South Pacific Regional Environment Programme

Training Unit H1

RESEARCH: THE SCIENTIFIC METHOD

USE OF THIS UNIT

This unit gives a simple explanation of the scientific method as a way of thinking about problems and searching for their solutions. It shows that anyone can use the scientific method, and often does so, even without formal scientific training. Each section should be carefully discussed with the group, using practical examples, until everyone understands the principles involved. The concept of research as explained here is essential to the whole training programme.

EXERCISES

This unit will need to be reinforced with several types of exercises. First, each point in the text should be supported by group discussion, focussing on concrete examples from the local environment similar to those used in the text.

After reviewing the whole text, group exercises should be organized to discuss and develop case studies of the application of the scientific method. The group should go through the different steps of defining a problem, thinking about possible explanations or solutions, and designing experiments or studies to prove them. Where the group is large, it can be broken up into working groups of about 5 people, each considering a specific problem assigned by the group leader. Examples of local problems that could be discussed are a water shortage in a village, a field with declining agricultural productivity, a pest like rats or giant african snails, the declining catch of an important food fish or bird, etc.

The following exercises can be done individually or in the group to develop powers of observation:

> Coins are something we handle frequently without really looking at them. Describe in as much detail as you can one of the common local coins (specified by the group leader) and explain the significance of what is on it. Only afterwards should you look at the coin to see how accurate you were.
>
> Look closely at a tree and describe as much as you can about it (species, age, history, condition, health, probable future, etc.).

Select a plant or animal and try thinking about it at different scales: as part of a larger community or ecosystem; as one of a population of that species; as an individual struggling for survival, and trying to produce offspring; as a collection of organs each contributing to the functioning of the organism; as a host to many insects, microbes and other tiny forms of life. Look at it from each perspective to see what evidence you can find for each of its roles.

The cartoons sometimes published in newspapers in which one tries to find hidden errors or differences between nearly identical drawings can also be used to develop powers of observation.

(Unit written by A. L. Dahl)
[Revision 22/08/85]

TEXT

RESEARCH: THE SCIENTIFIC METHOD

For many people, scientists are mysterious figures with a deep knowledge that ordinary people cannot understand. They are thus regarded with the same awe tinged with mistrust that in former times was reserved for the sorcerers and holders of magical powers. It is true that a scientist must learn many facts and even the scientific language used in his specialty. The facts are the accumulated knowledge of many generations of scientific work, and the language or terminology allows him to communicate with other specialists around the world. However the scientific method is basically very simple, being more a way of thinking about problems and their solution.

While the knowledge and language of science are useful, they are not always necessary for scientific solutions to local environmental problems. They can be replaced by long experience in a place and good powers of observation. Most local languages have names for the plants, animals, places and other parts of the environment; while it may be difficult to use them to communicate outside the language group, they may be perfectly adequate for local use. It should thus be possible for someone like you with reasonable intelligence, good powers of observation, and an understanding of the scientific method, to become a kind of local expert or scientist able to do research and find solutions to local problems.

Research means to study something carefully in order to learn something new about it. The scientific method is a way of doing research. It usually involves several steps which will be explained below:

definition of the problem,
looking for explanations or solutions, and
measuring and experimenting.

It is often necessary to go through this process several times, as the results one set of experiments or observations may raise new questions or suggest other explanations. Also, one of the proofs of successful science is that others should be able to repeat the same experiments and to get the same results.

Definition of the problem

Defining what the problem is in a way that it can be studied scientifically is perhaps the hardest step in the process. Sometimes people know that something is wrong, but they cannot think about it very clearly. Often they are so used to the way things are that it never occurs to them to think about them or to look for ways to change them. Recognizing the possibility of change or improvement is the most creative step in the scientific method.

For example, suppose people have always climbed a mountain by a particular path. Most would never stop to think that there might be another way up the mountain. Asking the question "Is there a better way up the mountain?" is the first step in the scientific method.

Problems can be defined in different ways, perhaps best illustrated by different types of questions.

They can be problems of description:
What is there?
What is it made of or how is it made?

They can concern a process or cause and effect:
Why has that happened?
How does it work?

They can raise questions of time or place:
What was that like before?
What will it be like?
Where did it come from or go to?
Is it the same here as there?

They can be problems of human activity or control:
What can be done to change that?
How can we keep that from happening?
Is there a better way to do it?
If I do this, what will happen?
How can we get more, or do it more easily?

Almost any problem can be put in the form of a question. However, if a problem or question is too general, it will be impossible to use the scientific method to solve it. The more specific you can make a problem, the better the chance of finding a solution.

For instance, suppose you are a fisherman. You could ask "How can I catch more fish?", but this will not be very helpful. If you ask "How can I catch more fish with my trap?, you have already focussed on a specific case where you could consider the form of the trap, the materials it is made of, the bait used, the location and time for setting it, etc. An even more specific question, such as "What kind of bait will attract the most fish to my trap?" will make the search for a solution or improvement that much easier.

Looking for explanations or solutions

Once you have defined your problem as specifically as possible, it is normal to think about what the solution might be. Often we can imagine different possibilities or explanations based on what we already know about the problem. For instance, in the example of the path up the mountain, we may already have an idea of other routes that could be tried. As we think about the problem, we may see that there is a choice between two or more solutions which at first glance seem equally good.

We also must define very clearly what our criteria are for judging what is a good or bad solution. A good path up the mountain for a man on foot may not be good for a horse, and even less so for a road for cars and trucks. The man may prefer a short steep path, where a car could get there faster on a long gently sloping route.

Our way of thinking about problems and explaining them depends on our background and education. Different cultures have their own sets of values and ways of explaining natural phenomena. Even in science, schools of thought vary from one country to another, and it is not possible to say one is necessarily better than another. For instance, Chinese medicine is very different from French medicine or American medicine, yet each succeeds in curing many illnesses, and each can be enriched by learning from the experience of the other. This is an area that is closely tied to culture, language, and religion, among other fields that are beyond the scope of this training programme. For our purposes, what is important is that you think through clearly and carefully what the solutions or explanations might be in your own cultural context, so that you know what you are trying to test with the scientific method.

Again, the more specific you are in your proposed solutions or explanations, the better the chances of proving them right or wrong.

Measuring and experimenting

Once you know precisely what you want to test, you can make measurements or experiments to prove or disprove your explanation or to establish the best choice. An experiment is a test or trial to find out how something works or to see what happens. Often it means doing something on a small scale or in a simplified way in order to answer your question. For some kinds of problems, the answer can come from making certain measurements or observations. For example, in the case of different paths up the mountain, after having looked at the mountain from a distance or on a map to see what routes might be practical (your possible solutions), you might then test each possible route by walking up it, to see if there is not some hidden obstacle, and to judge if it might be easier or faster than the present route. Or having thought over the different possible baits for your fish trap, you would then experiment by trying each one several times to see which was the most successful in attracting fish.

The design of a good experiment is not always as easy as it seems. There should be only one possible cause of the result of an experiment, that will either prove or disprove your explanation. If more than one interpretation is possible, then your question will not be answered (except perhaps by another experiment).

It is most important in an experiment to change only the one thing you want to test. Everything else should stay the same. This will require great care in conducting your experiments. For instance, suppose you are testing baits in your fish trap. If you put one kind of bait in one trap, and another in another trap, you must be sure that the traps are exactly the same, and are in exactly the same kind of place, or the difference in catch could be from the kind of bait or the kind of trap or the location of the trap. If you decide to put the different baits in the same trap on different nights, you must be sure that there is no difference between the nights (moon-lit or cloudy, high or low tide, windy or calm, etc.) or these other factors might be the cause of the difference and your experiment will not prove anything.

Often it is necessary to do an experiment and a control. A control should be just like the experiment, but without changing the thing you want to test. If a doctor wants to test a medicine, he may take two groups of similar people, and give the medicine to one group while the other group (the control) gets similar looking pills without the medicine. No one (often not even the doctor) will know which is which until after the test. This is because people often get well just because they think they are taking a good medicine, and even the doctor might unconsciously judge the results differently if he knew which patients were taking the real medicine. The control group makes it possible to prove that the medicine made a real difference.

In the same way, you might need to set up two sets of fish traps. In one set (the control) you would put a bait which you know will catch a certain number of fish. In the other (the experiment) you would put the new bait to be tested. You could then say whether under that set of conditions the new bait attracted more or less fish than the other.

Another problem with experiments is the number of times an experiment is done. Many things change just by chance. The same fish traps with the same bait will not always catch the same number of fish. To prove that an experiment worked, the difference must be more than what might be caused by chance. Scientists use complicated methods with statistics (a kind of mathematics) to calculate if the result of an experiment is within the range of what might happen by chance, or is sufficiently different that the probability is high that it was caused by the experimental change. What is important to remember is that the more times an experiment is done, the greater the probability that a difference between the experimental and control group is significant. Also, the larger the number of experiments, the smaller is the difference that can be detected. You will probably not be able to check your results for statistical significance, but you should do an experiment enough times to be reasonably sure of the result.

One important proof in science is repeatability. Anyone anywhere should be able to do the experiment under the same conditions and get the same result. If you (or someone else) cannot repeat your experiment, there may have been some hidden variable that was not controlled. You will need to try to find what it was and then plan your experiment more carefully.

An experiment is often a way of trying something out on a small scale to see what it does or if it works before investing time and effort in a full scale use. You experiment with a new bait on a small scale before using it in all your fish traps. Be careful that nothing changes between your small scale experiment and full scale use. Sometimes the increase in scale itself can create new problems. Suppose your new bait works well in a small experimental trial, but when used in larger quantities it attracts too many sharks who damage the fish traps. A new crop may grow well in a trial, but when planted on a large scale it may be easily attacked by some pest. It may be necessary to make first a small experiment, then a larger one, and finally a full-scale trial to prove that the change is worthwhile.

People in rural areas are very conservative in the way they do things because the old ways have proven themselves over many years and the proposed changes are largely untested. An experiment or trial can show them that a change is good at the same time that it may show how to adapt the change to local conditions.

Importance of careful observation

This unit has described the essential principles of the scientific method: defining a problem, looking for explanations or solutions, and testing those solutions with carefully controlled experiments. There is a skill that is fundamental to success in the use of the scientific method, and that is the power of careful observation. A scientist must learn to look carefully at the world around him, whether it be to identify problems, look for solutions, or to follow and record the results of experiments. Much of the training of a scientist involves teaching him to observe and giving him the knowledge to understand and interpret the results.

Many of you who have grown up in rural areas may have learned to observe the world around you quite naturally, because rural life has always depended on an understanding of the environment. If you already have that skill, it will be easy to use it to apply the scientific method in your own local context. The exercises accompanying this unit can also help to develop your skills as an observer.

Examples

It is easier to understand the scientific approach to a problem through specific examples, a few of which are developed below.

The problem of the best path up the mountain has already been mentioned. In many places the same routes have been used for centuries, and follow paths first traced by animals or people traveling on foot. Today the destinations, means of transportation and methods of construction have all changed, and the old route may no longer be the best. The first step is recognizing the need to look for a new route (the problem). The criteria for a good route are then defined (distance, slope, ease of construction, etc.) and one or more alternatives are identified. The question to be tested is "Which is the best route?" The test would involve measuring the different routes for distance and slope, examining the rock and soil along the route for problems of construction, etc., to provide the information on which a choice can be made. In this case the old path is the control against which the alternatives are compared.

The problem of improving the catch in fish traps has also be mentioned. A test of fish traps might look into their form, the materials of which they are made, their location, the timing of their placement and retrieval, and the bait used. We can select just this last item and ask what is the best bait to use for catching a particular fish. There may already be a traditional bait, but many new things are now available that did not exist in former times, so why not see if any of them are better. Different possible baits could be selected on the basis of colour, form, odour, texture, cost, availability, etc., and some trials prepared in which perhaps 5 traps are baited with the traditional bait and 5 with a new bait (depending on the number of traps available). The traps, carefully marked as to type of bait, are all placed in similar areas, and the total catch with each bait is compared. If a new bait looks promising, it can then be tried on a larger scale or in different situations, leading possibly to its adoption as a replacement for the traditional bait.

Consider as another type of problem a field of taro that has been damaged in a cyclone or storm. To define the problem we must ask what precisely caused the damage. This will require listing all the possible causes or explanations: wind damage, plants buried in silt or drowned by flooding, soil washed away, salt carried in from the sea, etc. We should then examine the field carefully for evidence to support one or another of our possible explanations. Once we have found the real cause of the damage, we can ask how it can be prevented the next time. This may require trials of different types of windbreaks, flood controls or drainage before one is finally adopted. If it helps to protect the taro from the next storm, some progress will have been made in the community.

The scientific method is not so new in most traditional societies. People have always tried new things out, and kept what seemed to work. A scientist simply does this more consciously and systematically. In pre-European New Caledonia, the "Master of the Yams" had a small sacred garden near his house where he performed different rites associated with growing yams. These gardens may have served as small experimental gardens where he could observe the condition and development of the crop, and make recommendations accordingly to the people of the village. The method is similar to that used by modern agricultural scientists.

QUESTIONS

What is the first step in the scientific method?

How do you find an explanation or possible solution for a problem?

What are different ways of proving an explanation true or false?

How do you design an experiment?

What is a control?

What does it mean if you repeat an experiment and do not get the same result?

Can you think of examples of people who may have used the scientific method without realizing it?

How do you think traditional knowledge of the environment was discovered?

Are scientists the only ones who can use the scientific method?

What are the advantages of the scientific method over simple trial and error?

South Pacific Regional Environment Programme

Training Unit H2

RESEARCH AND MONITORING INSTRUMENTS AND TECHNIQUES

USE OF THIS UNIT

Scientific research does not always require complicated instruments and elaborate techniques. The purpose of this unit is to show some of the simple ways that information about the environment can be collected using materials available almost anywhere and equipment that can be built by oneself.

The unit is subdivided into sections concerning different techniques or resources. It would be good to go over all the sections at least briefly, as they may give ideas for techniques to be used with other resources. More time can then be spent on those sections most appropriate to the local environment or to the problems the participants face at home.

It has only been possible to include a selection of techniques here to give an idea of what can be done with a little imagination and not much else. The participants should be encouraged to think up their own methods adapted to their own particular problems.

EXERCISES

Those methods most useful to the participants should be tried in the field as individual or group exercises. A person will have more confidence in himself if he or she has done something at least once under supervision. Attention should be paid to the following points in the practical exercises:

--- the respect of any principles involved in the construction of measuring devices,

--- the care with which the measurements are made, and

--- the recording of the measurements or information in a form that is properly dated and identified, and is clear and easily interpreted.

Methods and techniques can always be improved, and new ones may be developed that could be of interest to the whole region. Comments on these methods and suggestions for new ones would be greatly appreciated, and should be sent to: South Pacific Regional Environment Programme, South Pacific Commission, P. O. Box D5, Noumea Cedex, New Caledonia.

SUPPLEMENTARY MATERIALS

The method for studying coral reefs is described more completely in the Coral Reef Monitoring Handbook by Arthur Lyon Dahl, first published by the South Pacific Commission in 1981, and reprinted as Reference Methods for Marine Pollution Studies No. 25, United Nations Environment Programme, 1984. If this method is important for the course, then copies of this handbook should be obtained for each participant.

(Unit written by A. L. Dahl)
[Revised 22/10/85]

TEXT

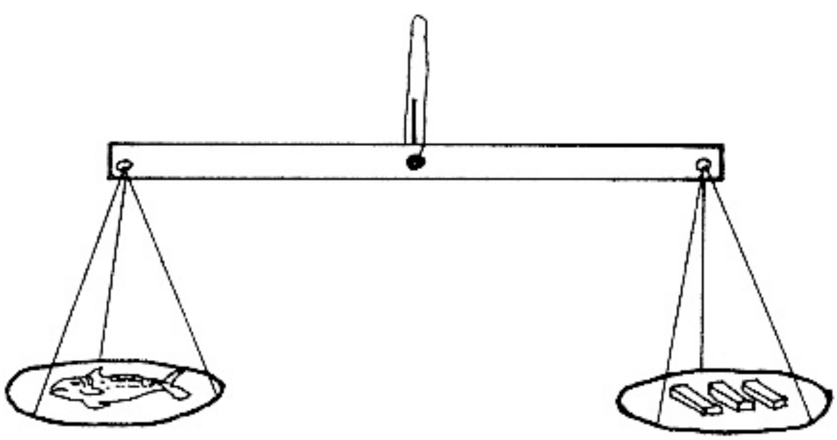
RESEARCH AND MONITORING INSTRUMENTS AND TECHNIQUES

Scientific research and environmental monitoring do not always require laboratories and expensive equipment. There are many research and monitoring techniques that do not need special knowledge or training and that can be done with things you can make yourself. Some examples of these simple methods are given on the following sheets. If you need other kinds of information, you can probably think of ways of getting it using simple techniques like these.

Remember that many details that may be important to scientists that must communicate their work to others will not be necessary if the information is just for your own use at the local level. For instance, scientists usually measure things using international systems of measurement such as metres, litres and grams, that make it possible for everyone to compare what they are measuring. If you do not have a metre stick, ruler or measuring tape, you can invent your own measures. For instance, a length of rope can be used for surveying (for example: 5 ropes from house to tree; 12 ropes from tree to fence, etc.). As long as the same length of rope serves as the unit, your measurements will be consistent, and if you keep the rope safely, it will always be possible to measure it later and make the conversion to standard units (if the rope is 5 metres, the distance from house to tree in the example would be 25 metres). A wooden pole can also be used as a unit of measure; it can be laid end to end, or used to make regular marks on a measuring rope. Long ago people used fingers, hands, arms and feet as units of measure. One English measure is still called the foot. Today it is often possible to find something already measured or marked off at regular intervals, like ruled paper, that can be used to make measuring devices.

Similarly, a simple balance can be built to give comparative weights or changes in weight. Two pans are hung from a rod that is suspended in the middle, perhaps with a wire or nail sticking up to show when it is level. Once it is adjusted so that it is level when empty, it can be used to weigh things by placing the object on one pan and counterweights on the opposite pan until it is again level. Today it is not hard to find things of uniform weight that can be used as counterweights and units of measure, such as coins, marbles, canned goods, fishing weights, etc. Some things even have their weights written on them.

A simple balance



Another approach is to record the measurements directly without using a system of measurement. For instance, if you are measuring the amount of rain every day in a rain gauge and keeping the record on a wooden board, you could put a dry stick in the rain gauge, then lay it on the board and cut marks with a knife showing the length of the stick that was wet. Such marks made along a line each day, with symbols showing the season or time of year, will produce a good graph of the rainfall. It is not even necessary to be able to read and write. The same technique can be used to measure the diameter of tree trunks or the length of fish; a string is wrapped around the trunk or laid along the fish, and then placed on a board or sheet of paper where the length is marked and identified.

Since most measurements for local environmental management will be for inventories or comparisons of changes over time, what is most important is that the same techniques and measures be used each time. Standard measures make this easier, but they are by no means absolutely necessary unless your information must be compared with that from other places. You will probably not need as much precision as a scientist in making your measurements, so the above techniques should give adequate results.

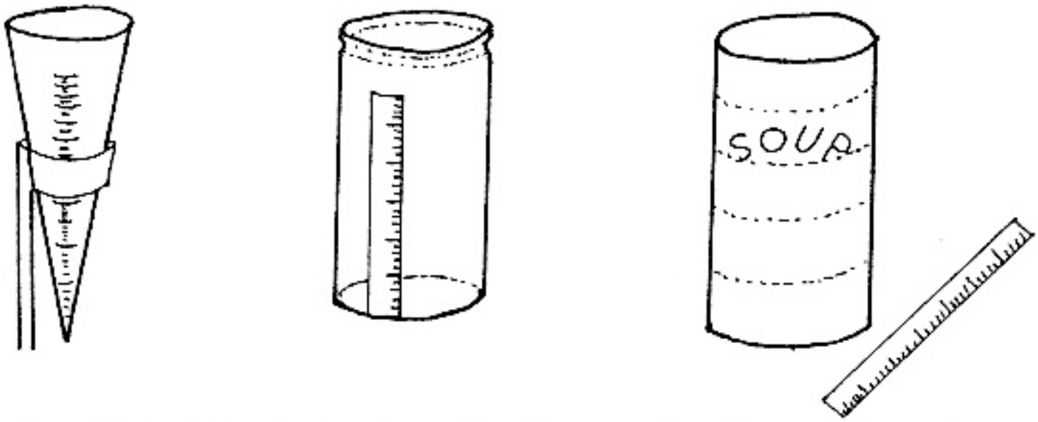
RAINFALL

Fresh water is one of the most important island resources. It is therefore essential for agriculture, for village water supplies, for flood protection and other uses to know how much rain falls, when it falls during the year, how much can fall in a short period of time, how long are the periods without any rainfall, and how much these amounts change from year to year.

Most island countries have at least one weather station where rainfall is measured, and this information is usually available for the location of the station. However, rainfall can vary a great deal from place to place on an island, depending on whether it is the wet or dry side, high or low, exposed or protected, etc. It is important to understand how these places with microclimates differ from the main weather station. One way to do this is to make your own records of local rainfall, which can be done very simply by catching the rain in a rain gauge and measuring it.

It is sometimes possible to buy clear plastic rain gauges already marked with a scale showing the amount of rain. If these are not available, you can make one out of any can or cylindrical glass jar with straight sides, a flat bottom, and a mouth as wide as the sides. The container must be straight from mouth to bottom so that the depth of the water (the amount of rain) can be measured with a plastic ruler or other measuring stick. A clear plastic or glass container is better because you can read the depth through the side of the bottle.

Rain gauges



The rain gauge needs to be placed in the open far from walls, roofs, trees or other things that might either shelter it from the rain or drain extra rainwater into it. It should be fixed upright where it cannot be knocked over, and where children cannot play with it or animals drink from it.

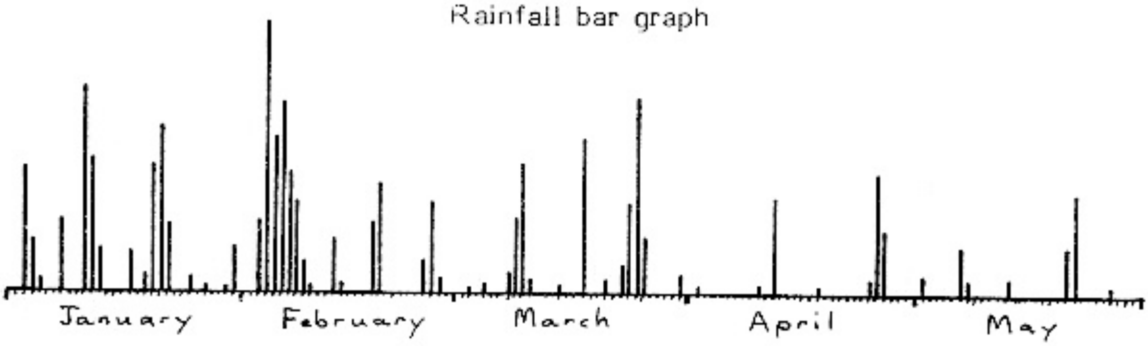
The rainfall is determined by measuring the depth of water in the rain gauge. This can be done with a ruler (like a child's school ruler) or other scale attached to the outside of a clear container, or by putting a ruler in the water and reading the level on the scale (be sure that the ruler reads from the very end; many rulers have a space before the scale starts, and this space will have to be cut off to measure the depth inside the container.

If no ruler is available, the depth can be measured by the direct method. Pick a stick or rod of a material that changes colour or otherwise shows clearly when it is wet. It should not be too absorbant, or the water will creep up it before you have a chance to record the mark. Dip the stick to the bottom of the container, then quickly place it on your record sheet and mark off the level of the water on the sheet. The stick should be as small and thin as possible, so that it will not raise the level of the water too much when it is put in the rain gauge. Be sure to empty the water out of the container after making the measurement, so that the gauge is ready to catch the next day's rain.

The ideal is to measure the rainfall every day at the same time of day. If this is not possible, try recording the rainfall every two or three days, or at least once a week, perhaps in conjunction with some regular activity like going to church. If you wait too long between measurements, the rain gauge might overflow if there is heavy rain, or if it is hot and dry, the rain water might evaporate before you measure it. If you miss a measurement, note this with your next measurement and either show the amount for the day when the most rain fell, or divide it evenly between the days which the measurement covers. If dirt or leaves get into the gauge, remove large pieces if possible before making the measurement, and clean out the gauge thoroughly before putting it back in place.

With each measurement, be sure to record the date and the number of days that the measurement represents. If there was no rain, this also should be recorded. One of the best ways to show rainfall patterns is to make a long bar graph with marks on the bottom line for each day or week of the year, and with bars showing the depth of the rain in the gauge for each day it fell.

Rainfall bar graph



As rainfall information is collected from year to year, it will become more and more useful. You can compare your rainfall with that at your nearest weather station. You can also compare the current year with previous years to see how much they change. You may also be able to relate rainfall patterns to the best time for planting or harvesting, to the fruiting of trees, the occurrence of plant diseases, or the numbers and behavior of coastal fish. Such information can help to achieve the best management of your natural resources.

TEMPERATURE

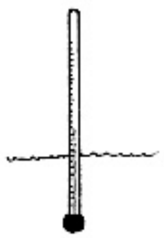
In the South Pacific, the temperature is not as much of a problem for resource management as it is in deserts or colder temperate areas. It is usually the extreme temperatures, such as particularly hot days or cold nights, that may have an effect on agriculture or housing design. However, the water temperature in the lagoon and coastal waters may be more significant for fisheries and coral reef management. Even a small change from the usual temperature may result in the death of corals or the disappearance of fish.

The temperature must be measured with a thermometer. There are no non-technical methods that are sufficiently accurate for monitoring temperature changes. Fortunately it is usually possible to find inexpensive household thermometers that are sufficient for local monitoring purposes. For measuring water temperatures in the sea, a thermometer with a plastic support is usually best, as paper will dissolve in the water and metal will rust or corrode.

To get the high and low temperatures during the day, it is best to read the thermometer in the middle of the afternoon when the sun is still high, and late at night or in the very early morning when it is coldest. A thermometer should always be hung outside but in the shade and not held where the hand could warm it while reading the temperature.

When taking the water temperature, the bottom of the thermometer should be in the water for at least 1 to 2 minutes before reading the temperature, and the reading should be made while the bulb is still in the water. There can be big local differences in the temperature of coastal waters depending on their depth and the amount of circulation, so be sure to choose a place where the water is representative of the environment you want to monitor. Ocean temperatures do not change from day to night, but only with the time of year. However, there can be some daily change in the temperature of shallow coastal waters.

The ideal thermometer for environmental monitoring is called a maximum-minimum thermometer. It is shaped like a U and has little metal slides inside that show the highest and lowest temperatures reached since the last resetting. The slides are usually reset with a magnet. With such a thermometer, environmental readings need only be taken at whatever time is convenient during the day, or even say once a week to record seasonal changes in high and low temperatures. Such thermometers are easy to use and not very expensive, but they may be difficult to find in most parts of the Pacific.



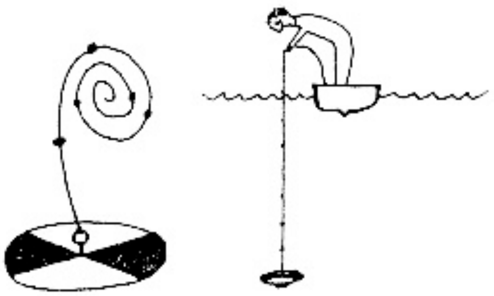
Thermometer

Maximum/minimum thermometer

TURBIDITY

Turbidity is a measure of how cloudy or muddy the water is, based on showing how far light can travel through the water (sometimes called its transparency). Turbidity is a good measure of water pollution, or the effects of sediments or erosion on lakes, rivers, or coastal waters. Turbidity can be caused by fine silt, mud or soil in the water, by organic or chemical pollutants, or by dense blooms of tiny algae (plants) or animals which may grow quickly when there are fertilizers or other pollutants present. Monitoring turbidity is a good way of measuring the quality of the water or the health of a lagoon.

The classic way for scientists to measure the turbidity where the water is deep enough is with a Secchi disk, and it is so simple that anyone can do it. A Secchi disk is a circular disk usually 25 centimetres in diameter, attached in its middle along with a weight at the end of a rope. The disk is painted white, or preferably divided in quarters with two white quarters and two black quarters. The rope is measured and marked at regular intervals, usually every metre, so that it is easy to tell how long it is.



Secchi disc to measure turbidity

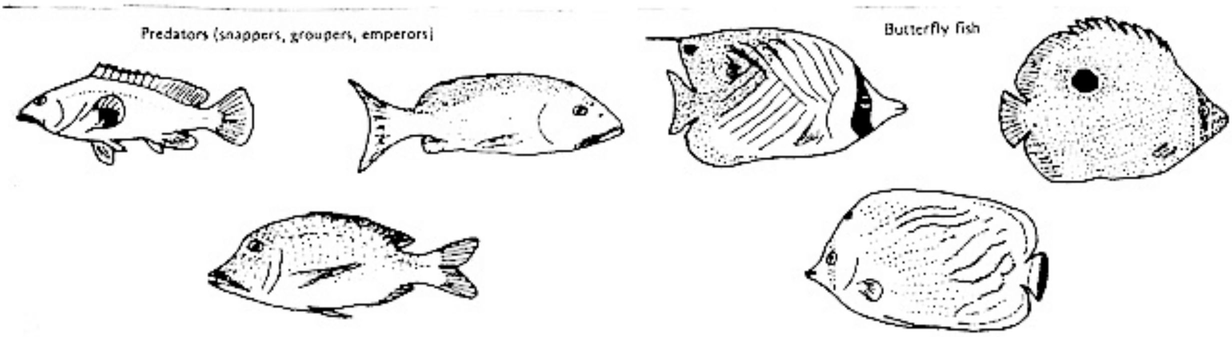
To measure turbidity with a Secchi disk, you need to be over reasonably deep water in a boat or at the end of a dock. It is best to measure the turbidity in the middle of the day when the light is bright. Avoid working in the shadow of the boat or dock. Lower the disk into the water and watch it go down, counting the length of the rope as it goes. When you can no longer see the disk, write down the length of the rope from the water's surface to the disk. Lower the disk a little more, then pull it up until you can just see it again, and count the length of rope from the surface to the disk as you pull it back up. Add the two lengths together and divide by two to get the average distance to where the disk was no longer visible. This distance is a measure of the transparency or turbidity in the water.

Depending on the circumstances, it would be useful to measure coastal turbidity once a week to get seasonal changes. More measurements would be needed after storms or pollution incidents. If the turbidity changes with the tides, currents or wind directions, then frequent measurements should be made under different conditions, or all measurements should be made when these conditions are the same.

CORAL REEF AND FISH MONITORING

The South Pacific Commission has already developed simple techniques for coral reef monitoring, which are explained in more detail in the Coral Reef Monitoring Handbook by Arthur Lyon Dahl (South Pacific Commission, Noumea, New Caledonia, 1981, and UNEP, 1984).

Fish populations along a coral reef can be estimated by swimming with a mask or goggles back and forth for 100 metres along the edge of the reef (measure the distance by following along a 100 metre length of rope). Fish are counted that are within about 2½ metres of the rope on either side. On the swim out, count the number of large predatory (fish-eating) fish such as snappers, groupers and emperors. These fish are often the first to be caught by fishermen on the reef and their number is a measure of the fishing pressure; if there are none along the front of the reef, or their number declines over several counts, then there may be a problem of overfishing. On the swim back along the rope count the number of butterfly fish. These brightly coloured reef fish often swim in pairs and have a special way of biting and sucking around corals. If there are less than ten along the 100 metres of reef, or their numbers decrease with succeeding counts, then something may have damaged the reef ecosystem.



The coral reef itself can be monitored by surveying fixed points on the reef chosen as representative of what the reef is like. A piece of iron reinforcing rod can be driven into the reef to mark the survey spot permanently. A rope 4 metres long with a loop at one end to go over the rod is used to measure the circle to be surveyed, which is easily covered by swimming or walking around near the end of the rope. The bottom is first described as being mostly mud, sand, rubble, blocks or solid rock. Then an estimate is made of the amount of bottom covered by live hard corals, soft corals and sponges, dead standing coral, crustose coralline algae, and marine plants. The major shapes of corals, soft corals, and plants in the circle are noted. Finally large or conspicuous animals in the circle are counted.

The Handbook explains all these measures, and includes simple forms on which the information can be noted. When the survey is repeated in the same place, changes in the coral reef and its populations can be observed. An explanation of the possible meaning of these changes in included.

Simple monitoring techniques like these make it possible to follow coral reef resources closely and to observe what changes are taking place. With this information, and perhaps some expert advice if necessary, it may be easier to manage coral reef resources.

FOREST MONITORING

Forest areas can be monitored using methods similar to those described for coral reefs. In most Pacific Island forests, the bird populations are similar to the fish in the sea, and the trees and plants are like the corals and seaweeds. However, the size of the trees and the impossibility of swimming over them means that the method must be modified accordingly.

Forest birds can be monitored by someone who knows the local birds well by walking a certain distance (perhaps 1 kilometre) along a forest trail in the early morning and counting the number of each important kind of bird seen or heard. Some care is required to avoid counting the same bird more than once. Using this standard measure, changes in the bird populations can be measured from season to season and from year to year.

The composition of trees in the forest can also be monitored over time, using a series of survey circles. Select and mark one tree as the centre point in the survey circle. Do not always choose the same kind of tree as a centre point, but be sure you can find the tree again when you want to repeat the survey 1 to 5 years later. Take a rope marked at 1 metre intervals and tie it around the centre tree so that at least 10 metres of rope extend from the tree. The size of the circle can be made smaller or larger depending on the density of trees and the number of different kinds of trees in the forest. A larger circle is necessary if there are many kinds of trees, but if a circle has too many trees it will take too long to survey.

To survey the circle, use the rope to measure the distance to each tree in the circle, and write down on a piece of paper the kind of tree, its position and its distance from the centre tree. Measure only trees with a trunk large enough at breast height that two hands cannot reach around it. When the survey is repeated from the same tree, it should be possible by comparing notes to see which trees have fallen or been cut down, and which new ones have grown up to be large enough to count. The total number of trees and any changes in the kinds of trees in the forest can also be estimated.

Within the same circle, a count can also be made of any rare or significant animals or plants like orchids, or introduced pests like guava, lantana or the giant African snail. Changes in these counts over time can also be a sign that important changes are taking place in the forest.

SOIL ANALYSES

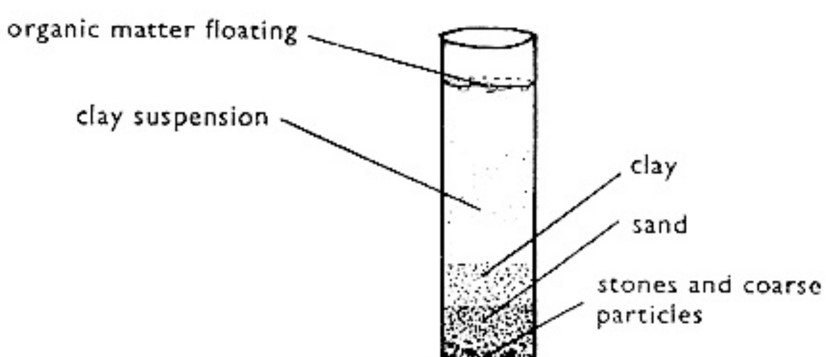
The soil is one of the most essential island resources, on which both agriculture and forestry depend for their productivity. Careful management of the soil is essential to maintain its good qualities. To do this, it is helpful to be able to measure some of the characteristics of the soil and to monitor any changes. The following are some simple ways to analyse a soil for its qualities.

Soil composition

Soils are made mostly of sand, silt and clay. Sand has large grains that are easy to see with the naked eye. Silt has finer grains like the mud left behind where water has receded. Clay is the finest of all and usually sticks together in a slippery mass when it is wet, or becomes very hard when it is dry. The amount of each of these determines the composition of a soil and gives it its texture. A good soil, called loam, has about 15% sand, 30% silt and 55% clay.

An easy way to see the composition of a soil is to take a clear glass jar or bottle with a tight fitting top and straight sides that are easy to see through. Fill the jar less than half full with the soil to be tested, add water until it is almost full, put on the top, and shake well until the soil is thoroughly mixed with the water. Then set the jar quickly in a quiet place and do not move it for at least a day.

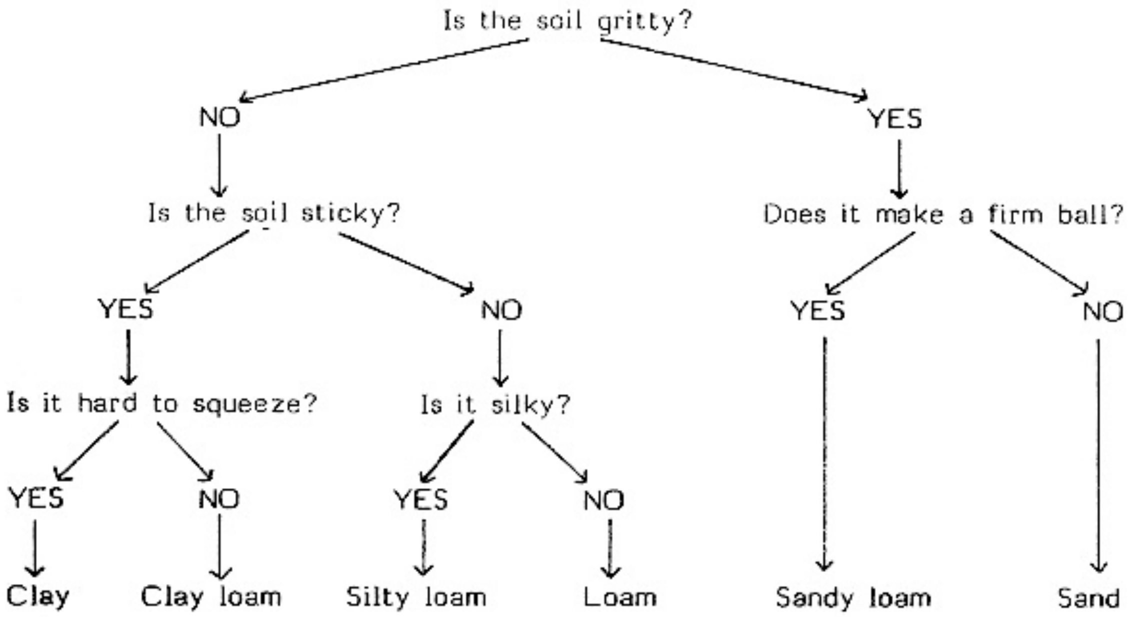
Look closely at the layers of soil particles in the jar. The largest and heaviest particles settle out first. Stones will be on the bottom, then sand, followed by silt and finally clay. Some fine clay particles may stay suspended in the water, and large particles of humus or organic matter like wood will float to the top. The thickness of each layer shows the proportions of that particle type in the soil sample.



Soil texture

The soil texture is the way the soil looks and feels, and it depends on how much of each kind of soil particle is in it. The texture or feel of a soil changes as these proportions change.

To test a soil for its texture, take a small amount of the soil and crumble it in the palm of your hand. Add a little bit of water to the soil and try to work it into a small ball. Use the questions and answers below to find the texture of the soil.

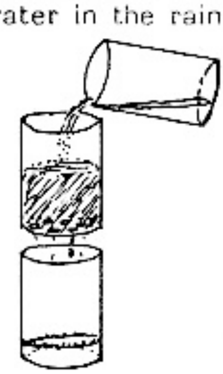


By following each soil sample through the above questions, you can determine the general type and texture of a soil.

Soil and water

One of the important characteristics of a soil is what it does when it rains and the soil gets wet. It is important to know how quickly water is absorbed or soaks down into the soil (called its porosity), how quickly it passes through the soil (its permeability), and how much water is held in the soil (its field capacity). If water is absorbed quickly into a soil, there will be less danger of its running off and causing erosion or floods. If it passes through the soil quickly, then the ground water will be recharged rapidly. If the soil holds a lot of water, then it will not dry out so quickly after a rain and crops will grow better. The following simple test will show how a soil rates for these qualities.

Take three cans of the same size, like those that beer or soft drinks come in, and remove the tops. Mark each can in the same place half way up, so that you can tell when the can is half full. Punch several small holes in the bottom of one can with a nail or other pointed instrument, and fill it half full with the soil to be tested. The soil should be dry and well packed down in the can. Fill another can half full of water. You will need a clock or watch that can time in seconds. Hold the can of soil over the empty can, pour the half can of water on top of the soil, and start timing immediately. Count the number of seconds it takes for the first drop of water to fall into the bottom can; this shows the rate that water passes through the soil (its permeability). Also count how long it takes for all the water to disappear from the surface of the soil, which show how fast the soil absorbs water (its porosity). Then wait for 10 minutes, and measure how much water is in the bottom can (remember that you started with half a can of water). This shows how much water stayed in the soil (its field capacity). You can measure the amount of water in the same way you measured the water in the rain gauge. Write down each of these figures for the soil sample.



There are no easy ways to test a soil for the amounts of essential nutrients for plant growth, such as nitrogen (N), phosphorus (P) and potassium (K), but it may be possible to buy a simple soil analysis kit from an agricultural supplier. If so, it would be good to test for these nutrients too, following the instructions supplied with the kit.

If you are testing the soil in a field or garden, it would be best to test at least three samples from different parts of the field with each of the above tests to see how much difference there is between samples. If you do the tests every year with soil samples from the same place, you can monitor the soil and see how it may be changing over time and whether management actions are needed to protect soil quality.

CENSUSING AND SAMPLING

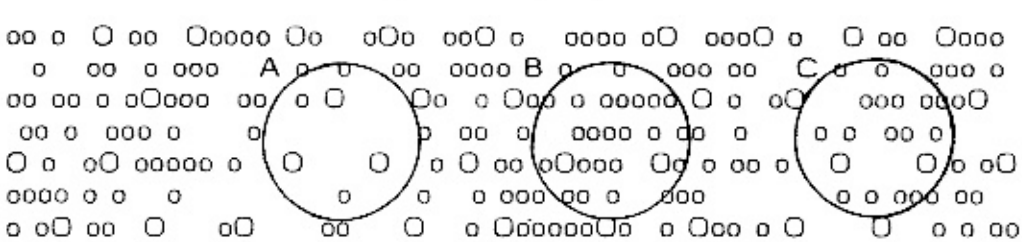
It is often necessary as part of an inventory or monitoring programme to find how many there are of something, whether it be cattle on the range or people in the village. This can be done by making a census, which is a complete count of whatever is of interest. Governments usually make a census of the population every 5 to 10 years, counting the people in every family and village. A census requires either visiting every place where the count is to be made, or else gathering everything together for the count, as is often done with cattle.

When a census is repeated, it is possible to see what changes in numbers have occurred since the last census. Some may no longer be there, having died or moved away, and new ones may be added through births or immigration. The total change in numbers gives some idea of the rate of growth or decline, depending on whether there is an increase or decrease in numbers. Such figures are often important for environmental management. A census often collects data on age as well, since it may be important to know the age structure of the population, that is how many there are in each age group (often taken in 5 year groupings). This information shows if a population is getting younger or older. For people, knowing this helps in planning social services like schools, jobs or extra health care for the elderly.

Often it is not possible or not worthwhile to count everything as is done in a census, so it is necessary to take a sample, which is a part of the whole that may show something about the whole. Sampling is a very useful technique in research, but there is always a problem in knowing how much is a good sample. Whether a sample is good can be complicated, and depends on the total numbers involved, the distribution of the things being sampled (such as whether they are scattered at random, evenly spaced, or perhaps clumped together) and their diversity, or how many different kinds of things are mixed together.

To show the problem of sampling error, suppose something occurs in clumps of several individuals separated by large empty spaces. If your sample falls in the middle of a clump, you would have the impression that there are many of the things, but if it falls between clumps, you would think that there are few or none at all. With sampling there is always a problem of establishing what is a significant difference between samples, as opposed to a chance difference caused by sampling errors. Increasing the number of samples or the size of the samples reduces the error, but it also requires more work.

An example of sampling error



Sample A: O=3, o=3. Sample B: O=2, o=22. Sample C: O=2, o=16.

Scientists often measure the chance of error in their samples in terms of the probability that the sample is good or that the difference is significant. Normally they will only accept a result if the chance that the difference in the samples is not real is only 5 percent or 1 percent. There are many statistical and mathematical tests to check this significance.

Another problem with sampling is that the person doing the sampling may be biased or may be expecting a certain result. Often the person is unaware of this effect, and he or she may not realize that an unconscious preference is affecting the choice of samples. Sometimes scientists use techniques to select the samples at random to avoid this problem. More samples may be needed with random sampling, but the result is closer to the true situation.

It is not possible in a brief review of research techniques to discuss this subject in much detail. What is important to remember is that you should not make judgements or base important decisions on too small a sample of environmental information or research. It never hurts to repeat something in order to confirm an earlier result. If the second result is different, then actions based on the first result might have been wrong. You may need to repeat an experiment or measurement several times to see how much of the difference occurs by chance (or sampling error) and how much represents a significant difference.

Coral Reef Monitoring Handbook

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South Pacific Commission

Based on techniques developed at an
Expert Meeting on Coral Reef Monitoring
(Motupore Island Research Centre, Papua New Guinea August 1978)

SOUTH PACIFIC COMMISSION
NOUMEA, NEW CALEDONIA

Illustrations by Arthur Lyon Dahl

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Note to the user of this handbook

This handbook is printed on waterproof paper and bound with waterproof materials so that it can be used as a field reference without risk, or even taken into the water during training or while conducting surveys. It should, however be rinsed in fresh water and be left open to dry after such use.

Contents

List of figures

List of contributors

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Introduction

Coral reefs and lagoons are an important resource for tropical islands and coastal areas. They provide fish, other animals and seaweeds as food for local people. Reefs protect the coastline from waves and make natural harbours. They are a source of materials for construction and for handicrafts, provide tourism and recreation areas, and have potential for aquaculture. The animals, plants and ecosystems of coral reefs and lagoons are part of each country's natural heritage to be conserved for future generations, just like natural areas on land. Yet increasingly these resources are being damaged by overfishing, pollution, or the many other changes that come with development.

Coral reefs are very complex communities with many kinds of animals, plants and fishes, too many to be easily counted or understood. It is still hard for scientists to tell what all the plants and animals are that live on a reef or how the reef ecosystem works. If reef resources are to be developed, managed or protected, information about them must be collected, so that those responsible will know what is happening to them. This handbook explains a simple way to measure certain things on a reef or in a lagoon to show what the area is like and how it may be changing.

The first time a survey is done, it will give basic information on the condition or health of the coral reef ecosystem, measure some of the resources present, and perhaps show where more detailed studies are needed. Repeating the survey later in the same place will show what changes have taken place, whether natural or caused by man. The kind of changes and the rate at which they are taking place can show whether action is needed and perhaps what should be done to maintain an important resource.

The methods in this handbook were designed to be used both by scientists and by people without a scientific background who receive initial expert advice and some training in the methods. It is best, however, if those doing the surveys are at least familiar with the sea and reef areas, perhaps as fishermen or from living near the sea. Indeed, many traditional cultures have extensive knowledge of reef and lagoon life with local names for the corals, plants and animals, and this knowledge can be very useful. Simple indicators have been chosen for ease in definition and reliability in use under field conditions. Choosing more general measures and applying them only in small areas means overlooking many distinctive features of a particular reef, but the combination of measures should permit reasonable comparisons over time and between different areas even if much significant detail is not recorded.

It is necessary to use a mask or goggles and snorkel, and preferably flippers or fins, while making the various counts and measures, so reasonable swimming ability is essential. Depending on the location of the reefs a boat may be required to reach the survey sites. If trained scuba divers are available, surveys can be done in deeper water but this is not essential for satisfactory monitoring, as shallow reefs should be an indicator of the changes in the general state of the reefs in an area.

The techniques described here were developed by an Expert Meeting on Coral Reef Monitoring held in August 1978 at the Motupore Island Research Centre of the University of Papua New Guinea. The meeting was organized by the South Pacific Commission with the financial support of the Commonwealth Fund for Technical Cooperation, and involved fifteen participants from five countries (see list page vi) selected for their knowledge of various aspects of coral reefs or monitoring techniques.

This simple approach to coral reef surveys should be useful wherever a rapid measure of the state of particular reef areas is required and trained specialists are not available. It should be appropriate for:

- government resource management programmes,
- fisheries studies,
- environmental baseline studies and impact assessments,
- marine parks and reserves and other conservation programmes,
- rural or village fisheries management,
- scientific studies as a basis for comparisons or for further elaboration.

As this is a first attempt to define simple ways to measure a very complex system, there are bound to be problems that will arise. Any criticisms or suggestions for modification or improvement will be welcome and should be sent to:

Regional Ecological Adviser
South Pacific Commission
P.O. Box D 5
NOUMEA CEDEX, New Caledonia

1. Steps in establishing a coral reef survey

1.1. Initial expert advice

Before starting a coral reef survey or monitoring programme, it will be necessary to have the help of an expert to choose the areas to be surveyed, to adapt the handbook and methods to particular local conditions, and to train local survey personnel in the techniques. If no expert in coral reef studies is available locally, a short-term consultant will be needed. Depending on the amount of reef to be studied, the weather and working conditions, and the information already available, a few weeks to a few months should be sufficient for this expert assistance. The expert should complete points 1.2 to 1.7 below.

1.2. Aerial photographs

To get an overall view of the whole reef and lagoon area, a detailed study of aerial photographs will be needed. These should be vertical, map-quality photographs, such as are now available for most areas where mapping has recently been done. If such photographs are not available, the expert may need to fly over the area himself and perhaps take pictures from which the outlines of the reef areas can be taken. Other existing information on the reefs can be reviewed at the same time.

1.3. Choice of priority areas for study

On the basis of the purpose of the survey, the requirements of the government or other user of the data, and the analysis of the aerial photographs for general reef structure and relationships, priority areas can then be selected for detailed study.

1.4. Mapping

An outline map of the reef and lagoon areas of interest can be made from the aerial photographs, showing the major reef zones and discontinuities. Other useful information can also be added to this map, such as water circulation patterns, prevailing wind directions and terrestrial influences, which will help to interpret the results of specific plot surveys.

1.5. Field checks of map

Rapid field checks can then be made of the area to confirm the major zones determined from aerial photography. This can be done by swimming or walking across the area if it is small, by towing a swimmer with mask behind a boat, or by spot checks from a boat (by looking through a viewing box or by swimming around the boat).

1.6. Training of survey personnel

The people who will make the actual plot surveys should then be trained in the technique described in this handbook. They should be able to identify consistently the different categories of substrate, corals, plants, animals and fish in the field, and should preferably do several survey plots under the guidance of the expert to ensure that the procedure is well understood and the results repeatable. The expert can at the same time make any necessary modifications to the handbook and methods to adapt them to particular local organisms and circumstances.

1.7. Selection of study plots

Having determined the general zones on the reef, it is necessary to characterize those zones by describing the major corals, plants and animals that occur in them. The great density of reef life makes this extremely difficult, yet it is these that will change most quickly if the reef ecosystem is damaged or altered. The method described here is based on selecting plots that are typical of significant reef zones and then making measurements in those plots as described below.

Plots should be in the centre of reef zones identified above, rather than in boundary areas where the results will be difficult to interpret. They can be arranged along a line or transect across the reef, which may make it easier to find them again, but this is not essential. The following is the recommended priority order for reef and lagoon zones to be surveyed (see Figure 1):

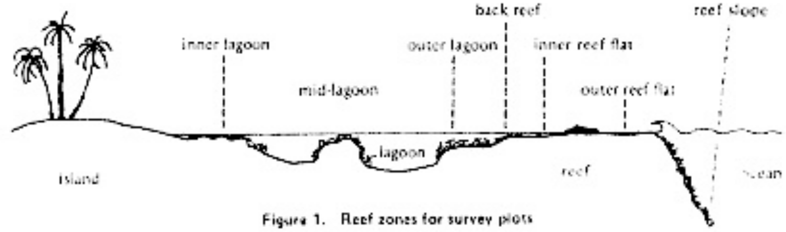


Figure 1. Reef zones for survey plots

back reef	the back side of the reef as it slopes into the lagoon
inner reef flat	the reef flat behind the rubble bank or boulder line (if present)
reef slope	the outer or seaward slope of the reef
outer reef flat	the reef flat between the outer reef slope or reef crest and the rubble bank (if distinct from the inner reef flat)
outer lagoon	– the shallow lagoon bottom just inside the reef
inner lagoon	the lagoon bottom near the shore
mid-lagoon	– the centre of the lagoon if this is large enough, or possibly a patch reef in the lagoon

Some of these zones may not be present on certain reefs, and others may not be accessible because of weather or wave conditions, reducing the number of zones where survey plots are practical. Plot sites should be no deeper than two to four metres so that they can be surveyed from the surface, unless a diving capability is available.

Within each zone, plots should be chosen that seem typical or characteristic of the zone, avoiding channels or discontinuities. This judgement will be necessarily subjective, but the bias introduced by such an expert judgement will in most cases be less than that of a single sample at random in a highly variable environment.

The number of plots will depend on the purpose of the study, the diversity of the reef areas, and the resources available. For general monitoring, a single plot in each zone for a major section of reef may be sufficient. For environmental impact studies, some array of plots at different distances from the point of expected impact (sewage outfall, construction site, etc.) may be needed, as well as control plots on a similar reef beyond the range of possible impacts.

1.8. Frequency of surveys

The first survey of a reef will give a general measure of its actual state. However, reef communities may be very variable over time, either naturally or because of human impact. Repeating the measurements in the same survey plots will show what changes are taking place, and may suggest what the possible causes are. This monitoring of reef and lagoon areas is one of the principal uses for the present techniques.

For general monitoring of the state of reef resources, measurement once a year may be sufficient. Such measurements should be taken at the same time of year to avoid the seasonal changes that occur in certain plants and animals.

Wherever changes are expected, as in environmental impact monitoring, or are detected by annual monitoring, measurement of the plots every two months will be necessary. This will provide an early warning of problems as they arise.

Where it is intended to monitor the effects of an industrial, commercial or residential development likely to affect the coastal area, plots should be surveyed at two-month intervals for at least a year before the project begins. This will measure the amount of natural change in the area, and possibly suggest ways of modifying the project to reduce its impact. Monitoring should be continued during construction and after the project is operational to confirm expected impacts and to detect unexpected effects that might require corrective action.

Shallow plots should be re-surveyed whenever possible at the same tide level, as some measures may vary with the tide. Showing the water depth on the data sheet can help in correcting the data for tidal variations.

2. Monitoring plots

2.1. Establishment of plots

Survey plots for reef monitoring must be easy to find again since it is essential that the repeated surveys be done in exactly the same place. Otherwise, the results will be meaningless because the reef is so different from place to place. Finding the same spot underwater is not easy, so, if possible, plots should be easily related to objects visible to a swimmer, such as a channel or large coral block, or a line of sight on a major building, marker, headland or other coastal feature.

The centre of each plot should be permanently marked in some way, such as by a metal stake or ring concreted into the reef, a hole drilled in the reef rock, or a distinctive coral head. If a marker is too obvious, it may be taken by children or fishermen, yet it must not be too hard to find either.

All the information needed to find a plot should be carefully written down when it is established, preferably with a sketch map showing its relation to major reef features. Plot locations should also be marked on the map of reef zones described above.

Each survey plot is a circle with a radius of four metres (156 inches) around the central marker, covering an area of 50 square metres. This area is easily determined in the field with a rope attached to the central marker.

2.2. Parameters to be surveyed

Several different things will be looked for or counted in the circle, including the substrate (what the bottom is made of), the amount of bottom covered by corals, plants, etc. (percent cover), the presence of major types of coral and plants, and the numbers of certain animals. Fish will be counted not in the circle but along a line. These parameters are defined in detail in the following sub-sections.

2.2.1 Fish counts

Since fish are disturbed by a swimmer in the water, they cannot easily be counted in a circle. Another way is needed to measure them. The method is to swim along the reef for 100 metres counting certain fish for two and a half metres on either side (width of the area counted: five metres; total area: 500 m²). The simplest way to swim for 100 metres is to attach one end of a 100 m rope or line to the plot marker or an anchored buoy, hold on to the other end, and swim until the line is stretched to its full length. Another count can be made by swimming back to the starting marker. A floating polypropylene rope line is best as it has less chance of getting tangled in coral. For frequent monitoring, permanent markers can be installed 100 metres apart. The lines should be parallel to the reef edge, with a first line along the back reef, a second, if conditions permit, along the outer reef slope, and a third across the reef flat if the water depth is sufficient. Changes in the depth of the reef along the line should be avoided if possible. In many cases where there is a slope, the 5 m width will go from the edge of the reef to near the depth at which fish become hard to recognize. Fish counting should either be done first before other activities have frightened the fish, or else a little away from the circle plots.

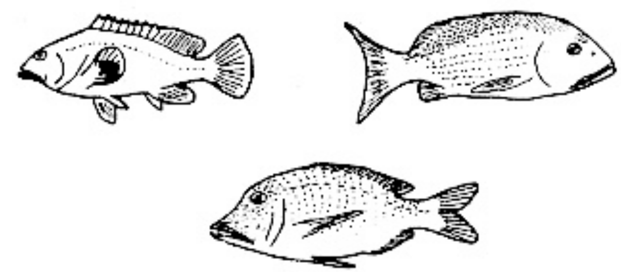
Two groups of fish are to be counted (see Figure 2):

Predators: These are larger fish, longer than an outstretched hand, that eat other fish, and include the groupers (Serranidae), the snappers (Lutjanidae) and the emperors (Lethrinidae). They should be counted first as they may be frightened away by a swimmer going by.

Butterfly fish: The butterfly fish or chaetodontids are small, brightly coloured reef fish that are quite easy to tell from other fish on the reef. They often swim in pairs and have a special way of biting and sucking around corals. They are not so disturbed by swimmers, tending to stay over the same part of the reef, and so can be counted on the return swim to the starting point.

All the other measures will be made inside the circle that marks the survey plot.

Predators (snappers, groupers, emperors)



Butterfly fish

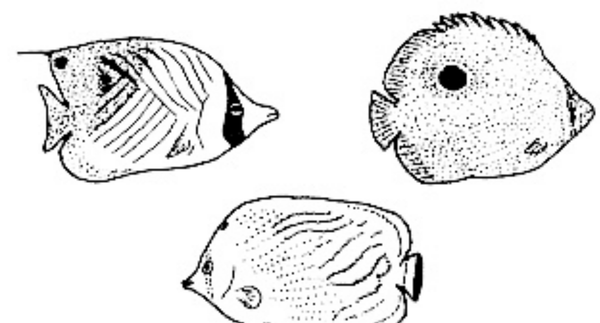


Figure 2. Fish to be counted (details of shape and colour pattern may vary; not to scale)

2.2.2 Percent cover

When looking at the bottom in the circle, you will see sand or bare rock in some places, and corals, plants or other things that are attached or fixed in place on the bottom.

(i) The first measure is what the bottom is made of. Much of a reef is solid hard rock all cemented together, but in some places, and particularly on the lagoon floor, there is loose rock or sand on top of this. For the survey, only the loose material is counted, and everything else is assumed to be solid rock of the reef. Measure what you see at the surface, not what you think is underneath if you dig down. The loose material is called "sediment" and is subdivided into four types based on the size of the individual grains:

mud	very fine and soft, individual particles not distinguishable
sand	small bits of rock or shell where you can see the separate grains but smaller than rubble
rubble	pieces of broken coral or rock ranging from the size of a finger joint up to the size of a human head.
blocks	coral rocks larger than a human head but still not attached or cemented to the bottom. Any rock that is a solid part of the bottom is not counted

(ii) A second measure is of the amount of bottom covered by major biological groups attached to it. The following categories are distinguished:

live hard corals — these corals feel hard because they have a stony skeleton, and are covered by the tiny animals or polyps that live in holes in the skeleton. The holes may be like tiny craters, pinholes or valleys and are often rough or sharp around the edge.
The corals generally look "clean" and are coloured by the animal tissues. They may be of many shapes: big like boulders, small and branched like bushes, or just a crust on the rock.

soft corals and sponges — these may have shapes like corals but they are soft to the touch, sometimes slimy or rough and flexible. Some are very brightly coloured. If there are waves, they may move back and forth.

dead standing coral — when hard coral dies, only the white skeleton is left. Fuzzy plants may then grow on it, giving it a dirty brown, blackish, pinkish or reddish colour, but the outline of the coral skeleton is still very clear and it is still standing in the place where it grew. This is dead standing coral, and it is coral that has died not too long ago. Eventually the skeleton is broken up, eroded or overgrown by other things and becomes part of the reef rock or rubble. Then it is no longer counted as dead standing coral. If it is not clear that something is dead standing coral, do not count it.

marine plants — these include the sea grasses and seaweeds and can range from a cushion-like turf to big floppy plants. They may be green, red or brown in colour. Only plants or clumps of plants large enough to grab hold of should be counted; fine algal fuzzes and films are too difficult to quantify.

(iii) The estimation of the percent cover, or area of the circle occupied by either a class of sediment or a group of organisms, is not easy and requires a certain educated judgement. Six classes coded 0 to 5 are used here:

none	0%	=	0
a little	1 – 5%	=	1
some	6 – 30%	=	2
nearly half	31 – 50%	=	3
more than half	51 – 75%	=	4
almost all	76 – 100%	=	5

It is difficult to make accurate judgements for the area covered by many small scattered things, a few big things, and things that are unevenly distributed. Figure 3 illustrates some different amounts and types of area coverage. Area coverage is measured as a percentage of the whole area separately for sediments and organisms, but in neither case will the figures total 100 per cent because the first measure excludes solid rock and the second does not count areas without organisms.

CORAL REEF MONITORING HANDBOOK

ERRATA

The following paragraph should be added to section 2.2.2 (ii), on page 6, between "dead standing coral" and "marine plants":

crustose corallines – these are plants (algae) that have a stony skeleton like corals and grow as a crust on dead parts of the reef, cementing it together. They range from dark pink to whitish-yellow in color (gray in deeper water) and have a smooth or lumpy surface like paint spilled on the reef.

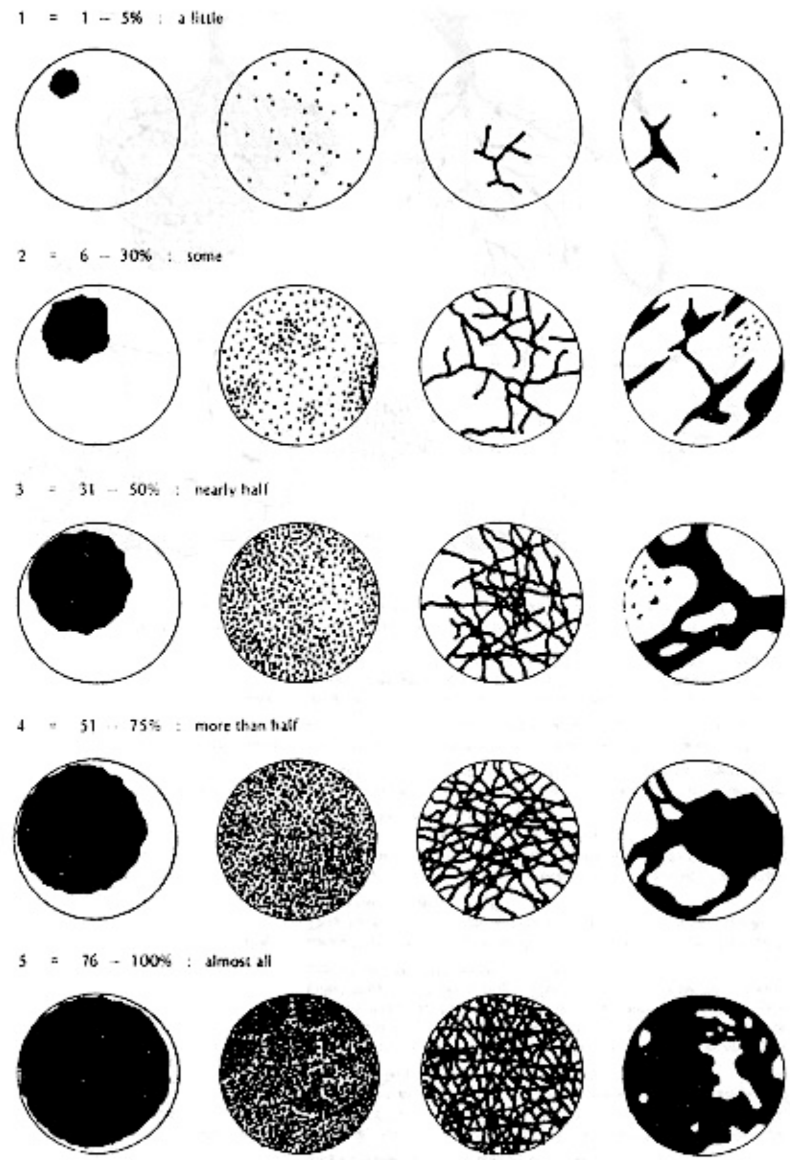


Figure 3. Percent cover

2.2.3 Forms present and dominant

This part of the survey records which major types of corals and plants are seen in the circle and which are the most important or dominant in their visual impact (what you see) and in the area they cover. There are three groups based on the categories for which percent cover is measured, each with two or more subgroups.

Hard corals — these are subdivided into eight different shapes corresponding to the major types of coral (see Figure 4):

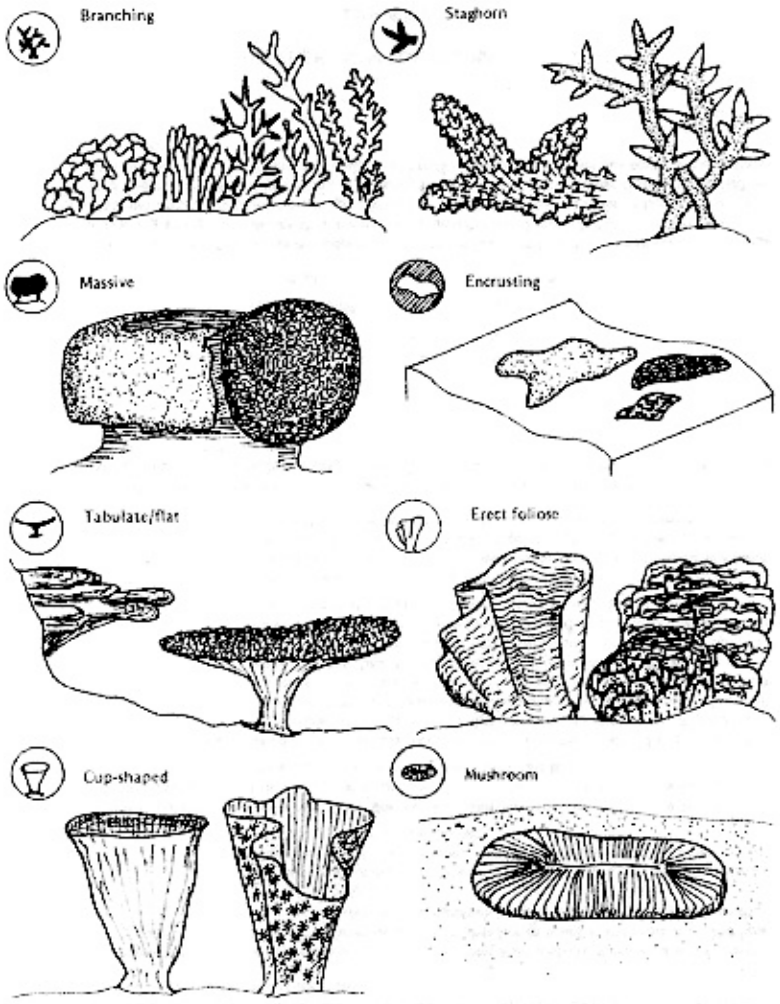


Figure 4. Hard coral forms

- branching: these corals have branches that are longer than they are thick; they may be delicate or very stubby or lumpy.
- staghorn: this is a certain kind of branching coral with branches about the thickness of a thumb or finger. The tips of the branches are pointed, often white or very pale compared to the rest of the branch, and have quite large holes for the coral polyps.
- massive: these ball-shaped or boulder-like corals may be as small as an egg or as big as a house. If some parts of the coral are killed they may develop irregular bulges, and in shallow water where the top is killed they can form a ring. The coral surface may be smooth, dented, or with little knobs or ridges.
- encrusting: corals that grow as a thin layer or crust on the surface of the reef. They have a hard, rough surface like other corals, with little holes or pits for the coral animals.
- tabulate/flat: these corals are like a table or a platform with a broad, flat surface (often with small lumps or knobs) facing up towards the surface of the water. They may stand on a central stem or be attached on one side like a bracket or shelf.
- erect foliose: these corals grow in flattened sheets or plates that stick up from the reef. The sheets may be smooth, folded or joined together.
- cup-shaped: corals that grow up from the reef in the shape of cups or pots. Corals that are not clearly cup-shaped should be classed as "erect foliose".
- mushroom: these are distinctive round or oval corals that lie on the bottom as loose plates and look a little like mushrooms. They have many ridges which run from the edge of the plate to the central mouth.

Soft corals and sponges — the soft-bodied corals and sponges without stony skeletons may have many shapes; only two general categories are distinguished here (see Figure 5).

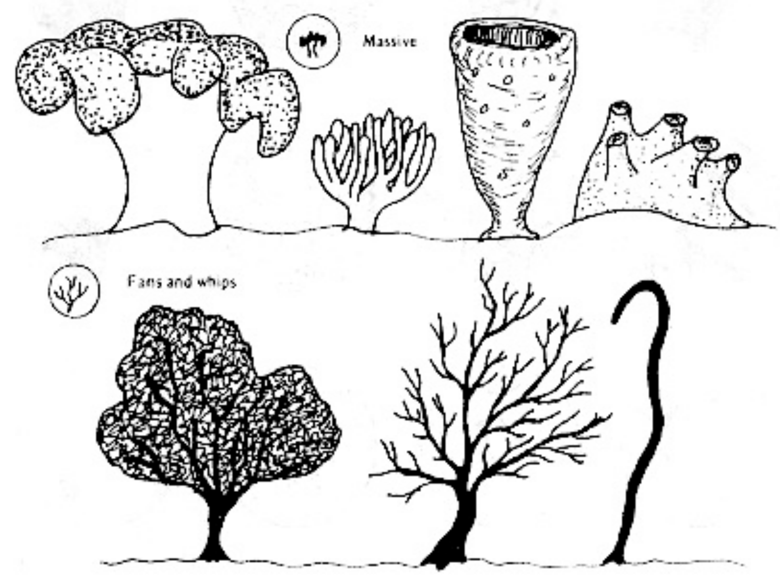


Figure 5. Soft coral and sponge forms

— massive: any big, thick or lumpy soft corals or sponges, whether or not they have branches or are cup-shaped or encrusting.

— fans and whips: this includes the sea fans (delicately branched or flat and often lacy animals that wave back and forth and often look like plants) and the sea whips, straight single stems the thickness of a child's finger and sometimes as long as a person is tall.

Plants — the plants on the reef are often very different from plants on land, since not all of them are green. Six categories are distinguished (see Figure 6):

— thick turf: this is made up of many small plants crowded together like the turf of a lawn or a thick carpet and feeling a little soft or spongy. Its colour is variable depending on the plants in it. Do not include the very fine fuzz of algae that covers many reef surfaces, but only turfs thick enough to get a hold of.

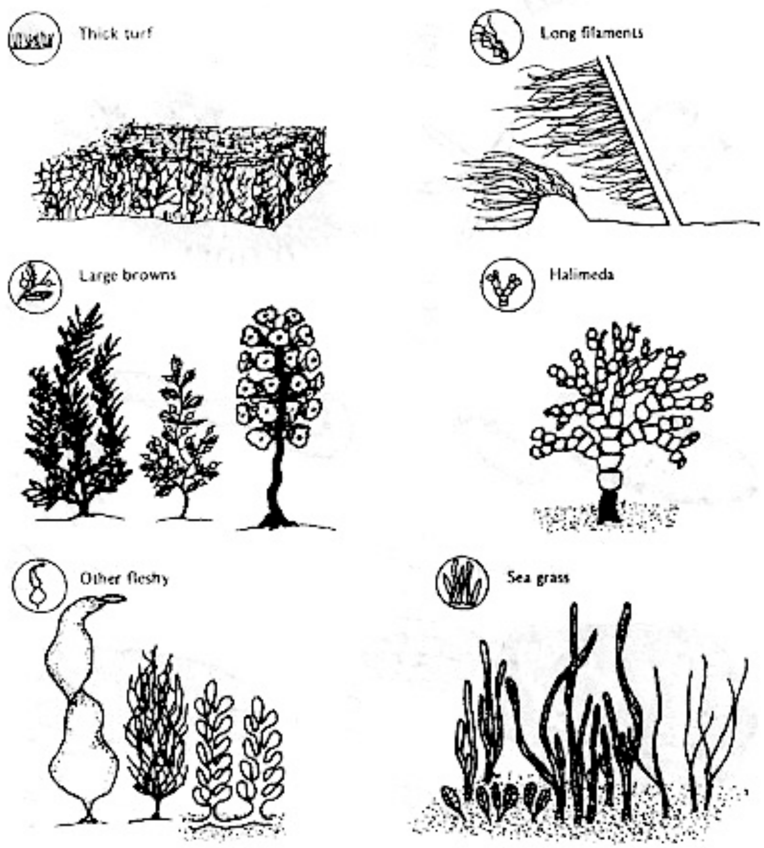


Figure 6. Plant forms

— long filaments: these algae look like tufts or mats of hair, and may be black, brown, red or green. They should only be counted if they are long and obvious.

— large browns: the large brown or yellow-brown seaweeds are branched with leaves, spiny projections or little round floats. They are generally tough and rubbery in feel.

— halimeda: this is the name for a group of green seaweeds made up of branched chains of hard discs, plates or cylinders.

— other fleshy: all other seaweeds (algae) big enough to grab hold of are grouped here. They may be green, red or brown, flat or highly branched, soft or tough, stiff or floppy.

— sea grass: the sea grasses look very much like green grasses on land, with flat or occasionally cylindrical blades. They usually grow rooted in sand or mud.

For each of the three groups of forms (hard corals, soft corals and sponges, and plants) three things are noted: first, whether each particular form is present in the circle plot; second, which form is dominant in its group, that is, which is the most obvious and covers the largest area of the circle; and third, the most common size in the dominant form. Size is measured in three classes, coded 1, 2 and 3 as follows:

1 : the size of a fist,

2 : in size or diameter about the length of a forearm,

3 : the size or span of outstretched arms from hand to hand

For intermediate sizes, choose the closest class. If there are different sizes in the dominant group, the largest size present should be recorded.

2.2.4 Counts of animals

Some animals are relatively easy to see and can indicate the health of the reef. The number of each kind seen in the circle should be counted. If the number is more than 20, then a simple indication "more than 20" (> 20) is sufficient, as counting large numbers of animals can take too much time. Several animals are to be counted (see Figure 7):

Mushroom coral — These unattached plate-like corals are also included above as a form of hard coral, but the number present is also of interest, so they should be counted as well.

Giant clams — The different kinds of giant clams, with their coloured mantles, are combined here. They can be the size of a fist or of a pig, and free standing, attached or embedded in reef rock.

Synaptids — This group of holothurians looks like wrinkled intestines with a flower at one end, waving slowly in a snake-like fashion.

Other holothurians — Often known as "beche-de-mer" or sea-cucumbers, these sausage-shaped animals are most common in sandy areas.

Acanthaster — The Crown-of-Thorns starfish is easily recognized by its covering of sharp spines.

Other starfish — All starfish other than Acanthaster are grouped here.

Urchins — The sea urchins or sea eggs are a distinctive group with their round shell and prominent movable spines.

Trochus — This large conical snail with a thick shell is often collected for export.

Other — If some other animal is particularly distinctive or obvious in a plot it should be noted as well.

2.2.5 Visible pollution

Several kinds of pollution can be recorded if seen: cans, bottles, plastics, tyres or other man-made objects (give the kind and number in the circle); leaves, palm logs, wood or other land plant debris; sediment or fine material making the water cloudy, milky or turbid and reducing visibility; the cloudiness or fuzziness and often a change in temperature that shows that fresh water is mixing with salt water; oil floating as a film on the surface or stuck on rocks as tar; etc.

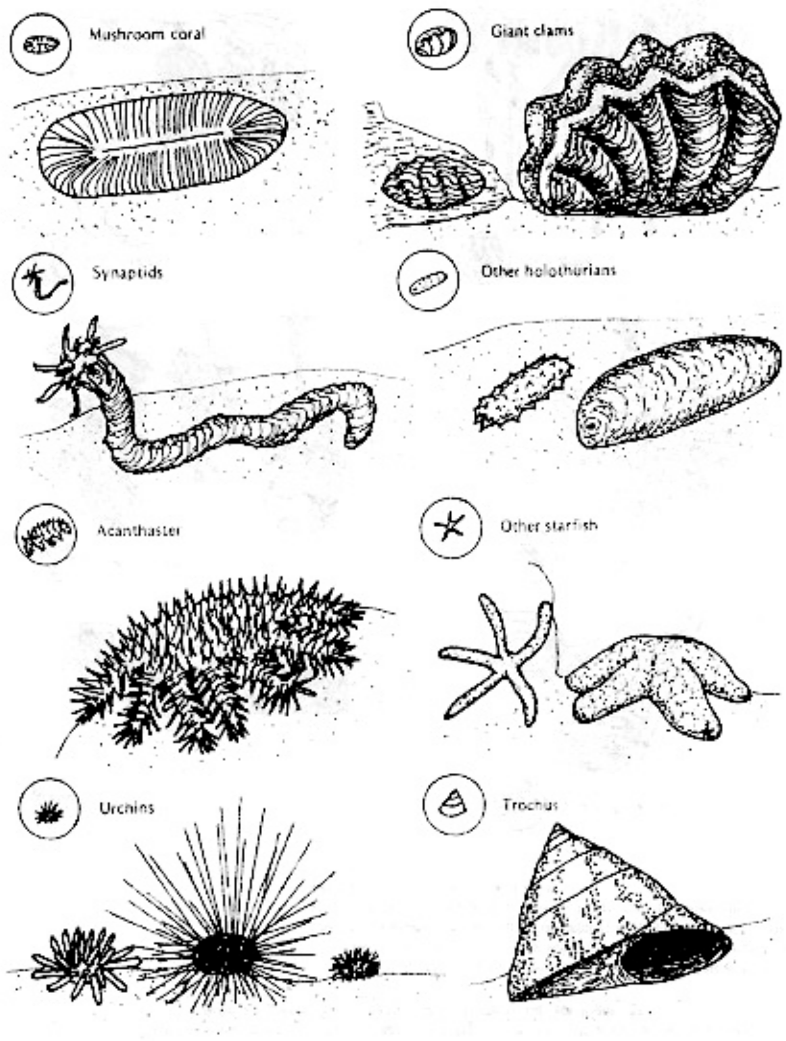


Figure 7. Animals to be counted

2.2.6 Other notes

Brief note can be made of any other observation that may help to interpret the survey results, such as the occurrence of a big storm since the last survey, some human activity affecting the survey plot (dynamiting, construction, etc.) or the loss of an earlier plot marker making the site of the survey only approximate.

2.3. Field survey procedure

Assuming that the plots have already been chosen and markers established, the following is the procedure for surveying the plots. Start with the most difficult part of the reef to reach, since you may be tired later and the wave and tide conditions may get worse. Fill out the top of the data sheet (locality, date, your name, circle number, reef zone, water depth). As your actions may frighten the fish away, do the fish count first along a 100 m line. Then attach a short rope to the marker in the middle of the survey plot, so that the free end is four metres long and ends in a loop, as this is easier to hold on to. (If you start with a four metre rope, it will be too short by the time you have tied the knots, so use a five metre rope to allow some extra.) Swim or walk around the circle holding the end of the rope in your outer outstretched arm. Choose an obvious feature for a starting point so that you can remember when you have made a complete circle. If the reef is very rough and it is hard to see all of the circle in one turn, it may be necessary to go around again looking at the middle part of the circle.

As you go around holding the rope in front of you, it will help you to measure or count as it crosses things of interest. Do not count anything outside the area covered by the rope. On your first time around, look at the amount of bottom (percent cover) of the different kinds of sediment (mud, sand, rubble, blocks) and write the code numbers on the data sheet. Do a second circle to estimate the percent cover of live hard coral. Then make circles for the percent cover of soft corals and sponges, dead standing coral, crustose corallines and marine plants.

Mark off the forms present (hard corals, soft corals and sponges, and plants), making as many circles as necessary to look for all the forms on the list. When you have checked all the forms that are inside the circle, go back and estimate which is the dominant form in each group, and write in the code for the largest size of that form.

For the counts of animals, make circles to count each kind of animal on the list. You may need to make one or more circles for each kind of animal, unless they are very rare. You can either make the count in your head and write it down when you have finished circling, or make a mark each time you see an animal in the circle, and then add up the marks later.

If there are signs of pollution or things made by man (garbage, oil, etc.), write down what they are, and how many are in the circle if it is something you can count. Finish the survey by making notes of any other things that seem unusual or important. Write everything down immediately, and make sure you can read all your notes by going over them again when you get out of the water.

All of the survey information for three survey plots can be written on a data sheet like those included with this handbook. Ideally, the data sheets should be printed or photocopied on waterproof paper. They can then be clipped to a clipboard or attached to a board, so that they are easy to write on under water with a pencil. The pencil should be tied to the board or it will float away or get lost. Make the string long enough to allow for ease of writing. The data sheet format can also be copied on to or scratched into sheets of plastic with a roughened surface on which a pencil can be used. Almost any flat, hard plastic (not polyethylene or vinyl) can be used if the surface is roughened with sandpaper. The data can then be carefully recopied on to plain paper forms after the survey, and the plastic sheet prepared for re-use by erasing the pencil or washing with scouring powder or cleanser.

Figure 8 shows a sample data sheet giving examples of the way it can be filled out. A blank data sheet suitable for photocopying is included at the end of the handbook (see Figure 1[illegible]

CORAL REEF MONITORING DATA SHEET

Locality: Mopapea	Date: 2 February 1982	Recorder: S. Ale	
Circle number	1	2	3
Location on reef	Reef slope	Inner reef flat	Back reef
Water depth	1-2 metres	0.5 m	1 m
FISH COUNTS (100 metre line)			
Predators	3	—	0
Butterfly fish	16	—	11
PERCENT COVER (Code: 0% = 0, 1–5% = 1, 6–30% = 2, 31–50% = 3, 51–75% = 4, 76–100% = 5)			
Sediment: mud	0	0	0
Sediment: sand	0	1	3
Sediment: rubble	2	4	1
Sediment: blocks	0	2	2
Live hard coral	3	2	2
Soft corals and sponges	0	1	2
Dead standing coral	1	2	2
Crustose corallines	3	2	1
Marine plants	1	3	3

FORMS PRESENT AND DOMINANT — Size code: fist = 1, forearm = 2, arm span = 3

		1 PRES	1 DOM	1 SIZE	2 PRES	2 DOM	2 SIZE	3 PRES	3 DOM	3 SIZE
Hard corals	branching	✓			✓			✓	✓	3
	staghorn				✓	✓	1	✓		
	massive	✓	✓	2	✓			✓		
	encrusting	✓			✓					
	tabulate/flat	✓								
	erect foliose							✓		
	cup shaped									
	mushroom	✓						✓		
Soft coral and sponges	massive				✓	✓	2	✓	✓	2
	fans and whips							✓		
Plants	thick turf	✓			✓	✓	1	✓		
	long filaments							✓		
	large browns				✓			✓		
	halimeda	✓	✓	1	✓			✓		
	other fleshy	✓			✓			✓		
	sea grass							✓	✓	2

COUNTS OF ANIMALS	1	2	3
Mushroom coral	2	0	3
Giant clams	0	7	6
Synaptids	0	0	5
Other holothurians	3	4	7
Acanthaster	0	0	1
Other starfish	2	3	2
Urchins	>20	4	2
Trochus	0	0	0
Other (specify)			1 lobster
VISIBLE POLLUTION (specify/count)	none	none	1 bottle, 2 cans
OTHER NOTES			3 recently dead corals from Acanthaster

3. Other samples and measures

The above survey tells us something about what is living on the bottom and in the water, but we also need some information about the water itself. It may not be possible to make measurements at each survey plot, but they should be made at least at one place in the lagoon as near as possible to the survey plots, and also outside the reef if there are survey plots on the reef slope.

3.1. Temperature

The temperature of the water can be measured by holding a thermometer [Figure 9(a)] under water for one minute or more, and then quickly reading it, preferably while the bulb end is still in the water. A better measurement is to use a maximum/minimum thermometer [Figure 9(b)], which measures both the warmest and the coldest that the water has been since the thermometer was last set. Such a thermometer can be used when re-surveying an area every one or two months, and between surveys it should be left in the water firmly attached to a pole or survey marker below the lowest tide level in a place where it will not be damaged or stolen. It should then be removed, read, reset and re-attached each time the survey is done.

3.2. Turbidity

Turbidity means how cloudy the water is, and is a measure of how far you can see under water and how far down the light can go. It is measured with a secchi disc [Figure 9(c)] which is a disc 20 cm in diameter painted black and white and attached to a weighted rope which is marked each metre to show its length. These can be easily made or purchased. To use the secchi disc go by boat or swim until the water is sufficiently deep, and lower the disc until you can no longer see it. Then slowly pull up the disc until you can just see it again from the surface, and write down the distance to the disc as measured by the marks on the rope. If you do not know which mark it is, count them as you pull the disc back up.

3.3. Salinity

Salinity is a measure of how much salt is in the water, and thus tells whether fresh water or rain water has been mixed with the seawater. There are three simple ways to measure salinity, but some require expensive equipment. To measure salinity, you will need to collect a sample of water from the surface at the same place where you measured the turbidity. Put the sample in a clean bottle of a size appropriate to the technique being used, and take it back to the shore for measurement.

(i) Hydrometer

The hydrometer [Figure 9(d)] is a weighted glass tube that floats at a different depth in the water depending on the salinity (or specific gravity). Put the hydrometer in a transparent cylinder or deep jar and fill with sample water until the hydrometer floats. Then put your eye at the level of the water and read the number on the hydrometer scale. Write down the reading on the data sheet, remove the hydrometer, take the temperature of the same water and write this alongside the hydrometer reading. Hydrometers are very fragile and easily broken, so be very careful.

(ii) Refractometer

A refractometer [Figure 9(e)] is a little like a telescope with a measuring scale in it. It is more expensive than a hydrometer, but less fragile and easier to use. Take a small sample of the water and put it under the little cover. Hold the cover down without blocking the light, and read the salinity (or refractive index) by looking through the eye piece. Write down the reading.

(iii) Conductivity meter

A conductivity meter [Figure 9(f)] is an expensive instrument that measures salinity by passing electricity through the water. Follow the instructions with the meter for measuring the sample and for compensating for the temperature, and write down the reading. You may or may not need to record the temperature also.

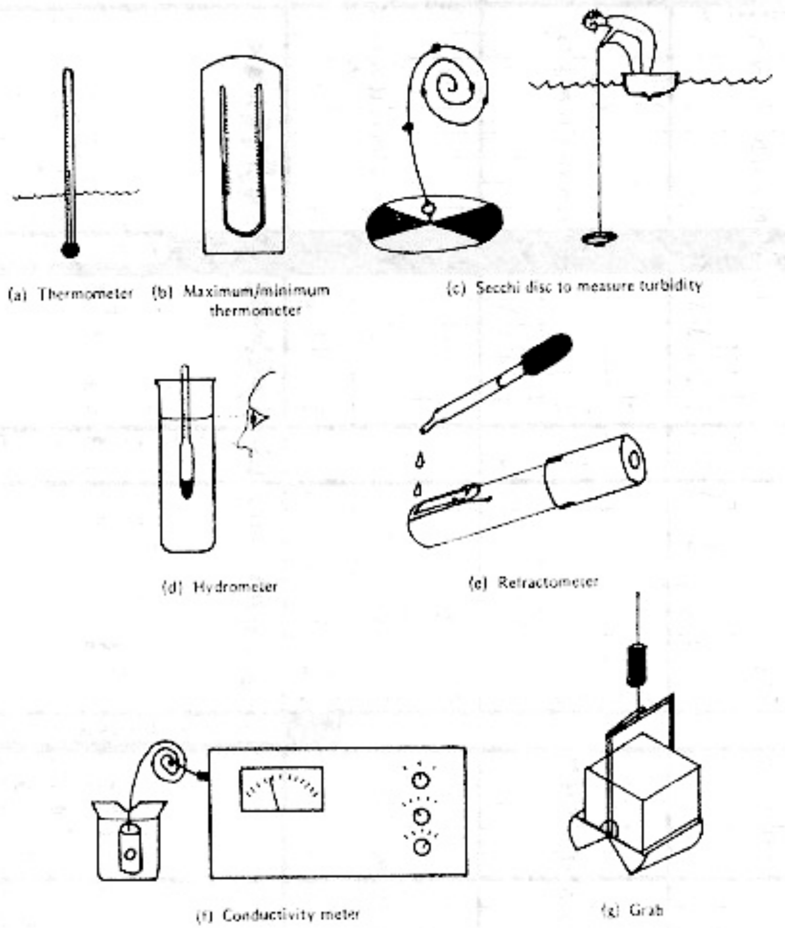


Figure 9. Measuring instruments

3.4. Samples for chemical analysis

If chemical pollution is expected in an area, samples will need to be collected for chemical analysis. The following are some very simple ways to collect samples for certain important pollutants. The samples should be sent, with complete labels telling how, when, where and by whom they were collected, to an analytical laboratory. If possible, use containers supplied by the laboratory. For any more than the simplest sampling, consult a qualified person in advance.

Trace metals: Mud or sediment from the bottom of the lagoon, estuary or harbour is used for trace metal analysis. Collect the sample in the centre of the area, just downstream from the discharge or expected discharge of pollutants

or in the area likely to be affected. Samples should be collected both before and after the discharge if possible. The sample of surface sediment should be taken with a grab [Figure 9(g)], if available, or with a bucket attached to a rope. Three handfuls of sediments are then removed from the middle of the sample, placed in a flat, shallow, plastic tray to dry in the sun. Then they are packed in 500 ml widemouth polyethylene plastic jars to be sent to the laboratory. Do not use metal tools or let the sample touch metal during sampling.

Pesticides: Persistent pesticides are often concentrated in fish livers. Collect livers from five fish of the same species of top predators (such as snapper), ensuring the fish are from the same catch or area and of about the same size. Place a layer of salt in the bottom of a clean jar. Put a few livers on this, not touching each other, and cover them with another layer of salt. Add more livers and layers of salt until all the livers are completely covered by the salt, which will preserve them. Finish filling the jar with salt, and pack it carefully to send to the laboratory.

Excessive nutrients: Nitrate, phosphate and other nutrients may accumulate from sewage or excessive fertilizer use and cause too much growth of algae and seaweeds. Collect a sample of the water in a specially cleaned one-litre all-glass bottle. Fill the bottle so that there is no air or bubble inside when it is closed with the glass stopper. Tape down the stopper if necessary, and pack carefully in a plastic container to send to the laboratory.

Do not forget to attach a label to each sample telling where it is from and when it was collected. There are simple testing kits for doing some analyses with pre-measured chemicals if frequent analyses for water quality, trace metals or nutrients are required.

4. Evaluation and interpretation

Once the data sheets have been filled out and the survey has been completed, it is then necessary to see what the results can show about the health of the reef or how it may be changing.

If some of the measures are very high or very low in a plot, this can suggest that the reef is very poor or has some problem.

Three or more consecutive surveys at the same plot can also be compared. If some of the measures show a continuing increase or decrease of two points (classes) or more over three surveys, this might suggest that important changes are taking place. Small variations of only one point could be due to errors in counting or estimation, and are not significant. The important measures or changes are shown on the key sheet (see Figure 10).

For small-scale surveys, the original data-sheet columns for a particular survey plot or circle can be compared directly, but for long or complex monitoring surveys, the data should be compiled separately for each circle so that long-term changes or comparisons can be followed more easily. A clean data sheet can be used as a data compilation form. Use one sheet for each survey circle, and copy the data from the original data sheet each time the circle is re-surveyed. The original data sheets should never be thrown away, but should be carefully filed for permanent reference as they contain other information that may help in establishing what is the natural situation on the reef, and in interpreting later changes.

The key sheet in Figure 10 permits a quick evaluation of the data collected. Column 1 gives values that should be considered danger or problem levels in most coral reef areas. If at any time a survey plot reaches that level for any measure, there may be a serious problem on the reef. Column 2 is for evaluating three or more consecutive surveys of the same circle over time. A change between two surveys

1 Problem indicator level for any one survey	2 Change (in three consecutive measures) suggesting a problem	3 Interpretations (see pages 17, 19)		
FISH COUNTS (100 metre line)				
0 on reef front only	decrease	B	Predators	
10 or less, reef front or back	decrease	B	Butterfly fish	
PERCENT COVER				
3 or more (except in lagoon)	increase	C	mud	Sediment
			sand	Sediment
4 or more (except in lagoon)	increase	C	rubble	Sediment
			blocks	Sediment
0	decrease	A	Live hard corals	
4 or more		A	Soft corals and sponges	
3 or more		A	Dead standing coral	
		H	Crustose corallines	
5		A, D	Marine plants	
FORMS PRESENT AND DOMINANT				
	disappearance or change in dominant	H	branching	Hard corals
	disappearance or change in dominant	H	staghorn	Hard corals
	disappearance or change in dominant	H	massive	Hard corals
	disappearance or change in dominant	H	encrusting	Hard corals
	disappearance or change in dominant	H	tabulate/flat	Hard corals
	disappearance or change in dominant	H	erect foliose	Hard corals
	disappearance or change in dominant	H	cup-shaped	Hard corals
	disappearance or change in dominant	E	mushroom	Hard corals
	disappearance	H	massive	Soft coral and sponges
	disappearance	H	fans and whips	Soft coral and sponges
	appearance / change in dominant / disappearance	D	thick turf	Plants
	appearance / change in dominant / disappearance	D	long filaments	Plants
	appearance / change in dominant / disappearance	D	large browns	Plants
	appearance / change in dominant / disappearance	D	halimeda	Plants
	appearance / change in dominant / disappearance	D	other fleshy	Plants
	appearance / change in dominant / disappearance	D	sea grass	Plants
COUNTS OF ANIMALS				
	decrease	E	Mushroom coral	
	decrease	B	Giant clams	
6 or more	increase	G	Synaptids	
		H	Other holothurians	
4 or more	increase	E	Acanthaster	
	increase	H	Other starfish	
		H	Urchins	
	decrease	B	Trochus	
			Other	
VISIBLE POLLUTION (specify/count)	increase	I		
PHYSICAL MEASURES				
			temperature	
	increase		turbidity	
			salinity	

Figure 10. Key for evaluating data sheets

may not be significant unless a problem level in Column 1 is reached, but a change that continues in the direction indicated after a third survey can also suggest a problem on the reef.

All the indicators on the key sheet should be reviewed by the expert who first establishes the survey plots, to be sure they are suitable for the particular coral reef area.

The key sheet is arranged so that a quick review of a survey can be made by lining up the left-hand margin of the key with the appropriate column and lines of the data sheet and directly comparing the survey results with the key. Significant values can be circled in colour or otherwise marked.

The letters in Column 3 refer to possible interpretations of a significant result in Column 1 or 2, which are given in the paragraphs below. If a significant result is observed, surveys in the area should be repeated more often, and if necessary a coral reef specialist should be consulted to determine the cause of the problem and to suggest possible remedies.

A. These are often signs that the reef is under stress or has been damaged by some event. The damage could be natural, as in a storm or cyclone, or could be caused by man through pollution from industry, chemicals, human sewage, mining, construction, etc. If the reef changes happen at the same time that new factories, town areas or mines are built, then these may well be the cause. Further surveys should be made every two months, and more survey circles could be established to see how far the damage has spread. The problem should be discussed within the government, and if necessary outside help should be requested.

B. The number of large predatory fish (snappers, groupers, emperors) and of large shellfish like giant clams and trochus is a good measure of the fishing pressure on the reef. If they become rare, there has probably been overfishing. The small reef fish like the butterfly fish show whether the reef can support many larger fish. They may decrease as a result of bad fishing methods like explosives, poisons, small mesh nets or traps, or because of aquarium fish collectors. Control of the kinds of fishing methods or the amount of fishing, either at the village level or by the government, can help to solve these problems.

The number of fish can also decrease because something has damaged the coral and other things that give the fish food and shelter (see A). This is serious and should be studied further through more surveys and by consulting appropriate experts.

C. Mud and sediment can smother coral reefs. Large or increasing amounts of mud are caused by increased amounts of run-off and erosion from land, resulting from bad agricultural practices, construction or mining. Rubble comes from broken, dead coral, so increasing rubble suggests that more coral has been or is being killed, again a sign of reef damage.

D. It is normal for some plants to come and go with the seasons, but pollution from agriculture or sewage can increase the number of plants and change the kinds seen. If the plants are crowding out and killing the corals, there may be a serious pollution problem. Sea grasses are important to the reef, and can be hurt by some kinds of pollution and by disturbing the bottom. An increase in plants may also be caused by over-collecting of shells and other plant-eating animals by villagers or tourists. Some control of such collecting may be necessary.

E. Mushroom corals are among the first things picked up by tourists. Their disappearance is a measure of tourist and visitor pressure on the reef resources.

F. The Crown-of-Thorns starfish, *Acanthaster planci*, eats corals. A few *Acanthaster* on a reef are normal and healthy, but large numbers can seriously damage the corals. Control measures may be necessary in areas important for local fishing or tourism.

G. Synaptid holothurians increase in coral reef areas with bad urban or organic pollution. They may indicate reef damage by pollution, although they may also be naturally common in some places.

H. The disappearance or change in dominance of major kinds of coral and other reef forms may happen naturally over long periods of time, but sudden changes could be caused by man and should be studied in more detail, particularly if other changes are also seen.

I. Some kinds of visible pollution (like bottles, tyres, etc.) can be ecologically harmless, although damaging to the tourist industry. Others can be damaging, or even associated with ciguatera fish poisoning. The presence of visual pollution can indicate that the reef is subject to other kinds of human pressures as well.

5. Limitations and possible modifications

The coral reef survey and monitoring techniques described in this handbook can only suggest that changes are taking place on a reef and that something might be wrong. They cannot give a complete and reliable picture of the state of the reef; reefs are too complex for that. Their intention is to provide an early warning that further studies and possible action are needed. In particular, major management decisions should not be made without confirmation of the survey results by appropriately trained experts, if this is possible.

The results will only be as good as the care taken in making the surveys. Errors can come from not repeating the surveys in exactly the same place, from changing observers between surveys, or from carelessness in writing down or re-copying data. Underwater work is not easy, since attention is divided between the work at hand and such basic things as breathing and personal safety. It is, therefore, important to re-read the whole handbook before starting a survey, so that the procedures and definitions are clear and consistent for each survey.

The survey procedure has been kept as simple as possible so as to require a minimum of time and expertise. It can, of course, be elaborated upon while keeping the standardization that makes it useful for comparative studies. For instance, the reef zones, for which the survey plots serve as indicative samples, can be described more completely during the initial field work, and periodic broad surveys of the zones, using trained observers towed behind a boat, can relate the observations in the circle surveys to the general state of the zones. Transect profiles can also be made perpendicular to the reef to determine the overall reef structure and composition as elaborately as time and expertise permit. The circle surveys can then become reference points along the transect.

It would also be possible to amplify the parameters recorded within individual survey plots. Individual species of butterfly fish may have indicator value and could be separately recorded. The sizes or size ranges could be given for each form of coral, etc. Such modifications should only be made where there is sufficient local expertise to carry them out, and when the extra precision is expected to provide additional sensitivity or information critical to the purpose of the survey.

The collection of information about coral reef resources using the methods described in this handbook will certainly be of interest to science. However, this is only the first step towards the national management of these resources. Those collecting the information must see that it is fed into the planning and decision-making processes of government, leading eventually to active management plans for coral reef areas. Such active management based on continuing knowledge of the status of the resource should make possible sustained reef productivity for the benefit of the country and its people.

CORAL REEF MONITORING DATA SHEET

Locality	Date		Recorder
Circle number			
Location on reef			
Water depth			
FISH COUNTS (100 metre line)			
Predators			
Butterfly fish			
PERCENT COVER — Code: 0% = 0 1–5% = 1 6–30% = 2 31–50% = 3 51–75% = 4 76–100% = 5			
Sediment: mud			
Sediment: sand			
Sediment: rubble			
Sediment: blocks			
Live hard coral			
Soft corals and sponges			
Dead standing coral			
Crustose corallines			
Marine plants			

FORMS PRESENT AND DOMINANT — Size code: fist = 1 forearm = 2 arm span = 3

	PRES	DOM	SIZE	PRES	DOM	SIZE	PRES	DOM	SIZE
Hard corals: branching									
staghorn									
massive									
encrusting									
tabulate/flat									
erect foliose									
cup-shaped									
mushroom									
Soft coral and sponges: massive									
fans and whips									
Plants: thick turf									
long filaments									
large browns									
halimeda									
other fleshy									
sea grass									

COUNTS OF ANIMALS			
Mushroom coral			
Giant clams			
Synaptids			
Other holothurians			
Acanthaster			
Other starfish			
Urchins			
Trochus			
Other (specify)			
VISIBLE POLLUTION (specify/count)			
OTHER NOTES			

Figure 11. Coral reef monitoring data sheet

South Pacific Regional Environment Programme

Training Unit H3

RECORDING AND ANALYZING DATA

USE OF THIS UNIT

This unit describes one of the most critical aspects of scientific research and environmental monitoring, the careful recording and analysis of the data or observations. It is of no value to conduct experiments or to make careful observations if they are not written down or otherwise recorded in a way that the same person or others can go back later and remember what was done or make a comparison with the same place at a later time.

The participants first need to understand what should be recorded. This should be discussed fully until everyone sees the reasons for recording each kind of information. The five basic questions (What, Where, When, Who, Why) should be memorized.

Many ways of keeping records are then described, so it should be clear that anyone can keep good records using whatever materials are available. The special types of records, documentation, and ways of marking a site should also be discussed. It is important that the participants realize that it is the content and not the form of a record that is important.

The analysis of the data in records is only introduced here in the simplest terms. Most scientific types of data analysis are too detailed and complicated for use at this level, but the methods described should be just as useful for the kinds of observations and experiments described in these materials. This section should be discussed until both the principles of data analysis and some of the methods are well understood. Practical exercises in both making records and analyzing them will help to consolidate the understanding of this unit.

EXERCISES

The discussion leader may want to prepare some examples of records and of data analysis to use as models in the discussion. These could be based on local situations or on some of the examples in unit H1.

A field excursion could also be organized, with the participants asked to make records of what they observe. The results should then be reviewed and discussed in the group.

Exercises in data analysis could also be developed using local or imaginary examples. The calculation of monthly and annual totals, means and extremes should be practiced.

(Unit written by A. L. Dahl)
[Revised 25/10/85]

TEXT

RECORDING AND ANALYZING DATA

No one can keep everything they have seen in their head. We all have a tendency to forget things as time passes. If someone moves away or dies, their knowledge and experience are lost to the community. Therefore all societies have developed ways of making and preserving records, ranging from oral traditions passed down from generation to generation, through scratchings on stone and clay, to written records and computer data banks.

One of the most essential parts of any scientific work is the careful recording of the results or observations, and the same is true for any description or monitoring of the local environment. Making careful records will take some time, but it is not necessarily difficult, and for some kinds of data it is not even necessary to be able to write well. What is important is that you (or even someone else) can go back to your records several years later and understand what happened or make comparisons.

What to record

The first step in making a record is to know what to record. Three types of information are essential for any record:

WHAT This is the content of the record. It could be the amount of rainfall in a day, the lengths of each fish caught, the description of a diseased taro leaf, a map of the area flooded in a cyclone, or the data on a monitoring circle in a forest. Whatever it is, it should be described as completely as possible, so that there can be no doubt as to exactly what is meant. Do not forget to show how the measurement was made and what the units of measure are. If some of this is the same for every record, it can be included once at the beginning in a description of the methods used, and need not be repeated for each record unless there is a change in the method.

WHERE The place where the information was collected or the record was made should be clearly stated with as much detail as possible, so that someone later can go back and find exactly the same place.

WHEN Every record must have the day, month and year, and perhaps even the time of day, as these will be important in making comparisons with other months or other years, or to see if there is any change over time.

A record that is not clearly described, or that lacks the place or date, quickly becomes worthless, and the effort that went into making it is wasted.

Two other kinds of information are also very useful in a record even if they are not essential:

WHO The person who makes an observation or record should include his name somewhere with the record. While you may know what you have done, it may help anyone else referring to the record later to know who made it.

WHY There may be some special reason why you made the record or experiment, or some unusual event associated with the record, and this should be mentioned. Perhaps you are measuring fish lengths because you suspect an effect of overfishing, or the rainfall was very heavy because of the passage of cyclone Camille, or on the day of the bird count it was very hot and there was no wind. Such information can be very helpful later in interpreting the results. In the same way it can be important to know that there was nothing unusual or abnormal at the time of a measurement.

If there is any doubt as to the importance or usefulness of some information, is is always better to include too much and not use some of it, than to record too little and later find that you are missing something essential.

When making a record, always ask yourself if you have answered the five basic questions: **What? Where? When? Who? Why?**

How to record it

There are many ways to keep records. It all depends on what you have available and how the records are going to be stored and used. Most scientists keep written records on paper, but this may not always be possible or even desirable in a rural village. Some of the many kinds of materials for records are described below to show what is possible depending on local circumstances.

Paper is easy to write on and widely available, so it is generally preferred for written records. However, it can be damaged or destroyed if it gets wet, and, in the tropics, paper may turn mouldy or be eaten by cockroaches, silverfish, termites or other insects. Some cheap paper like newspaper also turns yellow with age and breaks into pieces. For records to be kept a long time, try to choose the best quality paper available.

Since individual sheets of paper can easily be lost or mixed up, it may be better to keep your records in a notebook or school exercise book. Then you know that the records will stay in the order in which they were made. If the records will be handled a lot, a record book with a strong binding or some other kind of protective cover may be desirable. Where records may need to be grouped later in other than chronological order, it may be useful to keep them in a loose-leaf binder or some kind of folder.

The kind of writing also can be important in permanent records. Most typewriters make good records, but they are seldom available in village areas. Ball-point pens or pen and ink are also good, but try to choose a permanent ink that does not wash in water, in case the paper accidentally gets wet. To test your ink, try wetting and rubbing a little piece of paper with some writing on it. Pencil can be erased or smudged if it is rubbed, but it is better than a washable ink if water may be a problem.

Words and numbers are not the only things that can be written. Drawings, maps, pictograms (simple pictures), symbols, tallies or marks can all be used to record information. However, whenever possible an explanation of any symbols or marks should be included somewhere in the records so that others can understand what is written.

If paper is not available or not certain to last under local conditions, then records can be made on other things found on or around the village. Pieces of wood can be written on with ink or carved in with a knife. Writing or drawings can be scratched on bamboo and then rubbed with charcoal to make them more visible. Pandanus or coconut leaves, or tapa cloth can be used as a substitute for paper.

Other materials can also be used to keep some kinds of records. Lengths can be recorded with pieces of rope or string, perhaps with knots in them to tell them apart, or bundled by period of measurement. Counts or tallies can be kept on notched sticks or knotted strings. Cloth or oilcloth can be written on, and maps, rainfall measurements and other data can be stitched with coloured thread into pieces of cloth. Sheets of metal can also be used to write records on; aluminium beverage cans can be cut open and their sides flattened out to make sheets on which it is possible to write with a pointed instrument. Information can be embossed into clay like that used to make pottery, which can then be baked like pots to make permanent records.

What is perhaps most important is that the records, whatever they are written on, are kept in a safe place and protected from whatever might damage or destroy them. In the Pacific, the greatest dangers to records probably come from water damage during leaks, floods or cyclones, insect attack, mold and rot, children damaging or losing records, and people accidentally misusing the material such as by taking the paper for use in personal hygiene. Much time, effort and irreplaceable information can be lost if care is not taken to protect essential records from harm.

Recording and documenting information

When recording an observation, try to include as much information as possible. For some things a sample or example of the object can also be preserved and kept for future reference. For instance, suppose you catch a new kind of fish. In the record, you would describe its size, colour, shape, where it was caught and by what method, etc. If you hope to have a scientist identify it later, perhaps the fish itself can be salted and preserved, or at least its skeleton could be cleaned and dried to show the scientist along with the description. Pieces of plants can similarly be flattened between pieces of newspaper or matting and dried to show what plant is referred to in the record.

There is a similar need to document any place referred to in a record, whether it be the site of an observation or the location of a marker. The place should be located on a map, or positioned by reference to some obvious and permanent features. This is especially important if you plan to go back to the same place later to repeat a monitoring survey. One way to describe a location precisely is to determine two lines of sight with pairs of obvious features; lining up the first two gives a line that one can walk (or swim) along until the other two features are also lined up to show where the spot is. These lines of sight should be described in the record, and perhaps shown on a sketch map as well. In choosing reference features, remember that trees can be cut or blow down, telephone poles can be changed, buildings can be torn down or replaced, roads can be realigned, and other features may not be as permanent as they seem. The longer you expect to wait between surveys, the more permanent the features should be. If possible, plan so that the loss of any one feature will not make it impossible to find the site.

It will often be necessary to make marks at the place itself to identify a site or survey area. Marks should be as permanent as possible, but not so obvious that they invite vandalism or disfigure the area. Anything of value used as a marker is apt to be picked up and taken away by someone. Important survey markers can be cemented into place. Identifying marks can also be chiseled into stone or cement, or cut into tree bark. Large nails can be driven into trees or coral (but remember that trees and coral grow and will cover up the marks if they are not renewed from time to time). Pieces of steel reinforcing rod can be driven into the ground, or into the reef, perhaps to mark the centre of a survey circle; short pieces of rod usually do not have enough value to attract attention, but they are not too difficult to find again, even in the middle of a coral reef.

When recording such things as the height of flood waters or the level of the sea, try to find a point of reference that is as permanent as possible, such as a ledge in the cliff, the wall of a church, or a large healthy tree. The next flood might not be for 30 years or more, and it would be valuable to have the same point of reference for comparative purposes.

Photographs can be very helpful to record the appearance or position of things if you have access to a camera. For a picture to be useful, however, you should record the same information for the picture as for any other record: what, when and where it was taken, and perhaps the exact position of the camera if you hope to take a picture from the same place later and compare the two.

Recording information underwater is a special problem. While waterproof paper exists that can be written on underwater, it is not generally available in the Pacific. However, a pencil can be used to write underwater on any surface that is a little rough, such as hard plastic or aluminium that has been rubbed with sandpaper, pumice or sand. The information written on such a slate can be recopied afterwards onto a notebook page or record sheet, and the slate scoured again to erase it for reuse. It is wise to tie the pencil to the slate with a string, as a wooden pencil can too easily float away.

Analyzing data

The information collected in records such as those described above is usually not in the best form for easy analysis and interpretation. While some similarities or differences may be obvious from reading the records, there are often ways that the data can be converted to make them easier to understand. In a bar graph, for instance, the amounts in each record are shown as the heights of bars, usually in chronological order, like the rainfall bar graph shown in unit H2. If several years are being compared, the data might be grouped by month, using different colours or shading for the bars showing each year's records.

Changes in land uses that have been mapped, or in monitoring circles that have been drawn, can be shown by overlaying the maps or drawings for the different records, assuming that they are all drawn to the same scale. The maps can be drawn on tracing paper, so that one can be seen through the other. If tracing paper is not available, redraw the maps on any relatively thin paper, and then lightly oil or wax the paper to make it translucent. By laying one map on top of the other, any differences between them can be seen very easily.

It can be interesting to compare the data from different places to see just how they are different, or to see if certain areas are sufficiently similar that they can be developed or managed in the same way.

Very often data from different years is compared to see what changes may be taking place over time, or to identify patterns or events that may repeat themselves at certain intervals. The data for each year then need to be organized so that the comparison between years can be made more easily. The same thing is done to identify seasonal changes. The data for each month or season are grouped and compared to show whatever differences there may be between seasons.

When you have collected a series of numbers, whether of the amount of rain, the fish catch, or the water temperature, there are some simple calculations that can be used to give figures that are easier to compare. For instance, it might be interesting to add up the numbers for each month to give a monthly total, or for the whole year to give the annual rainfall or total catch. If the total is divided by the number of months or the number of days, the resulting figure will be the average monthly or daily amount. Comparing averages can be easier than comparing all the data, since averaging evens out the small often random changes from one day to another. Since it is sometimes the extreme conditions that are the most important for the environment, it can be useful to determine the highest and lowest figures for each month, or for the whole year.

Even with these calculations, there is still the same problem of deciding if a difference is significant or not. The question of significance has already been discussed in the previous units. In general, the larger the number of measurements being compared, the greater the chance that the observed difference is significant.

Measuring effort

One type of analysis that can be very useful in studying the use of environmental resources is to estimate the effort that went into producing a certain result. For example, suppose 10 fishermen go fishing on 50 days of the year and catch 500 fish. The next year there are 12 fishermen each fishing for 50 days, but they still only catch 500 fish. The third year, the 12 fishermen must go fishing for 70 days each to catch the same 500 fish. If you looked only at the number of fish caught (500 each year), you might say that the fishing was just as good, but if you calculate the number of fish caught per fisherman per day spent fishing (in other words the fishing effort), the catch has gotten steadily worse.

It is thus useful to collect some records of the amount of effort (in area planted, hours worked, trees harvested, etc.) and include it in the analysis on order to see if any difference observed is the result of a change in the productivity of the resource or of the effort put into exploiting it.