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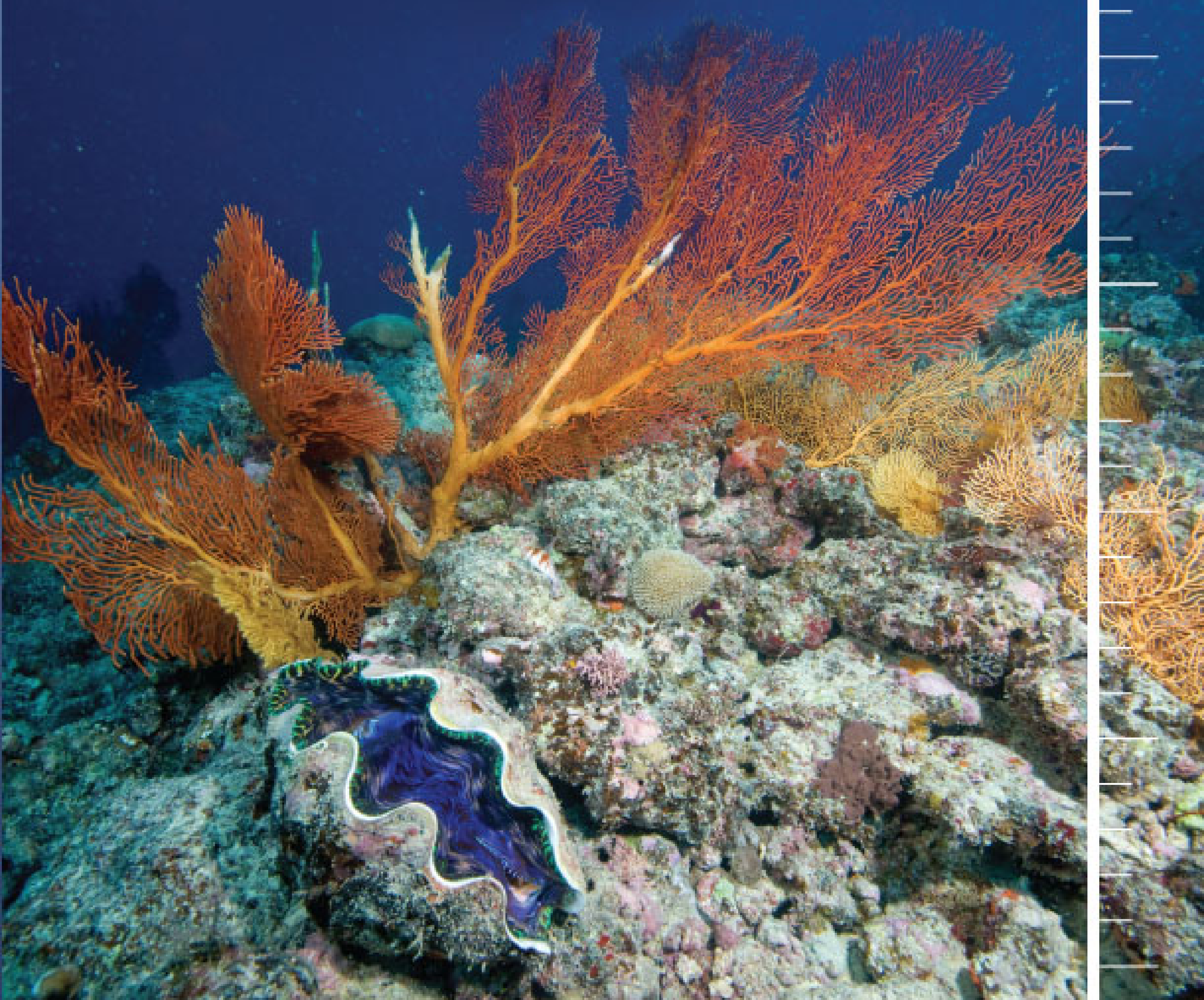
Assessing Tropical Marine Invertebrates



A Manual for Pacific Island Resource Managers

Assessing Tropical Marine Invertebrates: a Manual for Pacific Island Resource Managers

Coastal Fisheries Science and Management Section
Secretariat of the Pacific Community

by

Kalo Pakoa, Kim Friedman, Bradley Moore, Emmanuel Tardy and Ian Bertram

European Union

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Secretariat of the Pacific Community
Coastal Fisheries Programme
BP D5, 98848 Noumea Cedex, New Caledonia
Tel: +687 26 20 00
Fax: +687 26 38 18
Email: spc@spc.int; http://www.spc.int/

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Abbreviations

CI	confidence interval
cm	centimetre(s)
COTS	crown-of-thorns starfish
CPUE	catch per unit of effort
DWSs	deepwater timed scuba search
EIA	environmental impact assessment
g	gram(s)
GIS	geographic information system
GPS	global positioning system
ha	hectare(s)
ind.	indivivual(s)
kg	kilogram(s)
km	kilometre(s)
km^2	square kilometre(s)
m	metre(s)
min.	minute(s)
mm	millimetre(s)
MOPt	mother-of-pearl transect
MPA	marine protected area
PICTs	Pacific Island countries and territories
RBt	reef benthos transect
RFID	Reef Fisheries Integrated Database
RFs	reef-front timed swim
RFw	reef-front timed walk
LNs	lobster night search
SBt	soft benthos transect
SE	standard error
STD	standard deviation
SCNs	sea cucumber night search
scuba	self-contained underwater breathing apparatus
SiQ	soft infaunal quadrat
SPC	Secretariat of the Pacific Community
SWSt	shallow water scuba transect
SWSs	shallow-water timed scuba search
WPT	waypoint

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1. Introduction

1.1 Resource surveys as part of fisheries management

Although the Pacific Islands region is relatively free from the pressures of large-scale industrialised exploitation, marine biodiversity and species of importance for food security or commercialisation are under pressure from a combination of subsistence harvesting (where coastal populations are high), commercial fishing activity and coastal development. Although there are few documented cases of widespread collapses, a lack of understanding of the status of resources and the health of coastal systems is a recognised shortfall in the ability to manage stocks over time. Managing resources and habitat by way of day-to-day perceptions suffers from a constant shift in understanding with changing generations.

The various pressures on invertebrate resources must be understood in order to devise controls to maintain their productivity. This is critically important for maintaining food security, and ensuring the cultural integrity of Pacific Island peoples. Measurable 'yardsticks' are needed to understand changes in the status of resources following periods of fishing or habitat change. As well, a quantitative understanding of stock recovery under active adaptive fisheries management regimes will allow greater insights into the affects of fishing and management.

Many invertebrate resource monitoring programmes introduced in the Pacific Islands region have not been sustainable because they are driven by project funding and so end when funding ceases. Many types of resource assessments have been introduced in Pacific Island countries and territories (PICTs) to assess the health of invertebrate resource stocks, including underwater visual census, mark-recapture, and catch per unit effort (CPUE) studies. These surveys are based on sampling a representative number of areas and using the data from previous surveys to make generalisations about the status of resource stock population by area, island or country using various statistical tools. The continuing problem with doing this, however, is that statistics can be complicated, daunting, and require considerable training and resources. In addition, surveys undertaken in the past have been designed separately, making it difficult to compare results to provide a broader understanding of resources status or to enable countries to share experiences and learn from each other. The lack of accurate information and expertise on invertebrate resource assessments is testament to the current lack of information on invertebrate resources and, thus, the need for effective and sustainable monitoring programmes to be established in PICTs.

Studies conducted by the Secretariat of the Pacific Community (SPC) since 2002 have sought to provide information to Pacific Island governments, administrations and communities to allow them to gauge the condition of reef and lagoon invertebrate fisheries, and to enable them to adopt relevant management measures, plans and regulations. The information from these studies has been used in the development of this manual.

1.2 Purpose of this manual

This manual is designed for fisheries and environmental officers, and non-governmental partners who are tasked with assessing the state of fisheries resources and macroinvertebrate communities. Promoting the use of the standardised survey methodologies and analytical procedures presented in this manual allows survey results to be compared across different countries and/or regions, and ensures a broader geographical perspective on invertebrate resources.

This manual adopts a simplistic approach by beginning with a clear management question, followed by a discussion of survey design and selection of fisheries-independent survey methodologies to use, and the basic analytical techniques for indicating stock health. This manual does not make suggestions on 'how to manage', but focuses on how to attain a useful and repeatable measure of resource stock condition for the sustainable management of invertebrate resources.

The three main uses of this manual (described in greater detail in Section 2) are:

1. Estimating the status of stocks of certain fishery resources in order to provide management advice.
2. Assessing the impact of development activities or a natural disaster (commonly referred to as an environmental impact assessment, or EIA).
3. Long-term monitoring to detect changes due to development, human habitation or environmental changes such as climate change.

1.3 How this manual is organised

This manual consists of four sections plus support material in the appendices that provide:

- a guide on how to plan and design an invertebrate survey (Section 2);
- detailed descriptions of a range of survey techniques that can be used (Section 3); and
- basic analytical techniques and interpretations of typical data recorded during the surveys (Section 4).

The appendices give further details on measuring invertebrates (Appendix 1), safety precautions when undertaking field surveys (Appendix 2), species identification guides (Appendix 3) and regionally compiled data on species of interest to fisheries, including additional information on survey methods for species such as spiny lobster, coconut crabs, land crabs and octopus (Appendix 4). Appendix 5 contains field datasheet templates for the techniques described in this manual. Appendix 6 provides estimates of time, personnel numbers, and equipment required to complete various survey methodologies. Appendix 7 covers data analysis techniques for various types of survey data, with specific examples. Appendix 8 contains data for converting sea cucumber lengths to wet and dry weights.

2. Planning and designing an invertebrate survey

2.1 What are resource surveys and why do them?

Invertebrate resource surveys collect information that helps to assess the status of resources and the condition of their habitats. Resource surveys can produce comprehensive information on the status of stocks (species diversity, abundance, size frequency), and make it possible to: 1) determine where resources are found; 2) assess the variation in the 'health' of these resources among locations (e.g. fished and non-fished areas and/or areas under special management); and 3) provide an overall assessment of the stock across the whole fishery (when compared with other similar places and fishing areas).

Repeated assessments of invertebrate resources (monitoring programmes) make it possible to determine changes in the status of a resource over time, starting from the first assessment (baseline). Such monitoring programmes require the use of standardised survey designs and methodologies, and a clear understanding of the indicators and thresholds to use to understand changes in the status of invertebrate resources. It is generally agreed that invertebrate populations are declining in most PICTs, and that reliable and comparable time-series datasets are needed. Standardised assessment protocols that use simple indicators for the status of invertebrate stocks will enable more effective stock assessments and management interventions that will ensure the sustainability of invertebrate resources.

2.2 What kinds of questions can resource surveys answer?

Resource surveys gather information on the state of resources and how they change in response to stresses such as fishing, which is useful for fisheries managers and stakeholders. By monitoring invertebrate resources over time, changes in stock conditions including pressure on stocks can assist fisheries managers in determining sustainable fishing levels or assessing the effectiveness of management measures (e.g. closed areas or size limits).

2.3 What and who is the survey for?

Before beginning a survey, it is essential to be clear about what the information will be used for, and by whom. This will influence the type of surveys to be carried out, the range of data to be collected, and how the data should be analysed and presented. For example, if the intention is to provide a national assessment of a resource, then broad-scale surveys are needed. However, if the aim is to inform communities about the status of their resources, finer-scale surveys are needed.

2.4 Planning a survey

Monitoring the condition of a stock will not necessarily achieve a conservation or sustainable fishery outcome unless it is linked to an understanding of where in the biological cycle the resource is coming under pressure, and using that information to develop ways to manage (e.g. through fisheries controls) or circumvent that pressure, such as implementing temporal and spatial closures (e.g. habitat protection, offering alternative sources of food or income).

To make sure the intended surveys are clearly focused on the issue that needs to be addressed, it is important to spend time planning and designing the survey before any field work is started. With proper planning, it is possible to avoid spending time and resources conducting surveys that will not achieve the necessary outcomes.

The planning stage can be looked at as a series of questions that will, when answered thoroughly and carefully, help deliver what is needed for management based on the assessments.

The key questions in the planning procedure will make it possible to move through the general planning stage to more focused and detailed plans. The key questions that should be addressed in the planning phase are:

1. What are the questions that are being asked, and by whom?
2. What are the key pieces of information needed to answer the questions?
3. What indicator datasets will provide a time-series to inform these decisions?
4. What methods are most effective and efficient in providing this information?
5. Where and when is the best time to collect these data to ensure they are representative?
6. How are data going to be analysed and reported?
7. When are the results and management advice (supported by the results) expected from the survey, and what timeline is required to get the job completed?
8. Are skilled personnel available to conduct the survey and complete the reporting; if not, then what are the options?
9. Knowing the level of sampling effort and logistics required, is there sufficient funding to conduct the survey?

2.5 The basis of survey design

Resource surveys should be designed to ensure that ‘sufficient’ data are collected to inform management decisions. Invertebrate species may be highly aggregated in specific habitats, or evenly distributed over a reef system and among a number of different habitats and depths. A careful and well-planned survey design is important for capturing all potential habitats and typical characteristics of a species of interest in order to present a representative sample in a defined area. Many invertebrate species are of importance to fisheries for economic, subsistence and food security reasons; they are also important as indicators of ecological change in the marine environment.

Survey points or stations are selected across the site of interest. A greater number of stations is needed for situations where there is less certainty about the distribution of stocks (e.g. for a baseline survey), and where stocks are widespread and/or in low abundance, and for larger scale surveys. The basic design (default) for surveying these points or survey ‘stations’ is to assess six standardised replicates per station for all survey types (Fig. 1). This level of replication per station yields high quality data that are consistent with SPC's Reef Fisheries Integrated Database (RFID) design, although in each case the number of stations to use in an area of interest can vary based on initial questions, survey time, the spatial area under consideration, and available resources.

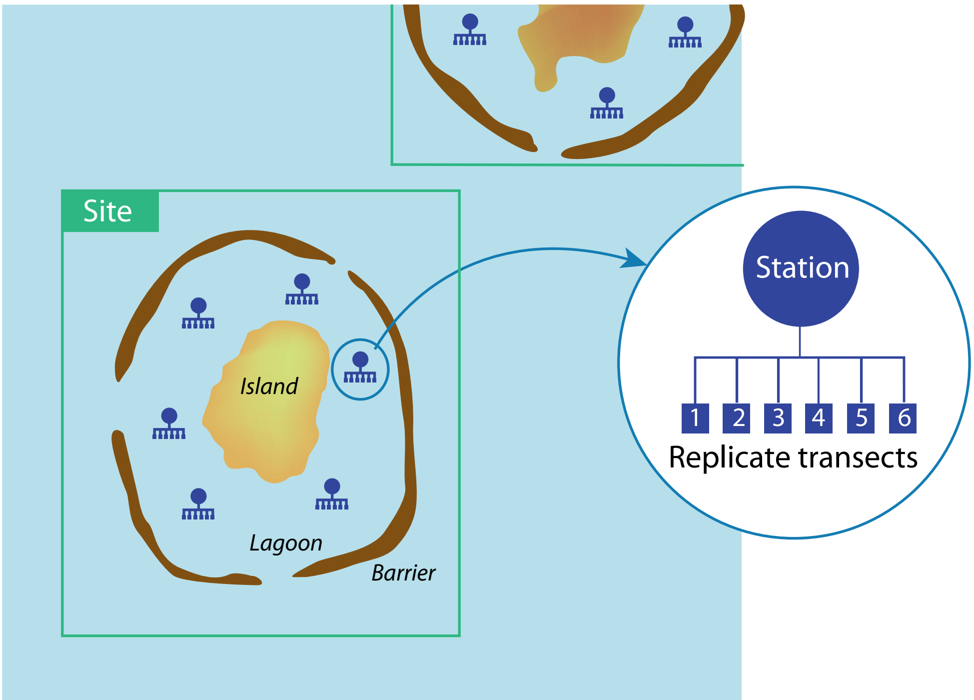


Figure 1. *A survey design should include a reasonable number of replicate stations, and should be consistent with the Reef Fisheries Integrated Database.*

In a first-time survey, broad-scale techniques should be employed to rapidly cover large distances prior to conducting a habitat-specific, fine-scale survey. The information generated from broad-scale surveys is most useful for providing a general overview of the distribution and relative abundance of widespread stocks, and in locating habitats and areas where there are higher densities of stocks of interest, which can later be surveyed through a precise, fine-scale survey (described in Section 3).

The following paragraphs provide a guide on how to design an invertebrate survey for the following three purposes: 1) estimating the status of stocks of certain fishery resources in order to provide management advice; 2) assessing the impact of development activity or a natural disaster (i.e. an EIA); and 3) long-term monitoring to detect changes due to development, human habitation or environmental changes such as climate change.

1) A survey to estimate the status of stocks of certain fishery resources in order to provide management advice

Specific questions

The aim of this type of survey is to assess the status of an invertebrate stock, or to assess the effectiveness of current management decisions and suggest additional or improved management measures. The initial question should identify the resource of interest; for example, overall sea cucumber resources (all species) or specific species of sea cucumber. Once the resources have been identified, the next step is to determine which factors of the resources are of interest.

Information required to answer the question (which indicators will be measured through time?)

The purpose of this step is to define the type of data needed to answer the question. For example, for assessing the status of sea cucumber resources in an area, the following data are required:

Stock condition data

- Density (number per unit of area with error terms) of sea cucumber species present in available representative areas (habitat types and depths) across the area of interest.
- Size of representative areas (habitat types and depths) to allow total counts of individuals (by species) to be calculated (with error terms) for both individual representative areas and the whole area of interest.
- Species size or weight data to provide an indication of recruitment and stock maturity (information on measuring invertebrates is found in Appendix 1).
- Comparable data from the same area taken previously, or comparable data from a different place with similar habitats for comparison of results.

Pressure data

- An indication of the fishing history of the area of interest.
- An indication of any recent (i.e. within last 5–10 years) major change in the habitat within the area of interest that might have impacted the stock (e.g. major coral bleaching event, fish kill, flood, cyclone).

Management controls

- An indication of any management controls that are in place (e.g. catch or size limits, closed areas).

2) A survey to assess the impact of a development activity or natural disaster

Fisheries Departments throughout the Pacific Islands region are increasingly being asked to assist in conducting EIAs for macroinvertebrates for development projects. Changes in the abundance of important indicator species (also called sentinel or keystone species) can provide an indication of changes in habitat condition.

Coastal developments can have significant impacts on natural habitats and the invertebrate resources that inhabit them. For example, cutting a channel through a reef so that large vessels can gain access to a lagoon will result in changes in tidal circulation and wave patterns inside the lagoon. These changes can, in turn, affect water physicochemistry (temperature, salinity, ocean-terrestrial water exchange in the lagoon) and geomorphology (movement of sand around islands), which can further affect the suitability of the area for marine invertebrates. These changes may result in changes in habitat characteristics and a shift in invertebrate species composition due to different tolerance levels of individual species. Such changes might be immediately obvious, but if they, say, affect larval retention in the lagoon (loss of invertebrate larvae from the lagoon to the open ocean), such changes may only become apparent when future generations of stocks are due to be fished (e.g. 5–10 years in the future).

Specific questions

The aim of this type of survey is to assess the effects of acute short-term pressures on a subset of important macroinvertebrate species and their habitats. Determining the status of these factors before and after a development project makes it possible to identify any potential negative impacts, and facilitate the development of successful mitigation measures. In this instance, a large subset of important macroinvertebrate species and their habitats would be assessed in the area of impact and related areas. The next step would be to identify factors to be monitored.

Information required to answer the question (which indicators will be measured through time?)

The purpose of this step is to define the type of condition and pressure data that are needed to answer the question. In this case it is necessary to record the condition of the habitats that are at risk and a large subset of macroinvertebrate species that may be affected by the development project. In addition it is important to record the changes brought about by the development itself (the pressure). These condition and pressure factors need to be assessed before, during and after the development project, at sites directly impacted by the development, as well as a subset of sites removed from the impact of the development (called 'control' sites).

Habitat and stock condition data		Pressure data
• Changes in habitats that are at direct risk from the development project (e.g. declines in live coral cover, seagrass density, increases in sand and rubble) compared with habitats distant from the development.	• Differential changes in species abundance (density) before and after the development from areas at direct risk from the development compared with those distant from the development. This could be a localised change with shifts in the spatial distribution of aggregations and depth distributions of stocks across the area of interest or over the entire stock.	• Measure differential changes through time and across near and far sites related to the pressure itself (e.g. increased sedimentation, changes in water current speeds).
• Changes in species-specific size-frequency data before and after development to determine if there are shifts in recruitment or mortality of certain age groups as a result of the development project.	• Changes in biodiversity (e.g. new species entering the site or lost from the site).	**Management controls** • Any management controls put in place to mitigate the effects of the development project.

3) Long-term monitoring to detect changes due to development, human habitation or environmental changes such as climate change

Monitoring for longer term changes due to gradual, long-term chronic pressures such as population growth and climate change require a different focus than the above-mentioned examples, and data collection will be over a longer time period. In this situation, the effects of long-term, broad-scale impacts are informed by predictions from experts that highlight the most likely physicochemical pressures and related ecological impacts. This differs from the study of localised acute developments and will require the development of agreed upon monitoring frameworks across national and international boundaries to share information on both the impacts of these pressures and successful mitigation or adaptation measures.

Specific questions

The aim of this type of survey is to assess the impact of chronic pressures (e.g. increased fishing pressure due to population growth, temperature, ocean acidification and sea level increases) on marine habitats and invertebrate resources. To do so requires that the pressure that is suspected of being the main stressor be isolated, and that the factors that are susceptible to such changes be identified. In the case of increased population growth it is possible to monitor changes in the abundance and size of targeted invertebrates with increasing distance from the population centres. For climate change, increases in water temperature will directly impact some resources or have an indirect effect due to the decline or loss of habitats such as live corals, which provide a home and food for resource communities. This line of reasoning should be followed, with assistance from government, regional or research institutions, so that the most relevant indicators can be selected.

Data required

Some water quality (e.g. temperature) and habitat parameters might be more important than others, as will information on the invertebrate stock that is being fished. It is important to work with national and international partners because such pressures are broad scale and commonly seen in many PICTs.

2.6 Logistical planning of surveys

Properly planning a survey will help clarify exactly what is needed to conduct successful fieldwork, how and where the work will be carried out, when the work will begin and end, and how to organise the budget, staff and movement of people and gear from place to place. Improper planning will incur excessive expenses, and result in transportation problems or inaccurate data, which waste time and money. Below are some of the important considerations when planning invertebrate surveys.

Understanding the survey site

Having background knowledge of the site of interest is important for good planning. Previous studies, reports, fisheries information, and experience with the site by people who have worked in the area are all important in the planning phase. Consulting available maps and charts is another important component in planning a survey. Consultation with local communities can greatly improve the background understanding of a site.

Timing

When to undertake a survey is important, and should take into consideration a number of temporal factors, including season, time of day, moon phase and tide times.

Local community support

Fieldwork in PICTs is normally carried out in community-owned marine areas. Community acceptance and support are, therefore, essential to the success of field survey work. Communities must be fully informed and made aware of how they can be a part of, and benefit from, the activities undertaken. Some invertebrate species are habitat specific and local fishers have knowledge of species distribution in their area, therefore their input to the actual survey design and implementation in the field is invaluable. Local governing authorities such as local level government, island councils, provincial councils or state governments should be made aware of surveys in their respective areas. Communities in most areas like to know what the survey discovered in their areas, so planning should include a briefing to the community on preliminary survey findings.

Safety considerations

Safety is paramount at all times when working in coastal areas and at sea. In order to be most effective in the field, due consideration of the safety of all participants, as well as the boat and equipment is critically important. A safety instruction card (Appendix 2) provides more detailed information on safety issues to consider when conducting a resource survey. It is always necessary to have a survey team leader to take ultimate responsibility for decisions made, although all team members should be encouraged to contribute ideas in order that the best decisions are made.

Species identification

A common problem with in-water field surveys is the misidentification of species. Before collecting data from surveys it is important to ensure that all surveyors are familiar with the species of interest. Training in invertebrate identification should include classroom exercises using photos, books and other available species guides, and in-water exercises while snorkelling. A species identification guide for commonly encountered invertebrate species in the Pacific Islands region is included as Appendix 3.

3. Survey techniques and methodologies

3.1 Distribution of surveys across a typical reef system

The distribution of invertebrates on a reef system varies greatly in spatial scale and with the topography and complexity of an ecosystem (e.g. high islands tend to have higher nutrient discharge to the coast than low-lying islands). On a regional scale, invertebrate diversity is partially determined by the location of the ecosystem in relation to the centre of biodiversity. In the Pacific Islands region, species diversity generally decreases from a hot spot in the west (near Palau) to less speciose islands in the east (French Polynesia). On an individual island, the more extensive and complex the reef system, the greater the variety of niches for flora and fauna and, the greater the number of invertebrate species.

Basic knowledge of a reef system is essential in determining the location of sampling stations and assessing invertebrate resources. Figure 2 illustrates some typical types of surveys conducted on a complex reef system. Note that because coral reefs vary considerably in their structure, this illustration should be used only as a guide.

Figure 2. *Typical types of invertebrate surveys conducted on a complex reef system. (1) Manta tow assessment; (2) reef-front timed swim; (3) reef-front timed walk; (4) shallow-water timed scuba search; (5) deepwater timed scuba search; (6) night search; (7) reef benthos transect; (8) soft benthos transect; (9) shallow water scuba transect; (10) soft infaunal quadrat.*

This Section presents methodologies used to survey invertebrate species that are commonly of interest to Pacific Island fisheries, including sea cucumbers, clams, gastropods, and 'pest' species such as crown-of-thorns starfish (*Acanthaster planci*). Information on survey methodologies for additional species not targeted in these surveys, such as spiny lobsters, coconut crabs, marine and land crabs, and octopus are included in Appendix 4.

The survey protocols presented in this manual require surveyors to maintain standard methodologies to ensure that data are comparable with the Pacific Islands dataset maintained by SPC. The legend to the right (Fig. 3) has been developed to standardise the terminology in the diagrams presented in this section.

Sample sheets for all of these standard invertebrate surveys are provided in Appendix 5.

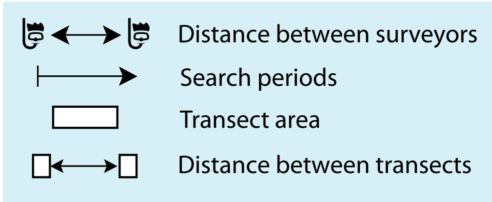


Figure 3. *Legend for survey methodologies in the following diagrams.*

3.2 Broad-scale survey techniques

Manta tow

A manta tow is used to assess large sedentary invertebrates and habitats using a tow board technique adapted from English et al. (1997) (see Section 5). A surveyor holds on to the manta board, which is towed behind a boat that travels at low speeds of less than 2.5 km per hour (Fig. 4), equivalent to half the normal pace of a pedestrian walking.

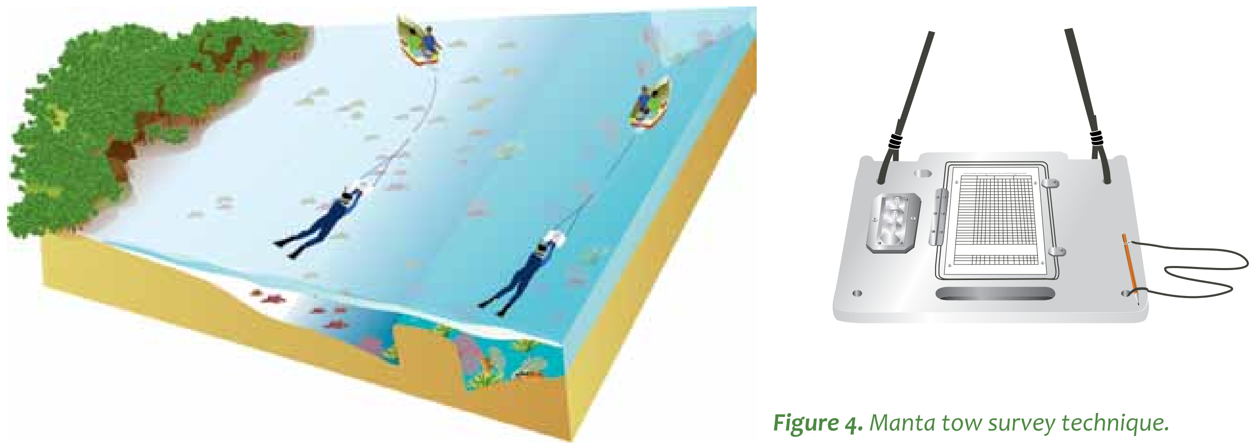


Figure 4. *Manta tow survey technique.*

Manta tow stations are positioned along fringing reefs, lagoon patch reefs, and the back- and outer-reefs of barrier reefs. Manta tow surveys are conducted in depths of 1 to < 10 m of water but usually around 1.5–6 m, covering coral substrates and sand, and the edges of reefs. Manta tows should not be conducted in areas that are too shallow for an outboard powered boat (< 1 m), murky waters where visibility is poor, adjacent to wave impacted reefs (reef top) and over swells that can be dangerous.

Each transect covers a distance of 300 m (total of 6 transects = 1,800 m or 1.8 km) along reef contours and habitats of interest. The transect length is calibrated using the odometer function within the 'trip computer' option of a global positioning system (GPS) unit or an equivalent. Waypoints are recorded at the start and end of each transect to an accuracy of within 10 m, depending on the model of GPS used. The surveyor records the number of large sedentary invertebrates observed within a 2 m swath.

Counts of observed invertebrates are made during the tow, and habitat observations are made at the end of each tow. A manta station comprising 6 manta tow replicates of 300 m length each, takes approximately 1 hour (7–8 minutes x 6, plus recording and moving time between transects). Hand counters are used to assist with enumerating common species.

By passing more slowly over the benthos and concentrating on a narrower (2 m) swath of the benthos, greater care can be taken to obtain a reliable measure of invertebrate presence. Slower speeds maximise efficiency in spotting and identifying cryptic invertebrates, while still covering areas that are large enough to make accurate representative measures.

OBJECTIVES

- Assess the range, abundance, size and condition of invertebrate species and their habitat across broad site scales (fringing reefs, lagoon patch reefs, back-reefs of barrier and outer reefs).
- Generate a broader understanding of a reef system and its habitats, and provide guidance on where to locate fine-scale assessments.
- Provide a general understanding of the reef condition, such as live coral cover and/or coral bleaching.

EQUIPMENT

- Boat with working engine
- GPS to record start and end positions of transect
- Manta tow board with pencil attached to a boat using a 20 m-long rope
- Invertebrate data record sheet (Appendix 5a), specific manta data sheet to record transect position from the GPS (Appendix 5b) and identification cards (Appendix 3) mounted on manta tow board
- Hand counter mounted on manta tow board
- Snorkelling gear, wetsuit and protective gloves

PERSONNEL

- A team of three people is the minimum number required, including a surveyor, a manta tow director who records GPS positions, and a skilful boat driver.

PROCEDURE

1. Locate where the manta tow survey will begin. Prior planning should help to point out where to conduct manta tows.
2. Mount the data record sheet on the manta board, and attach a pencil to the board using a string.
3. Ensure the manta rope is attached to the boat.
4. Follow the command of the manta tow director on the boat. He or she directs both the surveyor and skipper as to the start and end of each tow and where to go. The manta tow director is also in charge of the safety of the surveyor and should maintain visual contact with the surveyor at all times. The boat skipper is responsible for the safety of the boat and must coordinate with the manta tow director.
5. Conduct the manta tow survey along the flat or edge of a reef system. The manta tow director measures the distance (300 m) on the GPS using the 'odometer' function.
6. Stop the boat at the end of each tow so that the surveyor can record the habitat data for the completed manta tow replicate. The boat is then moved 10–20 m from the end position of the previous replicate, and in the general direction of the tows, before starting the next replicate. This ensures that the tows are not exactly contiguous but instead randomly placed. This is repeated until all 6 manta tows (replicates) have been completed for that station (see Fig. 1).

Reef-front timed swim

A reef-front timed swim (RFs) assesses the reef habitat along the reef front (where the waves reach the reef crest) when conditions are suitable (Fig. 5).

Two surveyors conduct three 5-minute searches (six 5-minute swims altogether or 30 minutes in total) along exposed reef front edges where trochus (*Tectus niloticus*), green snails (*Turbo marmoratus*) and other species such as clams and surf redfish (*Actinopyga mauritiana*) are generally aggregated. Due to the dynamic conditions of the reef front, it is not generally possible to lay transects; however, the start and end positions of reef front searches can be recorded with a GPS. The distance that is swum or covered varies between stations depending on environmental conditions such as wind and currents. Habitat observations are made at the end of the search.

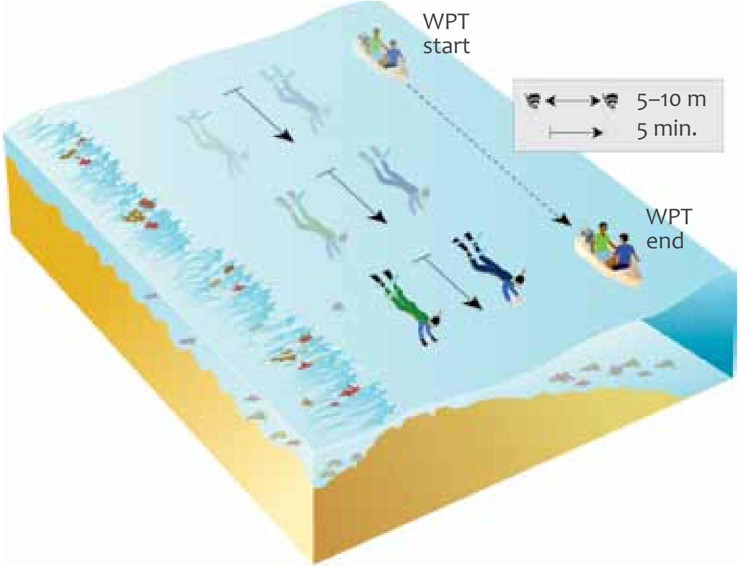


Figure 5. *Reef-front timed swim (RFs). WPT = waypoint.*

OBJECTIVE

- Assess the range and abundance of large sedentary species such as trochus, green snails, clams and surf redfish inhabiting the reef crest, reef front and shallow outer reef zones.

EQUIPMENT

- Boat with working engine
- GPS to record start and end positions of station
- Two stopwatches for timing, one per surveyor
- Two writing slates with pencil, one per surveyor
- Invertebrate data record sheet (Appendix 5a) and identification cards (Appendix 3) mounted on slates
- Snorkelling gear, wetsuit and protective gloves

PERSONNEL

- At least four people are required for this assessment: two surveyors, a boat skipper and an assistant. Surveyors should be fully equipped with a full body wetsuit, protective gloves, mask and snorkel. Note that a boat assistant is needed for this operation in order to assist surveyors and keep an eye on them so that the boat skipper can look after the boat.

PROCEDURE

1. Be aware of sea conditions and direction of the swim.
2. Record GPS positions at the start (when the surveyors get into the water) and at the end of the third 5-minute swim. Each surveyor can keep their own time or one surveyor can record the time and communicate the start and end of each 5-minute search to the other surveyor.
3. Two surveyors swim side-by-side (roughly 5–10 m apart) along the reef front behind the waves. Surveyors should keep a look out for each other.
4. Each surveyor records the abundance (counts) of large sedentary species such as trochus, green snails, clams and surf redfish.
5. Habitat observations are made at the end of the search.

Reef-front timed walk

A reef-front timed walk (RFw) is done by walking along the reef crest at low tide by two surveyors roughly 5–10 m apart (Fig. 6). Each surveyor completes three 5-minute search-walks (15 minutes altogether, plus time for recording habitat data at the end of each 5-minute walk) along the exposed reef crest where trochus (*Tectus niloticus*), turban snails (*Turbo setosus*), clams and surf redfish (*Actinopyga mauritiana*) are generally aggregated. On some atolls, greenfish (*Stichopus chloronotus*) and lollyfish (*Holothuria atra*) can also be found on the exposed reef flat. A GPS position is recorded at the start and end of each walk.

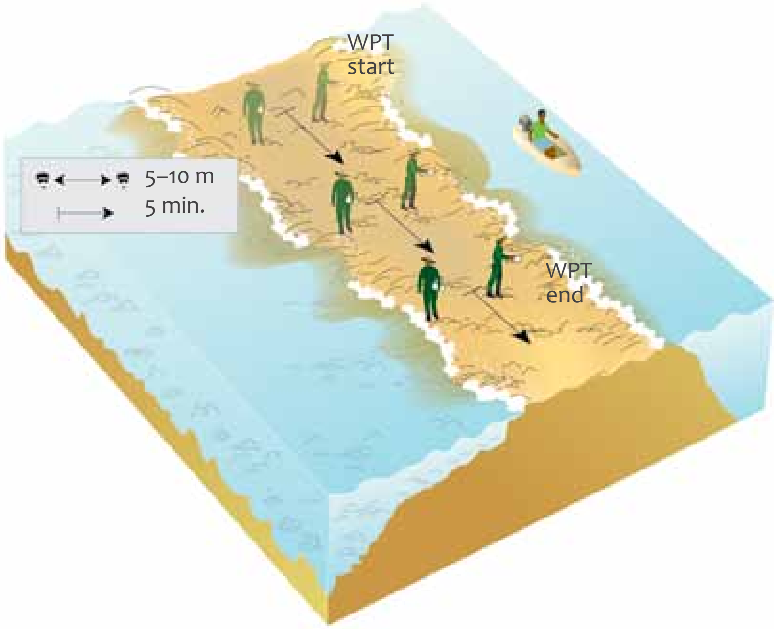


***Figure 6.** Reef-front timed walk (RFw). WPT = waypoint.*

OBJECTIVE

- Assess the range and abundance of large sedentary species such as trochus, turban snails, clams, surf redfish, greenfish and lollyfish aggregating on the reef crest.

EQUIPMENT

- Boat with working engine
- GPS to record start and end positions of replicate
- Two stopwatches for timing, one per surveyor
- Two writing slates with pencil, one per surveyor
- Invertebrate data record sheet (Appendix 5a) and identification cards (Appendix 3) mounted on slates
- Surveyors should wear booties or boots with a strong sole, protective gloves and a hat

PERSONNEL

- At least three people are required for this assessment: two surveyors and a boat skipper for transport to and from the reef front. In some cases the surveyors do not need a boat driver to reach the reef.

PROCEDURE

1. Record GPS positions at the start and at the end of each 5-minute walk. One time keeper is best for this assessment.
2. Two surveyors walk side-by-side (roughly 5–10 m apart) along the reef crest.
3. Each surveyor enumerates all of the sedentary species observed, such as trochus, turban snails, clams, surf redfish, greenfish and lollyfish, and records them on the slate.
4. Habitat observations are made at the end of the search.

Shallow-water timed scuba search

A shallow-water timed scuba search (SWSs) (Fig. 7) is first conducted as a broad-scale assessment to look for locations where mother-of-pearl shells such as trochus, green snails and pearl oysters can be found in reasonable densities. The depth range for these assessments is usually 3–8 m and generally should not exceed 12 m. Local knowledge of the area is important in order to be able to locate grounds where mother-of-pearl shells are generally found.

Two surveyors actively survey during three 5-minute searches (15 minutes for each diver, a total of 30 minutes). More than two individual mother-of-pearl shells found are considered to be sufficient to warrant a fine-scale assessment using shallow water scuba transects (SWSt). However, an SWSs should be completed before an SWSt is conducted.

***Figure 7.** Shallow-water timed scuba search (SWSs).*
WPT = waypoint.

OBJECTIVE

- Gain a broader understanding of where aggregations of large sedentary species, mother-of-pearl shells such as trochus, green snails and pearl oysters generally trochus, are found on the slopes of fringing reefs, lagoon patch reefs, barrier reefs and outer reefs.

EQUIPMENT

- Boat with working engine
- GPS to record start and end positions of station
- Two stopwatches for timing, one per surveyor
- Two writing slates with pencil, one per surveyor
- Invertebrate data record sheet (Appendix 5a) and identification cards (Appendix 3) mounted on slates
- Scuba gear, dive computer, wetsuit and protective gloves

PERSONNEL

- At least four people are required for this assessment: two surveyors, a boat skipper and a boat assistant.

PROCEDURE

1. Avoid shallow water areas close to breakers if the current or swell is strong.
2. Record GPS positions from the boat, at the start and the end of the station. One time keeper is recommended for this assessment.
3. Two surveyors dive side-by-side (roughly 5–10 m apart) at a depth of 3–12 m along the reef front. Because scuba diving presents some risk, surveyors should always be aware of each other, and ensure they are close enough from their partner to be able to render assistance if needed.
4. Each surveyor counts and measures the mother-of-pearl shells that are observed such as trochus, green snails and pearl oysters, and other species of interest.
5. Habitat observations are made at the end of the search.

Deepwater timed scuba search

A deepwater timed scuba search (DWSs) is conducted in depths of 15–40 m, and targets the base of slopes of fringing reefs, lagoon patch reefs and barrier reefs, which are subject to water flow (near passages) and where deepwater sea cucumber species are found (Fig. 8). The replicate distance is not calibrated, but indicative distance can be assessed using start and end waypoints of the dive as recorded from the boat.

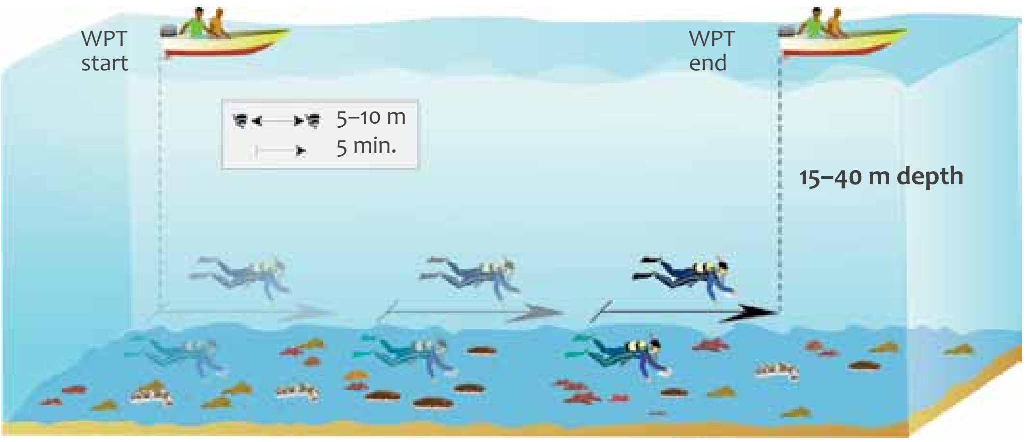


Figure 8. *Deepwater timed scuba search (DWSs).*
WPT = waypoint.

OBJECTIVE

- Assess the range, abundance and sizes of large sedentary species in deep water (generally concentrating on deepwater sea cucumber species such as *Holothuria fuscogilva* and *Thelenota* spp.).

EQUIPMENT

- Boat with working engine
- GPS to record start and end positions of station
- Two stopwatches for timing, one per surveyor
- Two writing slates with pencil, one per surveyor
- Invertebrate data record sheet (Appendix 5a) and identification cards (Appendix 3) mounted on slates
- Scuba gear, dive computer, wetsuit and protective gloves

PERSONNEL

- At least four people are required for this assessment: two surveyors, a boat skipper and a boat assistant.

PROCEDURE

1. Record GPS positions from the boat, at the start and the end of the station. Either surveyor can keep the time, or each surveyor can keep their own time; communication between divers should be maintained.
2. Two surveyors dive side-by-side (roughly 5–10 m apart) at a depth of 15–40 m. Surveyors should progress at the same pace parallel to one another and maintaining the same distance all the way. Because scuba diving presents some risk, surveyors should always be aware of each other, and ensure they are close enough from their partner to be able to render assistance if needed.
3. Each surveyor measures a sample of deepwater sea cucumber species and other large invertebrates. While a few specimens can be measured, this should not interfere too much with the search progression.
4. Habitat observations are made at the end of the search.

Sea cucumber night search

A sea cucumber night search (SCNs) is useful for locating nocturnally active sea cucumber species such as *Actinopyga miliaris* and *A. lecanora*, and is best conducted around fringing reefs and lagoon patch reefs (especially reefs with high relief that are affected by terrigenous influences) that are less than 4 m deep.

These searches are not distance calibrated but snorkelers record a waypoint when they enter the water and when they return to the boat (Fig. 9). A paddle canoe can be used for surveys in shallow water. A hand-held balance is needed to weigh the more variable shaped sea cucumbers (such as *A. miliaris*).

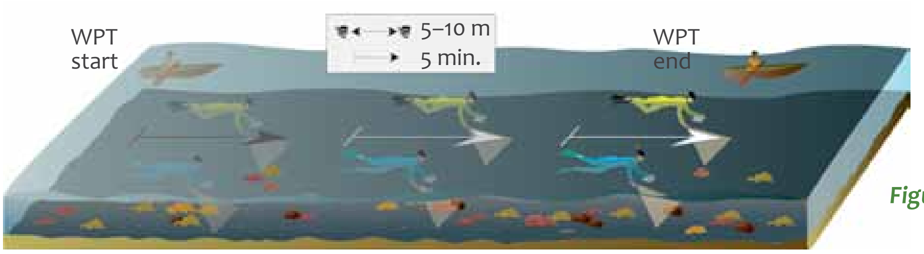


Figure 9. *Sea cucumber night search (SCNs). WPT = waypoint.*

OBJECTIVE

- Assess the abundance and measure the length of nocturnally active sea cucumber species.

PERSONNEL

- At least three people are required for this assessment: two surveyors and a boat driver.

EQUIPMENT

- Canoe or boat with working engine
- GPS to record start and end positions of station
- Two writing slates with pencil, one per surveyor
- Invertebrate data record sheet (Appendix 5a) and identification cards (Appendix 3) mounted on slates
- Snorkelling gear, wetsuit and protective gloves
- Underwater torches (flashlights), one per surveyor, and one for the boat driver to signal the boat

PROCEDURE

1. Locate a suitable site during the day, with waypoints logged for ease of locating the site at night. Surveyors can get to the site at dusk and into the water once night has fallen.
2. Record GPS waypoints from the boat, at the start and finish points from where the surveyors enter and leave the water.
3. Two surveyors snorkel side-by-side (roughly 5–10 m apart) at a depth of 0–4 m along fringing reefs and lagoon patch reefs. Surveyors should keep a look out for each other.
4. Surveyors count nocturnal sea cucumber species and record any other invertebrates of interest.
5. Surveyors collect any sea cucumbers that are to be weighed and place them in the boat. Specimens should be kept in some water (bottom of the canoe or boat, or water-filled bin) until they are weighed and returned to the sea quickly to limit any stress from the procedure.

Lobster night search

Rock lobsters and slipper lobsters are best assessed at night using night timed searches (LNs) outside the reef behind the breakers, and timed reef searches by walking along the reef crest at low tide.

Night searches for lobsters are done in the same manner as daytime timed searches along the same reef zone. Lobsters can be counted for a defined time (e.g. one hour) to collect information on the number of lobsters sighted per unit of effort. GPS records are taken at the start and end of each time period to estimate the distance covered during each search, which can be used to calculate lobster density. More information on this group of crustaceans, and potential survey methods, can be found in Appendix 4. Night assessments of lobsters outside the reef and close to breaking waves can be dangerous so caution must be taken when conducting these surveys.

3.3 Fine-scale survey techniques

Reef benthos transect

A fine-scale, reef benthos transect (RBt) survey is conducted on hard bottom substrates on fringing reefs, lagoon patch reefs, back-reefs, reef flats and reef crest areas to capture invertebrates associated with these habitats. RBt assessments provide a high level of accuracy of the range, abundance, size and condition of invertebrate species and their habitats on smaller spatial scales within fishing areas and areas of aggregated stocks.

For a RBt, a transect is run perpendicular to the shoreline, or across environmental gradients where possible (usually across reefs and not along reef edges). A RBt can also be conducted along the reef crest at low tide by walking and using a GPS odometer function to measure transect length. In this instance, transects are laid along the reef to assess species such as surf redfish, trochus and turban snails.

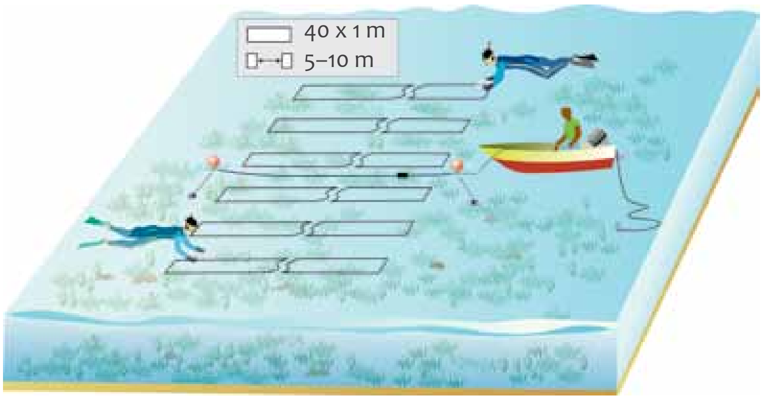


Figure 10. *Reef benthos transect (RBt).*

Surveys consist of six 40 m x 1 m transects. Observations are made by snorkelling or walking at low tide (Fig. 10). Species and habitat data are recorded and a single waypoint is logged for each station (to an accuracy of within 10 m).

OBJECTIVE

- Provide an accurate assessment of the abundance, size and condition of invertebrate species, including aggregations, on hard bottom habitats.

PERSONNEL

- At least three people are required for this assessment: two surveyors and a boat skipper.

EQUIPMENT

- Boat with working engine
- 40-m transect line with a weight and buoy at the end to indicate the length of the transect
- GPS to record start and end positions of station
- Two writing slates with pencil, one per surveyor
- Invertebrate data record sheet (Appendix 5a) and identification cards (Appendix 3) mounted on slates
- Snorkelling gear, wetsuit and protective gloves

PROCEDURE

1. Anchor the boat when a suitable reef benthos habitat is located. Record the GPS waypoint as close to the survey position as possible (only one position is required for the six replicate transects of the station).
2. Two surveyors get into the water (with their mask and snorkel) and attach one end of their 40-m line to a point on the reef (or places the weight) before swimming the other end of their line to a point 40 m away where the end weight is placed (or lines may be tied to dead coral).
3. Surveyors swim along each side of the transect line and record all epibenthic invertebrate resources, including gastropods, sea cucumbers, giant clams, sea stars and urchin species (as potential indicators of habitat condition) within a 1-m swath of benthos. An estimate of habitat cover is recorded at the end of each replicate.
4. Three transects are conducted by each surveyor giving a total of six replicates per station.
5. Habitat observations are made at the end of the search.

Soft benthos transect

The soft benthos transect (SBt) is used specifically for soft bottom, mangrove-associated seagrass beds in order to assess sea cucumbers and other associated species. Similar to an RBt, an SBt station comprises six 40 m x 1 m transects. Soft benthos transects are run perpendicular to the shoreline. Observations are made by snorkelling or by walking at low tide (Fig. 11). Species data and habitat estimate are recorded, and a GPS position is logged for each station (to an accuracy of within 10 m).

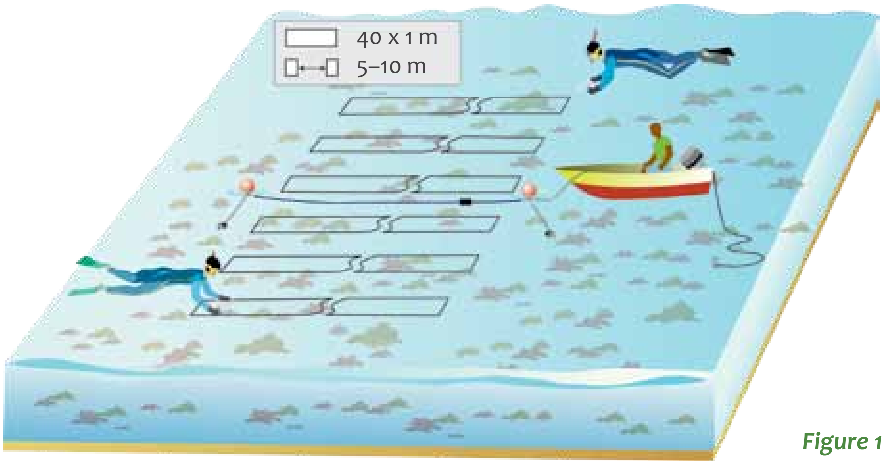


Figure 11. *Soft benthos transect (SBt).*

OBJECTIVE

- Provide an accurate assessment of the range, abundance, size and condition of invertebrate species, including aggregations, on soft bottom seagrass bed habitats.

EQUIPMENT

- Boat with working engine
- 40-m transect line with a weight and buoy at the end to indicate the length of the transect
- GPS to record start and end positions of station
- Two writing slates with pencil, one per surveyor
- Invertebrate data record sheet (Appendix 5a) and identification cards (Appendix 3) mounted on slates
- Snorkelling gear, wetsuit and protective gloves

PERSONNEL

- At least three people are required for this assessment: two surveyors and a boat skipper.

PROCEDURE

1. Anchor the boat when a suitable reef benthos habitat is located. Record the GPS waypoint as close to the survey position as possible (only one position is required for the six replicate transects of the station).
2. Two surveyors get into the water (with their mask and snorkel) and attach one end of their 40-m line to a point on the reef (or places the weight) before swimming the other end of their line to a point 40 m away where the end weight is placed (or lines may be tied to dead coral).
3. Surveyors swim along each side of the transect line and record all epibenthic invertebrate resources, including gastropods, sea cucumbers, giant clams, sea stars and urchin species (as potential indicators of habitat condition) within a 1-m swath of benthos. An estimate of habitat cover is recorded at the end of each replicate.
4. Three transects are conducted by each surveyor giving a total of six replicates per station.
5. Habitat observations are made at the end of the search.

Shallow water scuba transect[1]

A shallow water scuba transect (SWSt) entails six 40 m x 2 m transects (Fig. 12), and is designed to provide a fine-scale assessment of areas where aggregations of mother-of-pearl shells exist.

The depth range for this assessment is 3–12 m. Transects are placed randomly within identified areas, generally across depth and habitat gradients. A hip-mounted surveyor measurement system (e.g. Chainman®, thread release measures) is used to measure out the 40-m transects. Chainman® are easier to use than transect tape measures because they do not require retrieval. This saves time and energy, and speeds up the process for data collection in areas where working conditions are often dynamic.

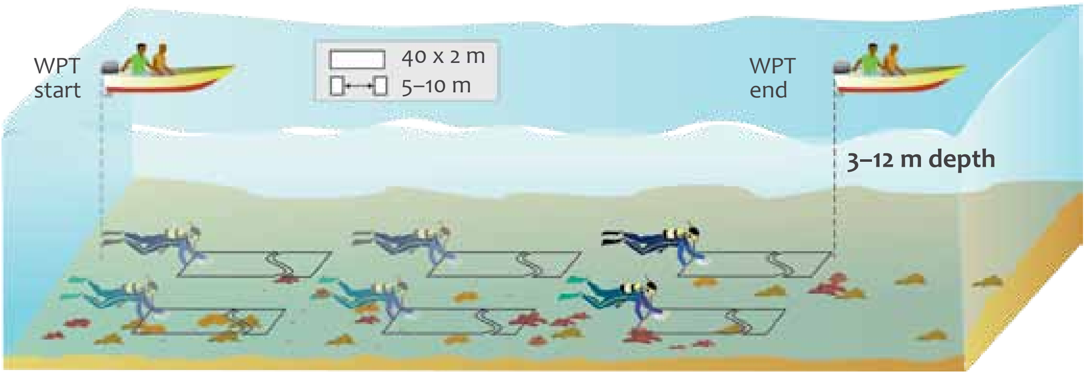


Figure 12. *Shallow water scuba transect (SWSt). WPT = waypoint.*

OBJECTIVE

- Collect accurate data from areas where populations of mother-of-pearl shells are found in reasonable densities. At these stations, the abundance and size distribution of large sedentary species are measured.

PERSONNEL

- At least four people are required for this assessment: two surveyors, a boat skipper and a boat assistant to support the divers and skipper.

EQUIPMENT

- Boat with working engine
- GPS to record start and end positions of station
- Two writing slates with pencil, one per surveyor
- Invertebrate data record sheet (Appendix 5a) and identification cards (Appendix 3) mounted on slates
- Chainman® loaded with thread line
- Scuba gear, dive computer, wetsuit and protective gloves

PROCEDURE

1. Allocate time at the end of each 40-m transect in order to complete all observations, including habitat data. A 5–10 m space is left between transects before a new transect is begun.
2. Two surveyors on scuba dive side-by-side (5–10 m apart) along the reef front at a depth range of 3–12 m. One surveyor controls the Chainman® and communicates the start and end point of each 40-m transect to the other surveyor. Because scuba diving presents some risk, surveyors should always be aware of each other, and ensure they are close enough from their partner to be able to render assistance if needed.
3. Surveyors should progress at a similar pace to the other surveyor, maintaining the same distance apart for the length of the transect. The surveyor who is not holding the Chainman® should ensure they stop their transect at the signal of the partner that has the Chainman®.
4. Each surveyor takes accurate measurements (to the nearest millimetre) of species observed such as trochus, gastropods and giant clams along the 40-m transect. For sea cucumber species, measurements can be rounded to the nearest 5 mm.
5. Surveyors record the size of a subset (e.g. 15–20) of the species of interest (if they are too numerous), and record the rest only as a count.

[1] This technique has also been referred to as mother-of-pearl transect (MOPt) in some SPC reports.

Soft infaunal quadrat survey

A soft infaunal quadrat (SiQ) survey is used to assess infaunal species (animals that burrow and live within the bottom substratum) such as *Anadara* spp., *Gafrarium* spp. and juveniles of other soft benthos species. An SiQ survey is usually done at low tide in seagrass areas (Fig. 13). SiQ is conducted within a 40 m x 2 m transect with eight sets of quadrats on either sides of the transect.

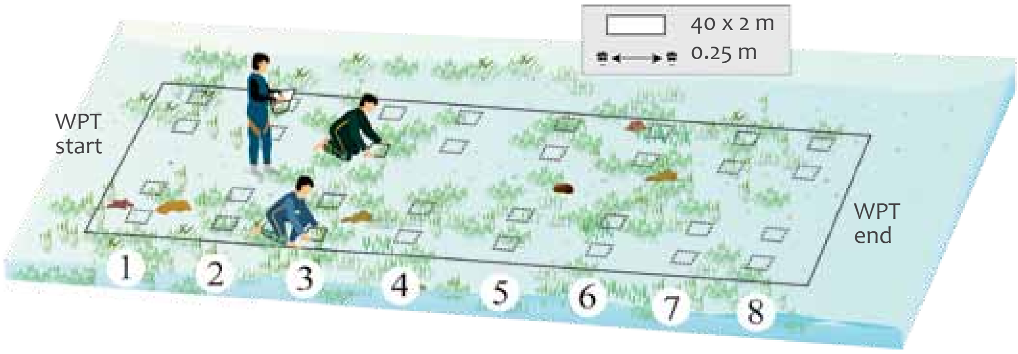


Figure 13. *Soft infaunal quadrat (SiQ) survey. WPT = waypoint.*

OBJECTIVE

- Assess the abundance, distribution and size of infaunal invertebrates (generally bivalve resources) at the scale of seagrass areas or shell beds.

EQUIPMENT

- GPS to record position of station
- One writing slate with pencil and ruler
- Invertebrate data record sheet (Appendix 5a), SiQ data record sheet (Appendix 5c) and identification cards (Appendix 3) mounted on slates
- Two 25 cm x 25 cm quadrats made of wire, one per surveyor
- Surveyors should wear booties or boots with a strong sole, protective gloves and a hat

PERSONNEL

- At least three people are required for this assessment: two surveyors and a recorder.

PROCEDURE

1. Identify an area to be sampled using the SiQ technique.
2. Consult a local tide chart to determine the time of day to conduct the survey. The best time to conduct these surveys is at low tide. Considering the short low tide time (around two hours), the survey team should make full use of the low tide period.
3. Record the GPS positions at the start and the end of each station. Habitat data should also be recorded.
4. Two surveyors side by side, randomly throw the quadrat and retrieve sediments within the quadrat down to approx 5–8 cm and sort through the sediment for infaunal species; species found are measured and recorded. Counts and size data are recorded onto the SiQ record sheet.
5. Sample eight groups of four quadrats every 5–6 m between the start and end points of the 40-m transect.

Techniques for surveying coconut crab

Coconut crabs (*Birgus latro*) live on high islands, low-lying islands and atolls. More information on this species can be found in Appendix 4.

High islands

Baited trails: Tethered opened coconuts are used as lures (similar to how subsistence communities hunt for coconut crabs). Baits are set out in an ordered grid system (equidistant apart and the same number of traps per survey sample) through the forest area. The baits are inspected regularly throughout the night. This involves setting a number of baits along a trail during the day and revisiting the baits after dark, collecting the crabs that are attracted to the baits. The density of crabs can only be estimated from catch per unit of effort (number of crabs per coconut bait). Size and sex ratio (male to female) information can also be gathered.

For more detailed information refer to Fletcher and Amos (1994) (see Section 5) and Appendix 4.

Low-lying islands and atolls

Small, low-lying islands and atolls can be surveyed more easily than larger high islands. On small islands and atolls, coconut crab stocks can be assessed by laying transects across the entire island. Transect length can be measured by taking a distance between two GPS points or from a GPS trip odometer function where GPS reception is good. A more traditional approach is to mark out several fixed transects (paths) across the island (from beach to beach) with a set width (e.g. 5 m) and survey these areas over time (during the night and day) to monitor changes in crab abundance, size and sex ratio. These data are used to calculate density, and if the total area of the island is known, a stock estimate can be made.

3.4 Quality of information from each survey technique

The distribution, density and size of species of interest are some of the key data that are needed to make an assessment of resource status. Different sampling techniques do not provide the same information, so the most appropriate survey technique needs to be selected, based on the species of interest and the survey objective. Table 1 provides information on the quality of data generated from each of the methods introduced in Section 3. The selection of the appropriate survey method to suit the project objectives and budget is an important consideration when planning a survey, and staff at SPC's Coastal Fisheries Programme are available to offer advice.

Resource distribution: Techniques covering broad spatial areas across a site can offer the most realistic understanding of resource distribution and help to locate areas where more focused surveys should be conducted. In this case, a manta tow is often a good choice because it covers a large area and, because it uses an engine, it can be relatively quick to complete over large spatial scales. RFs, RFw and SWSs can also be used at stations placed across considerable distances, but these techniques require more physical effort and more time to complete.

Specimen counts: In order to get counts of species of interest, the surveyor needs time to accurately count individuals. Therefore, techniques that allow the sampler to stop and carefully investigate an area are preferred. The following are considered the best techniques for obtaining high quality information on counts: RBt, SBt, SWSt, SiQ, RFw, SWSs, DWSs and LNs.

Resource density: Density calculations are based on counts made over a known surface area. High quality density estimations can be calculated from stations that allow accurate counts over a precisely defined area.

For broad-scale surveys that are not constrained by transect tapes or quadrats, the search area for transects and stations will vary depending on the distance the surveyor can swim or walk, and the width at which the surveyor can visually detect individual specimens. The actual distance and width of samples using timed swims and/or walks or approximate distance measurements, and the accuracy can vary due to water turbidity, depth, complexity of the environment, and current speed. Therefore, in order to have comparable data between stations of the same type it is essential to conduct surveys under similar field conditions at each station. Following these rules will allow a better comparison by lowering the variability of the area covered in the station.

Specimen size: Measuring the size of specimens is important for a variety of reasons. For example, to estimate the harvestable number of trochus within a population, measurements are compared to legal harvest sizes. Techniques that allow the surveyor to stop and take time to carefully measure the specimens (e.g. RBt, SBt, SiQ and SWSt) are the best techniques to adopt when accurate measures are needed. In some cases, less accurate measures are sufficient (e.g. ranking adult and juvenile size groupings of crown-of-thorns starfish); these types of measurements can be collected during manta tow surveys.

Table 1. Survey methods and the quality of information generated by each.

	Survey method		Species identification	Species distribution	Specimen count	Species density	Specimen size and population condition
BROAD-SCALE SURVEY	Manta tow	Manta tow	**Medium** (larger size species)	**High** (larger coverage area)	**Medium** (speed of survey, depth, clarity, current can limit observations)	**Medium** (transect length taken from GPS rather than measured *in situ*)	**Poor** (non-stop assessment, cannot stop to take ruler or tape measurements)
	Reef-front timed swim	RFs	**Medium** (for target species)	**Medium** (medium coverage area)	**Medium** (swim survey distant from the benthos)	**Low** (less accurate coverage area – GPS points)	**Poor** (no size record, need to cover larger area)
	Reef-front timed walk	RFw	**High** (for target species)	**Medium** (medium coverage area)	**High** (walk at slow speed, able to count accurately)	**Medium** (area estimated from GPS)	**High** (access to sufficient size measures)
	Shallow-water timed scuba search	SWSs	**Medium** (aim to locate aggregations)	**Medium** (medium coverage area)	**High** (moderate to low movement)	**Poor** (estimated area, with searching to find suitable habitat)	**Medium** (good access to species, but generally this is a search for trochus)
	Deepwater timed scuba search	DWSs	**Medium** (for target species)	**Medium** (medium coverage area but difficult to select suitable habitat from the surface)	**High** (moderate to low movement, able to pick up target species)	**Low** (coverage area less accurate from GPS points)	**Medium** (time limits for deep diving precludes multiple measures)
	Sea cucumber night search	SCNs	**High** (for target species)	**Low** (small coverage area)	**Low** (low lighting, clarity limit visibility)	**Poor** (coverage area is less accurate)	**Medium** (target sea cucumber species)
FINE-SCALE SURVEY	Reef benthos transect	RBt	**High** (accurately identify species)	**Low** (only per station, small coverage area)	**High** (target habitat and species aggregations)	**High** (well defined area and accurate count)	**High** (access to sufficient size measures)
	Soft benthos transect	SBt	**High** (accurately identify species)	**Low** (only per station, small coverage area)	**High** (target habitat and species aggregations)	**High** (well defined area and accurate count)	**High** (access to sufficient size measures)
	Shallow water scuba transect	SWSt	**High** (accurately identify species)	**Low** (small coverage area)	**High** (target habitat and species aggregations)	**High** (well defined area and accurate count)	**High** (access to sufficient size measures from aggregations)
	Soft infaunal quadrat	SiQ	**High** (for target species)	**Poor** (digging requirement limits area coverage)	**High** (survey covers the sampled area)	**High** (well defined area and count)	**High** (good access to target species)
	Lobster night search	LNs	**High** (for target species)	**Low** (coverage area limited)	**High** (for target species)	**Medium** (coverage area less accurate)	**Poor** (unable to measure sizes)
	Baited coconut	Crab bait	**High** (for target species)	**High** (able to cover a large area)	**High** (moderate to low movement, able to pick up target species)	**High** (estimated from the number of crabs per coconut bait)	**High** (access to sufficient size measures)

3.5 Time estimates and costs associated with conducting a survey

Appendix 6 provides estimated costs and equipment by survey method for completing a general invertebrate survey over a site of approximately 50 km^2 (10 km by 5 km). Such a survey needs approximately 50 hours and 40 minutes of field work to complete (around 6 days). However, this is the actual time needed on site and it does not include travel time to and from the site. As an example, if it takes 1 hour to get to the site and 1 hour to return, field work time would be a standard work day (8 hours) minus 2 hours for travel time, leaving 6 hours of field work per day. Therefore, in the example in Table 6.3 of Appendix 6, where 50 hours and 40 minutes are needed for the total survey time, the overall survey would take approximately 9 working days to complete based on a standard 8-hour day.

Knowing the amount of time it takes to complete a full survey, including travel time, allows the actual cost of the survey to be calculated. Staff costs can be calculated based on daily wages (or salary) for each survey member. Total boat expenses can be calculated if the hourly cost of boat use is known (including outboard fuel, oil and maintenance). The total cost for dive tanks is calculated from the individual cost for renting or refilling. If dive gear or other specialist equipment is needed, then these costs need to be added to the overall costing of the planned survey. Finally, a contingency should be factored in to cover unplanned events (e.g. bad weather).

4. Data entry and analysis to answer management questions

This Section presents the stages of processing and extracting information that are required after completing field data collection. For quality control purposes, the use of the standardised regional Reef Fisheries Integrated Database (RFID) developed for PICTs by SPC is recommended as the main data management tool. RFID is designed to make data entry and analysis easier, and provide quality control and safe storage of data for future comparisons. However, given the difficulties of such technologies in remote islands, Microsoft Excel spreadsheet procedures are provided as the second option for analysing data collected from field surveys.

The main stock status indicators of interest for fishery management are:

- Species lists
- Species distribution patterns
- Abundance and density measures
- Size frequency (size class structure)
- Standing stock measures

This Section provides guidance on analysing stock status indicators through working examples. The different ways of presenting results from the different assessments are provided to address the distribution and habitat specificity of species, the status of resources, and the success of management practices (e.g. fishery closures, habitat protection). This manual does not address management responses in detail, but rather provides information on how to collect and examine data for better-informed management and decision making.

4.1 Data entry and quality control

Before any data analysis is done, data must first be entered into the computer and checked for correctness. This important step ensures that correct results are produced, and that errors as a result of incorrect data entry are avoided. The use of RFID as a tool is encouraged in this manual in order to improve PICTs' data management and use.

Cleaning data (checking)

Data cleaning or checking begins in the field but the final checking is done during data entry and before any analysis is performed. This can be done either by an individual, or by two people cross-checking data together between the computer screen and the raw data. The latter is considered to be more useful because errors can be picked up easily.

Running queries in RFID

A database 'query' is a 'question' you ask of the information you have entered into the database. Results (output) of the query are information returned to you by the database management system. There are several queries in the database but the main ones used for invertebrate data analysis are:

- species presence by station type (to assess the number of species recorded);
- average density by species and/or transects and stations (to assess abundance); and
- length frequency by site and species (to assess size distribution).

Exporting data to excel spreadsheet

RFID is compatible with Microsoft Excel, and query results can be copied from RFID and pasted into Excel spreadsheets for further processing. Other data analysis software is available but Excel is most widely used in PICTs. Simply copy and paste the query summary table onto an Excel spreadsheet page.

In the absence of RFID, all data can be entered directly into a Microsoft Excel spreadsheet and associated functions can be used to extract desired results.

4.2 Analysis of stock status indicators

Number of species present

The number of species present is simply the total count of different invertebrate species observed in a site or a defined reef habitat area. This information is important for monitoring macroinvertebrate assemblages for baseline assessments or monitoring diversity in multispecies fisheries to assess the state of species that might require certain protection measures.

In resource assessments, the chances of detecting all the species of importance that are present at a site or station increases with increased sampling effort (number of stations or time at a station). That is, the higher the number of stations or transects (replicates) completed, the higher the number of species recorded until a certain point is reached where additional transects will not reveal any more species (all species present are counted). On the other hand, too little sampling effort will likely underestimate species presence. Therefore, a high number of stations and transect effort is always recommended to improve information about species presence in an area.

Species presence for baseline surveys

The assessment methods provided in this manual are specific to habitat types to enable distinction of data by habitats. Table 2 provides an example of how the number of species observed varies with different survey methods conducted in different habitat types. In this example, it can be seen that a combination of methods is required to capture the number of species that are present in an area more accurately. If the same amount of survey effort and observations are done at another reef or at the same reef at another time, relative species presence can be compared with some degree of certainty.

Table 2. Species detected by method and habitat type (based on hypothetical data).

Group	Scientific name	Manta tow Back-reef and lagoon slope	Reef benthos transect (RBt) Back-reef zone	Soft benthos transect (SBt) Seagrass bed
Echinoderm – Sea cucumber	*Actinopyga mauritiana*	+	+	+
Echinoderm – Sea cucumber	*Bohadschia argus*	+	+	
Echinoderm – Sea cucumber	*Holothuria atra*	+	+	+
Echinoderm – Sea cucumber	*Holothuria edulis*	+	+	
Echinoderm – Sea cucumber	*Holothuria whitmaei*		+	
Bivalve	*Pinctada margaritifera*	+		
Bivalve	*Tridacna maxima*	+	+	+
Gastropod	*Charonia tritonis*	+		
Gastropod	*Conus flavidus*		+	
Gastropod	*Cypraea annulus*		+	
Gastropod	*Lambis truncata*	+	+	
Gastropod	*Turbo setosus*		+	+
Echinoderm – Sea Star	*Linckia laevigata*	+		
Echinoderm – Sea Urchin	*Echinometra mathaei*	+	+	+
Echinoderm – Sea Urchin	*Echinothrix diadema*		+	
Echinoderm – Sea Urchin	*Tripneustes gratilla*	+	+	+
Total species count	***16***	***11***	***13***	***6***

Table 3. Species presence and ranking by number of individuals observed for a sea cucumber fishery (based on hypothetical data)

Common name	Scientific name	Presence	Number of individuals observed	Rank
Lollyfish	*Holothuria atra*	+	715	1
Chalkfish	*Bohadschia similis*	+	250	2
Sandfish	*Holothuria scabra*	+	221	3
Dragonfish	*Stichopus horrens*	+	108	4
Snakefish	*Holothuria coluber*	+	69	5
Greenfish	*Stichopus chloronotus*	+	60	6
Tigerfish / Leopardfish	*Bohadschia argus*	+	56	7
Brown sandfish	*Bohadschia vitiensis*	+	43	8
Hairy blackfish	*Actinopyga miliaris*	+	26	9
Pinkfish	*Holothuria edulis*	+	24	10
Curryfish	*Stichopus herrmanni*	+	23	11
Red snakefish	*Holothuria flavomaculata*	+	20	12
Golden sandfish	*Holothuria lessoni*	+	17	13
Black teatfish	*Holothuria whitmaei*	+	15	14
Elephant trunkfish	*Holothuria fuscopunctata*	+	13	15
White teatfish	*Holothuria fuscogilva*	+	12	16
Prickly redfish	*Thelenota ananas*	+	10	17
Flowerfish	*Pearsonothuria graeffei*	+	8	18
Surf redfish	*Actinopyga mauritiana*	+	6	19
Deepwater blackfish	*Actinopyga palauensis*	+	5	20
Stonefish	*Actinopyga lecanora*	+	4	21
Brown curryfish	*Stichopus vastus*	+	2	22
Amberfish	*Thelenota anax*	+	1	23
Total number of species recorded		***23***		

Species distribution patterns and habitat preferences

Invertebrate species are distributed unevenly from the shore to the outer reef (horizontal distribution), and from shallow to deep outer slope and passages (vertical distribution).

Species distribution patterns are closely correlated with the spatial patterns of different habitats (e.g. cover of seagrass or corals, sediment or substratum characteristics, and relative exposure to wave action and currents). For example, habitat preference for juveniles of some gastropods such as trochus (*Tectus niloticus*) are the back-reef and reef flat zones where there is high habitat relief and complexity, while adult trochus inhabit the outer reef and near passes where greater water flow is experienced. Figure 14 illustrates a typical complex reef profile indicating the location of different habitat zones and their nomenclature used in the description of species distributions in this manual.

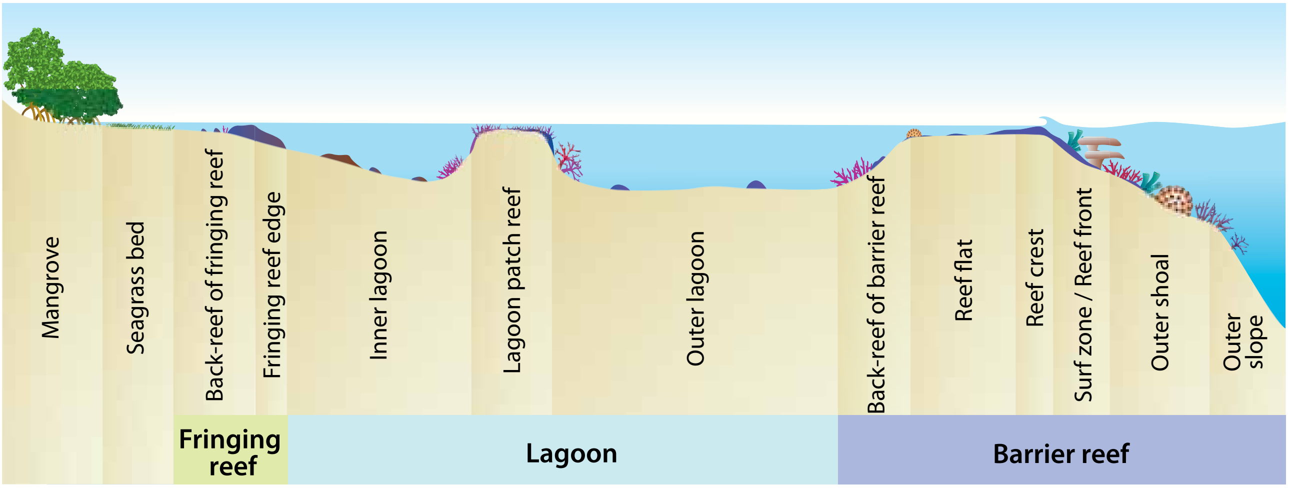


Figure 14. *Standardised terminology for habitat descriptions used in this manual.*

Horizontal distribution

GPS positions of stations and records of species present can be used to understand species and habitat distribution on the reef, as in the example in Figure 15. In this example, the horizontal distribution of surf redfish (*Actinopyga mauritiana*) is presented based on assessments conducted across the Pacific by SPC. The main habitat of *A. mauritiana* is along the reef crest, surf zone and outer shoal of the barrier reef, while moderate to low densities are found on the back-reef of the barrier reef, lagoon patch reefs and fringing reef edges. In a fringing reef system, this species would aggregate along the fringing reef edge.

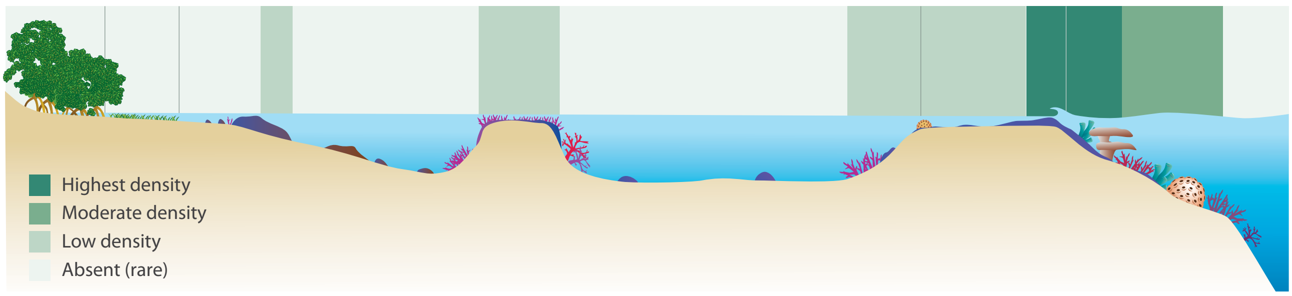


Figure 15. Actinopyga mauritiana *distribution profile in a complex reef system.*
Results presented here are from an amalgamated dataset from Pacific-wide surveys undertaken by SPC. White zones = not present; light green zones = low densities; green zones = medium densities; dark green = high densities.

Vertical distribution

Understanding patterns of species' vertical distribution (depth distribution) is equally important. Figure 16 shows an example of the vertical distribution of *Actinopyga mauritiana* based on pooled SPC data from multiple Pacific Island sites. From this information, it could be concluded that *A. mauritiana* is a shallow water species that is found in depths of 0–10 m with the highest density found within the first meter of depth. *A. mauritiana* is a very shallow water species that can be easily overharvested without effective management measures in place.

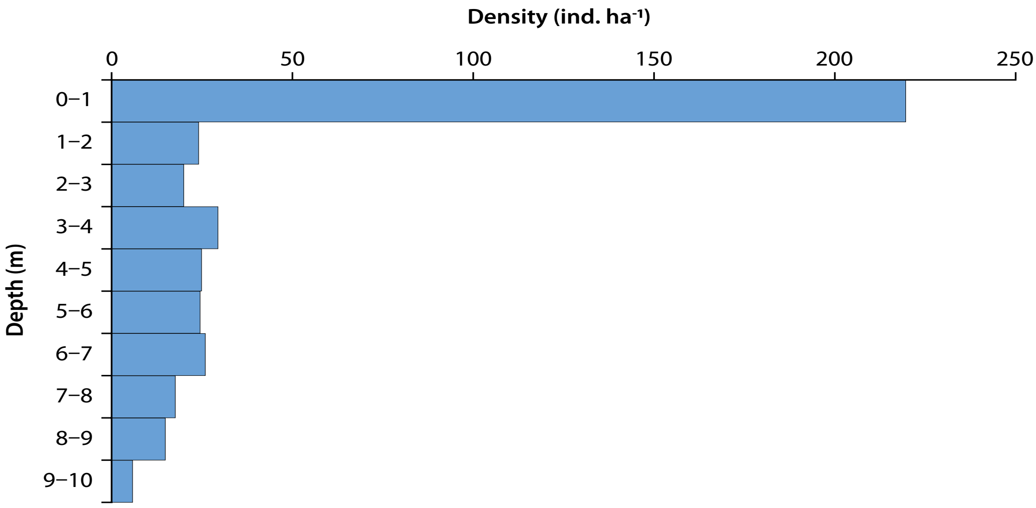


Figure 16. *Relative density of* Actinopyga mauritiana *by depth. Density estimates are from pooled data from Pacific Island sites surveyed by the Secretariat of the Pacific Community.*

Spatial distribution

Obtaining spatial distribution data of species across all stations in a survey area is becoming increasingly possible with the development of GPS recorders and geographic information system (GIS) mapping software technologies. Distribution of species and their local density by station enables better understanding of both the distribution of species and their aggregation across the site of interest. Further explanation on the causes of such distribution can then be provided, which could range from habitat type, distance from population centres, managed areas verses unmanaged areas or current flow patterns. This information is also of interest to fishers, which could lead to targeted fishing and overharvesting if suitable management measures are not in place when this information is published. The example in Figure 17 shows the spatial distribution of *Bohadschia argus* densities on the reef system of Yap (Federated States of Micronesia)

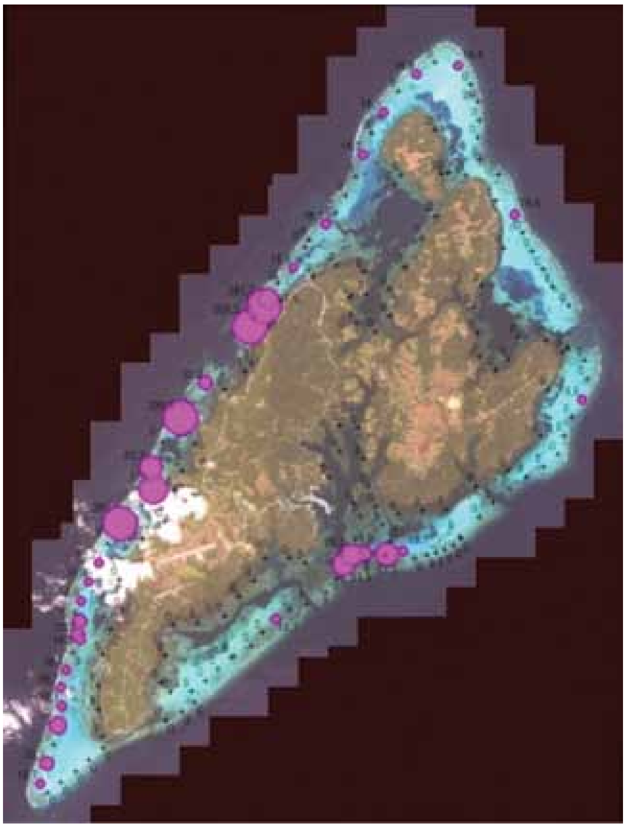


Figure 17. *Distribution of* Bohadschia argus *described by density measures from survey stations across an island in the Pacific (larger circles represent higher densities at survey stations).*

Abundance and density measures

Species density is the number of individuals of a species in a given area at a given time. Density can be used to determine the health of a fishery stock or ecosystem. Density of slow-moving or fixed-bottom living (sedentary) species are calculated by dividing the number of individuals in an area by the area assessed.

Density = Specimen count / area assessed in hectares (ha)

Density calculations are done automatically by RFID, and query and generated results can be copied to Microsoft Excel spreadsheets for further analysis and graphics. The calculation of densities in RFID is based on average area coverage by survey types provided in Table 4. Summary tables such as Table 5, yield two main types of mean densities ('Present mean density' and 'Overall mean density') with their standard errors. Indicative survey areas are provided for timed assessment types and it is recommended that the actual areas used in surveys be substituted for these general approximations.

Table 4. The standard and estimated area covered by each survey technique.

Survey method		Transect length (m)	Transect width (m)	Transect surface area (m^2)	Number of transects (replicates) per station	Station surface area (m^2)
BROAD-SCALE SURVEY TECHNIQUES						
Manta tow	Manta	300	2	600	6	3,600
Reef-front timed swim	RFs	~ 137*	3.5*	478*	6	2,870*
Reef-front timed walk	RFw	~ 141*	2.5*	353*	6	2,120*
Shallow-water timed scuba search	SWSs	~ 88*	3*	266*	6	1,596*
Deepwater timed scuba search	DWSs	~ 126*	6*	754*	6	4,524*
Sea cucumber night search	SCNs	73*	2*	146*	6	876*
FINE-SCALE SURVEY TECHNIQUES						
Reef benthos transect	RBt	40	1	40	6	240
Soft benthos transect	SBt	40	1	40	6	240
Shallow water scuba transect+	SWSt	40	2	80	6	480
Soft infaunal quadrat	SiQ	40	**	**	**	2

+ Also called MOPt in other reports by the Secretariat of the Pacific Community (SPC).

* Estimation based on hundreds of stations with the help of GPS start and finish records. GIS software allowed these estimated areas to be defined from SPC field experience.

** Soft infaunal quadrat stations consist of 32 quadrats of 25 cm x 25 cm.

Overall mean density

Overall mean density is the density of a species for all stations and transects and for the same survey type conducted at the site, including stations and transects with and without zero records.

Present mean density

The present mean density of a species is the density of a species calculated using only stations and transects of the same survey type where that species was recorded (record ≥ 1).

Both overall mean density and present mean density can be used to understand the nature of the distribution of species (patchiness and nature of aggregations) over the site of interest. Percentage present is the percentage of stations and/or transects (replicates) where the species is present. In Table 5, *Actinopyga mauritiana* was observed in 9% of transects and 15% of stations, indicating that the species may be relatively rare across the site and was never in dense aggregations even when it was located.

Standard error and standard deviation

Standard error (SE) is the standard deviation (STD) of the sample-mean's estimate of a population mean. It is calculated using the formula SE = STD / √n, where STD is the standard deviation, and n is the number of samples (e.g. stations or transects) from which the mean density is calculated. This is done automatically by RFID when the density query is run. Manual calculation of SE and STD using Microsoft Excel is provided in Appendix 7.

Table 5. Mean density for reef benthos transect surveys (density values are in number hectare^{-1}).

Species	All Transects			Transect_P				All Stations			Station_P			
	Overall mean	SE	n	Present mean	SE	n_P	%_P	Overall mean	SE	n	Present mean	SE	n_P	%_P
Actinopyga mauritiana	38.5	16.5	78	428.6	105.1	7	9.0	38.5	27.7	13	250.0	83.3	2	15.4
Holothuria atra	28.8	14.4	78	450.0	122.5	5	6.4	28.8	19.7	13	187.5	20.8	2	15.4
Tridacna maxima	3,003.2	381.7	78	3,718.3	425.6	63	80.8	3,003.2	889.4	13	3,253.5	927.8	12	92.3
Tectus niloticus	1253.2	255.9	78	2,715.3	445.7	36	46.2	1253.2	572.3	13	1,810.2	763.9	9	75.0

Mean = mean density (in number ha^{-1}); Transect_P = results of transect where species is present; Station_P = results of station where species is present; n = number of transects or stations; SE = standard error; n_P = number of transects or stations where species is present; % _P = percentage of transects and stations when a record is present.

In this example, the coverage area for all transects and all stations surveyed are the same, and therefore derive the same overall mean densities. Note that the present density is typically higher for Transect_P than Station_P because Transect_P assesses density of all transects with records while Station_P contains some transects with zero records.

Presentation of species density by individual survey type

Species density by survey type can be presented graphically. For example, Figure 18 shows a graphical presentation of mean density for 18 sea cucumber species from RBt assessments from a Pacific Island site. Standard errors indicate the spread in the range of data that was used to calculate the mean. Presenting data in this manner clearly demonstrates densities of individual species and allows for comparisons among species or treatments (e.g. marine protected area or marine managed area versus marine non-protected area or non-managed marine area sites). In the example below, three species of sea cucumber occurred in greater densities than the others: *Bohadschia similis*, *Holothuria* atra and the high-value *H. scabra*. From such graphical displays, it is possible to compare this site's data with similar sites in the Pacific, and discuss reasons as to why the high density of some species was recorded (e.g. whether there is a managed area at the site or whether the fishery has been closed).

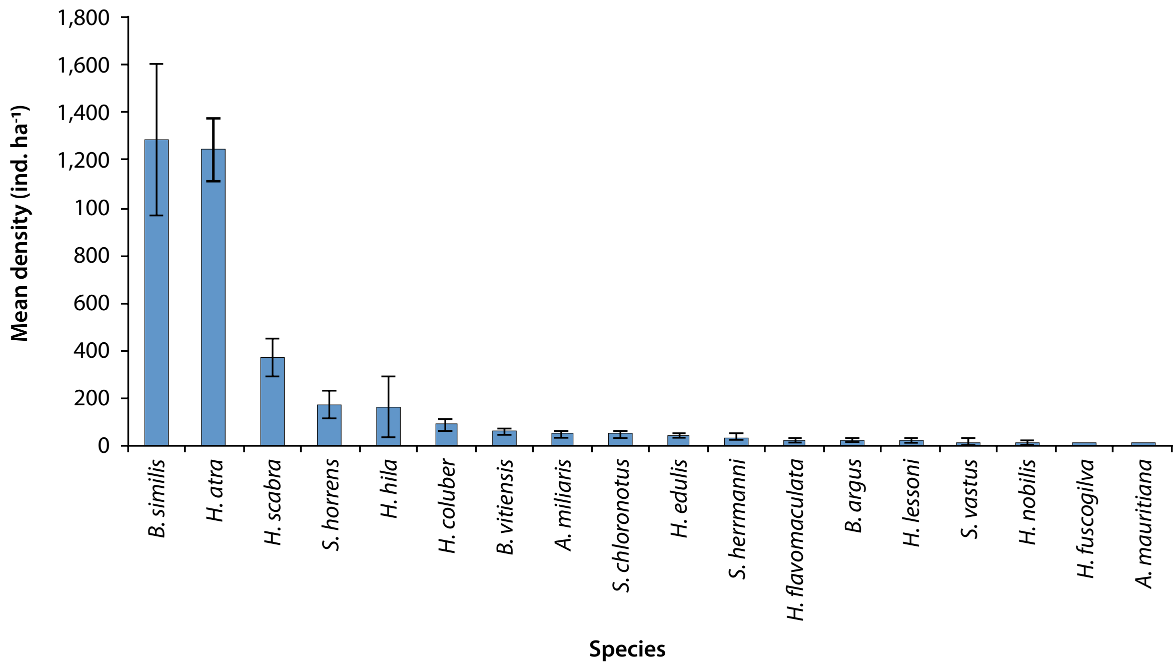


Figure 18. *Mean density of sea cucumbers (± SE) from soft benthos transect surveys conducted at a Pacific Island site.*

Presentation of species density combined across different survey types

Data collected using assessment methodologies that survey the same area such as RBt, SBt and SWSt can be grouped to assess overall densities of invertebrate species. This is frequently necessary in invertebrate assessments where different methods are used in different habitats to obtain overall densities of a species for stock estimation purposes and for comparisons among sites or surveys to better understand trends in resource status. This can be achieved in RFID by selecting the desired methodologies (e.g. RBt and SBt, or RBt and SWSt) when establishing a query. Density assessments from manta tow surveys should be treated separately because the sample area is larger than the sampled area of RBt, SBt and SWSt. This presents some issues when assessing overall densities for species such as lollyfish, which can be surveyed across multiple habitats using multiple methods (e.g. manta tow, RBt, SBt). A solution would be to look at estimating the density based on the area of reef zone covered by the different assessment methods.

Harvest assessment reference points

Harvest assessment reference points, whether they are based on complicated stock viability analyses or on comparative datasets taken from similar sites across a fishery, offer useful information (rules of thumb) that fisheries managers can use to swiftly and efficiently assess whether their stocks are harvested to a point of potential recruitment depletion or are still in good shape. If fished to below what is considered to be a healthy reference point, stocks may be less able to supply juveniles to sustain or increase the population.

Stock density can be an informative reference point for assessing the status of invertebrate resources. Because there is too little information known about the life history of many species and the fisheries that impact these resources, SPC has developed 'rule of thumb' density reference points to help managers assess the health of their stocks by comparing data against what might be considered to be a 'natural' or close to a natural density for that species. In reality, site-specific species density reference points are more accurate because species density varies by geographical location, island type, habitat and local oceanographic conditions. For the purposes of this manual, regional species reference points have been calculated using numerous records from past and present assessments from around the Pacific. For trochus fisheries, a healthy stock density reference for all trochus sizes has been established at 500–600 individuals per hectare.

Healthy stock reference densities for 18 sea cucumber species (by survey method) have been developed (Table 6) for use in the absence of site-specific density references and as a guide to developing new site density reference points. These figures were derived from individual species densities across 91 sites assessed in 17 countries over the period 2002–2012 and taking the mean of the upper 25% of these densities. Effectively, they are an average of the 25% of the highest abundance (densities) from the Pacific Island dataset. These regional densities can be used as a baseline to check for healthy abundances of sea cucumbers, however more work is recommended to refine these densities for each individual situation (e.g. island type). Results of size distribution can be used in conjunction with reference densities to determine suitable harvest quotas.

Table 6. Pacific regional reference densities for healthy sea cucumber stocks (Pacific dataset[2]).

Common name	Scientific name	Code	Reference densities (ind. ha^{-1})	
			Manta	RBt; SBt
Lollyfish	*Holothuria atra*	LF	2,400	5,600*
Greenfish	*Stichopus chloronotus*	GF	1,000	3,500**
Chalkfish	*Bohadschia similis*	CHF	-	1,400***
Snakefish	*Holothuria coluber*	SNF	350	1,100*
Sandfish	*Holothuria scabra*	SF	-	700***
Pinkfish	*Holothuria edulis*	PF	250	260*
Surf redfish	*Actinopyga mauritiana*	SRF	20	200**
Brown sandfish	*Bohadschia vitiensis*	BSF	160	100*
Hairy blackfish	*Actinopyga miliaris*	HBF	-	150***
Curryfish	*Stichopus herrmanni*	CF	130	100*
Tigerfish / Leopardfish	*Bohadschia argus*	TF	50	120**
Flowerfish	*Pearsonothuria graeffei*	FF	50	100**
Black teatfish	*Holothuria whitmaei*	BTF	10	50*
Prickly redfish	*Thelenota ananas*	PRF	10	30**
Amberfish	*Thelenota anax*	AF	20	-
White teatfish	*Holothuria fuscogilva*	WTF	-	20*
Elephant trunkfish	*Holothuria fuscopunctata*	ETF	10	10*
Stonefish	*Actinopyga lecanora*	STF	-	10**

* = RBt and SBt combined; ** = RBt only; *** = SBt only.

[2] Reference densities were derived from 1,122 manta tow stations, 1,493 reef benthos stations and 476 soft benthos stations.

Stock biomass and weight

Stock biomass is important information in fisheries management and development because it enables the evaluation of production trends and marketable value of a resource. Biomass is typically obtained from abundance data coupled with size (length or width) or weight data.

Therefore, to help fishery management, conversion ratios are used for converting length measurements to weight, and wet weight to commercial product dry weights. Often, there is also a requirement to convert the hard and soft edible portions of invertebrates into meaningful measures (e.g. when considering the ratio of trochus or clam shells to trochus or clam meat).

Soft-bodied invertebrates that can vary significantly in length within the same species (e.g. sea cucumbers) are often very difficult to measure or weigh with precision when they are alive. Most commercial sea cucumbers contract when handled, so body length can differ greatly from the length of undisturbed animals. Some species contract and expand markedly, so size limits based on weight, rather than length, may be more appropriate. This is particularly true for most *Actinopyga* spp., *Stichopus herrmanni* and *Holothuria atra*. Sea cucumbers can also gain in width and/or body height while their body weight remains unchanged. Currently, a mean weight to length ratio is used to deal with this limitation in the absence of more detailed length-weight conversion ratios for each species (Appendix 8). In contrast, some other species, such as *H. scabra* and *H. lessoni*, undergo minor contractions of body length compared with other species and are, thus, less problematic to manage using length-based measures.

Size distribution and recruitment

The size range and number of specimens found in the small, medium and large size classes of invertebrates from a single species give critical information for understanding the health of that population. This information also demonstrates how well a species is sustaining its population by indicating the presence of new recruits and juveniles, and the status of large breeding adults. If the size structure of a species consists of a high proportion of small animals compared with mature fishable adults, then the stock is likely to be young with a lower mean size. In this case, fishing would not be recommended because individuals have not reached reproductive maturity. In addition, larger individuals typically produce substantially more eggs that have better survivorship than smaller individuals. In the example in Figure 19, the majority of trochus shells assessed at this site are under the minimum legal harvest size and, therefore, a commercial harvest would not be recommended. The high abundance of individuals in the 30–80 mm size range suggests active recruitment, which is a good sign for the future recovery of the fishery.

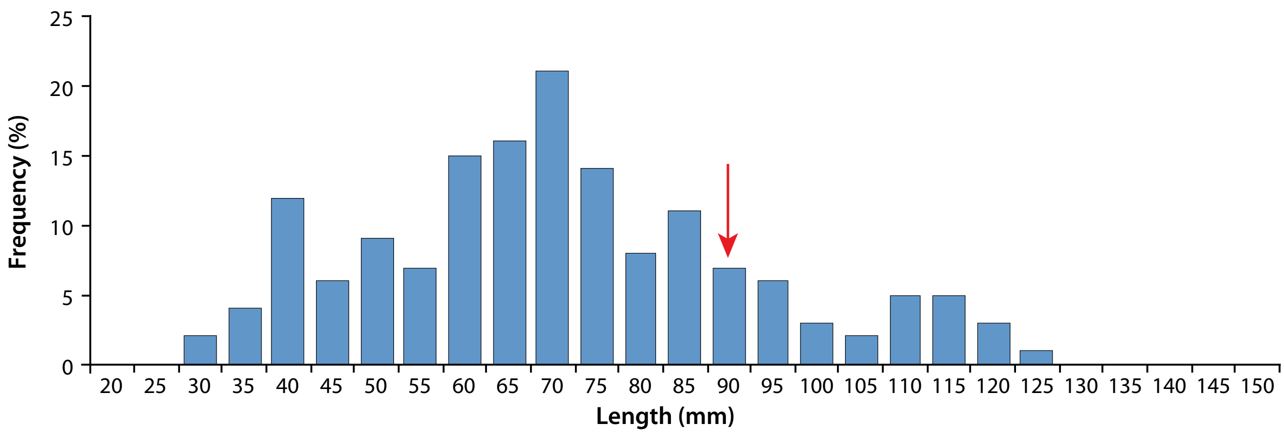


Figure 19. *Trochus size distribution for a Pacific Island site.*
Red arrow indicates a minimum legal size of 90 mm.

Studies to determine maturity sizes

Data on the individual size of specimens and stages of reproductive maturity are important for determining minimum harvest sizes for fisheries management purposes. However, reproductive maturity information requires significant amounts of data collected over a long period of time, or sizes at maturity and spawning season information can be gathered from interviews with fishers. Once the size at maturity is known, it is important to give the species a minimum of one full spawning year before harvesting is considered. In species such as octopus that only breed once, fishers must leave a proportion of the octopus population undisturbed in order to ensure a future for the fishery.

Comparisons of size structure among sites

The effectiveness of a management decision, such as an area closure, can be assessed by analysing population characteristics (density and size structure) of a selected indicator species and comparing these with an open access area within the same site. The example in Figure 20 shows the size structure for sandfish (*Holothuria scabra*) in a no-take area (marine protected area, or MPA) and an open access area (non-MPA) for a Pacific Island site. In this example, it is clear that the MPA has more and larger *H. scabra* (mean size 236 mm) than the open access area (non-MPA area). In addition, a higher percentage of the *H. scabra* population in the MPA is larger than the length at maturity (160 mm) than the population in the non-MPA area. This indicates a fishing impact in the open access area from which the individuals in the MPA are protected.

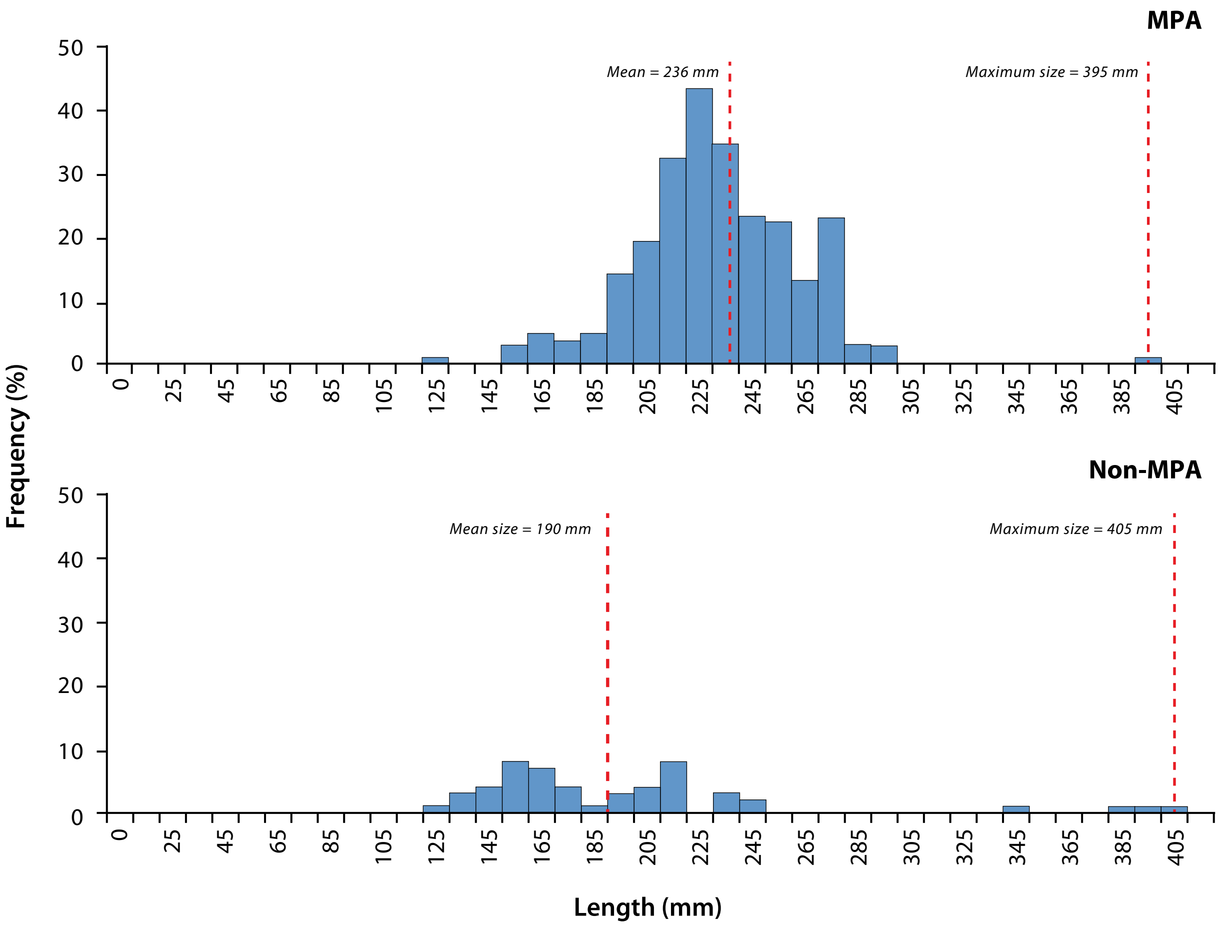


Figure 20. *Mean size frequency of* Holothuria scabra *within a marine protected area (n = 210) and a non-marine protected area (n = 46) at a hypothetical site. Mean and maximum sizes are also displayed.*

Estimating total and fishable stock

Estimating a stock is done by multiplying species density by total area of habitat of interest at a particular site. The recommended density to use is the overall mean density, as this is more accurate than using present mean density because it is the density for all transects. These calculations can be conducted on data for all habitats, but are most accurate when habitat type is taken into account. To estimate stocks, several steps need to be performed.

Step 1: Estimate density (as outlined above).

Step 2: Calculate reef or habitat area in hectares. This is done by using GIS and maps of the area of interest.

Step 3: Calculate standing stock and harvestable stock levels. This is derived by multiplying species density estimates by reef habitat area of interest, and the result is the total estimated standing stock (total estimated number of individuals). For some fisheries, information on sustainable harvest levels are needed (e.g. total number of individuals above a minimum harvestable size or total number of individuals between a minimum and maximum harvest size limit as used in some trochus fisheries).

Standing stock and harvestable stock estimates can be converted to biomass to determine production quantity. A proportion of this biomass can be proposed as the harvest level (see example in Appendix 7).

Step 4: Conversion to dry mass. Conversions can be performed from wet weight or wet length to dry weight or dry length as necessary in order to better understand changes in quantity or to derive an estimate of the economic value of the resource in an area. Standard wet to dry conversion ratios used to perform these conversions are provided for sea cucumber species in Appendix 8. The example box below shows how to perform this type of calculation.

Example

Conversion of 200 pieces of wet white teatfish (*Holothuria whitmaei*) to dry weight. The wet-dry conversion ratio of 0.08 or 8% weight retention and mean live weight of 2,500 g per animal are used as follows:
Total dry weight = number of pieces x average live weight (g) x conversion ratio
= (200 x 2,500) x 0.08
= 40,000 g
= 40 kg

Dry weight for 200 pieces of live white teatfish is 40 kg.
Back calculation can be performed to convert dry mass to wet mass.

Confidence intervals for stock estimation

A confidence interval (CI) is a range of stock estimate figures that is believed to include the true population parameter of a species most of the time it is assessed. The 95% confidence limit around the mean suggests that if the sampling procedure was repeated many times (e.g. 1,000 times), the calculated interval would include the true mean of the average stock estimate 95% of the time (e.g. 950 times out of 1,000). The desired level of confidence is set by the researcher (not determined by data) and the common choices for the confidence level are 0.90, 0.95 and 0.99. These levels correspond to percentages of the area of the normal distribution curve. For example, a 95% CI covers 95% of the normal curve; this means the probability of observing a value outside of this area is less than 5%.

Certain factors may affect the confidence interval size including size of sample, level of confidence and population variability. A larger sample size normally leads to a better estimate of the population parameter. CI gives an estimate of the degree of confidence that the standing stocks are derived from reliable estimates that are used from a stock survey.

The steps and functions to calculate CI using Excel are outlined in Appendix 7.

Survey power

Power analysis is used to calculate the minimum sample size (number of stations or replicates) required to detect a change ('effect size') within any sampling design. This is useful for conducting resource assessments to prevent an undersample (unable to detect change) or oversample (waste time and money).

Factors influencing power

Statistical power may depend on a number of factors. At a minimum, survey power nearly always depends on the following three factors:

- the statistical significance criterion used in the test;
- the magnitude of the effect (or the change in stock size) in the population; and
- the sample size used to detect the effect.

The amount of survey effort required to provide significant power should be considered on a case-by-case basis. For advice on survey power, please contact SPC's Coastal Fisheries Programme.

4.3 Data communication

After surveys have been completed and the resulting data analysed, it is important to present the results in a format that is useful to key stakeholders. The actual data and analyses are more relevant to scientific audiences, but for community consultative meetings it may be more effective to communicate by talking and using visual presentations (e.g. advisory sheets, posters) than through written reports.

Where relevant, it is essential to communicate the survey results with community leaders such as chiefs, resource custodians and religious leaders, who can interpret the results of the monitoring efforts, and explain the value of management actions to the broader community. The steps in this process should include identifying the:

- target audience;
- key messages to get across and when; and
- communication products that will best suit the needs of the project (many products may be required for different audiences).

Writing a resource survey report

A resource survey report should follow the typical scientific report format as outlined below.

Title
The title should be concise and give clear indication of the survey.

Acknowledgement
Acknowledge the people, funding bodies etc that provided support for the assessment.

Abstract or summary
The abstract or summary of the survey summarises the whole report, usually in a page or less, and usually includes introductory statements, objective, methods, results and findings and brief conclusions and recommendations.

Introduction
Background information of the fishery that is being assessed, relevance of the fishery to the economy of the country, fishing activities, livelihood, production, exports, current knowledge, past resources assessments, current management practices and the purpose of the survey.

Methods
The methods section outlines the location of the survey, data collection methods and how the data were analysed. This section should include enough detail to allow the reader to replicate the work.

Results
The results section contains a series of figures and tables with text to explain the findings presented in the figures.

Discussion and recommendations
Discussion and recommendations sections often go together. This Section is dedicated to recommendations preferably in dot point format to clearly explain the findings and their implications on the fishery based on current management measures. Recommendations for alternative management measures to improve the situation can be included.

References
List of all studies referenced in the report.

Appendix / Annex
Supplementary or supporting information that are relevant to the report but would be too lengthy to include in the report itself.

5. Further readings

Resource surveys

English S., Wilkinson C. and Baker V. (eds). 1997. Survey manual for tropical marine resources. 2nd ed. Australian Institute of Marine Science, Townsville, Australia. 390 p.

Fletcher W.J. and Amos M. 1994. Stock assessment and management of coconut crabs (*Birgus latro*): A manual. Australian Centre for International Agricultural Research Monograph Series no. 29. 32 p.

Pinca S., Kronen M., Friedman K., Magron F., Chapman L., Tardy E., Pakoa K., Awira R., Boblin P. and Lasi F. 2010. Regional assessment report: Profiles and results from survey work at 63 sites across 17 Pacific Island countries and territories. Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish/C/CoFish). Noumea, New Caledonia: Secretariat of the Pacific Community. 467 p.

Species identification

Purcell S.W., Samyn Y. and Conand C. 2012. Commercially important sea cucumbers of the world. FAO Species Catalogue for Fishery purposes. No. 6. Rome, Italy: Food and Agricultural Organization. 223 p.

Purcell S.W., Tardy E., Desurmont A. and Friedman K.J. 2008. Commercial holothurians of the tropical Pacific [Poster]. Noumea, New Caledonia: Secretariat of the Pacific Community.
[http://www.spc.int/DigitalLibrary/Doc/FAME/Posters/Holothurians.pdf]

Anon. 2007. Marine invertebrates of the Pacific Islands [Poster]. Noumea, New Caledonia: Secretariat of the Pacific Community.
[http://www.spc.int/DigitalLibrary/Doc/FAME/Posters/Invertebrates.pdf]

Anon. 2004. Pacific Island sea cucumber and beche-de-mer identification cards. Noumea, New Caledonia: Secretariat of the Pacific Community.
[http://www.spc.int/DigitalLibrary/Doc/FAME/Manuals/Anon_04_ID_BDM.pdf]

Anon. 2012. Guide & Information sheets for fishing communities (2nd edition). Noumea, New Caledonia: Secretariat of the Pacific Community.
[http://www.spc.int/DigitalLibrary/Doc/FAME/Manuals/Anon_12_Guide_Leaflet_InfoSheetsForCommunities.pdf]

Application of methods in this manual

Assessing sea cucumber stock status from manta tow and reef transect information. Friedman K., Eriksson H., Tardy E. and Pakoa K. 2011. Management of sea cucumber stocks: Patterns of vulnerability and recovery of sea cucumber stocks impacted by fishing. Fish and Fisheries 12:75–93.

Assessing sea cucumber stock status from manta tow surveys. Eriksson H., de la Torre-Castro M., Eklöf J. and Jiddawi N. 2010. Resource degradation of the sea cucumber fishery in Zanzibar, Tanzania: A need for management reform. Aquatic Living Resources 23:387–398.

Determining sea cucumber stock health. Friedman K., Purcell S., Bell J. and Hair C. 2008. Sea cucumber fisheries: A manager's toolbox. ACIAR Monograph No. 135. Canberra. Australian Centre for International Agriculture Research. 32 pp.

Assessing a single sea cucumber species using manta tow and reef transect surveys. Eriksson H., Thorne B.V. and Byrne M. 2013. Population metrics in protected commercial sea cucumber populations (curryfish: *Stichopus herrmanni*) on One Tree Reef, Great Barrier Reef. Marine Ecological Progress Series 473:225–234.

Sea cucumber resources status assessment. Tardy E. and Pakoa K. 2009. The status of sea cucumbers in Yap State, Federated States of Micronesia. Noumea, New Caledonia: Secretariat of the Pacific Community. 68 p.

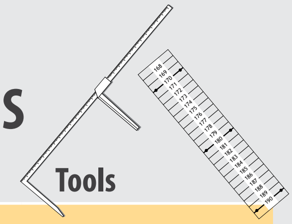
Sea cucumber resources status assessment. Pakoa K., Lasi F., Tardy E. and Friedman K. 2009. The status of sea cucumbers exploited by Palau's subsistence fishery. Noumea, New Caledonia: Secretariat of the Pacific Community. 44 p.

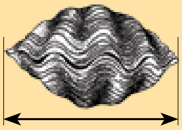
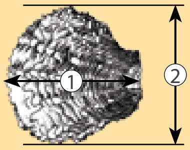
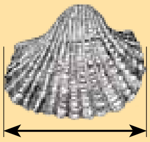
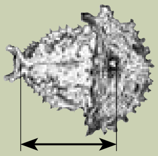
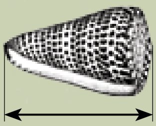
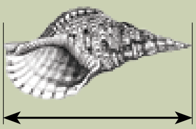
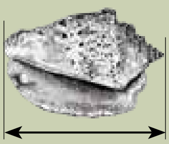
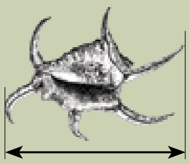
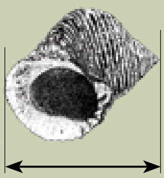
Trochus resources status assessment. Tardy E., Pakoa K. and Friedman K. 2008. Assessment of the trochus resources of Pohnpei Island and recommendations for management. Noumea, New Caledonia: Secretariat of the Pacific Community. 63 p.

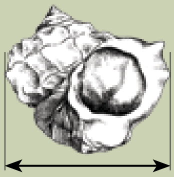
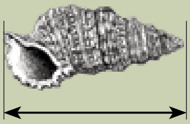
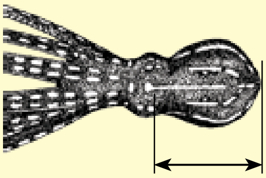
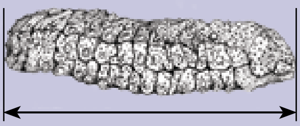
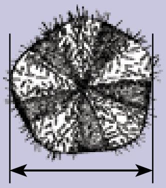
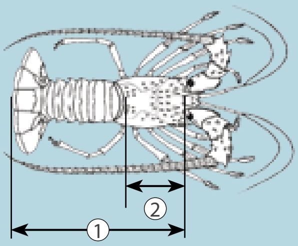
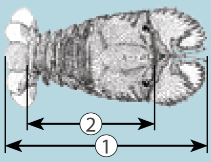
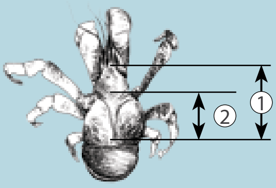
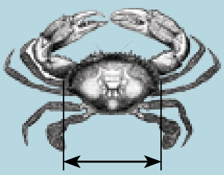
Trochus resources status assessment. Tardy E., Pakoa K. and Friedman K. 2008. Assessment of the trochus resources of Kosrae Island and recommendations for management. Noumea, New Caledonia: Secretariat of the Pacific Community. 56 p.

Appendix 1. Measuring sizes of various macroinvertebrates

IDENTIFICATION CARDS FOR MARINE INVERTEBRATE SURVEYS IN THE PACIFIC ISLANDS



		Measurements	Tools
Bivalves			
Giant clam		Longest length	Caliper Ruler
Oyster		1: Distance from hinge to opposite edge 2: Shell width	Caliper Ruler
Ark shell (*Anadara* sp.)		Shell width	Caliper Ruler
Penguin's wing (*Pteria penguin*)		Umbo-ventral length	Caliper Ruler
Gastropods			
Sea hare		Total length	Caliper Ruler
Trochus		Basal diameter (measure across the base of the shell)	Caliper Ruler
Cone shell		Total length	Caliper Ruler
Triton shell		Total length	Caliper Ruler
Strombus shell		Total length	Caliper Ruler
Conch shell (*Lambis chiragra*)		Total length (end of shell to end of furtherest spike)	Caliper Ruler
Turban snail (*Turbo setosus*)		Longest width (end of apex to end of outer edge of whorl opening)	Caliper Ruler

		Measurements	Tools
Gastropods			
Green snail		Longest width	Caliper Ruler
Cowry shell		Total length	Caliper Ruler
Cerith (*Cerithium* sp.)		Total length	Caliper Ruler
Cephalopods			
Octopus		Mantle height	Ruler
Echinoderms			
Sea cucumber		Length	Ruler
Sea urchin		Length without spines	Caliper Ruler
Crustaceans			
Spiny lobster		1: Length from front edge of carapace to rear edge of telson 2: Carapace length	Caliper Ruler
Slipper lobster		1: Total length 2: Length from eyeline to front of telson	Caliper Ruler
Coconut crab		1: Cephalo-thoracic length (CL) 2: Thoracic length (TL)	Caliper Ruler
Mangrove crab		Carapace width	Ruler

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Appendix 2. Safety during in-water surveys

Safety Checklist
for underwater survey work

PLANNING:

- Designate a team leader who should coordinate planning
- Team leader to delegate tasks and make decisions
- Allocate personal gear to users for individual responsibility
- Establish a work plan and discuss with team members
- Designate a contact person who knows the work plan
- Study the survey location using maps and local information
- Ensure you have effective communication by radio or mobile phone
- Arrange secure packing of gear and materials

DIVING CREDENTIALS AND INSURANCE:

- Check that all divers have a minimum open water level certification
- Only allow active divers who have dived in the last 6 months to participate
- Check that all divers have insurance and a valid annual medical clearance to dive
- Ensure you can contact the local emergency agency
- Ensure someone in the group knows relevant first aid procedures

WEATHER AND GENERAL CONDITIONS:

- Monitor daily weather forecasts
- Seek local advice where necessary
- Plan activities according to daily weather conditions and tidal changes
- Avoid diving in rough seas and strong tidal currents
- Always dive in the same direction as the current
- In channels always dive into the lagoon
- Avoid areas of poor visibility

HEALTH:

- Do not dive if you have a head cold or are not feeling well
- Change daily plans to suit the needs of the team if necessary
- Keep a medical kit onboard
- Ensure at least two team members have basic first aid skills
- Don't dive under influence of alcohol or drugs, even the night before
- Have oxygen equipment on board when diving to depths of over 40 m

BOAT SAFETY:

- Ensure the boat is a suitable size and design for the work plan
- Check that all basic safety gear is onboard (see SPC sea safety booklet)
- Check engine and keep additional fuel onboard, crosscheck with operator
- Safely stow objects onboard
- Ensure the boat operator knows the whereabouts of all divers and be alert for other swimmers and fishers in the water
- Stay away from ascending divers (10 m at least); move in when they have surfaced
- Position the boat into the wind and swells in all operations
- Ensure there is an assistant onboard to help divers back into the boat
- Do not leave boat unattended or move away from work site
- Ensure that enough food and water is onboard in case of delayed return

DIVE EQUIPMENT:

- Ensure all equipment is serviced regularly
- Pack an additional set of equipment
- Check gear for proper fit and leakage; replace with spare set if faulty
- Ensure divers know their weight system
- Check regulator and BCD for leaks and trapped hose
- Be familiar with your equipment; avoid subserviced and unfamiliar gear
- Keep fragile equipment in cases out of sun and saltwater when not in use

BEFORE-DIVE CHECKS:

- Check that your buddy's gear is in good order
- Secure, within easy reach, a spare octopus, regulator and dive computer
- Test air supply, check weight system and depth gauge before and on descent
- Be clear on your dive plan before entering water; ask if you are unsure
- Ensure your writing slate is in order and pencil and record sheet are ready
- Ensure all divers have basic understanding of standard dive sign language

UNDERWATER:

- Never dive alone
- Maintain the same depth as your buddy and stay within view of each other
- Stay focused and do not stray from the dive plan
- Signal immediately if you sense a problem (e.g. tiredness, air running low, gear failure)
- Adjust your weight belt and buoyancy system
- Fix problems as soon as they happen, don't let them build up
- If you lose your buddy, stop work and look around the area for 2 minutes; if you cannot locate your buddy, ascend safely and alert the boat operator

Safety Checklist
for underwater survey work

USING A COMPRESSOR:

- A person should be in charge of the compressor
- Ensure the machine is serviced before going into the field
- Secure sufficient fuel to run the compressor
- Check for clean air before refilling
- Take care of the machine and keep a spare one if necessary

DETECTING PROBLEMS:

- Observe yourself and your buddy regularly for signs of problems
- Signs of problems include: rapid breathing, no response to signals, awkward kicking, tears in eyes, eyes wide open, jerky movements, using arms to swim, ejecting mask and regulator, bolting to the surface
- On the surface, problems include: lagging behind, choking, coughing, vomiting, moving the head back, treading high out of the water, using hands and arms, and no snorkel or regulator in the mouth

ASCENDING:

- Always ascend together; follow decompression stop rules
- Ascend up the wall face if near a reef wall
- Always face your buddy when ascending in mid-water
- Stay closer together in low-visibility waters
- If using a sausage float, use exhaled air to fill the sausage
- In deep dives, keep spare scuba tanks and regulator at least 10–15 m below the boat
- Always check above for the boat or objects before surfacing
- Keep watch on the boat when moving closer and getting onboard
- Be careful when removing weight belts, as they can fall off easily

ENVIRONMENTAL DANGERS:

- Avoid actions that attract sharks such as fishing: stay away from fishers
- Wear full wetsuits, boots and gloves for maximum protection
- Follow local advice
- Do not touch anything if unsure
- Stay away from estuaries and murky waters in countries where crocodiles are endemic

ACCIDENT:

- Implement responses to accidents that you have practiced. e.g. throw life-float to victim
- Ensure that the process of assisting the victim does not endanger the life of other team members
- Work out a plan of action with the others onboard
- Bring the boat closer to the victim, extend anything available to reach the victim
- Place the diver gently in a comfortable position onboard
- Commence ABC checks (airway, breathing, circulation)
- Allocate tasks to team members
- Alert relevant authorities for assistance as soon as possible
- Record changes in condition of distressed diver, activities and time of events

AFTER DIVE CHECKS:

- Remove gear and safely stow it
- Put fragile equipment – GPS, computers, mask, camera – in cases
- Turn off dive tanks onboard and keep tanks secure when the boat is moving
- Avoid free diving immediately after a deep dive
- Wear a wind breaker on cold and windy days
- Check that all data are recorded before leaving a site
- Ensure safe keeping of completed record sheets
- Do not travel by plane within 24 hours of completing a dive

GENERAL CONDUCT:

- Seek permission from the community and local authorities for access to work site
- Use a local guide at all times and follow his or her instructions
- Respect local rules, code of conduct and culturally significant sites
- Team leader is responsible for maintaining order at all times
- Maintain good behaviour
- Ensure good communication is maintained at all times

This Safety Checklist should be used alongside:

The SPC Manual for Safety at Sea, a scuba dive regulation manual, and any marine environmental safety guide.

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Secretariat of the Pacific Community

European Union

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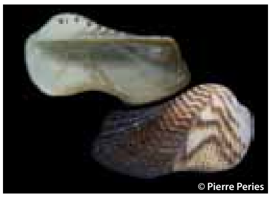
Produced by the Coastal Fisheries Science and Management Section

Appendix 3. Species identification guides

BIVALVES

Arcidae

Anadara antiquata



Arca ventricosa

Cardiidae

Fragum fragum

Fragum unedo

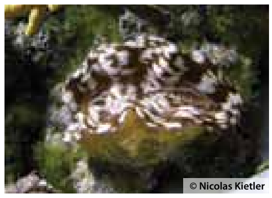
Fulvia laevigata

Hippopus hippopus

Hippopus porcellanus

Lyrocardium lyratum

Tridacna crocea



Tridacna derasa

Tridacna gigas

Tridacna maxima

Tridacna squamosa

Tridacna tevoroa

Vasticardium angulatum

Vasticardium elongatum

Vasticardium flavum

Carditidae

Beguina semiorbiculata

Chamidae

Chama croceata

Chama macerophylla

Chama pacifica

Donacidae

Donax cuneatus

Donax faba

Gryphaeidae

Hyotissa hyotis

Lucinidae

Codakia punctata

Codakia tigerina

Fimbria fimbriata

Mesodesmatidae

Atactodea striata

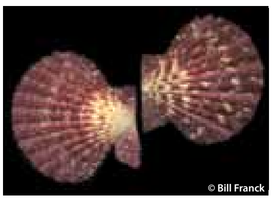
Mytilidae

Lithophaga spp.

Modiolus auriculatus

Septifer bilocularis

Pectinidae



Chlamys spp.

Pinnidae

Atrina vexillum

Pinna bicolor

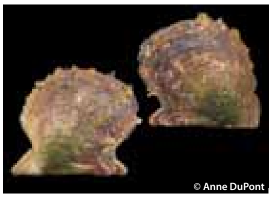
Pinna muricata

BIVALVES

Psammobiidae

Asaphis violascens

Pteriidae



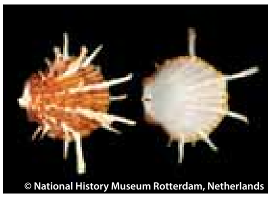
Pinctada imbricata

Pinctada margaritifera

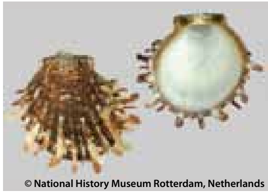
Pinctada maxima

Pteria penguin

Spondylidae



Spondylus sinensis

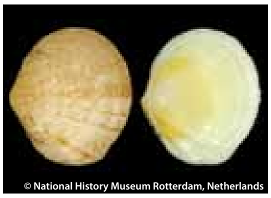


Spondylus squamosus

Spondylus varius

Tellinidae

Tellina palatum



Tellina scobinata

Veneridae

Gafrarium pectinatum

Lioconcha annettae

Lioconcha castrensis

Lioconcha fastigiata

Periglypta puerpera

Periglypta reticulata

Pitar hebraeus

Pitar prora

Tapes literatus

Timoclea marica

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CRUSTACEANS

Calappidae

Calappa spp.

Carpiliidae

Carpilius maculatus

Coenobitidae

Birgus latro

Coenobita perlatus

Diogenidae

Dardanus spp.

Eriphiidae

Eriphia sebana

Gecarcinidae

Cardisoma spp.

Cardisoma spp.

Grapsidae

Metopograpsus messor

Lysiosquillidae

Lysiosquillina maculata

Ocypodidae

Ocypode ceratophthalmus

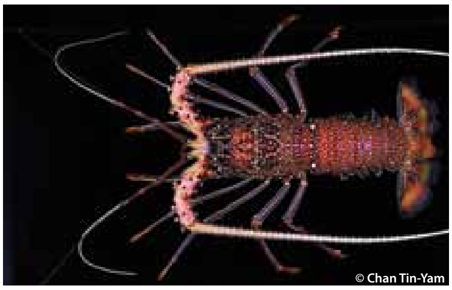
Odontodactylidae

Odontodactylus scyllarus

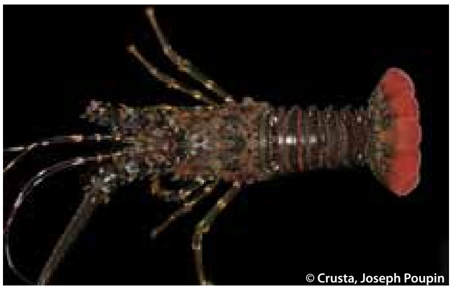
Palaemonidae

Macrobrachium rosenbergii

Palinuridae



Panulirus femoristriga



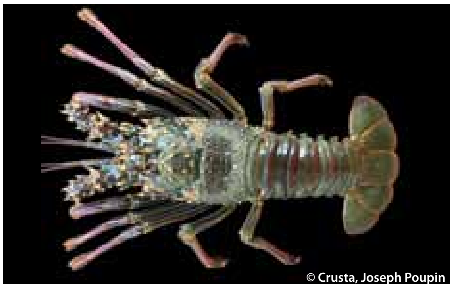
Panulirus homarus

CRUSTACEANS

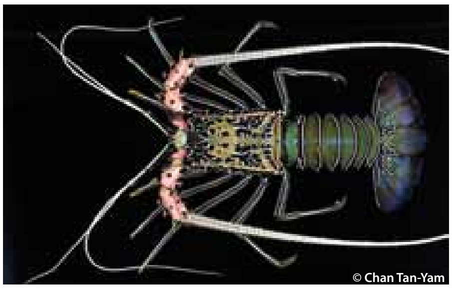
Palinuridae

Panulirus longipes

Panulirus ornatus



Panulirus penicillatus



Panulirus versicolor

Penaeidae

Penaeus monodon

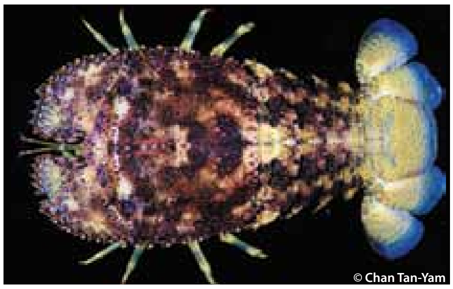
Portunidae

Scylla paramamosain

Scylla serrata

Thalamita crenata

Scyllaridae



Parribacus antarcticus

Parribacus caledonicus

Parribacus holthuisi

Parribacus scarlatinus

Sesarmidae

Parasesarma erythodactyla

Thalassinidae

Thalassina anomala

Xanthidae

Etisus splendidus

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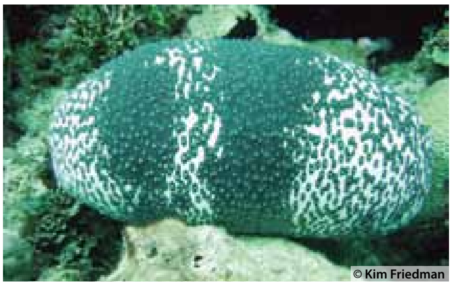
ECHINODERMS – SEA CUCUMBERS

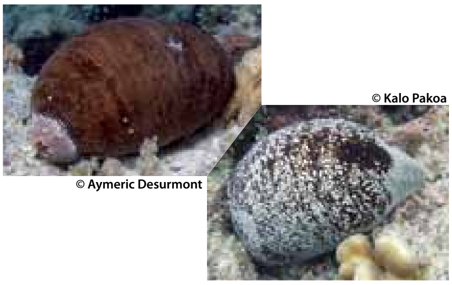
Actinopyga



Actinopyga caerulea

Actinopyga echinites / Deepwater redfish

Actinopyga flammea / Spiky deepwater redfish



Actinopyga lecanora / Stonefish

Actinopyga mauritiana / Surf redfish

Actinopyga miliaris / Hairy blackfish

Actinopyga palauensis / Deepwater blackfish

Actinopyga sp. / Hairy greyfish

Actinopyga spinea / Burying blackfish

Bohadschia

Bohadschia argus / Leopardfish

Bohadschia argus / Leopardfish

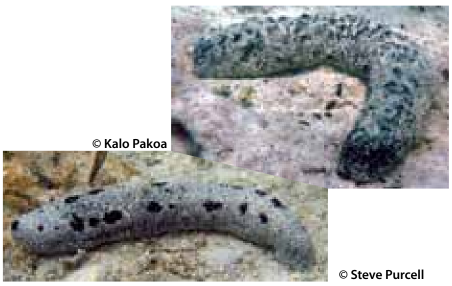
Bohadschia similis / Chalkfish

Bohadschia vitiensis / Brown sandfish

Bohadschia vitiensis / Brown sandfish

Bohadschia vitiensis / Brown sandfish

Holothuria



Holothuria atra / Lollyfish - Reef lollyfish

Holothuria coluber / Snakefish

Holothuria coronopertusa

ECHINODERMS – SEA CUCUMBERS

Holothuria edulis **/ Pinkfish**

Holothuria flavomaculata **/ Red snakefish**

Holothuria fuscogilva **/ White teatfish**

Holothuria fuscopunctata **/ Elephant trunkfish**

Holothuria lessoni **/ Golden sandfish**

Holothuria leucospilota **/ White threadsfish**

Holothuria scabra **/ Sandfish**

Holothuria whitmaei **/ Black teatfish**

Pearsonothuria

Pearsonothuria graeffei **/ Flowerfish**

Stichopus

Stichopus chloronotus **/ Greenfish**

Stichopus herrmanni **/ Curryfish**

Stichopus horrens **/ Dragonfish**

Stichopus horrens **/ Dragonfish**

Stichopus vastus **/ Brown curryfish**

Stichopus vastus **/ Brown curryfish**

Thelenota

Thelenota ananas **/ Prickly redfish**

Thelenota anax **/ Amberfish**

Thelenota rubralineata **/ Lemonfish**

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ECHINODERMS – SEA STARS

Acanthasteridae


© Emmanuel Tardy

Acanthaster planci

Asteropseidae


© David R

Valvaster striatus

Comasteridae


© Rainer Leidner

Comaster nobilis

Goniasteridae


© Allerina and Glen MacLarty

Anchitosia queenslandensis


© Sandrine Job

Fromia monilis

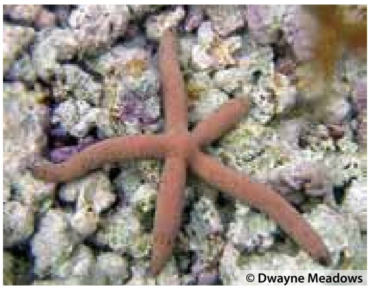
Ophidiasteridae


© Sandrine Job

Linckia laevigata


© Florent Charpin

Linckia laevigata


© Dwayne Meadows

Linckia multifora


© François Michonneau

Nardoa novaecaledoniae

Ophiothrichidae


© Ria Tan, Wildsingapore

Ophiothrix spp.

Oreasteridae


© Jan Messersmith

Choriaster granulatus


© Kalo Pakoa

Culcita novaeguineae


© Karel Jakubec

Protoreaster nodosus


© Ria Tan, Wildsingapore

Protoreaster nodosus

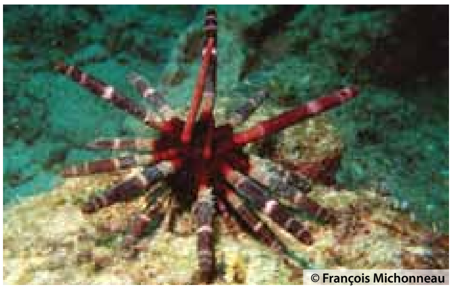
Tropiometridae


© Lyle Vail

Tropiometra afra

ECHINODERMS – SEA URCHINS

Cidaridae


© François Michonneau

Phyllacanthus imperialis

Diadematidae


© WJ Chen

Diadema savignyi


© Michael Wolf

Diadema setosum


© Ken Ichi

Echinothrix calamaris


© Shawn Miller

Echinothrix diadema

Echinometridae


© Andreas Kroh

Echinometra mathaei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Echinostrephus aciculatus


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Heterocentrotus mamillatus


© David Burdick

Heterocentrotus trigonarius

Parasaleniidae


© Kee Alfian

Parasalenia gratiosa

Strongylocentrotidae


© Jerry Kirkhart

Strongylocentrotus purpuratus

Temnopleuridae


© Ron DeCloux

Mespilia globulus


© Loh Kok Sheng

Salmacis belli

Toxopneustidae


© Nick Hobgood

Toxopneustes pileolus


© Emmanuel Tardy

Tripneustes gratilla

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GASTROPODS

Bursidae

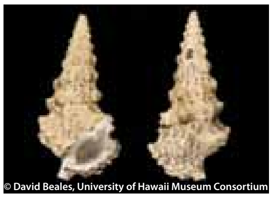
Tutufa bubo

Tutufa rubeta

Cassidae

Cassis cornuta

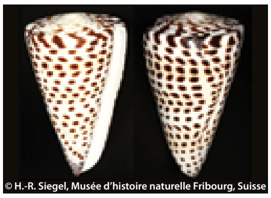
Cerithiidae



Cerithium nodulosum

Conidae

Conus leopardus



Conus litteratus

Conus marmoreus

Conus miles

Conus vexillum

Coralliophilidae

Coralliophila violacea

Cypraeidae

Cypraea annulus

Cypraea caputserpentis

Cypraea tigris

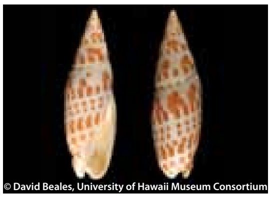
Fasciolariidae

Latirolagena smaragdula

Pleuroploca filamentosa

Pleuroploca trapezium

Mitridae



Mitra mitra

Muricidae

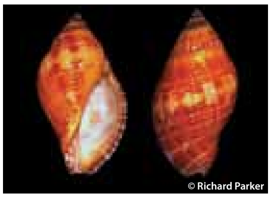
Chicoreus ramosus

Drupa morum

Drupa rubusidaeus

Morula granulata

Morula uva



Nassa francolina

Nassa serta

Reishia armigera

Thais aculeata

Thais bitubercularis

Thais intermedia

Thais tuberosa

Nassariidae

Nassarius spp.

Naticidae

Mammilla melanostoma

Polinices mammilla

Neritidae

Nerita albicilla

Nerita plicata

Nerita polita

GASTROPODS

Olividae

Oliva caerulea

Oliva miniacea

Ovulidae

Ovula ovum

Potamididae

Telescopium telescopium

Terebralia palustris

Ranellidae

Charonia tritonis

Seraphsidae

Terebellum terebellum

Strombidae

Lambis chiragra

Lambis crocata

Lambis lambis

Lambis millepeda

Lambis scorpius

Lambis truncata

Strombus chrysostomus

Strombus gibberulus

Strombus latissimus

Strombus luhuanus

Strombus mutabilis

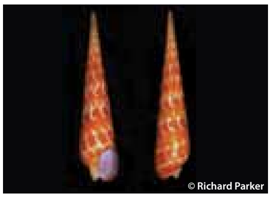
Strombus thersites

Tegulidae

Tectus niloticus

Tectus pyramis

Terebridae



Terebra dimidiata

Terebra maculata

Tonnidae

Tonna perdix

Trochidae

Trochus maculatus

Turbinellidae

Vasum ceramicum

Vasum turbinellus

Turbinidae

Astralium rhodostomum

Turbo argyrostomus

Turbo chrysostomus

Turbo crassus

Turbo marmoratus

Turbo petholatus

Turbo setosus

Vermetidae

Dendropoma maximum

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ALGAE AND SEAGRASS

Caulerpaceae


© Sabine Penisson - www.aquareefphoto.com

Caulerpa bikinensis


© Serge Andréfouët

Caulerpa pickeringii


© Ria Tan, Wildsingapore

Caulerpa racemosa


© Ria Tan, Wildsingapore

Caulerpa serrulata


© Ria Tan, Wildsingapore

Caulerpa sertularioides


© Serge Andréfouët

Caulerpa seuratii


© Ria Tan, Wildsingapore

Caulerpa taxifolia


© Serge Andréfouët

Caulerpa urvilleana

Codiaceae


© Claude Payri

Codium edule

Corallinaceae


© University of Guam

Jania tenella

Cymodoceaceae


© Ria Tan, Wildsingapore

Halodule uninervis


© Ria Tan, Wildsingapore

Syringodium isoetifolium

Dictyotaceae


© Claude Payri

Dictyota acutiloba


© Kalo Pakoa

Padina australis


© Kalo Pakoa

Padina sanctae-crucis

ALGAE AND SEAGRASS

Galaxauraceae

Galaxaura rugosa

Gracilariaceae

Gracilaria salicornia

Halimedaceae

Halimeda opuntia

Halimeda taenicola

Hydrocharitaceae

Enhalus acoroides

Halophila ovalis

Thalassia hemprichii

Thalassia testudinum

Oscillatoriaceae

Lyngbya spp.

Sargassaceae

Sargassum aquifolium

Sargassum obtusifolium

Sargassum spinuligerum

Turbinaria ornata

Udoteaceae

Chlorodesmis fastigiata

Valoniaceae

Valonia aegagropila

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TYPES OF HABITAT

Topography / Complexity


© Pierre Boblin
High topography


© Pierre Boblin
Low topography / Low complexity


© Sandrine Job
High complexity

Type of substrate


© Sandrine Job
Rubble


© Sandrine Job
Consolidated rubble


© Sandrine Job
Pavement


© Sandrine Job
Sand


© Sandrine Job
Silt

Corals


© Sandrine Job
Live coral


© Sandrine Job
Soft coral


© Sandrine Job
Encrusting coral

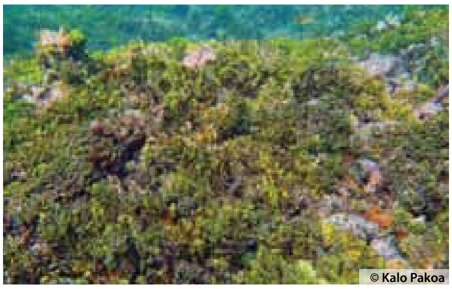

© Sandrine Job
Dead coral


© Sandrine Job
Bleaching coral

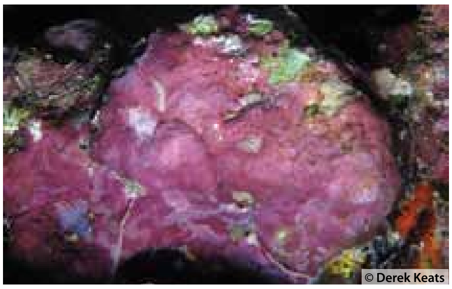

© Steve Martin
Crown-of-thorns feeding scar

Others

Algae



Coralline algae



Crustose coralline algae (CCA)

Fungids / Mushroom coral

Seagrass

Sponge

Prepared by the Coastal Fisheries Science and Management and the Fisheries Information Sections of the Secretariat of the Pacific Community.

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Appendix 4. Species of interest and assessing species not targeted by the Secretariat of the Pacific Community surveys

This appendix contains information on key representative invertebrate species as indicators for stock status assessments. Included is a description of each species and its geographical distribution, its feeding, its habitat preferences andaggregation on the reef, its depth range, its reproduction, its maximum size recorded, its recommended harvest size range, its healthy density reference point, and the recommended survey methods.

The species (or species groups) of interest are presented in the following order.

Gastropods (marine snails)

- Trochus (*Tectus niloticus*, formerly *Trochus niloticus*)
- Green snail (*Turbo marmoratus*)
- Turban snail (*Turbo setosus*)

Specimen and handicraft shells

Echinoderms

Sea cucumbers

- Lollyfish and reef lollyfish (*Holothuria atra*)
- Tigerfish or leopardfish (*Bohadschia argus*)
- Black teatfish (*Holothuria whitmaei*)
- Sandfish (*Holothuria scabra*)
- Hairy blackfish (*Actinopyga miliaris*)
- Surf redfish (*Actinopyga mauritiana*)
- White teatfish (*Holothuria fuscogilva*)

Other echinoderms

- Striped sea urchin or collector urchin (*Tripneustes gratilla*)
- Crown-of-thorns starfish (*Acanthaster planci*)

Bivalves

Giant clams

- Elongate giant clam (*Tridacna maxima*)
- Boring giant clam or crosus clam (*Tridacna crocea*)

- Fluted giant clam (*Tridacna squamosa*), smooth giant clam (*Tridacna derasa*) and true giant clam (*Tridacna gigas*)
- Bear paw giant clam (*Hippopus hippopus*)

Other bivalves

- Cockle or ark shells (*Anadara* spp.) (other infaunal species, such as *Gafrarium* spp.)

Crustaceans

- Spiny rock lobsters (*Panulirus* spp.)
- Slipper lobsters (Scyllaridae)
- Coconut crab (*Birgus latro*)
- Mangrove crab (*Scylla serrata*)
- Land crabs (*Cardisoma hiritipes*, *C. carnifex*)

Cephalopods

- Octopuses

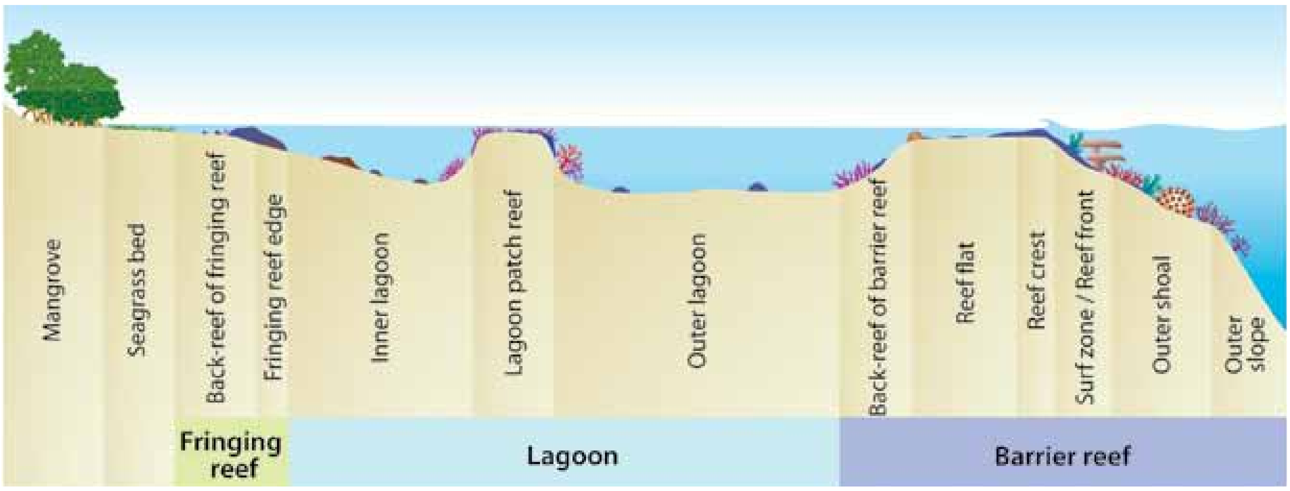
Full names and abreviations of survey methods used in this manual.

Broad-scale survey methods		Fine-scale survey methods	
Manta tow	Manta tow	Reef benthos transect	RBt
Reef-front timed swim	RFs	Soft benthos transect	SBt
Reef-front timed walk	RFw	Shallow water scuba transect	SWSt
Shallow-water timed scuba search	SWSs	Soft infaunal quadrat	SiQ
Deepwater timed scuba search	DWSs	Lobster night search	LNs
Sea cucumber night search	SCNs	Baited coconut	Crab bait

Legend illustrating density used in this manual.

Highest density
Low density
Moderate density
Absent (rare)

Standardised terminology for habitat descriptions used in this manual.



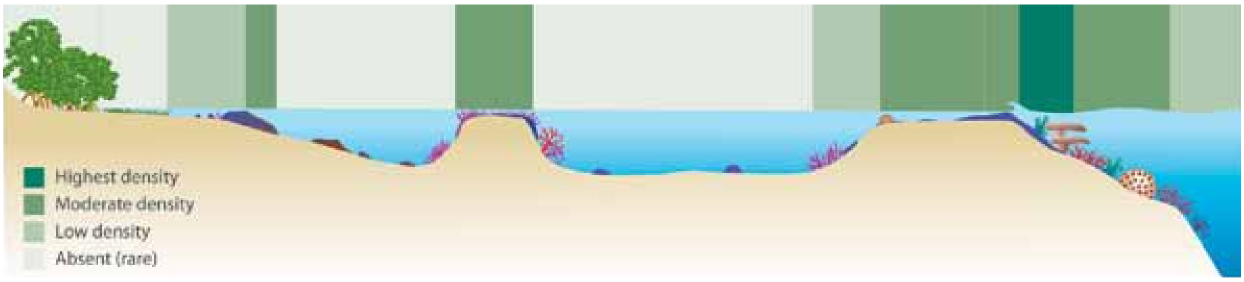
Gastropods (marine snails)

Many marine snails are of commercial value but trochus (*Tectus niloticus*) and green snail (*Turbo marmoratus*) are of particular importance to shell export industries. Trochus has been widely introduced across the Pacific, while green snail has a narrow distribution range, spanning Papua New Guinea, Solomon Islands and Vanuatu.

Trochus

(*Tectus niloticus*, formerly *Trochus niloticus*)

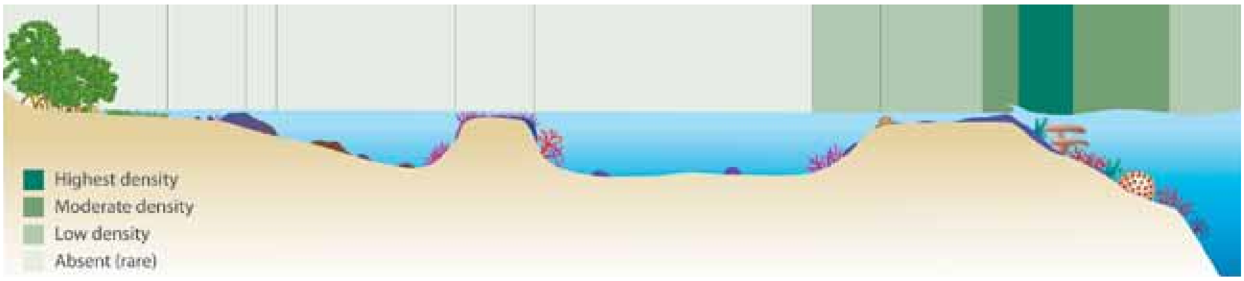
Species description and geographical distribution	Shell thick and heavy, and conical in shape. Aperture squarish, curved and smooth. Outer layer of shell is off-white with oblique purple-reddish stripes; interior layer is thick and pearly white. Harvested for its nacreous shell and used for mother-of-pearl buttons. *Distribution:* eastern Indian Ocean to Wallis Island, introduced farther east to French Polynesia.
Feeding	Grazes on encrusting fleshy and coralline algae.
Habitat and aggregation on reef	High aggregations found on reef fronts on atolls and high island fringing reefs; moderate aggregations on lagoon patch reefs, reef flats and fringing reef edges; and low aggregations found on back-reefs of fringing and barrier reefs.



Depth range	From surface down to 30 m but generally less than 8 m.
Reproduction	Separate sexes, begin reproducing when 50–70 mm in size and around 2 years in age. Spawn in warmer months. Juveniles settle after 5 days; less than one in every hundred survive to adult stage.
Maximum size	Up to 160 mm (basal diameter).
Recommended harvest size range	Size differs slightly by geographical location; large sizes > 110 mm are highly fecund but with poorer quality shells due to boring worm infection. Sexually mature shells should be allowed to breed at least once before being harvested; recommended harvest size range is 80–110 mm.
Healthy density reference point	500–600 ind. ha^{-1} on RBt and SWSt combined (site-specific density reference point is recommended).
Recommended survey methods	Manta tow and RFs can be done for broad-scale coverage where conditions permit but generally, the recommended methods are RBt and SWSt (fine-scale assessment).

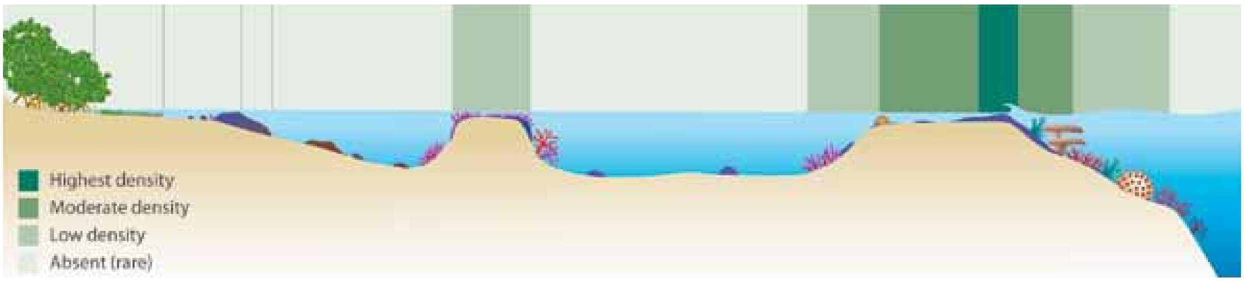
Green snail
(*Turbo marmoratus*)

Species description and geographical distribution	Green snail or turban snail is one of the largest tropical marine snails, growing up to 3 kg. Outer layer of shell greenish, inner layer pearly with large white operculum. Harvested for its meat and nacreous shell for mother-of-pearl buttons, jewellery and inlays. *Distribution:* Indian Ocean, Southeast Asia to Vanuatu; introduced farther east to Tonga and French Polynesia.
Feeding	Grazes on algae.
Habitat and aggregation on reef	Prefers surf zone of barrier reefs. Moderate densities on reef flats and outer shoal of barrier reefs, and edges of fringing reefs and reef slopes. Juveniles typically hide in crevices.



Depth range	From surface down to 15 m.
Reproduction	Separate sexes; begins reproducing at 130–150 mm after 4 years; fecundity increases with size and age. Spawns throughout year in tropics and in warmer months in cooler areas; external fertilisation; larvae settle after 3–5 days. Less than one in every thousand survives to adult stage.
Maximum size	Up to 230 mm (longest width) and 3 kg live weight.
Recommended harvest size range	Minimum recommended harvest size is 150 mm (longest width), maximum harvest size has not been used.
Healthy density reference point	Unknown, limited data available. This species is in decline across Melanesia where natural stocks exist; locally depleted in some places and remaining stocks status elsewhere are unknown.
Recommended survey methods	Manta tow and RFs along reef slope to assess distribution of adult aggregations (broad-scale assessment), and SWSt and RBt for very shallow stocks (fine-scale assessment).

Turban snail (*Turbo setosus*)		
Species description and geographical distribution	Shell heavy and thick, globular shaped. Large spire closest to opening, other spires are relatively short. Surface with strong unequal spiral cords. Space between spires almost always closed, opening large and oval. Cream with dark brown to black-green blotches. Thick calcareous operculum, white sometimes with green-brown thin border. *Distribution:* found throughout the Pacific.	
Feeding	Grazes on algae.	
Habitat and aggregation on reef	Ocean side of barrier reefs, from reef crest to shallow outer slope in wave-exposed reefs. Occasionally on back-reefs of barrier and lagoon patch reefs under a strong oceanic influence.	



Depth range	Within 4 m, with highest densities in upper 1 m.
Reproduction	Separate sexes; fecundity increases with size and age.
Maximum size	90 mm (longest width).
Recommended harvest size range	Not available.
Healthy density reference point	Not available.
Recommended survey methods	RFw (broad-scale assessment) and RBt (fine-scale assessment).

Note: Other turban snails (*Turbo agyrostomus*, *T. crassus*, *T. chrysostomus*) can also be found on reef tops.

Specimen and handicraft shells

A wide range of gastropods is used for the production of jewellery and ornamental specimens. Gastropods used in handicrafts are often those that are easily accessable and can be found in the intertidal and shoreline rocky habitat where sea spray and waves keep rock surfaces moist. Mangroves, seagrass and sandy habitats also contain other mollusc species used in handicrafts.

Specimen and handicraft shells	 
Species description and geographical distribution	A multi-species group of small gastropod species. *Distribution:* found throughout the Pacific.
Feeding	Varies among species.
Habitat and aggregation on reef	Varies among species; some species found in intertidal and rocky shorelines where sea spray and waves keep rock surfaces moist. Mangroves, seagrass beds and sandy habitats also contain other mollusc species used in handicrafts.
Depth range	Mostly intertidal but some species are subtidal.
Reproduction	Varies among species, generally not well understood.
Maximum size	Varies among species, generally less than 10 mm length.
Recommended harvest size range	Not available.
Healthy density reference point	Not available.
Recommended survey methods	Belt transect methods (e.g. RBt) are suitable for assessing rocky shore dwellers. Data can be analysed in a similar manner to transect techniques outlined in this manual. Depending on the dominance of molluscs used in a particular location, surveys can be designed using a hierarchical survey design by establishing stations within sites and using belt transects and/or quadrats as replicates. Depending on the natural densities of the molluscs, the number and size of replicates can be chosen, which will yield representative numbers of the target species.

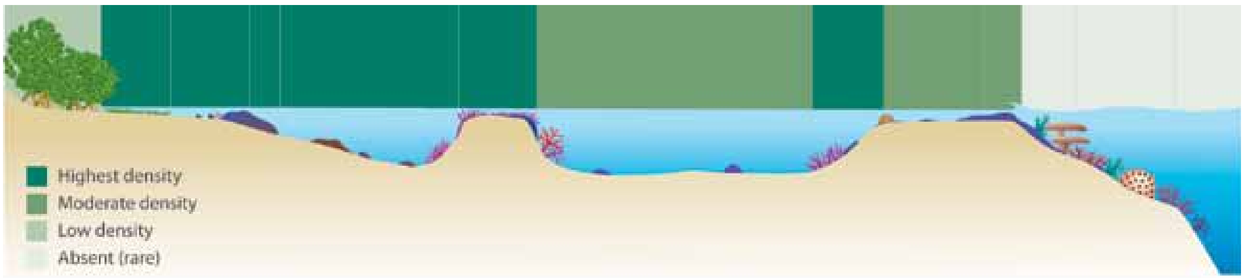
Echinoderms

Sea cucumbers

Sea cucumber species of commercial importance vary across the Pacific from five species in less complex reef systems to 26 species in more complex reef systems. Their habitat varies from sheltered inner reefs to deep lagoons and slopes, shallow intertidal areas to depths of over 50 meters. Prices vary by species and species groups and by processing quality. Information is presented on three species as indicators of value groups (*Holothuria atra*, *H. whitmaei*, *Bohadschia argus*), as habitat-restricted species (*H. scabra* for seagrass, *Actinopyga mauritiana* for reef crest and *H. fuscogilva* for deepwater species) and a nocturnal species (*A. miliaris*).

Lollyfish
and reef lollyfish
(*Holothuria atra*)

Species description and geographical distribution	Black, soft body, often covered in sand with bare spots on the upper part. Three morphs of the species are found throughout the region: small lollyfish (found on oceanic rocky islands), common lollyfish and reef lollyfish. Common lollyfish have soft, thin smooth body that stiffens when disturbed. Body surface of reef lollyfish can be rough in exposed habitats near reef crests. Gives off red-purple dye when rubbed. *Distribution:* found throughout the Pacific Islands, it is the most common sea cucumber species.
Feeding	Feeds on sand and detritus to digest microorganisms and excretes sand, a process that helps to recycle nutrients in the lagoon.
Habitat and aggregation on reef	High aggregations across most reef zones, moderate aggregations in some deep lagoons and low aggregations inside mangroves and outer reef slope.



Depth range	From surface down to 30 m, with highest densities in first 5 m.
Reproduction	Information is limited; adopts both sexual and asexual modes of reproduction.
Maximum size	650 mm, all morphs considered, average live length varies across the region, common size in the Pacific around 230 mm.
Recommended harvest size range	Three morphs pose problems, common size 230 mm throughout Pacific, size limit 300 mm live and 150 mm dry in Papua New Guinea, 165 mm live and 80 mm dry in Tonga.
Healthy density reference point	2,400 ind. ha^{-1} for manta tow surveys, 5,600 ind. ha^{-1} for RBt and SBt.
Recommended survey methods	Manta tow (broad-scale assessment); RBt and SBt combined (fine-scale assessment).

Note: See Purcell et al. 2012 (Section 5) for details).

Tigerfish or Leopardfish
(*Bohadschia argus*)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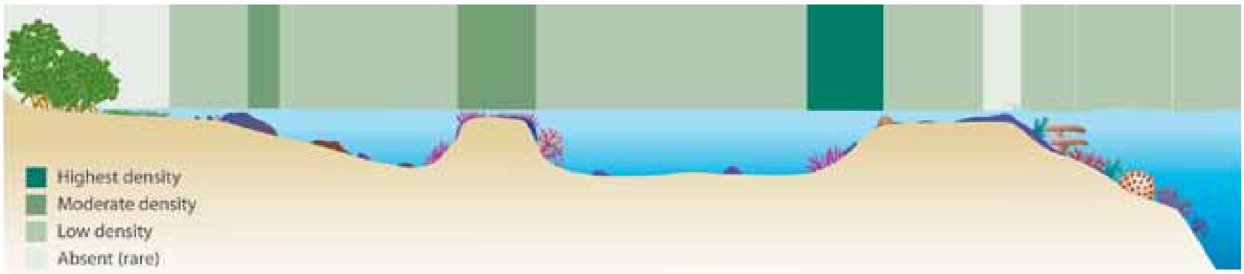
Species description and geographical distribution	Ranges from light grey to brown, with characteristic eye-like spots with dark centre. Cylindrical but slightly flattened body that is wider than higher. Ejects sticky white threads when disturbed. Medium-value species in the beche-de-mer trade. *Distribution:* occurs from India in the Indian Ocean throughout south-east Asia to French Polynesia in the Pacific.
Feeding	Feeds on detritus associated with sand.
Habitat and aggregation on reef	Found in shallow lagoons and outer reef slopes and on back-reefs of fringing reefs, lagoon patch reefs and back-reefs of barrier reefs.

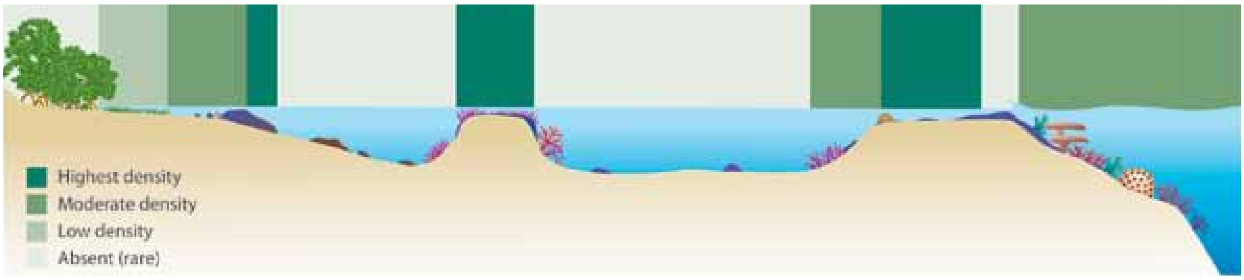


Depth range	From 1–43 m, but highest densities in upper 5 m.
Reproduction	Limited information available. Spawning occurs in December in New Caledonia and in June on the Great Barrier Reef in Australia.
Maximum size	600 mm, common size 370 mm in Pacific.
Recommended harvest size range	Varies by geographical location: 350 mm on the Great Barrier Reef, 200 mm in Papua New Guinea for live/fresh sea cucumber.
Healthy density reference point	50 ind. ha^{-1} for manta tow surveys and 120 ind. ha^{-1} for RBt.
Recommended survey methods	Manta tow survey (broad-scale assessment) and RBt (fine-scale assessment).

Note: See Purcell et al. 2012 (Section 5) for details).

Black teatfish
(*Holothuria whitmaei*)

Species description and geographical distribution	Always black, upper body coated with sand; dark grey lower body, juvenile can have white spots on the back. Solid thick body with thick protrusions on the sides ('teats'), rough body texture; small projections over body surface. Anus with small teeth visible at end of body. High-value species in beche-de-mer trade. *Distribution:* occurs across Asia-Pacific to French Polynesia.
Feeding	Feeds on detritus.
Habitat and aggregation on reef	Found mostly on shallow reef flats, often where some sand exists, but can be found in most zones of the reef system, including lower depths on the outer slope.

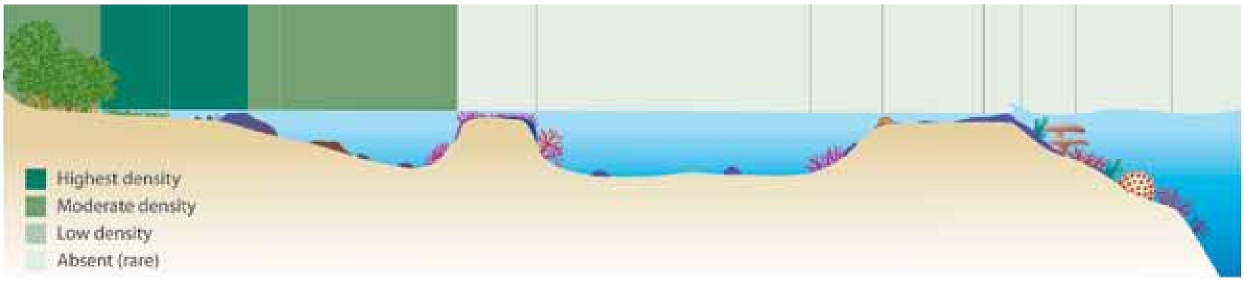


Depth range	From surface up to 34 m, highest densities in upper 12 m depth with maximum densities in the upper 4 m in high water flow habitat.
Reproduction	Limited information available. Spawning is thought to occur during the cooler months, with spawning occurring between April and June on the Great Barrier Reef and in New Caledonia.
Maximum size	540 mm with common length at 340 mm.
Recommended harvest size range	Varies by geographical locations, harvest size limit 300 mm in New Caledonia and Great Barrier Reef, 250–260 mm in Australia (Torres Strait).
Healthy density reference point	10 ind. ha^{-1} for manta tow survey, 50 ind. ha^{-1} for RBt (site-specific reference points recommended).
Recommended survey methods	Manta tow (broad-scale assessment) and RBt (fine-scale assessment).

Note: See Purcell et al. 2012 (Section 5) for details).

Sandfish
(*Holothuria scabra*)

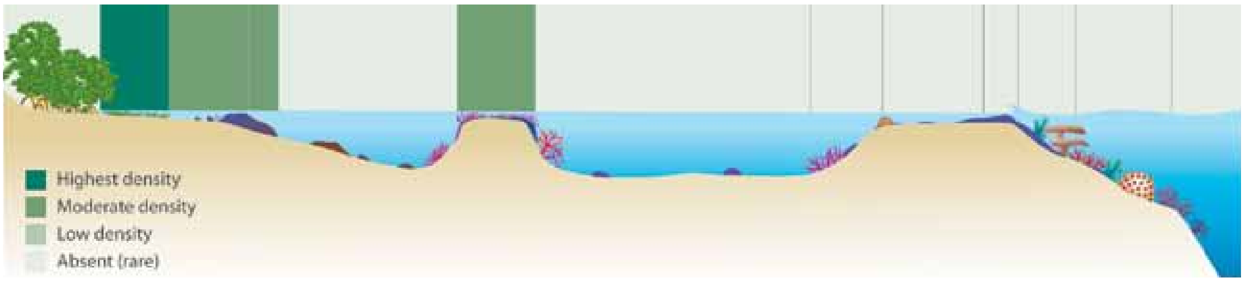
Species description and geographical distribution	Grey, dark grey with tiny black dots; lighter-coloured upper body surface. Somewhat cylindrical body with deep wrinkles on upper surface. Very short protrusions on body. High-value species in the beche-de-mer trade. *Distribution:* occurs from the Indian Ocean across Southeast Asia to as far as Wallis Island.
Feeding	Feeds on detritus in the sediment.
Habitat and aggregation on reef	Shallow bays, prefers soft sediment (muddy sand) with less dense seagrass growth, associated with mangroves where it buries itself. Sometimes low densities can be found in inner lagoons and in mangroves.



Depth range	Upper 3 m but highest densities are in the upper 1 m.
Reproduction	Attains sexual maturity at 160 mm in New Caledonia, 250 mm in northern Australia.
Maximum size	400 mm undisturbed length but individuals of this size are rare. Large adult size common at 230 mm in Pacific.
Recommended harvest size range	Varies by location, 200 mm size limit in New Caledonia, 180 mm in Australia (Torres Strait) and 220 mm in Papua New Guinea.
Healthy density reference point	Pacific regional reference point at 700 ind. ha^{-1} during SBt surveys (site-specific reference density recommended).
Recommended survey methods	SBt and SWSs to assess stocks in deep lagoons (fine-scale assessment).

Hairy blackfish (*Actinopyga miliaris*)		

Species description and geographical distribution	Black to dark brown with hairy protrusions and a slightly lighter lower surface. Solid, thick cylindrical body. Five conical anal teeth; contracts to a ball when handled or removed from the water. Active at night and often difficult to see during the day. Medium- to high-value species in the beche-de-mer trade. *Distribution:* occurs across South East Asia to Tonga in the Pacific.
Feeding	Feeds on detritus in the sediment.
Habitat and aggregation on reef	Seagrass beds and sandy areas, reef flats of fringing and lagoon patch reefs. Absent on barrier reefs. Prefers sheltered shallow lagoons with seagrass mixed with coralline algae, mangrove-influenced rubble reef flats. Hides inside rock crevices during the day.

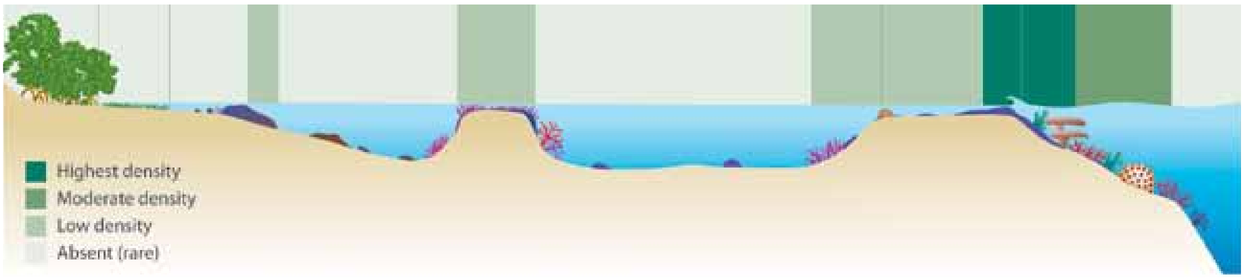


Depth range	Found in upper 10 m, but highest densities are in upper 4 m.
Reproduction	Limited information. Spawns in May and November in New Caledonia.
Maximum size	350 mm, common at 200 mm in Pacific. Length can be difficult to measure accurately because it shrinks quickly when disturbed.
Recommended harvest size range	Difficult to propose a size limit because of high plasticity (this species contracts or expands when handled), varying size limits are used in the region (e.g. 250 mm in New Caledonia, 200 mm in Papua New Guinea). Weight limit may be more appropriate due to high plasticity in size.
Healthy density reference point	Regional reference points of 150 ind. ha^{-1} for daytime SBt assessments in target habitat, 200 ind. ha^{-1} for SCNs in target habitat (site-specific reference points recommended).
Recommended survey methods	SBt is the recommended for daytime surveys; SCNs are also useful (fine-scale assessment).

Note: See Purcell et al. 2012 (Section 5) for details).

Surf redfish
(*Actinopyga mauritiana*)

Species description and geographical distribution	Rusty brown with whitish blotches and spots. Rigid body with flat lower surface covered in numerous tube feet that stick to hard surfaces. Five anal teeth at posterior end. *Distribution:* Indian Ocean to Asia-Pacific region.
Feeding	Feeds on detritus on hard reef surfaces.
Habitat and aggregation on reef	Prefers surf zone along reef crest, down to a few meters on outer slope. Occasionally found on back-reefs, lagoon patch reefs and edge of fringing reefs under strong oceanic influence.

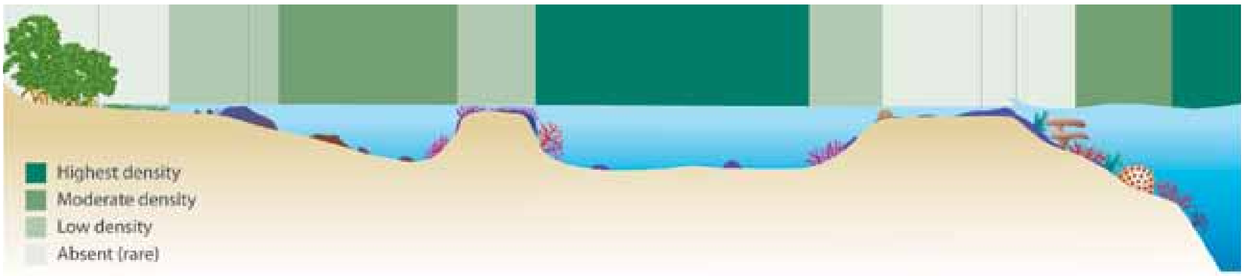


Depth range	Size at maturity reported at 230 mm, and 125–350 g. See Purcell et al. 2012 for details.
Reproduction	From surface down to 10 m with highest densities in upper 1 m. Concentrated on reef crests, occasionally exposed at low tide in atoll reef systems.
Maximum size	380 mm, with 240 mm being common.
Recommended harvest size range	Minimum live size limit is 200 mm in Papua New Guinea, 250 mm in New Caledonia and Great Barrier Reef. Notable size difference by reef system, relatively smaller sizes in atoll populations and larger sizes in high island populations.
Healthy density reference point	200 ind. ha^{-1} for RFs or RBt along reef crest.
Recommended survey methods	Manta tow on outside reef on high islands where conditions are suitable (broad-scale assessment); RBt on reef crest at low tide (fine-scale assessment).

Note: See Purcell et al. 2012 (Section 5) for details).

White teatfish
(*Holothuria fuscogilva*)

Species description and geographical distribution	Variable colour from dark brown or creamy white, with or without blotches on upper body; light brown lower body surface. Upper surface coated with sand. Solid, rigid body with pointed side protrusions ('teats'). Anus visible at posterior end with small anal teeth. High-value species in the beche-de-mer trade. *Distribution:* Indian Ocean across the Asia-Pacific region to French Polynesia.
Feeding	Feeds on detritus.
Habitat and aggregation on the reef	Mostly found on deep sandy and hard substrate. Common in lagoon passages at the base of reef slopes where currents of oceanic water are moderate to strong.

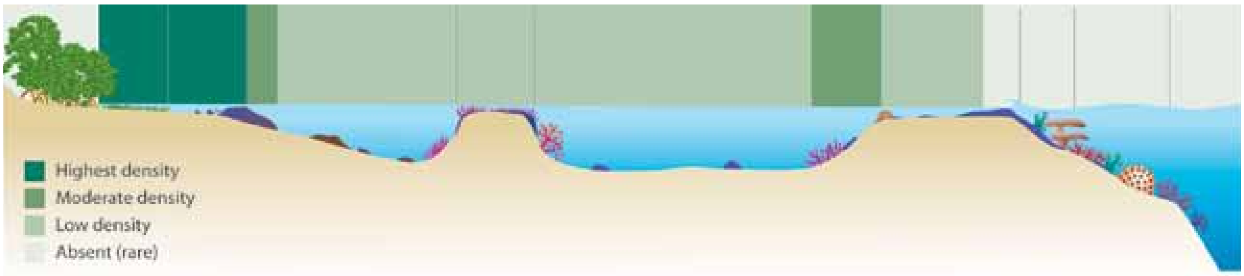


Depth range	Generally from 3–50+ m, but high densities found in the upper 15 m.
Reproduction	Size at maturity at 1,100 g. Spawn between November and January in New Caledonia, August to October in Solomon Islands.
Maximum size	570 mm.
Recommended harvest size range	380 mm is recommended but lower harvest limits of 350 mm are in force for Papua New Guinea and New Caledonia.
Healthy density reference point	20 ind. ha^{-1} for RBt and SBt combined; 20 ind. ha^{-1} for DWSs (site-specific reference densities are recommended).
Recommended survey methods	RBt (fine-scale assessment); manta tow in clear water and DWSs (broad-scale assessment).

Note: See Purcell et al. 2008, 2012 (Section 5) for details).

Other echinoderms

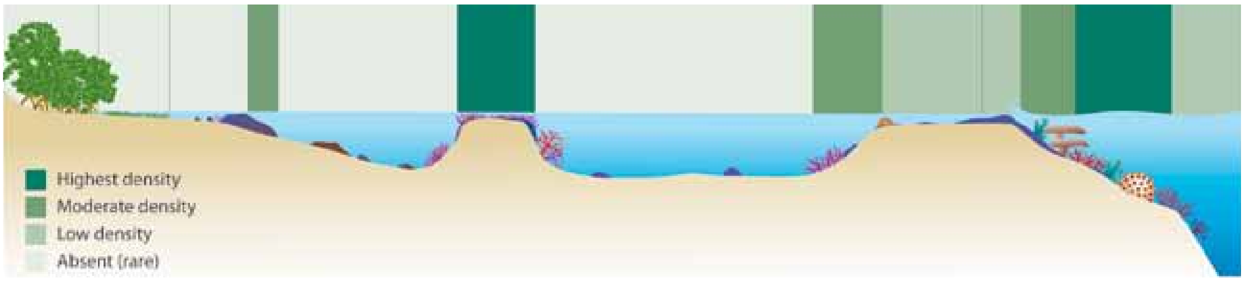
Striped sea urchin (*Tripneustes gratilla*)	 © Kalo Pakoa
Species description and geographical distribution	More or less hemispherical shape, flat underneath. Spines are short and tube feet are long and numerous. Outer shell is often purple, brown to violet; spines can be whitish, light brown to orange, grey-red and sometime almost black. Tube feet are black and white. Well hidden, covered with small pieces of algae, stone or corals. *Distribution:* occurs throughout the tropical and subtropical Indo-Pacific region.
Feeding	Grazes on algae, periphyton and seagrass.
Habitat and aggregation on reef	Common in most habitats but prefers sandy shallow calm waters, including seagrass beds. Can be common at depth on outer slopes of oceanic fringing reefs.



Depth range	From surface down to 32 m with highest densities within 3 m of surface.
Reproduction	Generally not well known.
Maximum size	140 mm (length without spines).
Recommended harvest size range	Not available.
Healthy density reference point	Not available.
Recommended survey methods	Manta tow surveys (broad-scale assessment); RBt and SBt for a detailed record of sizes (fine-scale assessment).

Crown-of-thorns starfish (COTS)
(*Acanthaster planci*)

Species description and geographical distribution	Body with large central area and up to 18 short arms with triangular shape. Numerous long spines on upper body that can cause painful stings. Usually green to reddish with orange to red spines. *Distribution:* occurs from the Red Sea and east coast of Africa throughout the tropical and subtropical Indo-Pacific region to the west coast of Central America.
Feeding	Feed on live hard corals wherever they occur. Commonly seen in *Acropora* thickets or plate coral where they remain hidden during the day. COTS play a part in the natural ecological equilibrium of the reef and are usually present in low densities on healthy reefs. Under certain circumstances, populations greatly increase in density and these outbreaks can be devastating for the living corals on which they feed. COTS can eat an area of coral approximately equal to their own size per day.
Habitat and aggregation on reef	Found where live corals are present on fringing reefs, lagoon patch reefs, back-reefs, reef fronts and outer reef slopes.



Depth range	From surface down to 35 m, but upper 15 m is where majority of coral damage occurs.
Reproduction	Mature at around 2–3 years old and breeds for 5–7 years. Spawns from December to April on the Great Barrier Reef. Each female can produce up to 60 million eggs during a single spawning season.
Maximum size	Over 1,000 mm in diameter.
Maximum density before outbreak	**Incipient outbreak** = density at which significant coral damage is likely, 8.25 ind. ha^{-1} (Manta). **Active outbreak** = significant reduction in coral cover, > 37.5 ind. ha^{-1} (Manta). Defining the size of COTS in outbreaks helps to define the current state of the outbreak. The size of COTS is not recorded by individual diameter, but in sub-classes of maturity: juveniles = < 150 mm diameter (< 2 years old); sub adults = 150–250 mm diameter (2 years old); adults = > 260 mm diameter (< 3 years old).
Recommended survey methods	Manta tow is suitable for assessing the scale of outbreak and area of estimated damage (broad-scale assessment).

How to reduce population in outbreak	Eradication programmes are very expensive if there are large numbers of COTS and, therefore, it is only possible to protect small key areas (approximately 5–10 ha) through COTS removal. Physical removal is the easiest and cheapest method for shallow water outbreaks, with COTS buried ashore. Has been done successfully in Indonesia and Mauritius. Cutting up COTS under water does not kill them and may risk their numbers increasing (starfish can regenerate from single arms). Killing individuals by injecting poison using a large mechanical syringe (type used on cattle or sheep) has also been used, but scuba diving skills are required. Sodium bisulphate is considered to be the most effective because it is relatively inexpensive and is thought to be harmless to other organisms when properly handled. Dedicated surveys might be necessary, but regular recording of COTs during resource surveys (e.g. manta and timed swims) may be sufficient for monitoring purposes.

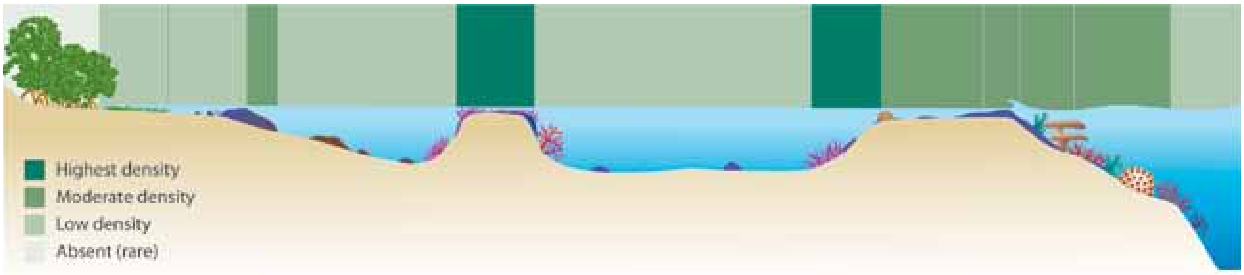
Bivalves

Giant clams

Eight species of giant clams are present in the Pacific, six of which are common in subsistence and commercial fisheries.

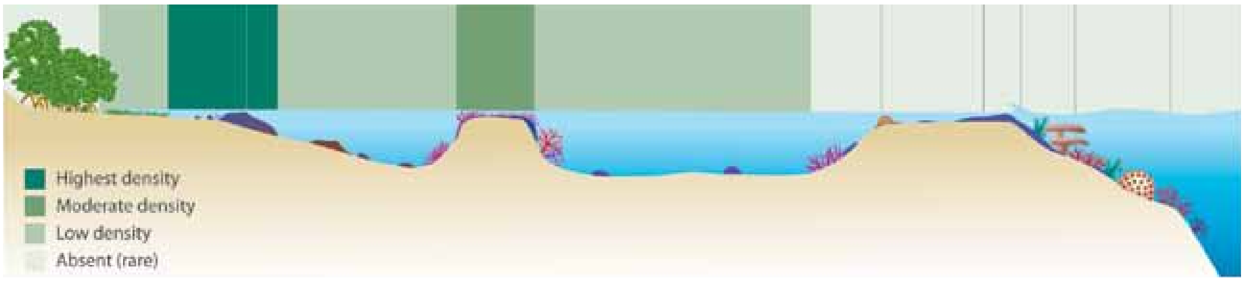
Elongate giant clam
(*Tridacna maxima*)

Species description and geographical distribution	Variable in shape; valves are strongly unequal and usually elongate-oval in outline. There are 6 or 7 broad, rib-like radial folds on the outer shell surface. Scales are present on the valves of the shell, but are smaller and closer together than in *T. squamosa*; scales eroded on embedded specimens. *T. maxima* exhibit a wide range of colours. *Distribution:* found throughout the Pacific.
Feeding	Feeds by filter feeding and from zooxanthellae activity.
Habitat and aggregation on reef	Across reef habitats but more common on reefs influenced by oceanic water along barrier reefs of atolls and fringing reef edges. High aggregations sometimes observed on lagoon patch reefs and back-reefs of barrier reefs.



Depth range	From surface down to 35 m, with highest densities in upper 2 m.
Reproduction	Hemathrodites, spawn eggs and sperm. Size at sexual maturity varies across the region. Starts spawning at 130–150 mm in Palau, and 55 mm in Tonga.
Maximum size	380 mm (longest length); maximum size decreases from western to eastern Pacific.
Recommended harvest size range	Varies by geographical location; minimum size limit in American Samoa, Guam and Niue is 180 mm, 160 mm in Samoa, 155 mm in Tonga, and 120 mm in French Polynesia.
Healthy density reference point	Regional reference for RBt surveys at 750 ind. ha^{-1} (site-specific density reference points are recommended).
Recommended survey methods	Manta tow (broad-scale assessment); RBt for accurate length data and also SWSt (fine-scale assessment).

Boring giant clam or crosus clam (*Tridacna crocea*)	 
Species description and geographical distribution	Smallest of all giant clams. Found deeply embedded in dead reefs or coral heads. Shell rounder than *T. maxima*, with 4 or 5 broad moderately flattened, rib-like folds. Outer surface of shell has small folds or striations, but is usually smooth; white interior often with yellow, orange to pink hues on margins. Small size can be confused with the elongate giant clam, when both species are deeply fixed on coral heads. *Distribution:* Southeast Asia and western Pacific to Vanuatu.
Feeding	Feeds by filter feeding and from zooxanthellae activity.
Habitat and aggregation on reef	Found in calm water on fringing reefs and lagoon patch reefs under strong terrestrial influence. Lives on hard reef bottoms, mostly deeply embedded in *Porites* coral heads of carbonated rock. *T. crocea* burrows inside limestone rock by excreting chemical that dissolve lime, and by opening and closing, which helps sink into rock. Smooth outer surface of shell usually results from rubbing against the rock it is imbedded in.



Depth range	From surface down to 9 m, mostly down to 3 m.
Reproduction	Hermaphrodites, spawn eggs and sperm. Spawns in warmer months.
Maximum size	195 mm (longest length).
Recommended harvest size range	Harvested for food and for live aquarium trade in the past, now trade in wild harvest is uncommon. 100 mm in length is recommended for harvest.
Healthy density reference point	In areas where clams are common, 5,000 ind. ha^{-1} (RBt stations) is sustainable density equivalent to one clam every 2 m^2.
Recommended survey methods	Manta tow surveys (broad-scale assessment) and RBt (fine-scale assessment).

Fluted giant clam (Tridacna squamosa)
Smooth giant clam (T. derasa)
True giant clam (T. gigas)

Species description and geographical distribution

Tridacna squamosa: shell moderately large, both valves almost equal with widely spaced fluted scales that become larger towards the edge of the valves.

Distribution: occurs from the Red Sea and east coast of Africa throughout the Indo-Pacific region to French Polynesia.

T. derasa: second largest species. Shell thick and heavy, valves unequal. Shell white and smooth, with 7–12 broad and low radial folds.

Distribution: occurs across South East Asia to Tonga in the Pacific.

T. gigas: largest species of giant clam. Shell thick and heavy, both valves almost equal. Shell white and smooth with 4–6 deep radial folds.

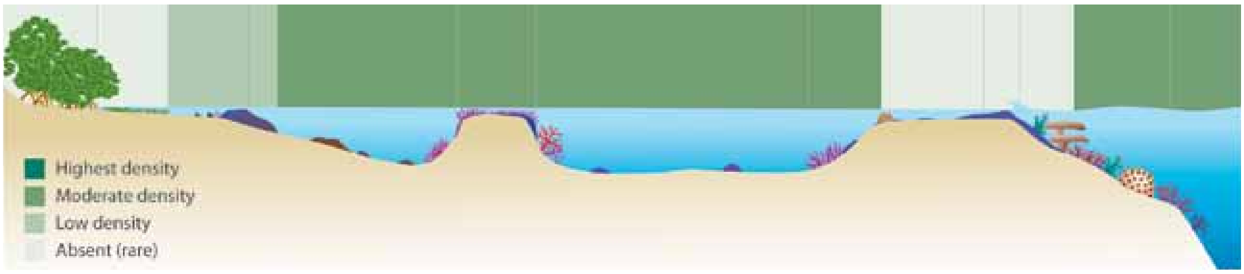
Distribution: occurs across South East Asia to Fiji in the Pacific. May be locally extinct in several PICTs.

Feeding

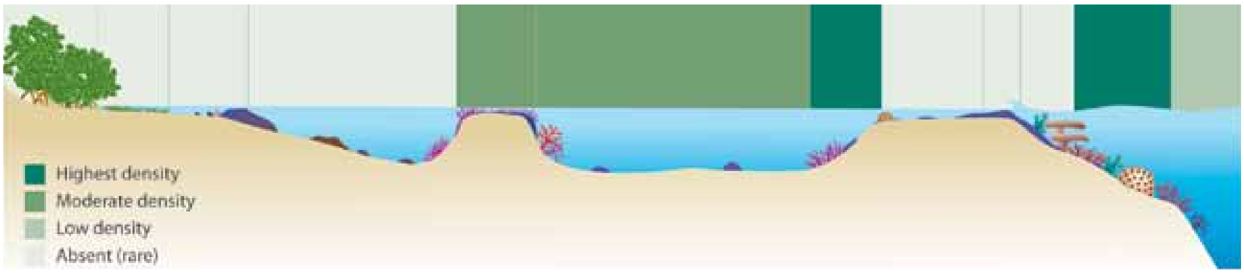
Feed by filter feeding and from zooxanthellae activity.

Habitat and aggregation on reef

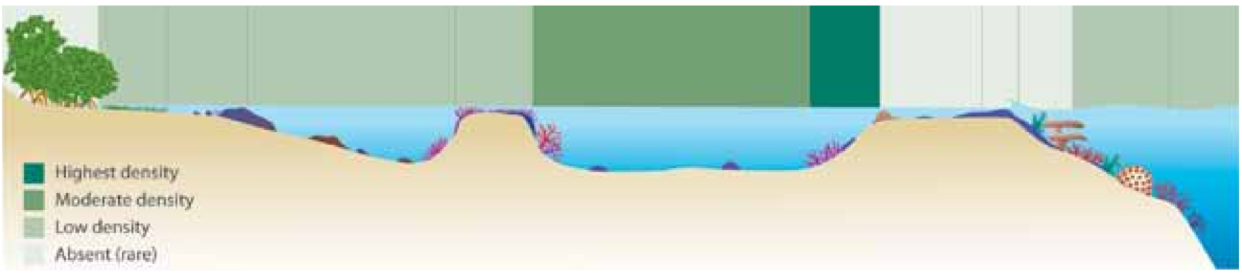
T. squamosa: relatively common species found from fringing reefs to barrier reefs. More common in deeper water than *T. maxima.*



T. derasa: mostly on outer reefs where there is high water flow and strong oceanic influence, rarely on fringing reefs.



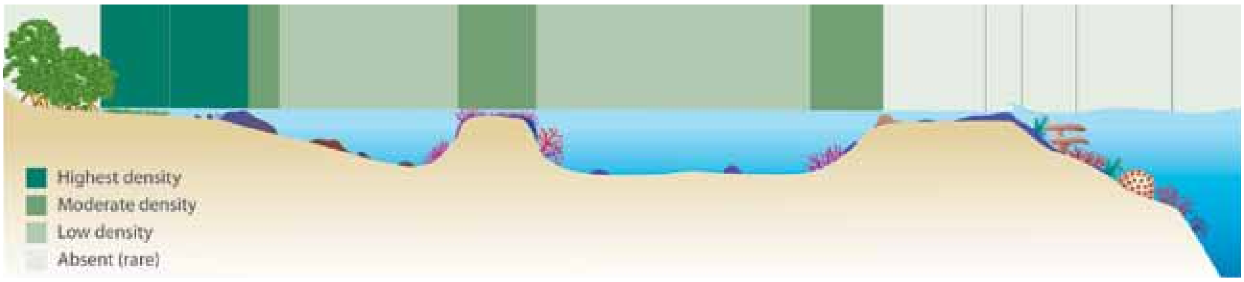
T. gigas: on sand, in coral reef areas. This species can be found in most reef zones, from frining reefs to outer reefs. Not common on reefs that are particularly exposed to land influence or wave action.



Depth range	*T. squamosa*: from surface down to 35 m. *T. derasa*: from 2–25 m. *T. gigas*: from 2–20 m.
Reproduction	Hermaphrodites, spawns eggs and sperm. Sizes at sexual maturity: *T. squamosa*: 150–200 mm in Palau, 200–250 mm in Tonga. *T. derasa*: 250–300 mm. *T. gigas*: 500 mm.
Maximum size	*T. squamosa*: 435 mm (longest length). *T. derasa*: 650 mm (longest length). *T. gigas*: 1,150 mm (longest length).
Recommended harvest size range	*T. squamosa*: 180 mm in Guam and Tonga, 200 mm in Samoa. *T. derasa*: 180 mm in Guam, 260 mm in Tonga. *T. gigas*: no size regulation in place. Note: in most places *T. gigas* is too rare to harvest and takes 10+ years to reach female reproductive maturity.
Healthy density reference point	*T. squamosa*: regional reference at 20–30 ind. ha^{-1} for RBt and SBt surveys (site-specific references recommended). Insufficient data on *T. derasa* and *T. gigas* for regional reference (site-specific references recommended).
Recommended survey methods	Manta tow and SWSs (broad-scale assessment); SWSt (fine-scale assessment).

Bear paw giant clam
(*Hippopus hippopus*)

Species description and geographical distribution	Shell thick and heavy. Radial folds on shell irregular. Relatively squarish in shape with a very rough surface and the upper margin is triangular. Mantle is dull grey. Shell is white with pinkish blotches. Sits loosely on reef habitat. *Distribution:* occurs across South East Asia to Vanuatu in the Pacific. Thought to be locally extinct further to the east.
Feeding	Feeds by filter feeding and from zooxanthellae activity.
Habitat and aggregation on reef	Calm shallow waters in areas adjacent to coral reefs where there is a mix of live coral, coral rubble and sediment, often in association with seagrass. High densities in fringing reefs. Lower densities on lagoon patch reefs and back-reefs.

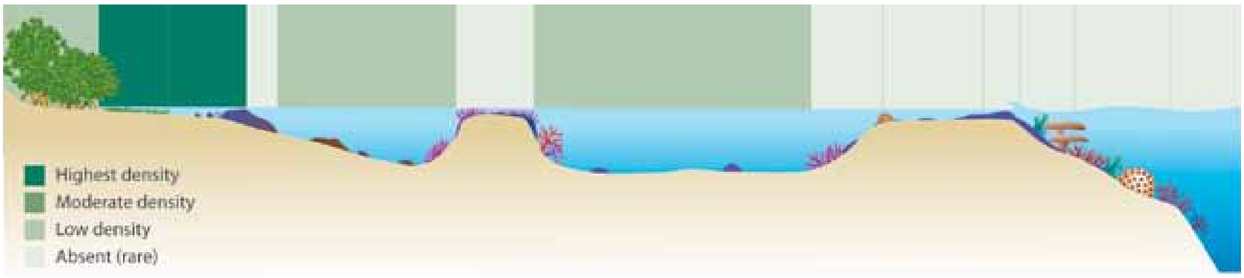


Depth range	Shallow waters, from surface down to 10 m although highest densities occur in upper 2 m.
Reproduction	Limited information available. Attains sexual maturity at 130–150 mm in Palau.
Maximum size	430 mm (longest length).
Recommended harvest size range	Not available. Minimum harvest size set at 180 mm in Guam.
Healthy density reference point	Pacific regional reference at 25–34 ind. ha^{-1} (site-specific references recommended).
Recommended survey methods	Manta tow survey (broad-scale assessment); SBt and RBt (fine-scale assessment).

Other bivalves

Cockle or ark shells (*Anadara* spp., also other infaunal species such as *Gafrarium* spp.)

Species description and geographical distribution	Shell thick and solid, equal valves and unequal shell edge, four-sided to ovate. Surface of shell has axial ribs. Long hinge, almost straight with many small transversal teeth. Several species, important in subsistence fishery and domestic sales. *Distribution:* found throughout the Pacific.
Feeding	Filter feeders.
Habitat and aggregation on reef	Epibenthic species; lives in shallow, soft sediments on of seagrass beds and fringing reefs.

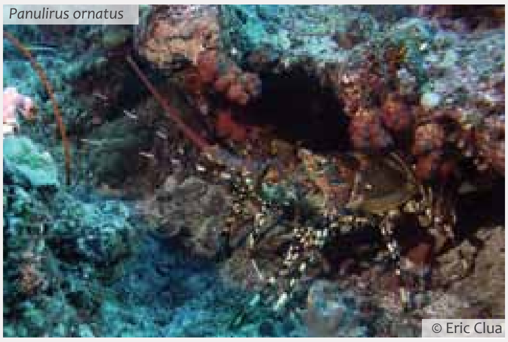


Depth range	From surface down to 5 m with highest densities in the intertidal zone.
Reproduction	Limited information available. Some species attain sexual maturity at 35 mm. Typically spawns during warmer months.
Maximum size	*Anadara antiquata*: 105 mm (shell width).
Recommended harvest size range	*Anadara antiquata*: 45 mm.
Healthy density reference point	2–5 shells per m^2.
Recommended survey methods	SiQ (fine-scale assessment).

Crustaceans

Information and suggested survey approaches for five crustaceans, including two lobsters, one mud crab, one land crab and coconut crab, are provided below. In general, survey techniques used for invertebrate species described in Section 3 can be adapted for the following species of interest but with changes in the size of individual samples (replicates, transects, search times).

Only generalised survey approaches and techniques are suggested here but the suggestions are based on the known life history traits of these species and are often adapted from local harvesting approaches. It is important to note that these suggested techniques have not been tested for their usefulness in obtaining realistic estimates of the status of populations, and are offered as a general guide only.

Spiny rock lobsters (*Panulirus* spp.)	 *Panulirus ornatus* © Eric Clua  *Panulirus penicillatus* © Joseph Poupin
Species description and geographical distribution	Large crustaceans with semi-cylindrical bodies with spines, horns over eyes, long antennae, but no large claws. Seven species of *Panulirus* exist in the tropical Pacific. Each species has distinctive bright colouration patterns. *Distribution: P. penicillatus* ranges across the Pacific to eastern Polynesia and is the main species harvested along with smaller quantities of *P. longipes spinosus*. *P. versicolor* is widespread but in low densities, while *P. ornatus* is important in Papua New Guinea. Other species are relatively uncommon across the Pacific.
Feeding	Forage at night, predominantly on mollusks and algae.
Habitat and aggregation on reef	Species respond differently to habitat gradients such as depth, turbidity, coral cover and wave action. Some species have generalised habitat requirements (e.g. *P. ornatus*) while others have more specific requirements (e.g. *P. penicillatus*). *P. penicillatus* is found on surf zone habitats of outer reefs, and moves onto reef flats to feed, but tends to prefer windward margins. *P. longipes* is generally found on shallow outer reefs and areas with moderate wave action and more coral than *P. penicillatus* habitats, especially in large and deep holes. *P. versicolor* is found in outer lagoon edges and lagoon patch reefs and in deeper habitats on outer reef slopes where more fragile coral forms are located. *P. ornatus* is found in island coastal habitats adjacent to the shore, including shallow lagoons and fringing reefs. *P. femoristriga* is found on outer reef flats and shallow outer slopes. *P. homarus* is found on fringing reefs where there is low terrestrial runoff. *P. polyphagus* is found on fringing reefs where there can be heavy terrestrial runoff.
Depth range	Surface to deep outer slopes, depending on species.

Reproduction	*P. penicillatus* is perhaps the most abundant lobster species found in the Pacific and more is known about its ecology than other species. Reproduction is continuous throughout the year in the Cook Islands. The relatively larger females carry fertilised eggs for about a month before releasing them, with an individual female having 8–11 broods per year. Males tend to have a relatively longer carapace length but are smaller in terms of body weight, total body length and tail width compared with females. The number of eggs per brood in females 70–130 mm in size ranges from 100,000–500,000. Females at sexual maturity are 75–79 mm carapace length (at about 3–5 years old) and live for about 20 years. In Tonga, *P. penicillatus* females were recorded to reach sexual maturity at about 60–70 mm carapace length. In contrast to the Cook Islands studies, *P. penicillatus* in Tonga showed seasonal spawning activity from September to March with peak spawning from October–December. *P. longipes spinosus* may spawn throughout the year in Tonga but there appears to be low spawning activity from May–July.
Recommended harvest size range	Size limit for *P. penicillatus* in French Polynesia is 180 mm.
Healthy density reference point	Limited information available. Densities of *P. pencillatus* have been recorded at 120–130 ind. km^{-2} of reef edge in the Solomon Islands and Marshall Islands. On Palmerston Atoll in the Cook Islands, an average of 2.2 crayfish were caught per person per hour by walking along the reef crest, and 4 crayfish per hour for free diving along the reef front down to 4 m. This equates to approximately 20 kg of lobster per kilometer of reef crest.
Recommended survey methods	Surveys at night and at low tide by walking on the reef crest, as well as by free diving with torches. A standard survey area could be easily calculated if searches were restricted to a defined width and length (e.g. a 5 m swath), and distances could be accurately determined by using a GPS. Standardised distances of 500 m or 1,000 m (1 km) are recommended; this way, a density per unit of area (in this example, density per 2,500 m^2 or 5,000 m^2) could be recorded.

Slipper lobsters (Scyllaridae)	 Parribacus caledonicus © Matthieu Juncker  Parribacus antarcticus © Chan Tin-Yam
Species description and geographical distribution	Related to spiny lobsters but have flattened bodies with no horns and very short, flattened antennae. Second antennae are expanded and flattened into large plates that extend horizontally forward from the animal's head. There are five other species (besides *Parribacus caledonicus*) in this group, including *P. antarcticus, Scyllarides squamosa, Scyllarus cultrifa* and *Thenus orientalis*. *Distribution: P. caledonicus* is widely distributed in the western Pacific; *P. antarcticus* is found in all oceans, including the Pacific; *Scyllarides squamosa* and *Scyllarus cultrifa* have been recorded in Tonga on or near rocky coral reefs; *Thenus orientalis* is distributed in the Indian and Pacific oceans.
Feeding	Hunt at night on gastropods, mollusks, polychaetes and other invertebrates.
Habitat and aggregation on the reef	Slipper lobsters are bottom dwellers and live in the shallow waters of lagoons and in crevices on reefs. Some (e.g. *P. caledonicus*) live in cavities or nests with small openings. Burrow in sand or hide on reefs during the day.
Depth range	*P. caledonicus* occurs in shallow inshore waters down to 20 m near coral and rocky reefs. *S. squamosa* occurs subtidally down to 80 m in Tonga.
Reproduction	Reaches sexual maturity at about 3 years of age. *P. caledonicus* spawn from September to January with peak activity in November, and little evidence of spawning activity the rest of the year. Females release up to 100,000 eggs which are carried beneath the body for 2 weeks or more as eggs develop and change colour from orange to brown. Eggs hatch into floating larvae and drift at sea for up to 11 months, with very few surviving to the juvenile stage. Life expectancy is approximately 10 years once a lobster has settled and metamorphosed into a juvenile.
Maximum size	*P. caledonicus* – up to 180 mm total length; *P. antarcticus* – up to 280 mm total length and a weight of over 0.5 kg.
Recommended harvest size range	Not available.
Healthy density reference point	Not available.
Recommended survey methods	RFw adapted for long-distance replicates for *P. penicillatus*, on a scale of 500–1,000 m per replicate of reef front may be required. The range of species habitat preferences and generally low abundances suggest that accurate stock assessments will be difficult to conduct. An overlap of habitat preference of *P. caledonicus* with some spiny lobster species suggests that there may be scope for density estimates for both groups using similar survey methods. Use of mark-release-capture studies also could be a useful technique for status estimates.

Coconut crab *(Birgus latro)*	 
Species description and geographical distribution	Related to hermit crabs and is the largest of all crabs. Adults have large crushing claws and long legs that enable them to climb trees. Colour of adults varies from light violet to deep purple and brown. Slow-growing species that can live up to 30 years. It is estimated that it takes up to 10 years for individual to reach market size. *Distribution:* from far western Pacific to as far east as French Polynesia.
Feeding	Feeds on coconuts, dead leaves and bush vines and fruits; some high island crabs can be toxic if eaten, especially if it feeds on certain bush plants.
Habitat and aggregation on reef	Larval stages spend about a month in the ocean developing through several larval stages before returning to land as young. Juveniles live in gastropod shells like other hermit crabs until they grow to a larger size where the adult lives independently of a shell. After developing into adults, they spend their life in coastal vegetation (sometimes far inland, up to 6 km from the sea) and only females return to the sea edge to release eggs during breeding season. Adults live alone in underground burrows and rock crevices and generally remain hidden during the day, coming out at night to look for food.
Depth range	Not applicable. Lives on land.
Reproduction	Sexual maturity reached at ~ 5 years of age (at an approximate thoracic length of 25 cm for females). Outer skeleton is shed in order to grow; crabs remain hidden (for protection) for up to 30 days as they develop a new hard outer skeleton.
Maximum size	Adults can reach weights of over 4 kg.
Recommended harvest size range	Size limits vary by country: cephalothoracic length – 75 mm in American Samoa, 90 mm in Vanuatu; thoracic length – 36 mm in Wallis and Futuna and Niue.
Healthy density reference point	Not available.

Recommended survey methods	Different techniques are required for juvenile and the adults. ***Baited trails:*** Opened coconut shells used as lures (similar to how subsistence fishers hunt for them) and set out on a grid system through the forest area, and then surveyed regularly. A number of baits are set out along a trail during the day and revisited at night, collecting the crabs that are attracted to the baits. Density can only be estimated from catch per unit of effort (number of crabs per coconut bait). ***Direct capture and capture in moulting burrows:*** Transects of a set distance and width (e.g. 5 m x 50 m; 6 transects per station; chosen number of stations per site) are laid out. These can be analysed in the same manner as marine benthic transect data. This method requires some skill in handling crabs and measuring their carapace length. A direct estimation of the number of coconut crabs in a given area is difficult. Mark and recapture estimates have been made on a number of small islands, but on large islands recapture rates are too low for reasonable estimates to be made. To overcome this problem, Fletcher et al. (1994) (see Section 5) determined the relationship between the relative abundance measure (number of crabs caught per bait set) and the absolute stock size through the calculation of the catchability coefficient (q). This was determined from experiments in Vanuatu where a catch per unit of effort (CPUE) of 1 crab per bait corresponded to a population density of 1,200 ha^{-1}. This coefficient only relates to CPUE data collected during the wet season, using baits set at locations where crabs are likely to be found. The area measurement obviously should only encompass areas of suitable habitat for coconut crabs. The catchability coefficient has been used to estimate remaining crab stocks in various parts of Vanuatu, and it is likely that it could be applied equally, but with caution, to crab stocks in any area. Fisheries-dependant data, in particular CPUE and landings at markets, are useful information for assessing population structure occurrences of illegally caught sizes and production trends.

Mangrove crab (*Scylla serrata*)	 © Matthieu Juncker  © Richard Ling
Species description and geographical distribution	Crustaceans with claws and hard outer body skeletons. Shell varies from deep mottled green to very dark brown or purple. *S. serrata* is a swimming crab. Other related genuses may exist in same habitat. *Distribution:* found in tropical and subtropical inshore areas from Africa to Pacific Islands in association with mangroves and estuarine systems; widespread distribution throughout the Pacific.
Feeding	Feeds on small clams, shrimps, barnacles, small fish and plant material and other crabs. Small juveniles are prey for wading birds and fish; adults are preyed on by larger fish and sharks.
Habitat and aggregation on the reef	Widely distributed in all habitats on coral reefs associated with mangrove and seagrass habitats. *S. serrata* is generally a nocturnal species. *S. serrata* is estimated to have a life span of approximately 5 years, becoming sexually mature at 2–3 years of age.
Depth range	Generally shallow areas; lives in mud and brackish water associated with mangrove and estuarine environments.
Reproduction	Separate males and females. Females carry fertilised eggs for around 12 days, move to sea to release eggs, juvenile crabs settle to bottom after approximately 3 weeks.
Maximum size	Around 3.5 kg and 240 mm (carapace width).
Recommended harvest size range	Minimum harvest sizes can be set from 120–150 mm carapace width.
Healthy density reference point	Not available.
Recommended survey methods	Mangrove mud crabs are particularly difficult to survey but the most appropriate data will probably come from set traps. Mark-release-capture approaches can provide useful stock estimates. Fisheries-dependant data, in particular CPUE and landings at markets, are useful information for managers to assess population structure occurrences of illegally caught sizes and production trends.

Land crabs (*Cardisoma* spp.)	 
Species description and geographical distribution	Crustaceans principally adapted to life on land though the reproductive stage requires larvae to develop from eggs in the ocean. *Distribution:* widespread throughout the Pacific.
Feeding	Land crabs are omnivorous and feed on a wide range of animal and plant material, including their own young. Their diet is usually limited to items found in close proximity to their burrows.
Habitat and aggregation on reef	Typically occur in coastal vegetation areas. Land crabs are difficult to detect because they generally forage at night or are more active out of their burrows at dawn and dusk.
Depth range	Not applicable. Lives on land.
Reproduction	Land crab eggs need to be in salt water in order to hatch. Cardisoma hirtipes females migrate from their holes in the forest to beaches to release their eggs in the sea during the few days before or after the full moon. Land crabs are easily harvested during this migration, and are also harvested at other times of the month when they emerge from their burrows to feed in the early morning or late afternoon.
Maximum size	Limited study on growth and lack of size limits in most fisheries.
Recommended harvest size range	Not available.
Healthy density reference point	Not available.
Recommended survey methods	The land crab's general nocturnal foraging behaviour means that night surveys are required. Land crabs also migrate to the beach for breeding (like coconut crabs) so this time of year can be used to estimate the status of breeding females, although the status of other components of the population (males, juveniles) will have to be assessed by night surveys. Transects (similar to those used for coconut crabs) or large grid (quadrat) sampling methods can be established to determine density estimates per unit area. As a guide, grids could be up to 6 per station, and each grid 5–10 m^2. Fisheries-dependant data, in particular CPUE and landings at markets, are useful information for managers to assess population structure and production trends.

Cephalopods

Octopuses	 
Species description and geographical distribution	Octopuses are related to squids and have eight arms with suckers, soft saclike bodies, and strong, beaklike jaws. *Distribution:* at least 100 species of octopuses are distributed in seas around the world.
Feeding	Feed on a range on invertebrates and fishes. Most octopuses feed at night but the big blue or day octopus, *Octopus cyanea*, feeds during the day, leaving their holes infrequently to forage.
Habitta and aggregation on reef	Octopuses can be found under ledges or in holes on reef flats and shallow outer slopes, and the location of these can often be recognised by rubble and remains of their food (e.g. empty shells) at the entrance to their hole. Holes are not continuously occupied by the same individual but have been observed up to 35 days in the same location.
Depth range	Fringing reefs to outer reef slope depths.
Reproduction	Octopuses have separate sexes. Males insert packets of sperm (called spermatophores) into a female's mantle cavity using a specialised tentacle (called a hectocotylus). Female releases hundreds of eggs that are fertilised by the stored sperm. Female lays fertilised eggs in bunches under a ledge or within a nest on the reef. Females protect eggs and do not hunt for a period of several weeks until eggs hatch. Newly hatched forms (drifting larval stages) look like small adults and swim for about a month. Only a few, perhaps one in every hundred, survive to settle onto the sea floor as juveniles.
Maximum size	Octopuses vary greatly in size but *O. cyanea* are widely distributed on coral reefs in the Pacific and grow to an overall length of about 1 m.
Recommended harvest size range	Varies among species.
Healthy density reference point	Not available.
Recommended survey methods	An experienced observer may be able to give some estimates of the number of holes where octopus are likely to be found, but an accurate estimate of octopuses is extremely difficult to make due to the cryptic behaviour and general mobility. Counting individuals when they are out of hiding and foraging can also provide an approximate estimate of abundance. In the absence of resource data, fisher data are useful, CPUE and landings and catch sizes at local markets, are useful for managers to gain an approximate idea of the trend of octopus status.

Appendix 5. Field survey datasheets

Appendix 5a. Invertebrate survey main record sheet (all surveys except SiQ and crab bait)

DATE		RECORDER		Pg No	

STATION NAME																		
WPT / WIDTH OF REPLICATE																		
RELIEF / COMPLEXITY 1- 5																		
OCEAN INFLUENCE 1- 5																		
DEPTH (M)																		
% SOFT SED (M – S – CS)																		
% RUBBLE / BOULDERS																		
% CONSOL RUBBLE / PAVE																		
% CORAL *LIVE*																		
% CORAL *DEAD*																		
SOFT / SPONGE / FUNGIDS																		
ALGAE *CCA*																		
CORALLINE																		
OTHER																		
GRASS																		
EPIPHYTES 1-5 / SILT 1-5																		
BLEACHING: % of benthos																		
ENTERED / CHECKED																		

Appendix 5b. Manta tow summary sheet

	DATE		Pg	

	WPT START	DISTANCE	WPT FINISH	SPEED
1				
2				
3				
4				
5				
6				

TIME START:

MAPS & NOTES

TIME FINISH:

	WPT START	DISTANCE	WPT FINISH	SPEED
1				
2				
3				
4				
5				
6				

TIME START:

MAPS & NOTES

TIME FINISH:

	WPT START	DISTANCE	WPT FINISH	SPEED
1				
2				
3				
4				
5				
6				

TIME START:

MAPS & NOTES

TIME FINISH:

Appendix 5c. Soft infaunal quadrat record sheet

DATE		Pg	

1				
2				
3				
4				
5				
6				
7				
8				

RELIEF / COMPLEXITY 1-5		DEPTH M	
OCEAN INFLUENCE 1-5			
% MUD / SAND			
% C SAND / SHELL-PEBBLE			
% RUBBLE / BOULDERS			
% CONS RUBBLE / PAVE			
% CORAL *LIVE* / *DEAD*			
SOFT / SPONGE / FUNGIDS			
ALGAE *CCA*			
CORALLINE			
OTHER			
GRASS			
EPIPHYTES 1-5 / SILT 1-5			

RELIEF / COMPLEXITY 1-5		DEPTH M	
OCEAN INFLUENCE 1-5			
% MUD / SAND			
% C SAND / SHELL-PEBBLE			
% RUBBLE / BOULDERS			
% CONS RUBBLE / PAVE			
% CORAL *LIVE* / *DEAD*			
SOFT / SPONGE / FUNGIDS			
ALGAE *CCA*			
CORALLINE			
OTHER			
GRASS			
EPIPHYTES 1-5 / SILT 1-5			

1				
2				
3				
4				
5				
6				
7				
8				

RELIEF / COMPLEXITY 1-5		DEPTH M	
OCEAN INFLUENCE 1-5			
% MUD / SAND			
% C SAND / SHELL-PEBBLE			
% RUBBLE / BOULDERS			
% CONS RUBBLE / PAVE			
% CORAL *LIVE* / *DEAD*			
SOFT / SPONGE / FUNGIDS			
ALGAE *CCA*			
CORALLINE			
OTHER			
GRASS			
EPIPHYTES 1-5 / SILT 1-5			

RELIEF / COMPLEXITY 1-5		DEPTH M	
OCEAN INFLUENCE 1-5			
% MUD / SAND			
% C SAND / SHELL-PEBBLE			
% RUBBLE / BOULDERS			
% CONS RUBBLE / PAVE			
% CORAL *LIVE* / *DEAD*			
SOFT / SPONGE / FUNGIDS			
ALGAE *CCA*			
CORALLINE			
OTHER			
GRASS			
EPIPHYTES 1-5 / SILT 1-5			

Appendix 6. Estimates of time, equipment and personnel required by survey method

Table 6.1 Time and number of people required to complete one station for each survey method.

Station type	Time	Surveyors	Assistant	Boat operator	Total personnel	Total person hours
Manta tow	1h00'	1	1	1	3	3h00'
RFs	0h30'	2	1	1	4	2h00'
RFw	0h40'	2		1	3	2h00'
SWSs	1h00'	2	1	1	4	4h00'
DWSs	1h00'	2	1	1	4	4h00'
SCNs	1h00'	2		1	3	3h00'
RBt	0h45'	2		1	3	2h15'
SBt	0h45'	2		1	3	2h15'
SWSt	1h00'	2	1	1	4	4h00'
SiQ	0h15'	2		1	3	0h45'

Table 6.2 Minimum equipment needed for each survey method.

Station type	Boat	Total tanks	Equipment
Manta tow	1	0	GPS, manta tow board with pencil, 20-m rope, data sheets, hand counter, snorkelling gear, wetsuit and protective gloves
RFs	1	0	GPS, two stopwatches, two writing slates with pencil, data sheets, snorkelling gear, wetsuit and protective gloves
RFw	1	0	GPS, two stopwatches, two writing slates with pencil, data sheets, snorkelling gear, wetsuit and protective gloves
SWSs	1	2**	GPS, two stopwatches, two writing slates with pencil, data sheets, scuba gear, dive computer, wetsuit and protective gloves
DWSs	1	2	GPS, two stopwatches, two writing slates with pencil, data sheets, scuba gear, dive computer, wetsuit and protective gloves
SCNs	1	0	GPS, two writing slates with pencil, data sheets, snorkelling gear, wetsuit, protective gloves and three underwater torches
RBt	1	0	40-m transect line, weight, buoy, GPS, two writing slates with pencil, data sheets, snorkelling gear, wetsuit and protective gloves
SBt	1	0	40-m transect line, weight, buoy, GPS, two writing slates with pencil, data sheets, snorkelling gear, wetsuit and protective gloves
SWSt	1	2**	GPS, two writing slates with pencil, data sheets, Chainman, scuba gear, dive computer, wetsuit and protective gloves
SiQ	1*	0	GPS, one writing slate with pencil, data sheets, two quadrats made of wire, booties or boots, protective gloves and hat
LNs			GPS, two stopwatches, two writing slates with pencil, data sheets, snorkelling gear, wetsuit, protective gloves and three underwater torches
Crab bait			GPS, two stopwatches, two writing slates with pencil, data sheets and two underwater torches

* If conditions allow, SiQ can be done from the shore, without a boat.
** In shallow and calm water condition, 1 tank can last two stations.

Table 6.3 Time estimates by survey method for a general invertebrate survey for all species over a site of approximately 50 km².

Station type	Number of stations	Time per station	Total time	Boat	Surveyor	Assistant	Boat Operator	Total personnel	Person-hours	Tanks per station	Total tanks
Manta	12	1h00'	12h00'	1	1	1	1	3	36h00'	0	0
RFs	4	0h30'	2h00'	1	2	1	1	4	6h00'	0	0
RFw	4	0h40'	2h40'	1	2		1	3	8h00'	0	0
SWSs	4	1h00'	4h00'	1	2	1	1	4	16h0'	2	8
DWSs	3	1h00'	3h00'	1	2	1	1	4	12h0'	2	6
SCNs	2	1h00'	2h00'	1	2		1	3	6h00'	0	0
RBt	12	0h45'	9h00'	1	2		1	3	27h00'	0	0
SBt	12	0h45'	9h00'	1	2		1	3	27h00'	0	0
SWSt	4	1h00'	4h00'	1	2	1	1	4	16h00'	2	8
SiQ	12	0h15'	3h00'	1	2	1	1	3	9h00'	0	0
Total time equivalent			**50h40'**	**50h40'**	**89h20'**	**26h00'**	**50h40'**		**166h00'**		**22**

Appendix 7. Data analysis using Microsoft Excel

These calculations can be generated automatically in the Reef Fisheries Integrated Database (RFID), if it is available for use.

Number of species present

Using the example from Table 3 in the main text, the number of species observed at a site (or area of interest) is simply calculated by using the function: '=COUNT(D2:D24)', where (D2:D24) are the cells where the total for all records for a site (or area of interest) are found, assuming one column contains all the species that were recorded, and corresponding rows contain the number of individuals of each species. To arrange the rank abundance using mean density: 1) select the whole data table; and 2) click on: 'Data' – 'Sort' – 'Sort -'Mean Density', and select 'Order': 'largest to smallest.'

Calculating mean densities from survey data

In an Excel spreadsheet, the raw data from a single station is shown in example Table 7.1, so this is repeated for each station from a site:

Table 7.1 Raw data of clam densities from a Manta survey site showing the data from one station (of many stations that were surveyed).

	A	B	C	D	E	F
1				Transects		
2	Stn	Tr	No.Clams	Density/m^2	Density/ha	
3	1	1	28	0.047	466.7	
4	1	2	10	0.017	166.7	
5	1	3	44	0.073	733.3	
6	1	4	3	0.005	50.0	
7	1	5	8	0.013	133.3	
8	1	6	18	0.030	300.0	
9				*	**	
10				Mean density/ha	308.33	
11				STD	254.24	
12				n	6	
13				SE	103.79	

Step 1

The density of clams per transect area in m² (600 m² each transect)
(Note this step can be left out if you are only interested in the density per hectare, in which case start at step 2):

- In column D, the number of individuals counted in each transect (from column C) is divided by the surface area of the transect (600 m^2).

  ***column D = density for transect 1 in m^2**
  = C3 / 600
  = No. clams / 600 m^2

Step 2

The density of clams per transect converted to hectares

- The density of clams per m^2 is converted to density per ha by using the number of clams per transect and multiplying this by the conversion factor (10,000 per area surveyed per transect), where 1 ha = 10,000 m^2.

  ****column E = density for transect 1 in ha**
  = (C3 x 10,000) / 600
  = (number of clams x 10,000) / 600
  (i.e. using the actual number of individuals)

  or **= density for transect 1 in ha**
  = (D3) x 10,000
  = (density clams per m^2) x 10,000
  (i.e. using the mean density m^{-2})

- These calculations should be completed for Transects 2–6.
- The density measure per transect is used to calculate the standing stock of a site that has a number of survey stations within it.

Step 3

The mean number of clams per hectare for station 1

- The mean density per station is the sum of the transect densities (per ha) divided by the number of transects.

  Cell E10 = (SUM (E3:E8)) / 6

Step 4

The standard deviation (STD) of the mean per hectare for station 1

- The standard deviation of each station is calculated for each transect density using the Excel function (STDEV).

  Cell E12 = STDEV (E2:E7)

Step 5

The number of transects (n) in station 1

- The count of the number of transects in a station.

  Cell E12 = COUNT (B3:B8)

Step 6

The standard error (SE) of station 1 density

- The standard error of the station mean density is calculated from the formula (SE = SD/ √n).

  Cell E13 = E11 / (SQRT (E12))

- These basic calculations are repeated for the number of survey stations used for the site.
- The function to use for calculating a mean of clams per transect, for example, is '= AVERAGE (D3:D8)', where (D3:D8) is the column where the number of clams observed in each individual transect is entered.
- The FUNCTION to use for calculating a mean, ignoring any zero (0) values is: = AVERAGEIF (D3:D8, "> 0"). This is the case where stations recording no individuals of the species of interest are excluded from the calculations (i.e. 'Present' mean density).

Calculation of size distribution

To derive the frequency of individuals in each size class, use the FREQUENCY function, which is entered as = FREQUENCY (data_array, bins_array).
Data_array is an array value (here it is the trochus length measurements) for which you want to count frequencies. **Bins_array** is an array of intervals into which you want to group the values in data_array.

Steps

(i) Place all length measurements (Data_Array) in a single column.

(ii) Enter the size classes (maximum value for each class) or (Bins_Array) in the adjacent column (column C in the example below).

(iii) Select a number of cells in the adjacent column (column C in the example below) to the 'Bins_Array' plus an extra cell below the last (highest) class size maximum. The number of classes in the returned array is one more than the number of classes in 'bins_array'. The extra class in the returned array returns the count of any values above the highest interval.

(iv) Keep the cursor in the selected cells and write: =FREQUENCY(Data_Array, Bins_Array), then press CTRL+SHIFT+ENTER. (Select Data_Array and Bins_Array from the appropriate columns) (Fig. 7.1).

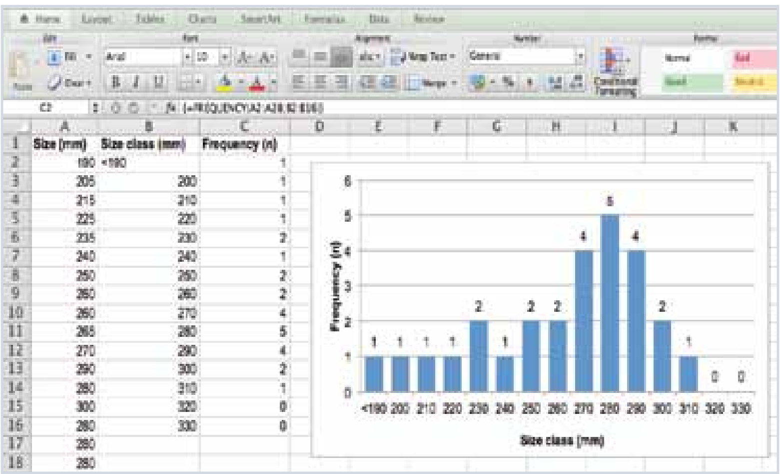


Figure 7.1 Size-frequency distribution from a hypothetical dataset.

Estimating standing stock

The following steps are undertaken to arrive at an estimate of the standing stock of trochus based on data from a Pacific Island site. The following steps are followed to arrive at the final stock estimate:

(1) Calculate density per zone
(2) Estimate habitat surface area per zone
(3) Extrapolate trochus numbers
(4) Calculate confidence interval
(5) Calculate harvestable stock

Step 1

Calculation of density, standard deviation and standard error

This is explained in earlier sections of this appendix. In this example, density includes all trochus sizes recorded from a single survey type (RBt) conducted in a marine protected area and four areas open to fishing at a Pacific Island site (Table 7.2).

Table 7.2 Trochus densities by reef zones.

	A	B	C	D	E	F	G	H	I	J
1		Sampled area (m^2)	Number of individuals	Number of stations	Number of transects	Mean density (ind/m^2)	Std dev	Std error	95% CI	Mean density (ind/ha)
2	MPA	480	31	2	12	0.06	7.8	5.5	10.8	646
3	Open Zone 1	1200	56	5	30	0.05	2.7	1.2	2.4	467
4	Open Zone 2	960	101	4	24	0.11	7.5	3.7	7.3	1052
5	Open Zone 3	960	60	4	24	0.06	9.0	4.5	8.8	625
6	Open Zone 4	1200	172	5	30	0.14	15.3	6.9	13.4	1433

Step 2

Estimation of total reef habitat area per zone

Trochus habitat area is estimated for each zone using a map and GIS software. For a conservative estimate, the total reef zone area in this example has been reduced by 20% by multiplying each zone area by 80% (Table 7.3).

Table 7.3 Estimated surface area of trochus habitat.

	A	B	C
1	Zone	Zone area (ha)	80% of zone area (ha)
2	MPA	8.0	6.4
3	Zone 1 - open	102.0	81.6
4	Zone 2 - open	125.0	100.0
5	Zone 3 - open	127.5	102.0
6	Zone 4 - open	133.0	106.4
7	Total area	495.5	396.4

Step 3

Trochus population estimates

From the derived density and surface area data, estimated stock sizes can be calculated for each zone as in Table 7.4, with confidence interval (CI) values at 95% confidence levels.

Table 7.4 Trochus stock estimates by reef zone.

	A	B	C	D	E	F	G	H
1		Mean density (Ind/m^2) (from Table 6.3)	95% CI of mean density (ind/m^2) (from Table 6.3)	Mean Density (Ind/ha) (from Table 6.3)	95% CI of mean density (ind/ha)	80% of zone area (ha) (from Table 7.3)	Estimated stock size	95% CI of estimated stock size
2	MPA	0.065	10.78	645.83	449	6.4	4133	2875
3	Open Zone 1	0.047	2.35	466.67	98	81.6	38080	7997
4	Open Zone 2	0.105	7.31	1052.08	304	100.0	105208	30442
5	Open Zone 3	0.063	8.80	625.00	367	102.0	63750	37407
6	Open Zone 4	0.143	13.45	1433.33	560	106.4	152507	59608
7	Total				**1779**	**396.4**	**363678**	**138329**

Excel procedure:

Estimated stock size for each zone is derived by multiplying the mean density (ind. ha^{-1}) (Column D) by zone area (Column F). For example, the estimated stock size in the marine protected area is:

= D2 x F2
= 645.83 x 6.4
= 4,133

Overall trochus stock estimate for the site:

= Sum (G2:G6)
= 363,678

Step 4

Calculating confidence intervals

Excel procedure

A function is available in Excel to calculate the confidence intervals at any level of probability. The 95% CI are derived from the **'CONFIDENCE'** function using the station densities in earlier tables. Note that the STD of the mean densities is used in the CI function. This is the same STD used to calculate the standard error (SE).

CI are calculated by typing the function in an empty cell:

= CONFIDENCE (alpha,standard_dev,size)

Alpha is the significance level used to compute the confidence level. The confidence level equals 100 * (1 - alpha)%; or, in other words, an alpha of 0.05 indicates a 95 percent CI. **Standard_dev** is the population STD for the data range and is assumed to be known. **Size** is the sample size or number of stations per transect surveyed ('n').

To calculate the 95% CI of the estimated stock size for Open Zone 1:

(1) First calculate the confidence interval of mean individuals per station
= CONFIDENCE (alpha, stdev, size)
= CONFIDENCE (0.05, G3, D3) (from Table 7.2)
= CONFIDENCE (0.05, 2.7, 5)
= 2.35

(2) Then divide by survey area and multiply by 10,000 (to convert to hectares):
= CONFIDENCE (0.05, 2.7, 5) / 240 x 10,000
= 2.35 / 240 x 10,000
= 98

(3) Then multiply 95% CI of mean density (ind. ha^{-1}) by zone area to derived 95% CI for estimated standing stock:
=E3 x F3 (in Table 7.4)
=98 x 81.6
=7,997

(4) Maximum and minimum confidence limits around the estimated stock size are calculated by adding and subtracting this value from the estimated stock size:
Maximum 95% CI for Open Zone 1:
= estimated stock size + 95% CI of estimated stock size
= 38,080 + 7,997
= 46,077

Step 5

Calculating harvestable stock estimates

Harvestable stock estimates are based on stocks above legal harvest sizes according to local regulations on legal minimum or maximum sizes where available, or a similar recommended size range if legal harvest sizes are not available. In this example, harvestable trochus sizes are between 80 mm and 110 mm basal diameter, and two harvest levels of 20% and 30% of the total estimates stock within this harvest size limits are provided for decision-making options. The proportion of the population of legal size (80–110 mm = 53%) was estimated from size frequency data and 4 wet harvestable trochus shells are assumed to weigh 1 kg (4 wet legal size trochus = 1 kg weight).

Table 7.5 Harvestable stock estimate trochus fishery.

	A	B	C	D	E	F	G	H
1		80% of zone area (ha) (from Table7.3)	Estimated stock size	95% CI minimum	95% CI maximum	53% legal size	20% harvest level	30% harvest level
2	MPA	6.4	4133	1258	7008	2191	-	-
3	Open Zone 1	81.6	38080	30083	46077	20182	4036	6055
4	Open Zone 2	100.0	105208	74766	135650	55760	11152	16728
5	Open Zone 3	102.0	63750	26343	101157	33788	6758	10136
6	Open Zone 4	106.4	152507	92899	212115	80829	16166	24249
7	**Total**	**396.4**	**363678**	**225349**	**502007**	**192750**	**38550**	**57825**

53% = legal harvest proportion based on size frequency; 20% or 30% = recommended harvest proportion.

Legal size stock estimate by zones

= Estimated stock size (C3) x proportion legal size (53%) for Open Zone 1
= 38,080 x 0.53
= 20,182 individuals

Harvest proportion at 20% for Open Zone 1

= Legal size stock estimate (F3) x 20%
= 20,182 x 0.2
= 4,036 individuals

Harvest proportion at 30% for Open Zone 1

= Legal size stock estimate (F3) x 30%
= 20,182 x 0.3
= 6,055 individuals

Step 6

Converting stock estimate into weight estimate

The estimated wet weight for 20% of harvest stock for Zone 1 = 4,036 individuals trochus divided by 4 (4 shells = 1 kg) = 1,009 kg or 1.009 tonnes of wet trochus. Conversion of wet weight to dry weight can also be worked out if the number of empty shells per kg is known.

In the above example, estimated harvestable quantities have been calculated based on the estimated stock size. For extra precaution, harvestable sizes could be calculated based on the lower 95% CI values. Using the data from the above example, this more conservative approach would equate as follows:

Legal size stock estimate by zones

= Lower 95% CI estimated stock size (D3) x proportion legal size (53%) for Open Zone 1
= 30,083 x 0.53
= 15,949 individuals

Harvest proportion at 20% for Open Zone 1

= Legal size stock estimate x 20%
= 15,949 x 0.2
= 3,189 individuals

Harvest proportion at 30% for Open Zone 1

= Legal size stock estimate x 30%
= 15,949 x 0.3
= 4,783 individuals

Appendix 8. Conversion ratio for length and weight of live and dried sea cucumber products and dry pieces per kilogram

Conversion ratios are used to convert dry lengths or weight to wet lengths or weight and vice versa. Regional conversion ratios have been developed for some species by the Secretariat of the Pacific Community based on past work in some locations for use in the absence of local conversion ratios and as a basis for developing site-specific wet:dry ratios.

Table 8.1 Conversion table for live and dry lengths and weights of sea cucumbers, and maximum dry pieces per kilogram.

Common name	Scientific name	Code	Mean live length (cm)	Mean live weight (g)	Mean dry weight (g)	Wet to dry recovery rate (%)	Conversion ratio	Maximum dry pieces per kg
Greenfish	*Stichopus chloronotus*	GF	22	300	9.00	3.0	0.030	115
Deepwater redfish	*Actinopyga echinites*	DWRF	20	400	22.00	5.5	0.055	45
Hairy blackfish	*Actinopyga miliaris*	HBF	n/a	500	27.50	5.5	0.050	37
Stonefish	*Actinopyga lecanora*	STF	18	650	35.75	5.5	0.055	30
Sandfish	*Holothuria scabra*	SF	22	750	37.50	5.0	0.050	28
Tigerfish / Leopardfish	*Bohadschia argus*	TF	35	1,000	40.00	4.0	0.040	27
Brown sandfish	*Bohadschia vitiensis*	BSF	30	1,000	40.00	4.0	0.040	26
Surf redfish	*Actinopyga mauritiana*	SRF	20	850	46.75	5.5	0.055	22
Golden sandfish	*Holothuria versicolor*	GSF	30	1,400	70.00	5.0	0.050	15
Curryfish	*Stichopus herrmanni*	CF	38	2,100	84.00	4.0	0.040	14
Deepwater blackfish	*Actinopyga palauensis*	PBF	n/a	1,500	82.50	5.5	0.055	12
Black teatfish	*Holothuria whitmaei*	BTF	30	2,400	168.00	7.0	0.070	6
Prickly redfish	*Thelenota ananas*	PRF	55	3,500	175.00	5.0	0.050	6
White teatfish	*Holothuria fuscogilva*	WTF	38	2,500	200.00	8.0	0.080	5
Amberfish	*Thelenota anax*	AF	55	3,500	192.50	5.5	0.055	5
Elephant trunkfish	*Holothuria fuscopuncatata*	ET	45	2,000	200.00	10.0	0.100	5