determine water depths are as follows:

i) Measurement of hydrostatic pressure. From hydrostatic pressure “p” of a water column the mean density of which is known, the depth “z” is obtained according to the hydrostatic basic equation

$$z = \frac{1}{pg}$$

here “g” = acceleration due to gravity and pressure measurements can be made with

Bourdon tubes or Well tubes.

ii) Measurement of sinking time of a free-falling probe offers a very simple method for the determination of depth.

iii) Special measurement by means of an echo sounder which sends a pulse through the water to the sea bed. This pulse returns to the receiver where conversion of the speed and time is made to obtain the depth (D) based on the formula:

$$D=0.5VT$$

where V = velocity of the pulse (1500m/s),
and T = time of travel of pulse.

The bottom profile of the sea is printed on the echo sounder paper as an echogram.

2.3.2 Measurement of tide (water level variation)

Two types of gauges are used for measuring tidal variations : non-registering and self-registering. Non-registering gauges require the presence of an observer to measure and record the height of the tide. Self-registering, or automatic gauges, automatically record the rise and fall of the tide while unattended.

Non-registering gauges include the tide staff, the simplest kind of which consists of a plain staff or board about 2-5cm thick and 5-15cm wide and graduated. The length of the staff should be sufficient to extend from the lowest to the highest tide in the locality where the staff is to be used. The staff is secured in a vertical position by fastening it to a pile or other suitable support. The height of tides can be read from the graduations on the staff.

Self-recording tide gauges include :

- Float gauges - with direct mechanical registration of the water level.
- Pneumatic gauge - in which a diving bell lies on the sea floor at such a depth that pressure variations due to surface waves can be ignored. By means of an air-filled tube, the hydrostatic pressure is connected with a recording manometer on shore on a measuring pole.
- Acoustic gauge - by means of acoustic signals sent to the seabed, the depth being determined by the time required for a sound wave to travel from the ship or boat (acoustic transmitter) to the bottom and for the echo to return.

A depth recorder can also be used to measure tides from submerged capsules and platforms. For accuracy, tidal readings must be related to a datum, the commonest being the chart datum.

2.3.3 Measurement of ocean surface waves

Waves can be measured from the sea floor, at the sea surface or from an aircraft. The most important method of measuring waves from the sea floor is the recording of bottom pressure fluctuations that reflect surface waves and which can be used to calculate surface displacements in accordance with the linear wave theory. In pressure gauges, the pressure sensor reacts exclusively on any variations of the hydrostatic pressure. Another method, though of less importance, is the measurement with a reversing echo sounder.

Float gauges and electrical measuring devices are suited for measurement from the sea surface. They are deployed from fixed platforms, like bridges at the coast or pole research towers. Float gauges are similar to those used for the measurement of tides. With electrical devices, variations of water level are converted into changes in electrical resistance capacitance. In the capacitive method, an insulated wire is stretched in a vertical position with a cylindrical capacitor in the range where it is wetted with water. The variation in length of wetted clinger, or the variations in size of the capacitor respectively, correspond to the variations in water level.

Wave observations from a ship can be carried out visually, photographically or by means of built-in measuring devices (slip burner recorders).

Accelerometer instrumented buoys are often used for wave measurements in deeper waters where pressure sensors cannot be used and where structures are not available for attachment of other types of wave sensors. Accelerometers can transmit wave measurements to a shore-based receiving station where wave data are recorded or monitored in real time.

Aircraft and satellites which orbit the earth carry sensors which can measure sea waves. However, the resolution and accuracy of wave data from atmospheric measurements is still poor when compared with that from sea-based instruments described above. A promising recent development permits recording of the state of the sea from simultaneous measurements of the sea surface temperature through infrared and microwave radiation.

2.3.4 Measurement of currents

Two quantities must be determined by sensors for current measurements. These are the absolute value and the direction of the velocity or its components in a right angled coordinate system. The absolute value is usually obtained by measuring the rotation rate of mechanical sensors such as propellers, rotors, paddle wheels, or turnstiles with hemispherical bowls. The direction is determined by means of a current vane relative to the north direction (magnetic compass, induction compass) or to the bearing of a fixed measuring stand.

The acoustic current metre, which makes use of the fact that sound is carried along with moving seawater, consists of two sonar paths for each co-ordinate direction through which the sound propagates in opposite directions. The difference in the travel times is a measure of the carrier velocity.

Measurements of currents can also be made from a moored vessel with the current metre lowered into the water.

Current measurements are ideally made at three depth levels *i.e.* near the surface (within 1.0m from the surface), mid-depth and near the bottom (within 1.0m from bottom). Such measurements provide a good current profile of the column of water.

2.3.5 Drift measurements

Drift measurements are made on the surface by a variety of floats. Systematic drift measurements in the near surface layers are carried out with drift bottles or with drift cards in plastic envelopes - they drift ashore. This method only gives the starting and final points and a rough estimate of the time span of the drift.

Parachute buoys used for drift measurements carry a mark, a radar reflector or a radio transmitter. The buoys are connected by a thin rope with a floating body at the selected depth to be measured. A parachute or another structure with high flow resistance is fixed to the float. Its trajectory can be tracked by taking the bearings of the surface buoys by means of optical, radar or radio direction finding either from a ship or a coastal station.

Fluorescent dye is also used to measure surface currents. Powdered dye is released on the surface, often in packets, and it dissolves leaving a readily visible patch. Its propagation can be traced visually and photographically from an aircraft or by the use of a fluorimeter from a ship.

Drift measurements in the bottom current can be performed with specially designed mushroom shaped floats made out of plastic. The “foot” which is weighted to result in a minimum degree of negative buoyancy, touches the sea floor slightly and the mushroom is carried along in small hops by the bottom current. Distance and time are obtained when they are retrieved in bottom trawls.

2.3.6 Water sampling devices

Properties of seawater are best measured *in situ*. If this is not possible, the water has to be collected and analysed in the laboratory. In such circumstances three precautions are necessary:

- the sample must be taken at known depths and position,
- it must be protected from any falsification, and
- it should be adequately preserved by keeping it in the freezer until analysed.

Water samplers differ in the release mechanism of the closing valve at the desired depth which can be triggered by one of the following devices :

- a messenger (usually a weight),
- a propeller that activates the valve as soon as the sampler is hoisted,
- hydrostatic pressure that activates the closing valve when a certain pressure (depth) is reached,
- an electric remote control achieved through a connecting cable.

A number of sampling bottles can be attached to the same wire of a hydrographic winch to obtain multiple samples simultaneously. The most common types of sampling bottles are the Nansen and spilhaus types.

2.3.7 Measurement of temperature

An ordinary mercury thermometer is the simplest way of obtaining the temperature of a surface water sample taken in a bucket. At the other extreme, sea surface temperature can also be read from aircraft and satellites by observing the intensity of the infrared radiation of sea water within the wavelength range of 8-12 μm.

Water temperature in deeper waters is measured with reversing thermometers with an accuracy of up to ±0.01°C.

Recently, electrical methods of measuring water temperature have gained importance. For this purpose, platinum resistance thermometers or thermistors are used almost exclusively as sensors and there is a variety of instruments with platinum thermometers or thermistors which usually employ Wheatstone Bridge methods.

2.3.8 Measurement of salinity

Salinity can be calculated on the basis of well-known functional relationships by determining physical properties such as density, optical refractive index, electrical conductivity, or sound velocity and, in addition, temperature and pressure.

Chemical methods, based on chlorine (Cl) content, can also be used to calculate the salinity of water samples. This involves chlorine titration using silver nitrate.

Progress in electronic measuring techniques have resulted in electrical conductivity salinometers almost replacing most other methods of determining salinity. *In situ* salinometers known as "Bathy sonde", "STD", "CTD" and "Multisonale", permit the simultaneous measurement of electrical conductivity (salinity), temperature, and pressure.

2.3.9 Measurement of sound velocity

Sea water distribution of sound velocity in space is determined either indirectly from measurements of temperature, salinity and pressure, or directly from measurements of travel time or wave length.

For the determination of travel time, the time interval "t" is measured by the time it takes for the sound signal to travel to and fro between transducers. The sound velocity "C" results from

$$C=\frac{x}{t}=x.f$$

with

$$f=\frac{1}{t}$$

The wave length measurement is based on the relation between sound velocity "C", wavelength "l" and frequency "f".

$$C=l.f=\frac{x}{n}.f$$

2.3.10 Measurement of density

In coastal waters with strong differences in hydrographic stratification, density is determined indirectly through salinity, temperature and pressure.

Direct measurements of the specific weight, however are required for fundamental determinations and also in cases when it is not certain that the content of sea water is constant.

Methods that might be applied for this determination include the weighing of a pycnometer (a glass vessel with exactly determined volume), the hydrostatic weight of a float, or the frequency determination of the characteristic oscillation of a body that is dependent upon the density of sea water.

2.3.11 Measurement of the content of suspended materials

Suspended particles are of different sizes and shapes and may be organic or inorganic. Methods of measurements are either direct or indirect.

Direct methods involve the filtration of water samples with the subsequent weighing and examination of the residue.

Indirect methods are based on the measurement of the attenuation and the scattering of light as well as the reflection of sound by the particles suspended in seawater.

Attenuation measuring devices, called turbidity meters or transparency meters, record the attenuation of a light beam over a certain measuring distance - spectral photometers are employed for laboratory work.

To measure scattered light, an installation is required whereby a selected volume of water is subjected to irradiation by a parallel light beam and the scattered light is measured at various angles relative to the beam.

2.3.12 Measurement of dissolved substances

Dissolved substances in sea water are measured for two principal purposes - the first is to determine the basic composition of these components which are only slightly influenced by biological processes, if at all. The second is to record whole ocean areas in space and time and to observe biochemical processes in a delimited region.

Gravimetric proportion analysis, volumetric and colorimetric methods were earlier used to measure the dissolved substances in water. More recently, spectral photometric methods are used for the direct determination of nutrients and for the measurement of several trace elements after they have been enriched and extracted. These methods include, atomic absorption spectrophotometry and neutron activation analysis, gas chromatography, potentiometric methods with ion-specific electrodes, inverse polarography and microbiological assays.

2.4 COASTAL PROCESSES SURVEY

2.4.1 Introduction

Coastal processes are those processes that affect the morphology of beaches (including coastal areas) and shallow nearshore waters. Such processes are usually the result of interactions between marine and fluvial processes and meteorological conditions. Such land/sea/atmosphere interactions can be modified by human activities and can lead to significant changes in coastal morphology.

Probably the most important natural force shaping coastlines is the force of waves. In deep water, fluid particles move in nearly closed exponential decaying circular orbits. But when the water depth decreases to about one-half of the wave length, waves approaching the coast start to "feel" the bottom. Particle motion becomes more and more elliptical and a velocity develops along the bottom that moves the bottom sediments. As the waves continue towards the beach, shoaling causes wave steepness to increase until a point where the depth is about 0.78 of the wave height. At this depth waves break. As waves break, water moves forward as a line of foam which carries fine sand in suspension toward the inner beach. When the foam line slows down, sand is deposited on the beach. Some of the remaining water, which has not percolated into the beach, returns as gravity flow down the beach taking sand with it. At the point where this flow meets the forward moving water of the next incoming wave, the outgoing material is deposited forming a low seaward facing beach slope that changes position with wave conditions.

Continuous pounding of beaches, especially sandy ones, results in beach profiles developing with time since the sediments are composed of movable particles.

Ocean waves affect beaches in two ways. Firstly, relatively steep wind waves cause beach erosion by taking sand and other materials from the area just above the water level and transporting them into deeper water. Secondly, waves approaching the beach at an angle break near the beach and generate a current that moves parallel to the shore line. This is called littoral current or longshore current and is most noticeable in the surf zone. Longshore current is an important coastal process since it carries large amounts of beach sand, stirred into suspension by the breaking waves, along the beach.

2.4.2 Causes of beach erosion

Beach erosion can be caused by both natural and human activities. These causes however, vary from area to area and in intensity. Some of the natural causes include: low lying topography, intense wave climate, vulnerable soil characteristics, nature of shelf width and topography and the occurrence of offshore canyons.

Anthropogenic activities causing beach erosion include : damming of rivers which reduces the sediment reaching the shoreline, construction of harbour protection structures and jetties, beach sand mining, removal of coastal vegetation and dredging activities.

Subsidence which may be induced by natural compaction of sediments or by human activities such as oil and groundwater extraction can also exacerbate rates of coastal erosion. Furthermore, the problems of coastal erosion worldwide are expected to be exacerbated by predicted sea level rise.

2.4.3 Beach erosion monitoring

Monitoring of beach erosion involves the analysis of beach sediment characteristics. Beach sediment samples taken at designated points on the beach should be analysed for their granulometric characteristics. This is done for sand by passing through sieves stacked up either in 0.25mm or 0.5mm intervals. For silt and clay particles, granulometric analysis is performed by pipette analysis or by using a sedigraph. The method of Folk is normally used to calculate the granulometric characteristics of sediment samples. Statistical parameters of importance in this regard are: mean grain size, standard deviation, skewness (measure of asymmetry) and kurtosis or peakedness.

There are two methods for obtaining statistical parameters. The most commonly used, is to plot the cumulative curve of the sample and read the diameter represented by various cumulative percentages (*e.g.* what grain size value corresponds to 25% of the sediment). Much more accurate results can be achieved if one plots the cumulative curve on probability paper. The equations for deriving these parameters from the sieve data are shown below.

Mean grain size (M_z)

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Incl. Graphic Std Dev (O_I)

$$O_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

Incl. Graphic Skewness (SK_I)

$$SK_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

Kurtosis (K_G)

$$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

For very good coverage of the beach at a designated station, it is recommended that sediment samples for analysis be taken at the foreshore, the berm crest and from the backshore.

2.4.4 Beach profiling

Beach profiling can be done either by levelling or by sighting, using a surveyor’s graduated staff.

Levelling involves establishing transect lines paced at specific intervals to cover the stretch of shore. Each transect line is referenced by two or more permanent markers placed above high water mark whose position and heights are accurately surveyed. Each transect line is then levelled from the shore as far into the water as possible at low tide. The distance between each profile station will depend on the general morphology of the beach as well as the severity of the erosion problem. The interval of profiling could also range from weekly to monthly, however profiling should be done immediately after any big storm.

The equipment needed to conduct this type of beach profiling comprises an engineer’s level with tripod, a levelling staff and 100m steel measuring tape.

The profile line which should be perpendicular to the general orientation of the beach should start as far back as the bench mark installed far behind the beach. The levelling procedure is as follows :

1. Place the level approximately half-way between the backsight staff (which is on the bench mark whose height is known) and the foresight staff (ahead of the level),
2. Level the instrument using the appropriate adjustments,
3. Read off the backsight staff,
4. Transit to foresight and read off the staff,
5. Measure the distance between A and B using steel tape,
6. Keeping the foresight staff in the same position, move the instrument ahead of it so that position B now becomes the backsight while a new foresight position is established,

Repeat steps 2 and 4. This procedure is continued along the same straight line until the last point is reached - which is usually some safe distance into the water.

The following precautions must be taken in order to minimise errors:

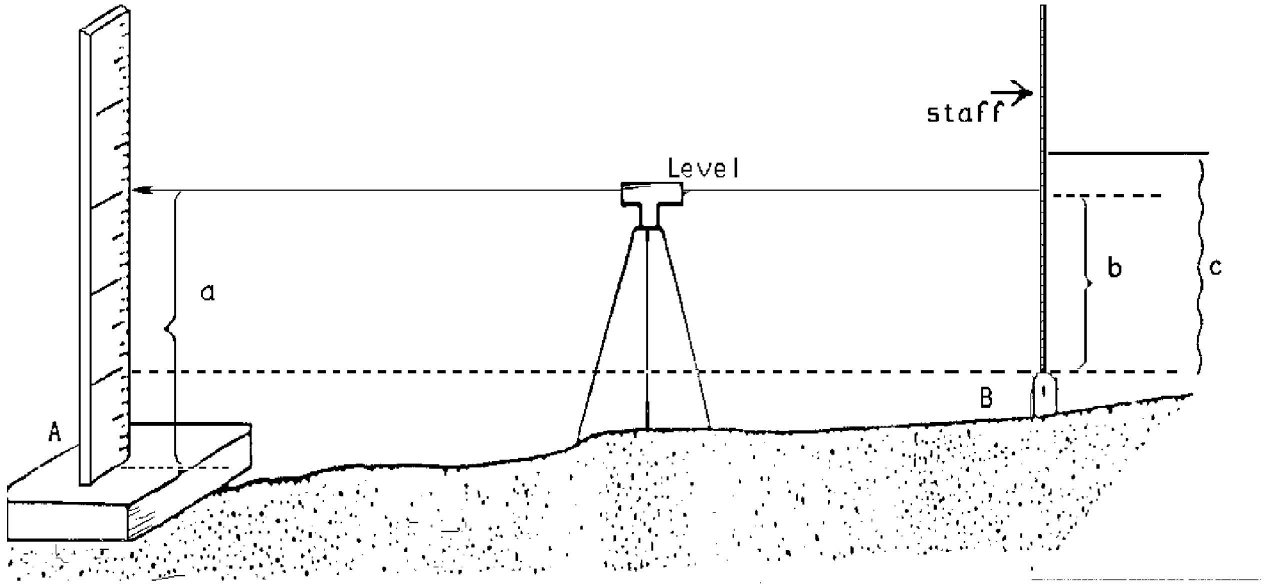


Figure 4. Beach profiling with the aid of a surveyor's level.

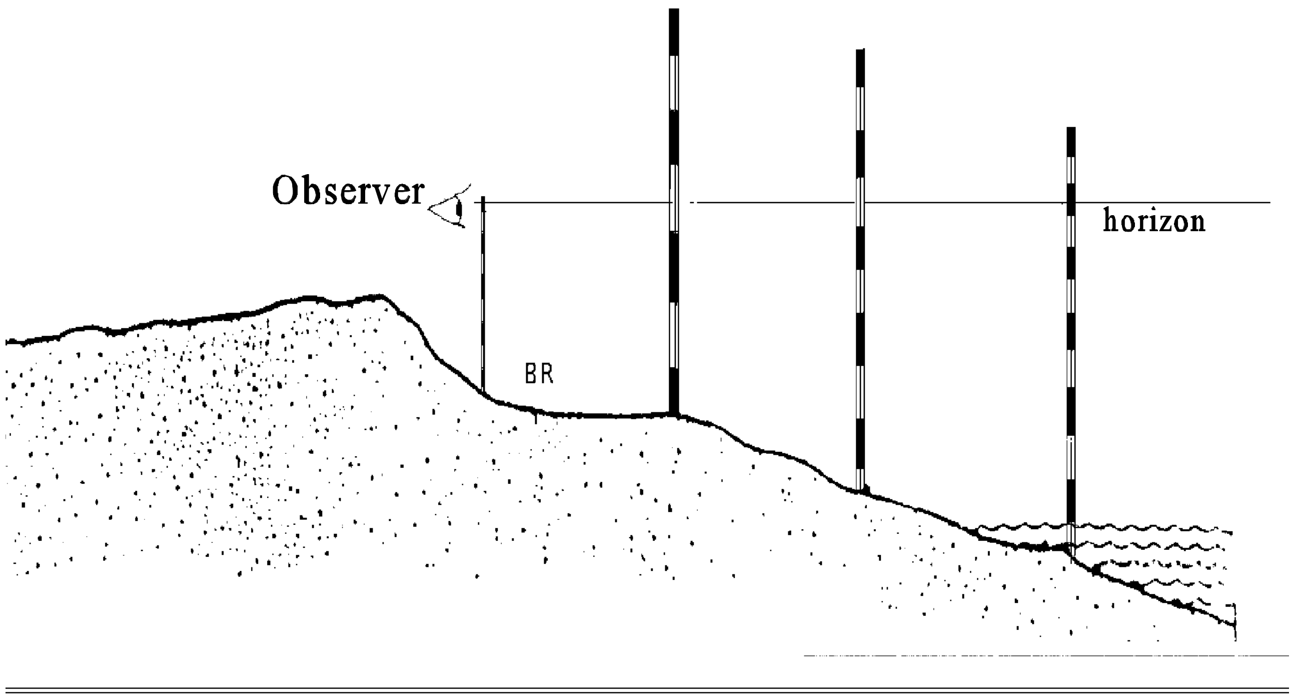


Figure 5. Beach profiling by an observer sighting the horizon from a fixed point.

- To eliminate cumulative errors, the level should preferably be at an equal distance from the forward staff and the backstaff.
- The instrument should always be levelled along the profile line before any reading is taken.
- Features along the profile line should be noted *e.g.* berm, high water line, low water line, any beach structure as well as the time.

Recording and computing of levelling data are made by reference to the rise and fall or sighting.

Parameters for the rise and fall method are as follows :

STATION	BACK SIGHT	FORE SIGHT	ALTITUDES	REMARKS
A	a	-	Ha	bench mark
B	c	b	Ha+(a-b)	berm
C	e	d	Hb+(c-d)	rock

Where "Ha" is the known altitude (*i.e.* fixed bench mark) which is the control point of the profile. To determine altitudes of B, C, etc, subtract the foresight reading from the backsight reading and add the results to the altitude of the station at backsight.

For example, the altitude of B = Ha + (a - b)

where	Ha	=	altitude of A
	a	=	backsight reading of staff on station A
	b	=	foresight reading of staff on station B

The above procedure is followed for subsequent points whose altitudes are to be determined.

When a level and other topographic equipment are not available profiles can still be easily done by a simple method of sighting with the aid of a 1.5m surveyor's staff which replaces the levelling instrument. It is placed vertically on the bench mark BR, with the observer sighting the horizon from behind the staff. The line of sight intercepts a height H on a graduated staff which is displaced along the profile of the beach, as in classical levelling. The distance from the stake to the observer is measured by means of a graduated tape. This simple method is relatively accurate when the measured distances and the slope of the beach do not force the observer to change position several times along a single profile.

Another method of profiling is to drive a row of galvanised steel tubes vertically into the sand to a depth of 2-3m at intervals of 10m and protruding from the sand to a height of 2m. The tubes can be driven into the sand with a pneumatic hammer on the exposed beach, or with a pneumatic gun on the underwater beach. Topographic variations are then measured by direct reading of the distance between the sand level and the top of the tube. Such readings can be taken regularly by a single unqualified observer, on the exposed beach, but they require an equipped diver for the underwater readings. The major drawback to this system is the risk of accidents caused by the protruding metal tubes to other beach users, fishermen and tourists. The risk of beach users removing the tubes also makes this method impracticable on most beaches.

2.4.5 Profile of the underwater beach

It is usually desirable to continue the beach profile beyond extreme low tide out to the limits of the breaking waves and even into the nearshore subtidal area (possibly as far as into a depth of 10m of water). Profiling into such water depths can be done with the aid of an echo sounder affixed to the side of a boat or a canoe. The boat is kept in line with the aid of a positioning system like a hand held GPS or by a combination of an electronic distance metre positioned on a level on the beach with the reflector prism on the boat with a two way communication system.

Fixes can be taken every 2 minutes by the fix button on the echo sounder which puts a straight line on the echogram. This will indicate the position of the boat at the fixed point while time marks can provide the surveyor with additional controls for plotting the results. The depths along the profile line can be read off from the echogram.

The levels are reduced to a known datum - LLWS and a profile of the area under study is drawn by means of contour lines to join points of equal height or depth.

Bathymetric surveys can also be done with seismic surveys which reveal the nature of the subsurface as well as the surface of the seabed. A uniboom or sparker can be used which produces good resolutions down from 100 to 200m.

When echo sounders are not available, a lead line can be used to obtain the general trend of the underwater beach. A lead line consists of a graduated line with a weight (ballast) at the end of the line. In this case the surface of the ocean is the reference level. To increase the level of accuracy when using this method, it is important that the intervals at which the depths are taken be very close. It is also important that the surveyor should keep along the line of profile.

The sea state, especially the tide, should be monitored during bathymetric surveys. This will help relate bathymetric data to a known datum.

2.4.6 Littoral environment observations

It is important that hydrodynamic characteristics be recorded at each station during each beach profiling. While sophisticated equipment is available to monitor these, they can be measured more simply by visual observation.

The main hydrodynamic variables that should be measured along the beach are:

- Wave type: This is done by visually observing the most prevalent type of breaking waves as either spilling, plunging, or surging.
- Amplitude of waves at breaking point (Hb): This is done by averaging 10 to 20 visual estimates of the amplitudes of successive waves. These estimates are made, if necessary, with a swell measuring rod graduated every 0.5m and permanently fixed in the breaking zone. A trained observer can estimate wave amplitude to within plus or minus 10cm.
- Period of waves: This is deduced from the time separating the breaking of 10 successive waves.
- Direction of the waves at the breaking point (b): This can be estimated by means of a simple protractor fixed horizontally to a post and with its base running parallel to the shoreline. Taking the averages of 10 consecutive visual estimates yields the direction of the propagation of the waves within a few degrees.
- Longshore currents: To measure the direction of the longshore current that is generated between the breaking zone and the shoreline, a float is thrown into the breaking waves and the direction of movement of the float is known as the direction of the longshore current. The average speed of the current is estimated by staking a distance of 10m and timing the displacement of the float over the staked distance. The current speed is then determined by dividing the staked distance of 10m by the time. This is done three or more times and the average is taken as the speed of the current.
- Width of the breaking zone (W): This is estimated visually as the distance between the breaking line and the shoreline.
- Sea level: This is observed by visual estimation of the average level on a graduated rod fixed in the sea near the shoreline; the same rod can be used to estimate the swell characteristics.

Other meteorological data that should be recorded during each beach visit, include:

- Air and water temperature: this is usually done with the aid of a simple thermometer.
- Wind speed: A hand held anemometer is used for this.
- Wind direction: This can be estimated by holding a handkerchief in the air and noting the direction of wind. The direction can then be estimated with the aid of a compass.
- General weather conditions: Brief and descriptive notes on any other weather conditions as well as anything else of interest on the beach should be recorded.

REFERENCES

Awosika, L F, Ibe, C E, Nwankwu, E O, Balogun, A and Adekoya, E A (1992) *Physical and Geological Factors Affecting the Transport, Dispersion and Deposition of Pollutants in the Lagos Lagoon, Nigeria.* WACAF II Phase 2 Project. A Progress report for IOC.

Cook, P (1994) Offshore Mineral Resources. In : Proceedings International Conference on Oceanography. Lisbon, November 1994.

Davis, R A (Jr), (1977) *Principles of Oceanography* Addison - Wesley.

Defant, A, (1961) *Physical Oceanography* Vol.I Pergamon Press.

Dietrich et al, (1972) *General Oceanography.*

Earle, M D, and Bishop J M (1984) *A Practical guide to Ocean Measurement and Analysis.* Published by ENDECO, Inc. Marion, MA U.S.A.

Ibe, A C, (1982) *A review of potential economic mineral resources in offshore Nigeria.* NIOMR Tech. Paper No. 8.

Ibe, A C, Ajao, E A, Oyewo, E O, Awosika, L F, Ihenyen, A E, Tiamiyu, A I, Ibe, C E, Inegbedion, L and Adekanye, J E (1988) *Physico-chemical Parameters and Dynamics of the Ocean off Lagos, Cruises 1, 2, and 3.* A report for the Nigerian Army.

Ibe, A C and Quelennec, R E (1989) *Methodology for the assessment and control of coastal erosion in West and Central Africa.* UNEP Regional Seas Reports and Studies No. 107. UNEP, Nairobi.

Knauss, J A, (1978) *Introductin to Physical Oceanography*. Prentice - Hall Inc.

Lewis, E L and Perkin, R G, (1981) The Practical Salinity Scale 1978. *Deep Sea Research* 28A(4): 307 - 328.

US Army Coastal Engineering Research Centre (CERC) (1973) *Shore Protection Manual*. U.S. Army Corps of Engineers, Fort Belvoir, Virginia.

PART 3 : LIVING RESOURCES ASSESSMENT METHODS

Living resources include all living things from mangroves to manatees to microbes. They also include ecosystem functioning, health and integrity and, for the purpose of coastal survey, they include also subsistence fishing as well as commercial, economic use of various resources. Living resources also include the living landscape - whatever gives a particular part of the globe its unique ecological and aesthetic character.

3.1 ECOLOGICAL SURVEY

One of the most common reasons for ecological survey is to document the ecological situation and establish a baseline of what needs to be managed and their condition.

This is basically a description of the biological environment including all its biota, their trophic relationships, various life stages and seasonal variations, the presence of rare and endangered species, and the presence of special populations or ecological communities such as mangroves, coral reefs, wetland systems, and seagrass meadows.

The biological environment often reflects, and has an influence on, the physical environment. For example, coral reefs and mangrove forests play a major role in controlling coastal erosion. It is therefore artificial to make a clear distinction between the biological and physical environment and ecological surveys usually address a holistic view.

3.1.1 Macro scale survey

Macro scale surveys utilize visual representations of data, often in a coarse format. Topographic maps, bathymetric charts and thematic maps (*e.g.* geology, vegetation) are the most common of the coarse data summaries. When coupled with local knowledge which can be superimposed on the base maps and after some validation by rapid checking in the field, they are often more than adequate as macro surveys.

Better definition and detail can be provided by aerial photographs whether taken vertically or

obliquely. Particularly when they are taken as a time series, aerial photographs can provide accurate information on trends in mangrove distribution, the migration of sand spits, the extent of seagrass meadows, etc.

3.1.2 Rapid rural appraisal

This is an excellent survey technique which can provide a quick preliminary assessment of the situation for comparatively little cost. It provides mainly a good “gut feeling” and may require follow-up, however, after an effective rapid rural appraisal, any follow-up can be targeted much better.

The techniques employed in rapid rural appraisal can include any combination of : review of existing data, direct personal observations, semi-structured interviews with local people, community meetings, relating of personal stories and experience, drawing of diagrams, etc.

Rapid rural appraisal can be used successfully to establish a baseline of the existing situation. It can then be repeated to record historical changes, particularly those within the collective living memory of a community. It can also provide a comprehensive analysis of single events such as a cyclone, a flood or an oil spill. It is also extremely valuable to provide an insight into the seasonal variability of a particular environment, especially when the investigator is limited to one particular time of the year.

A typical rapid rural appraisal would start with the investigator familiarising himself/herself with the main body of information already existing. This could mean a desk review of reports, study of aerial and other photographs, familiarisation with any published material. Armed with this preliminary information, the investigator could then convene a village meeting at which he/she will prompt information on whatever aspect of the environment is important. During this flexible approach, a skilled investigator will use “peer review” of the information which is volunteered, and note consensus and dissent. An effective approach is to use felt pens on a map base and record the information as it is provided and agreed to by the

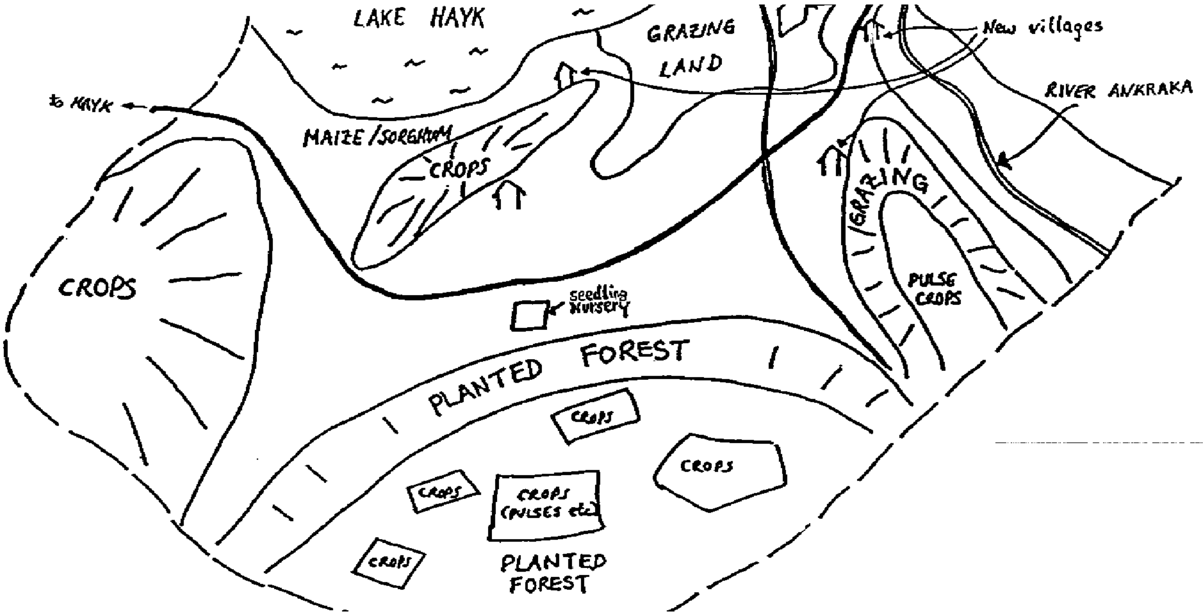


Figure 6. Sketch map of a peasantland-holding and activities in Ethiopia.

meeting participants. It is also possible to take one or two knowledgeable local people into the field to validate the critical information through spot checks. The data can then be refined and converted on to annotated maps, cross-sections of the environment, time sequences, etc. These will serve as a strong basis for any more thorough assessment or survey that is deemed necessary.

3.1.3 Remote sensing

While rapid rural appraisal is usually the least costly and most basic ecological survey methodology, remote sensing is often the most sophisticated and most expensive. However, it can also be the most objective and most accurate and, depending on the environment that is being surveyed, it can also be very cost-effective.

Remote sensing can be defined as the obtaining of data about a target without the sensor being in contact with the target.

There are many sensor and recording systems and they include photographic cameras (sometimes with specialized type of film), radiometers and radar systems which can record in photographic form or in digital form. Digital data, which depends on image processing systems to be transformed into useable imagery, is very versatile and can make corrections for radiometric and geometric "noise" and can also be enhanced using specialized spectral techniques.

Remote sensing using space satellites has been used to provide data on : ocean colour (which reflects productivity, sediment load, plankton blooms, etc), sea surface temperatures (can indicate upwelling), surface wind and wave conditions (essential when dealing with an oil spill), landuse (down to a resolution of 10 metres by the SPOT satellite), bathymetry, oil pollution, submerged (*e.g.* algae and seagrasses) and emergent (*e.g.* mangrove) vegetation distribution.

There are some serious limitations of satellite remote sensing techniques for coastal survey. With a return period of 16-26 days, it is not considered as providing sufficient temporal resolution for such a dynamic environment. Interpretation of satellite images is often hindered by tidal fluctuations and other influences (such as storm surges) on surface water levels. Cloud cover, which is very common in humid tropical coastal environments, is a big problem and can only be overcome by the use of microwave sensors. Finally, light penetration in water is limited and therefore the deeper one tries to read below the water surface, the less reliable the data becomes.

3.1.4 "On the ground" survey

On the ground ecological survey is the most common and relies on standard methodologies usually employing a sampling approach. For example :

- Transects - which record the presence (and abundance) or absence of biota and the nature of the environment along a linear path.
- Quadrats - usually a square metre and used in conjunction with a transect. Can consist of a photograph (*e.g.* to record the extent of cover by algae).
- Deep cores - to penetrate beneath the surface of sand or mud. Requires sieving and counting.
- Trawl - usually for a set period of time at a set speed, in mid-water or at the bottom, to record larger epibenthic biota.
- Plankton nets - tow nets can be towed for a set period of time, at a set speed and level in the water column; alternatively, weighted drop nets can be used to sample vertically the water column at a selected location.
- Gill nets - a standard length of net with a standard mesh size, set for a specific period of time at a specific depth level.

All the above methodologies rely on samples in order to interpret the overall situation. If the data from samples is to be extrapolated to the whole, the samples must be known to be representative according to reliable statistical techniques. The minimum number of replicate samples required to obtain representativness, is the number at which a 100% increase in sample numbers will only lead to a 5-10% improvement in accuracy.

It is also essential that samples are replicable so that results from different sites can be compared and contrasted, and so that repeat samples of the same site can be taken over time in order to observe any changes. The only way to ensure replicability is to record the approach and methodology used right from the planning stages, through to field work and subsequent analysis.

3.1.5 Some common sampling approaches

Estuarine finfish are best sampled by set gill nets, of about 75mm mesh size and about 150 metres long. It is probably best if the sampling net conforms to the equipment used by local fisherfolk. Aerial photographs are often used to determine the best location for setting the nets. They are usually set at high tide, parallel to the mangrove fringe or across small creeks, and collected some six hours later at low tide. The exercise needs to be repeated at least three times, depending on variability and the state of the tide must be consistent each time. Care must be taken to take into consideration the time of day and the weather conditions during the sampling period and immediately prior to it - fish behaviour can be influenced dramatically by these and similar parameters.

Reef finfish are best sampled by swimming along a transect for, say, 100 metres along the reef edge, and counting all the fish within 1-2 metres on either side of a rope floating on the surface. The counting could be repeated on the return swim. The transect rope can be placed permanently for better replicability. However, care must be taken to avoid the disturbance factor.

Pelagic fish are more difficult to sample. However, an idea of their distribution and density can be obtained through point counts. These are made by a solitary diver (using SCUBA) who is relatively stationary, and who scans a full 360^{o} circle, counting all fish within a set radius of, say, 10 metres. A larger area can be covered by repeating the solitary and stationary stations at pre-determined locations.

Bottom data and benthic biota can be recorded very accurately through the use of quadrats along a transect. The presence of sessile organisms is often expressed as a percentage of ground cover and this is usually made easier by working with quadrats which are one square metre in area. These quadrats can either remain fixed to the seabed or they can be repeated with reference to fixed markers. Photographs can also be extremely useful for bottom sampling.

With sessile organisms it is also possible to record competition for space, survival and succession. This is done by sampling the settlement patterns over a period of time. In planning such a survey, it is important to determine the frequency of sampling depending on the data required (*e.g.* bivalve settlement dates, growth rate, fouling organisms, etc). The substrate that is to be used to attract settlement must be chosen very carefully and a decision needs to be made on whether it is necessary to sample different levels in the water column. Common substrates include tiles, rope, bamboo, slate.

For this exercise, samples of the substrate material are deployed in pairs at the pre-determined depth or depths and at the pre-determined time intervals. On each visit, a new pair of substrate samples are deployed and one of the previous pair is removed for analysis. This provides a record of what settlement has taken place between visits and records the survival rate of different species and different age classes of the same species. It can also

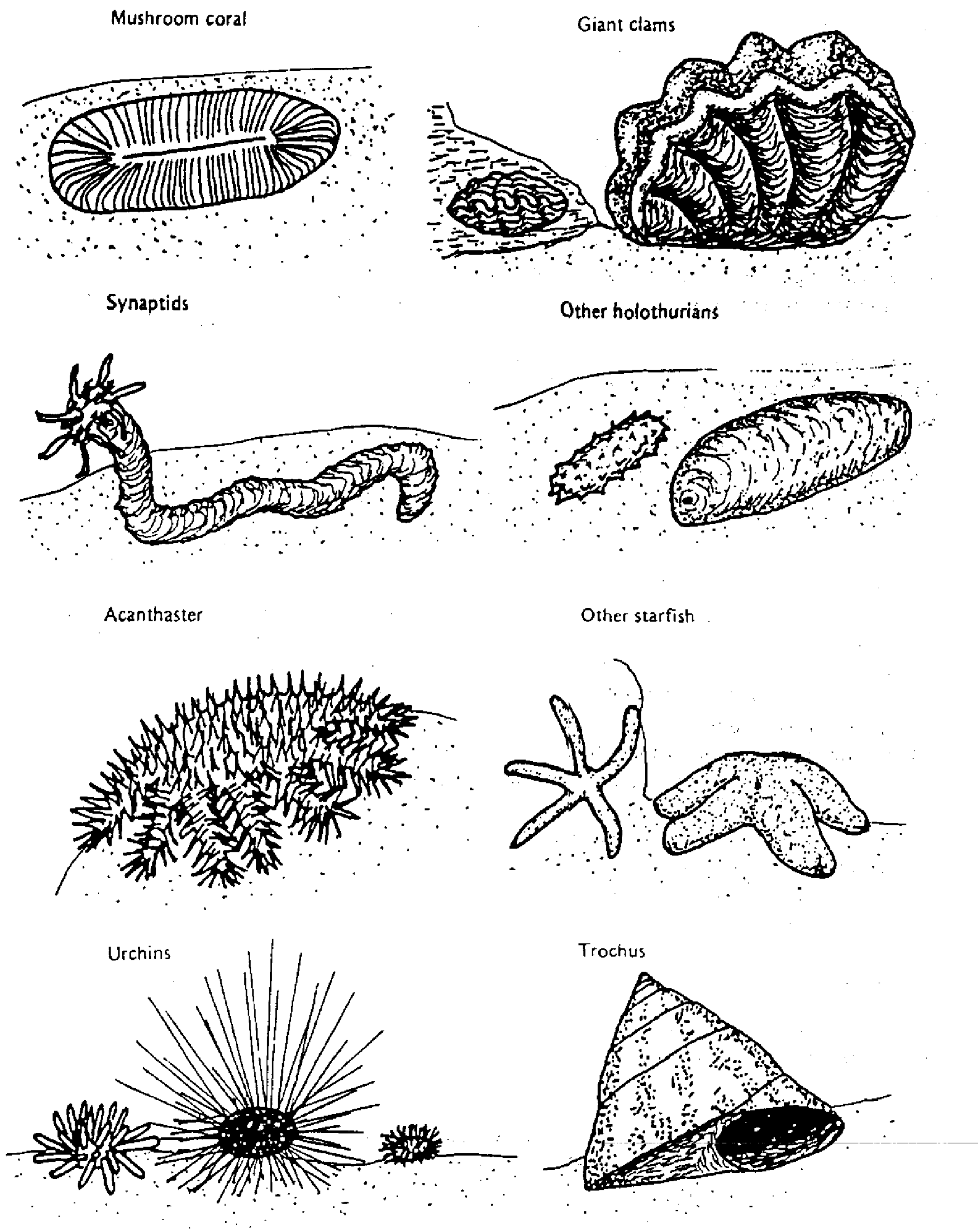


Figure 7. Five levels of percentage of ground cover for describing the presence of sessile organisms.

Figure 8. Common benthic organisms that could be counted during a survey transect.

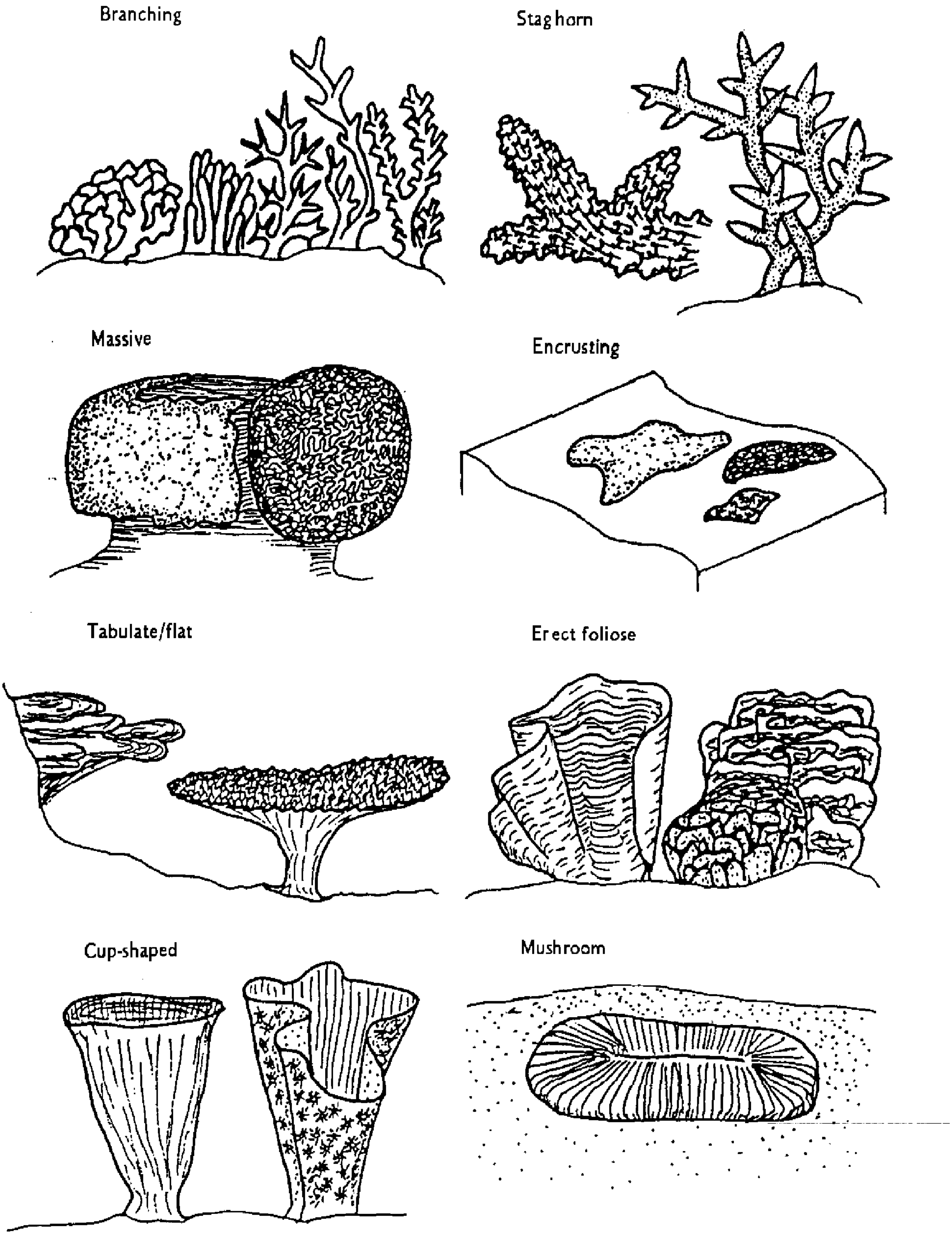


Figure 9. Various morphological types of hard coral and how they could be described in a survey transect.

indicate prefered substrates, provide an insight into zonation with depth, identify high and low seasons for different species and record succession patterns.

The picture can be made even more complete if the settlement sampling is complemented by plankton samples (see above). They should indicate the planktonic stages of sessile organisms before they settle and could permit reasonably accurate forecasting of settlement. The life stages can be taken back to an even earlier stage by sampling the adult population which is thought to be the source of the planktonic larvae and the subsequent settlement. By taking gonad samples and assessing their stage of maturity, it should be possible to predict when the larvae are going to appear in the plankton and when they are likely to start settling. Such a sampling strategy is often used to predict the settlement of mussels, oysters and other commercially valuable organisms.

3.2 MONITORING

3.2.1 Objectives and principles of monitoring

Survey is the methodical gathering of data while monitoring is regular, repetitive surveys.

Monitoring may be carried out for a variety of reasons :

- to discover what there is, find out the situation
- to discover change, determine trends
- to assess impact
- to check predictions and forecasts
- to check compliance with regulations
- to measure performance and effectiveness.

Having determined why monitoring needs to be carried out, it is important to determine what is to be monitored, and where - this requires planning.

Unfortunately much monitoring is undertaken without adequate justification or planning. This results in extravagant and expensive masses of data being collected, never to be used.

For monitoring to be meaningful, effective and fully justified, it must satisfy most, if not all, the following criteria -

- it must be according to clear objectives of what is to be monitored, and why;
- no more than the minimum number of simple measurements or observations should be made;
- monitoring should be carried out with the minimum frequency;
- the products of monitoring (data) must be subjected to meaningful processing, analysis and interpretation; and,
- monitoring must set in motion pre-determined action by previously identified individuals according to agreed contingency plans.

As an example, the objectives of a monitoring strategy following a coastal development, could be:

- to document the success or otherwise of the project;
- to ensure that impacts are no worse than predicted;
- to guard against unpredicted, unplanned outcomes;
- to act as an early warning system and provide an information base for necessary action.

Since monitoring can be very expensive and exasperating, care must be taken to ensure that measurements are no more than is necessary. Neither should measurements be any more than can be usefully anaylzed - excessive data are not only useless, they are also expensive.

Those undertaking field measurements, as are often necessary for survey and monitoring, may encounter a number of difficulties such as access to the site, weather, state of the tide, season, time of day, etc. It must be remembered that the easier it is to collect the data, the more likely that the data will be reliable, consistent and applicable.

It is also extremely important to guard against personal and subjective interpretation of the data. Most monitoring programmes are usually of long duration and they may go beyond the change of personnel. It is therefore imperative that interpretation of the data must be objective and according to measureable parameters, and does not rely on the analyst.

Routine and boring analyses, performed manually, increase the risk of mistakes. Therefore, if at all possible, repetitive tasks should be automated. This ensures consistency and reduces the chances of error.

A common objective of monitoring programmes is to ensure that certain criteria are being met, or other conditions upheld. In such cases, it is necessary to plan for what action will be taken when monitoring indicates that these limits are in danger of being exceeded. It is not enough to document and record the deterioration of the coastal environment - what is more important is the action that will be taken to arrest the deterioration before it exceeds what has been determined as acceptable. There needs to be a commitment to such remedial action with clearly identified responsibilities - who does what - which will be triggered by the results of monitoring.

3.2.2 Indicator species

Long-term monitoring seeks to identify changes that were not predicted. One way in which this can be done is through the sampling of a reliable indicator species.

Not every species can be used as an indicator species. Indicator species must show a marked response to environmental stress. They need to be either exrtremely tolerant or extremely susceptible to change. Their response can be manifested by their physical presence or absence, by their behaviour, or by their anatomical or physiological reactions. Ideally, the individual members of an indicator species should be of consistent and uniform morphology so that when anatomical changes occur they are uniform and noticeable. They must be easy to see and identify, and easy to sample if they are present.

The coral reef is a difficult environment to search for indicator species because the organisms and ecological assemblages are highly variable and changes are often not related to human activities. Factors which cause stress to corals may also do so in a manner which is difficult to distinguish.

However, an ecological expert with good local knowledge, may be able to select one or more indicator species even from among a difficult group such as corals. For example, corals with finely branching structures or those with cup-shaped morphology, are often more vulnerable to increases in suspended sediment than the massive coral varieties. While the growth pattern of some cup corals may be influenced by high sediment loads to make them more tolerant, their morphological adaptations can be used as indications of higher than normal sediment loads. The most common adaptation under such circumstances is for the cup corals to form only incomplete cups so sediment can be excluded at the base.

3.3 INFORMATION MANAGEMENT

What should be done with the results of survey and monitoring?

There is a distinction between data and information. Survey and monitoring produce data which are most often screeds of figures and raw observations of very little use to anyone in their crude state. These data must be transformed into information which is an accessible, retrievable and user-friendly product. The transformation of data into information comprises processing, analysis, interpretation and eventaully application and this process can be referred to as data or information management.

The type and format of information depends on the needs of the user or users, and this relates back to the objectives of survey and monitoring in the first place. The various formats for information management and display can be grouped loosely into six categories - simple tabulation, matrix, graphics, databases, maps and plans, and GIS.

3.3.1 Simple Tabulation

This is probably the most commonly used format for displaying numerical data. By using rows and columns in a logical manner, a table can provide visual relationships and connections and transform raw data into information.

3.3.2 Matrix

Almost by definition, a matrix is expected to be more complex than a simple tabulation. It provides an analytical relationship between data in a visual display - a cumulative visual summary of all impacts on all resources.

For example, a matrix can be used to assess the impacts on coastal resources of an activity such as dredging. In such a matrix, all resources (including amenity values, uses, etc) are listed on the vertical

LIST OF RESOURCES AND SIGNIFICANCE WEIGHTING							
Example of the coastal resources hat could be contained on the vertical axis (the extreme left hand column) of the matrix. Next to each resource is also a tentative weighting factor (from 1 to 5) reflecting perceived significance.							
PEOPLE		**ECOSYSTEMS**		**PHYSICAL**		**LANDSCAPE**	
residents' quality of life	5	shellfish productivity	4	current regime	4	landform	3
leadership	4	other estuarine fisheries	3	water quality	5	aesthetics	2
village / community	4	mangrove system	5	salinity		land / water interface	2
local administration	3	seagrass meadows	4		3	vegetation	3
people's health	5	seaweed resources	3	water clarity	3		
people's access	3	coral reef system	4	riverbank stability	4		
church	3	estuarine wetlands	4	sediment quality	2		
school, education	3	island systems	3	bathymetry	2	**OTHER**	
fisherfolk	4	rare, threatened species	5			industrial water intakes	3
traditional fishing rights	4	other sensitive systems	4			tourism facilities	4
subsistence fishing	4	locally-endemic species	3			recreational boating	2
commercial fishing	3	gene pool	5	**AGRICULTURE**		port facilities	4
aquaculture	3			drainage patterns	3		
other employment	4			soil quality	3		
markets	3			groundwater quality	4		
causeways, roads	4			irrigation water	4		
				stock watering	4		

LIST OF IMPACTS AND DURATION FACTOR							
Examples of the impacts (including the different phases, activities and processes) that could be expected from a dredging operation and could be listed on the horizontal axis of the matrix. Next to each impact is also a tentative indication of the expected duration factor.							
DREDGE OPERATION		**DREDGED ESTUARY**		**SPOIL DUMP**		**EARTHWORKS**	
stockpiling,operations yard	1	erosion		dust	2	reclamation	3
noise	1		2	smell	1	trampling (machinery)	2
hydrocarbon spillages	2	accretion	2	silt suspension	2	materials stockpiling	1
obstruction	1	salt-wedge intrusion	3	various leachates	2	armouring	3
wetlands destruction	2	groundwater contamination	3	barrier to drainage	3	transport of material	1
litter	1	removal of sediment	3	agriculture suppression	3	new access roads, etc	3
fire risk	1	increased flushing rate	3	mangrove suppression	3	seawalls	3
smell	1			other wetlands suppression	3		
silt in suspension	1			morphological profile	2		
various leachates	2			intrusive structures	2		

Worked examples of a few interface boxes of a matrix for tabulating data on the impacts expected from a dredging operation.
(Note that these are examples only and not intended for implementation).

RESOURCES	IMPACTS		
	NOISE	SEDIMENT/SILT	
RESIDENTS' QUALITY OF LIFE	Impact index 1X1X5= 5	Impact index 2X2X5= 20	
	WHO noise standards; determine dredge noise and distance from homes; work out tolerance; consultants $2500, 1 man/month.	indirect impact on people through impact on shellfish - see under shellfish.	
	no alternatives, no quieter dredge; limit operation to 10-hour day near homes; extra 3 months work.	see under shellfish.	
SHELLFISH RESOURCES	Impact index 0X1X4= 0	Impact index 2X2X4= 16	
	not applicable	determine sellfish beds downstream; determine tolerance; research IMR,$5000, 3 man/month	
	not applicable	alternative options - spoil dump management, geotextile curtain; implement management with curtain backup; additional cost minor.	

Figure 10. Examples of coastal resources and impacts and the way in which their relationship can be recorded on a matrix.

axis, together with a numerical weighting factor (say from 1 to 5) to reflect the perceived significance or value. All impacts (from various phases, activities and processes) are listed on the horizontal axis, together with a weighting factor reflecting the expected duration of the impact (1 = short term, 2 = long term, 3 = irreversible). In fact, the preparation of these two lists is already a very useful exercise providing a mental checklist of areas of contention.

Having listed all the resources and all the impacts, the next stage is to relate, in an analytical manner, the items on the vertical axis with those on the horizontal axis. This relationship can in most cases be translated into a numerical impact index. Wherever the grid intersects, a judgement is made of the severity of the particular impact on the particular resource, and this can range from 0 (no impact, not applicable) to 3 (high impact). The numerical value representing impact severity is multiplied by the figure for impact duration and the result is multiplied further by the figure representing the resource significance or value. The resulting figure can be called the impact index and it provides an excellent comparative picture of where the problem areas of a development are likely to arise. It must be stressed that the impact index is not an absolute figure but only a comparative one within the same impact assessment exercise. Although it is not able to be used for comparison across projects, it can certainly provide useful information on the comparative costs and benefits of various mitigation measures proposed within a project, as well as a good picture of cumulative impacts. Although it is only relative and indicative, rather than absolute, it can be a very useful and inexpensive data analytical tool in the hands of an experienced assessor.

Examples of the lists of resources and impacts and a worked example of a few interface boxes of the matrix are given in Figure 10 above.

3.3.3 Graphics

Graphic presentation of the results of survey and monitoring can range from common graphs to complicated illustrations. The latter can be hand-drawn or photographic images. Although they are not expected to have a degree of accuracy that will enable them to be used as identification guides, all illustrations of plants and animals should depict what they are trying to represent as accurately as possible. It is important for graphic representations to be kept simple, avoiding clutter and avoiding the need for interpretation - if they cannot convey the information without resorting to explanatory text, it may be better to simply rely on the text.

3.3.4 Databases

A database can be defined as a collection of data related to a particular topic or for a particular purpose. A database management system stores and retrieves data in the form of information. Simple databases can range from a field notebook, to a filing cabinet, a card index, a photo collection, a bibliography, etc.

A computerized database management system is a software programme used to store and retrieve data or information on computer. Much has been made of electronic databases in recent time and it is worth remembering that the database is made up of what the user puts in - the computer only provides the system that stores and retrieves data.

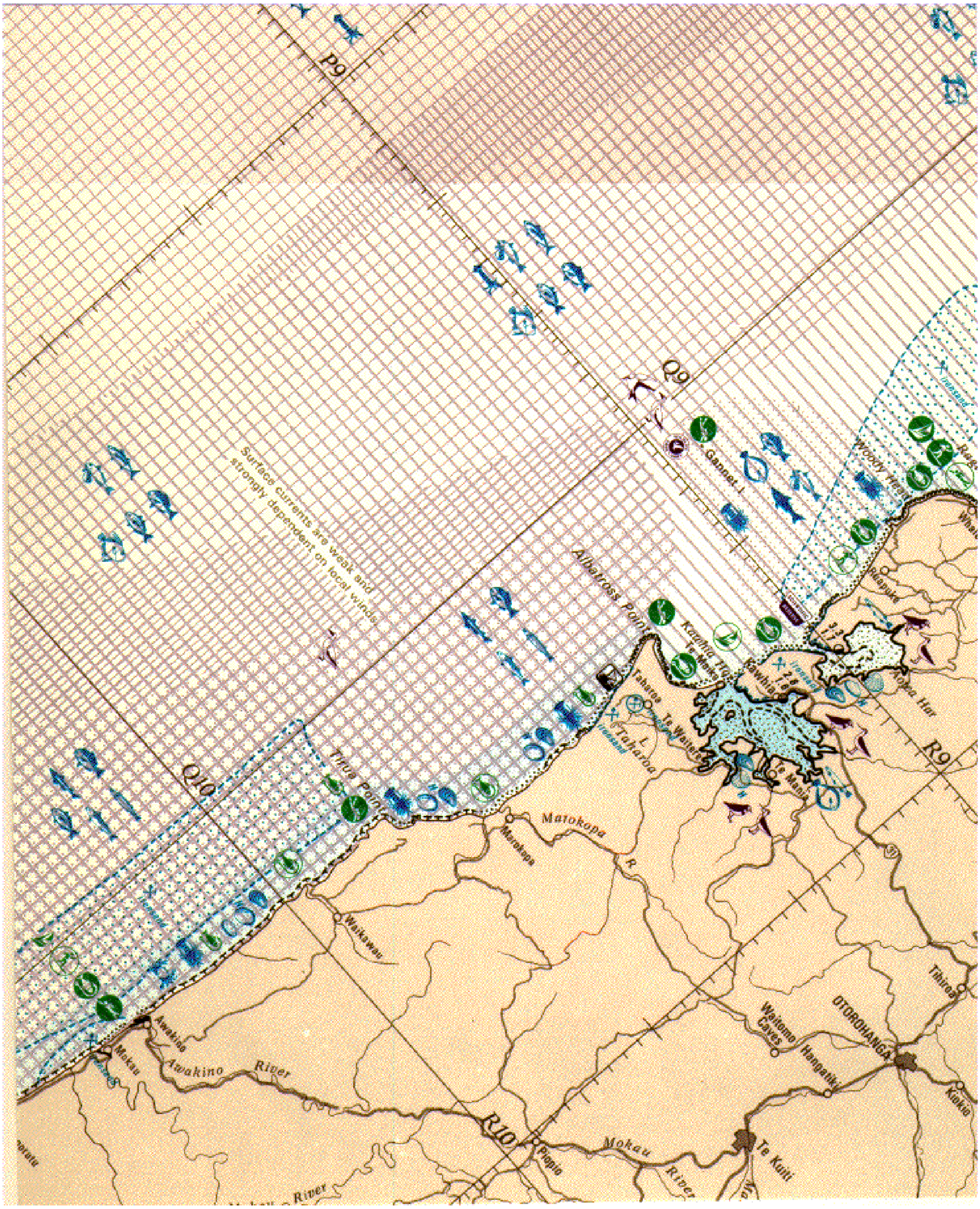
However, a relational database management system has the added ability to manage the system in a related manner. This means that changes or updates in one cluster of data, will be reflected in a related cluster.

Before investing time and money in setting up a database, especially if it is a sophisticated electronic one, it is essential to determine at the outset the purpose of the database, who will use it, what are his/her needs, which are the most important parameters or fields or data sets, and the relationship between them.

3.3.5 Maps and Plans

Maps and plans of coastal resources represent a significant advance from tabulations, matrices and graphic presentations of the results of survey and monitoring. Maps and plans truly transform data into information since they present the results within a spatial, geographic context, giving them an added dimension. Maps and plans allow the user to collate, analyse synthesise and apply large amounts of information, in a simple, visual representation. They can juxtapose resource data and demands on resources; and they can indicate conflicting demands and potential impacts before they occur.

Maps and plans are a versatile and sound basis for decisions on resource use. They are an



excellent tool for professional managers of coastal resources.

Figure 11. An example of a coastal resources map from *New Zealand Atlas of Coastal Resources.*

They can expose weaknesses in the available information base and help focus research efforts. They can inform members of the public, making them more sensitive to the multiple issues that need to be resolved. They are a good early guide for developers and a good departure point for any assessment of the potential impacts of a proposed development. They are a very good source of formal educational material both at the secondary and tertiary levels. Finally, they are an excellent record and a subsequent measure, for policies, objectives and goals for coastal area management.

Maps and plans can accommodate an enormous amount of information, but they need to be designed by a professional cartographer in order to finish up as a good, useful product. Figure 11 is an example of a resource map taken from the *New Zealand Atlas of Coastal Resources* (Tortell, 1981).

3.3.6 Geographic Information Systems (GIS)

A GIS is a computer-based system that can input, retrieve, analyze and display geographically referenced information. It is often erroneously regarded as synonymous with, or closely tied to remote sensing, database management, computer-aided design (CAD), and computer cartography. In fact, it is allied to all these and has some common elements with some of them. However, it is a unique tool, very sophisticated, and comprising elements of all except perhaps, remote sensing.

There are a number of benefits and advantages of GIS in resource management :

- it integrates data of various types (graphics, text, digital, analogue);
- it has an enhanced capacity for data exchange among disciplines or departments;
- it can process and analyse data very efficiently and effectively;
- it can apply models, testing and comparing alternative scenarios;
- it has a facility for efficient updating of data (including graphic data);
- it has the ability of handling large volumes of data.

The dimensions of integrated coastal area management are very broad and encompass the maritime influence on land as well as the terrestrial influence on water. They also include a third dimension of depth, taking in water volume with vertical variability. Coastal areas have fuzzy boundaries both physical (land and sea interface) and administrative (coastal area limits for management purposes). Finally, the coastal area has a wide array of scales and processes - from the microscopic biological processes, to chemical ones, from the spread of the Exclusive Economic Zone (EEZ) to the millimetres of sea level rise. An ideal GIS would be able to deal with these requirements and complexities, but none does as yet, at least not completely. Most good GIS programmes can handle the third dimension (depth), but a fourth dimension (time) is still beyond existing software.

GIS therefore has limitations, but in spite of these limitations, it is an excellent tool for coastal area planning and management and an efficient mechanism for handling data and tranforming it into information.

3.4 WORKED EXAMPLE

The following worked example is a summary of the processes described above, *i.e.* the role of survey and monitoring in integrated coastal area planning and management.

A fictitious locality called “Seaside Bay” will be used for the purpose of this example. Seaside Bay can be considered as an average sort of bay surrounded by a mixture of permanent residents, tourists and visitors in season, and a small amount of industrial activity.

3.4.1 The existing situation

A coastal area management plan has been developed and adopted for Seaside Bay with broad public participation. Through survey and data gathering, the plan reflects the community consensus on the ecological and other resources of Seaside Bay, their uses, the demands made on them, the value placed on them by the community, and the relative priorities. This baseline information is summarised in a detailed resource map of the bay which shows various zones which guide day-to-day managers and decision-makers.

For example, it has been determined that a particular part of the bay is excellent for oyster farming. It is also known that this activity provides employment for a significant number of families directly and an even greater number of families indirectly. Data are available on the income generated by the oyster farming industry through the sale of oysters, the servicing of the operation, and by attracting tourists. Oyster farming is therefore a priority resource which must be managed on a sustainable basis.

In order to ensure protection of the oyster farming industry, surveys have determined the most important requirements of oysters. These include, for example, no oil or other hydrocarbons in the water because of tainting, and a certain minimum concentration of dissolved oxygen. These two parameters, as well as a number of others, have been adopted as water quality standards for Seaside Bay. The local authority for Seaside Bay is seeking a mathematical model it can apply to determine the assimilative capacity of the bay for a number of critical parameters. Unfortunately, mathematical models are expensive and therefore, for the moment, the local authority ensures that water quality standards are not exceeded by an effective monitoring programme.

3.4.2 Proposed development

A developer proposes to build a factory and applies for the necessary permits and consents.

The Environmental Impact Assessment (EIA) Process is applied and closely tied to the integrated coastal area management process. Among other things, the factory is expected to require diesel as the fuel source and will have an effluent discharge which will include high biochemical oxygen demand (BOD).

Unless the original ecological data baseline is considered to still be reliable and up-to-date, a new survey will need to be undertaken by the developer for the EIA. There will be a number of submissions probably from individuals, from the oyster farmers and their organization, from the tourist hotel operators, and from others such as scientists, etc. Some of these individuals and groups will conduct their own survey and data gathering, or they may rely on information which already exists.

The EIA Review Board and/or the Planning Authority, will assess the proposal as described in the EIA, in the light of all the submissions received and having conducted its own survey and research. They are likely to ask for the advice of various experts and will eventually grant or decline the application. If the application is granted, conditions will need to be attached to ensure that the factory will not jeopardize the water quality standards and that the oyster farming industry is protected.

Once approval is given and the factory is built, the local authority staff will need to monitor the effluent discharge to ensure that the levels of contaminants set in the conditions of the permit are not being exceeded. They must also monitor the receiving waters of the bay to ensure that water quality standards are being respected. Finally, they must also do periodic checks of the various resources identified in the coastal area management plan to ensure that they are not at risk. Occasionally, the local authority will need to repeat its survey of ecological baseline conditions as a pre-emptive, precautionary measure. Eventually, new survey will be needed when the Integrated Coastal Area Management Plan is reviewed, which should be about every five years.

REFERENCES

Dahl, A L (1981) *Coral Reef Monitoring Handbook*. South Pacific Commission, Noumea.

Kam, S P, Paw, J N, and Loo, M (19xx) The use of remote sensing and geographic information systems in coastal zone management. In: *Integrative Framework and Methods for Coastal Area Management.* ICLARM, Manila.

McCracken, J A, Pretty, J N, and Conway, G R (undated) *An Introduction to Rapid Rural Appraisal for Agricultural Development*. International Institute for Environment and Development.

Tortell, Philip (1981) *New Zealand Atlas of Coastal Resources*. New Zealand Government Printer, Wellington.

Tortell, P, Collins, D, DuBois, R, Gwyther, D, and Sedlak, O (1992) *Environmental Guidelines for Dredging and River Improvement*. United Nations Food & Agriculture Organization (FAO), Rome.

Tortell, P (1992) Coastal Zone Sensitivity

Mapping and its Role in Marine Environmental Management. *Marine Pollution Bulletin* 25(1-4):88-93.