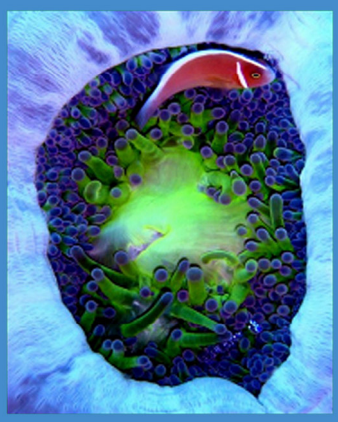
Wildlife Conservation Society
and
PNG National Fisheries Authority
Coastal Fisheries Management
and Development Project
MARINE TRAINING PROGRAMME





Marine Resources Training Manual 2006

WILDLIFE CONSERVATION SOCIETY

GPA

PNG NATIONAL FISHERIES AUTHORITY
COASTAL FISHERIES
Management and Development Project
ASIAN DEVELOPMENT BANK

Tautai

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PNG National Fisheries Authority's Coastal Fisheries Management and Development Program, and the Australian Government's Regional Natural Heritage Program.

FOREWORD

This manual represents four years of collective experience and expertise of the Wildlife Conservation Society's (WCS) PNG Marine Program, in collaboration with the National Fisheries Authority's Coastal Fisheries Management and Development Project (CFMDP) and marine scientists from the James Cook University, Townsville, Queensland.

WCS is committed to providing training and building the skills of young scientists on their way to becoming conservation leaders in their country. The annual marine training course is a key component of this effort. Each year around 20 candidates from Papua New Guinea and the Solomon Islands, from universities, NGOs and government, are selected to attend the one-month full-time course.

The CFMDP aims to increase Papua New Guinea's capacity for management and monitoring of its marine resources at a range of levels from village through provincial bodies and national institutions. This manual is part of the CFMDP's contribution to the technical training needed to support the monitoring of marine resources in the country.

This course is the first of its kind on offer in PNG. The manual contains all the teaching materials required for the training course, but can also be used for self-study. Its purpose is to promote a deeper understanding of the mechanisms for monitoring and management of marine resources in Papua New Guinea.

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LECTURE 1.1: TROPICAL MARINE ECOSYSTEMS

Coral Reefs

In the tropics, coral reefs are a conspicuous and important component in the livelihoods of many coastal communities. Coral reefs are amongst the most productive and diverse habitats in tropical oceans. The diversity of organisms on coral reefs is the highest per unit area of any known habitat. Coral reefs also act as barriers against the destructive power of oceanic waves, providing sheltered environments for the development of seagrass beds and mangrove systems. These same barriers also protect the coastline from erosion that could destroy property and houses in coastal villages. Older reef structures may also form the foundations on which communities build their houses. More importantly, from a human perspective, coral reefs have long provided a source of sustenance, livelihood and set of cultural values for many coastal communities.

We are quickly discovering, however, that coral reefs are actually very fragile marine habitats. The fine balance of life on coral reefs is easily upset by overexploitation, pollution or climate change. In most parts of the world, coral reefs are imminently threatened by a number of factors simultaneously. Many scientists believe that we no longer have any pristine reefs left anywhere in the world. All reefs have been damaged to a certain degree by human activities, and a large proportion (possibly as high as 25%) have been irreparably damaged. Based on historical and geological records, the condition of coral reef ecosystems has been noticeably decreasing due to human influence for at least two hundred years. However, this decrease has been most pronounced in the last 20 years due to the development of modern, more destructive and more efficient fishing techniques, rapid industrialization and mortality of coral communities due to global climate change.

Papua New Guinea's coral reefs contain some of the highest concentrations of marine life anywhere on the planet. PNG forms part of the diversity hotspot called the "coral triangle" along with Indonesia, and the Philippines. It is estimated that more than 2000 species of reef fishes and more than 500 species of corals are found on PNG's reefs. PNG also contains an entire array of coral reef habitats, from inshore fringing reefs, to barrier reef systems, to seamounts and atolls. However, harsh economic realities are rapidly forcing coastal populations in PNG to over-harvest their reef resources. The removal of economically important fish and invertebrates is, in turn, undermining the natural immunity of these ecosystems to fluctuations in environmental conditions. Across the globe, reef systems are showing their vulnerability to environmental and anthropogenic stresses through widespread bleaching and mortality events, and decreased fish and invertebrate density and diversity. Though these phenomena are only just beginning to manifest themselves in PNG, the trajectory of reef decline is readily predictable based on many examples from neighbouring countries, such as Indonesia.

Mangroves

Mangroves are a very diverse group (more than 20 different families) of specialised trees and shrubs growing in the intertidal zone in sheltered bays and estuaries. The food chain within mangrove habitats is heavily reliant upon the decomposing foliage of the mangrove trees and shrubs as a basic source of nutrients. Often the reference to "mangroves" is the ecosystem contained within and among the mangrove trees and shrubs.

Mangroves share several highly specialised adaptations for living in a saline, periodically immersed environment. These include exposed root systems to enable the trees to gain oxygen and "breathe" above the often anoxic sediment upon which they grow, salt excreting leaves to allow plants to utilise seawater for growth requirements, support roots and buttresses, and water dispersed propagules.

Mangroves have three very important roles that we are concerned with as resource managers and conservationists:

1. Coastal protection. Where mangroves have been removed from coastal areas, it has been found that storm surges (e.g. from cyclones) reach far further inland, and coastal erosion and land loss is higher. Mangroves are therefore suggested to be important in maintaining the structural integrity of coastal areas.
2. Nutrient production. Mangroves are a highly productive and nutrient rich ecosystem. This appears to be one of the prime reasons that many marine species use mangroves as a nursery ground for juveniles. Many of these species are of high commercial value, for example, there is a high dependence of banana prawns on mangroves for part of their life cycle.
3. Nutrient filtering. Because mangroves often line rivers and creeks, they form a filtering barrier between the land and the sea. Mangroves play an important role in preventing sediments from land runoff from entering the sea, thereby reducing siltation problems for inshore marine habitats (e.g. fringing coral reefs).

Unfortunately mangroves are one of the most threatened habitats in the world. At least 35% of the area of mangrove forest has been lost in the past two decades, losses that exceed those for coral reefs and tropical rain forests. Mangroves are cleared for coastal development and for building material and firewood. Mariculture development is responsible for the bulk of recent mangrove area loss, with the conversion of 'cheap' mangrove land to valuable shrimp, prawn and fish ponds.

Seagrasses

Seagrasses are a group of rhizomateous flowering marine plants that cover shallow water environments throughout tropical and temperate oceans. They are among the most productive of all marine communities with one half hectare area worth an estimated $15,000 per year in Australia prawn fisheries. The grasses themselves grow rapidly and there are a large variety of associated animals and algal species. Dense seagrass meadows are often colonised by a wide variety of fouling organisms, such as hydroids, seaweeds and sponges. Many invertebrate and fish species depend upon seagrass for both juvenile and adult habitat.

Soft bottom habitats

In many coastal areas, soft bottoms are the most common habitat type, such as lagoon bottoms and at the base of coral reefs. Soft sediments are a mixture of inorganic particles, organic particles and pore water. Benthic organisms are strongly affected by variation in all these constituents. The size of particles affects the lifestyles of benthic organisms and is often a reflection of current regime. Soft bottom habitats are a key area for secondary producers, such as sea cucumbers, that ingest sediment material and derive their nutrition from some fraction of the material. Soft benthic habitat harbours a high diversity and biomass of plankton (like copepods and polychaetes), which provide food for many reef organisms. The emergent plankton migrate vertically at night into the water column and provide food for fishes and corals. Emergent plankton from soft bottom habitats remain a neglected area of research in the study of trophic pathways on coral reefs.

Open ocean/pelagic habitats

The majority of organisms living in the previously mentioned habitats have a planktonic dispersal stage with larvae spending up to several months in open ocean, pelagic habitats. While the duration and mechanisms of this life cycle stage vary considerably, it represents an essential link between benthic and pelagic habitats. In addition, there is a large component of both zooplankton and phytoplankton which live their whole life in the pelagic environment. The enormous amount of phytoplankton in the world's oceans constitutes a larger carbon dioxide sink than tropical rainforests, countering some of the affects of global warming. Significant energy input to coral reefs comes from plankton carried onto coral reefs by currents and wave energy. Most corals derive at least part of their energy from plankton feeding either by day or by night. Corals reefs also provide food for many pelagic organisms. For example, whale sharks have been observed to feed on coral and fish eggs during spawning periods.

Connectivity between habitats

There are significant links between habitats and communities in tropical coastal areas. Large scale larval dispersal means that ecosystems 100's of kilometres apart can be connected via

currents and larval flow, from larval 'sources' to 'sinks'. This idea of connectivity can be demonstrated by fish species that spend some part of their life history in each type of habitat – mangrove to seagrass to coral reef. Understanding the connectivity of coastal areas is fundamental to managing marine biodiversity and resources. It is obvious that coral reef ecosystems cannot be understood or managed in isolation from the complex mosaic of interacting ecosystems in the tropical seascape. Critical adjacent habitats functioning as nurseries, foraging areas and physical and chemical buffer zones are often difficult to identify and may be overlooked in management strategies that focus only on coral reefs. Nevertheless they are potential bottlenecks causing major changes and even collapse of reef populations if they are damaged.

A recent study in the Caribbean found that mangroves strongly influence reef fish community structure in adjacent coral reefs (Mumby et al. 2004). The biomass of several commercially important fish species on coral reefs was found to be more than double where the reefs were located adjacent to mangroves. This study suggests that mangroves may provide a refuge for juvenile fish from predators and/or a plentiful supply of food that increases the survivorship of juveniles. Alternatively, mangroves may provide a significant input of energy or food to adjacent coral reefs, increasing the productivity of reef fish communities. This study shows how two habitats can be integrally linked, and the destruction of one of those habitats (mangroves) may affect the productivity of fisheries in the other habitat (coral reefs).

LECTURE 1.2: THREATS TO MARINE ECOSYSTEMS (WITH A FOCUS ON CORAL REEFS)

Coral reefs are amongst the most productive and diverse habitats in tropical oceans. The diversity of organisms on coral reefs is arguably the highest per unit area of any known habitat in the world. Coral reefs also act as barriers against the destructive power of oceanic waves, providing sheltered environments for the development of seagrass beds and mangrove systems. These same barriers also protect the coastline from erosion which could destroy property and houses in coastal villages. Older reef structures may also form the foundations on which communities build their houses. More importantly, from a human perspective, coral reefs have long provided a source of sustenance, livelihood and set of cultural values for many coastal communities.

Humans can affect the condition of coral reefs in a number of ways, either directly, (e.g. fishing, gleaning, mining) or indirectly (e.g. through pollution, deforestation or global warming). Geological evidence suggests that humans have been having noticeable impacts on coral reefs dating back several hundreds, or in some places, several thousands of years. However, the level of impact has increased dramatically in more modern times, particularly the last 50 years. In earlier times, the main human impacts on coral reefs were from small-scale fisheries, Due to the lack of reliable storage and trade of marine products, most of the extraction was purely for a subsistence lifestyle in coastal communities. The development of better storage facilities, such as refrigeration, as well as better transportation, has meant that products could be carted to further to markets for sale. The last 50 years has seen a dramatic increase in the development of trade links between coastal communities and population centers, as well as trade links between countries. For example, a major proportion of the reef fish caught in Indonesia now end up in the markets of Japan and Hong Kong.

The dramatic increase in technology over the last 50 years has also placed additional burdens on coral reefs. The introduction of small boat engines, including outboards and small diesel inboards, has seen a dramatic shift from traditional boats and canoes to powered vessels in many developing countries. This has meant a dramatic increase in the rate and efficiency with which resources are extracted. The invention of nylon has been also had a significant impact on extraction rates. Nylon is has replaced natural fibres in the construction of fishing lines and monofilament nets, which have a much-increased efficiency and durability. Indirect human impacts have also increased dramatically over recent decades. The use of agricultural, domestic and industrial chemicals and the use of machinery for large-scale land clearing has led to rapid increases in the amount of pollutants and sediment ending up on coral reefs. Many of the human impacts on coral

reefs can also be related to overpopulation problems. Some of the most overpopulated countries in the world also harbour the most diverse coral reefs. In these places the overwhelming pressure of populations has meant that the production of resources on coral reefs simply cannot keep up with the demand to feed expanding communities.

Many scientists agree that there are now no coral reefs to be found anywhere in the world that remain in a natural or pristine condition (free from human influence). Many of the world's coral reefs are quite the opposite. The Status of the Coral Reefs of the World Report in 2000 claimed that at least 11% of the world's coral reefs were lost and a further 16% were no longer fully functional. More recent estimates claim that at least 30% of the world's reefs are irreparably damaged.

Papua New Guinea has so far avoided the catastrophic declines seen in the reefs of neighbouring countries. However, PNG's coral reefs are not immune to these modern threats. Whilst many of PNG's reefs are in good shape when compared with countries such as the Philippines or Indonesia, reefs have already been noticeably impacted in some parts of PNG, especially close to population centres or where reef resources are targeted in commercial trades. Apart from deep systems, there are arguably no reefs remaining in PNG that are in pristine condition. Even the most remote reefs in PNG have been impacted by humans to a certain degree. The wave of exploitation seen in Indonesia may soon be on PNG's doorstep, as commercial fishermen and buyers search for new populations of valuable species to exploit.

The specific threats to coral reefs may be broken up into two groups:

- Natural threats.
- Anthropogenic (or human-induced) threats

Identifying the origins of threats is an important step in determining whether threats need to be or even can be addressed. Sometimes it is simple to determine whether a threat is natural or human-induced, for example, a coral that is smothered by a plastic garbage bag has obviously been affected by a human threat. We might have some control over this by convincing the provincial government to start up a garbage collection service, or by encouraging the local communities to use bilums rather than plastic bags for shopping. By comparison, a reef that is covered by ash from a recent volcanic eruption has obviously been affected by a natural threat and there is not much we can do about it.

However, some threats are difficult to place in either category. For example, Crown of Thorns Starfish (COTS) are a major predator of corals. They often have large outbreaks or plagues in reef systems which can kill an entire reef within a matter of weeks. However, it is still unclear whether these plagues are caused by human influence, or whether they are natural. One argument is that COTS occur in plagues because humans have decreased the abundance of their predators through overfishing. Another argument is that fertilizers that are added to agricultural crops and end up in coastal waters increase the productivity of plankton that is eaten by the COTS larvae, thereby increasing the number of juveniles settling on reefs. If either of these cases were true, then we should probably be making attempts to change human activities and behaviour, which could in turn have some impact on reducing plagues of COTS. However, a large body of scientists also argue that plagues of COTS are entirely natural and are a normal part of the function of a healthy reef ecosystem. They argue that because COTS primarily target the fast growing branching corals, they are important in maintaining a healthy balance on reefs between fast growing and slow growing corals. In this case it would be useless to try to enact conservation strategies for COTS, and in fact doing so, for example by physically removing COTS from reefs, may actually upset the natural balance of reef ecosystems.

When reef ecosystems are found to be damaged, it is sometimes very difficult to distinguish whether this was caused by human-induced from natural threats. However, this distinction may be critical to the management strategy that is developed for that particular situation. Finding a large number of broken corals on a reef might be an indication of the use of destructive fishing gears, such as dynamite, but it might also be an indication that there was a recent storm or earth movement that toppled or damaged the corals. A much larger dataset often needs to be gathered (e.g. history of recent weather, number of fishermen reported to use destructive fishing gears) in order to determine what is causing the damage

to reefs and whether and how something should be done to combat this damage.

Once you have identified whether a threat is natural or human-induced, it is also important to take into account the scale at which the threat is operating. Understanding the scale of operation of threats will also be critical in developing conservation or management strategies to combat these threats.

Threats can be broken up roughly into three scales, (roughly because there is some overlap between categories):

- Local
- Regional
- Global

Local-scale threats are those that happen on the smallest scale and are "often" the easiest to deal with. Local threats affect primarily the site/ village/bay etc. that you are working in. The same threat may occur elsewhere, but the mechanisms involved can be controlled locally. An example of a local threat might be that a few fishermen from the village you are working in are using large monofilament nets on the coral reefs and are damaging corals on the reefs in front of the village. Although the same type of fishing may occur elsewhere in PNG, the threat can be considered local because there are only a few fishermen that you will have to deal with in order to reduce the impacts of net fishing in that area.

Regional-scale threats are more widespread, affecting a large area or a number of areas simultaneously. Regional threats may have one or many sources and the impacts are likely being felt by a number of communities, reefs or islands simultaneously. An example of a regional threat could be the expansions of palm oil plantations within New Britain. The expansion of plantations may be causing coastal deforestation, leading to sedimentation and smothering of inshore reefs. The source of the threat is much larger than in the previous example, and a number of communities are likely to be affected by the threat. Addressing this threat will probably involve dealing with provincial and national government agencies and may require changes in policies on clearing practices or limits the expansion of the palm oil industry. Clearly, dealing with this threat may be more costly and politically challenging than for local threats, however, often regional or global-scale threats may override any successes achieved by eliminating local threats.

Global-scale threats are felt in a number of locations throughout the world simultaneously. These threats operate on a worldwide scale and addressing these threats will likely involve changes to global policies. A classic example of a global threat to coral reefs is coral bleaching. Coral bleaching is widely believed to be linked to global warming and increases in greenhouse gases. Addressing coral bleaching may be critical to the long-term survival of reefs as we know them, however, this will probably require a management strategy that addresses global policies on greenhouse gas emissions.

We will now examine some of the specific threats facing coral reefs in this region:

1) Natural Threats:

Crown of Thorns Starfish (*Acanthaster planci*): Natural or Human induced?

COTS outbreaks have decimated reefs in other locations, especially the Great Barrier Reef. COTS have been reported in a number of locations in Papua New Guinea, but have so far had only limited an localized impacts. As mentioned earlier, it is still unclear whether COTS outbreaks are caused by natural or human impacts.

Geological activity

In a number of regions in PNG, volcanic eruptions and earth movements have caused widespread destruction of coral communities (e.g. recently in Rabaul, Kimbe Bay, islands off Madang). In some cases areas may be rapidly recolonised by corals, for example where larva flows solidify, providing a solid substrate for recolonisation of corals. However, in other circumstances, for example when a reef is covered by a layer of ash and the substrate is unstable and shifting, recolonisation may take decades. These are events that you cannot control for, however, they are sometimes important to consider in planning a marine conservation strategy. It would be nice to know that the marine protected area you have been carefully patrolling for the last 10 years is not

going to be destroyed in the near future by the volcano looming over it.

Storms/cyclones

Storms and cyclones can have a huge impact on coral reefs. The wave energy developed in large storms can reduce coral cover on shallow reefs to almost zero in a very short period of time. This is another example of a threat that cannot be controlled, but should be taken into account when planning conservation strategies. Although you can never be sure where and when storm damage may occur, you can "spread the risk" by choosing to conserve a representative range of reefs that face different directions and have different levels exposure.

2) Human-Induced Threats

Overfishing

The life histories of the majority of species targeted in reef fisheries do not lend themselves to high levels of exploitation. Most vertebrate and many invertebrate reef species are long-lived and have slow turnover rates. The majority of targeted reef fish species live for at least 10 years, (some as long as 70 years). Some species of beche de mer can take more than 10 years to reach a size large enough for the market. Scientists and fisheries managers are now beginning to realise that only light levels of fishing pressure are possible in most reef fisheries in order to achieve sustainability.

In PNG, overfishing has not yet posed as much of a threat as in neighboring countries. However, increases in human populations and the planned expansion of a number of commercial reef fish trades in PNG is likely to produce noticeable impacts on reef fisheries stocks in the near future. In areas of PNG with already established commercial trades, stocks of the most valuable species of reef fishes (e.g. napoleon wrasse and bump head parrotfish) are already on the verge of local extinction. In addition, in areas where international buyers have been operating, valuable invertebrate stocks, such as beche de mer and trochus have been noticeably reduced. Giant clams are also threatened with local extinction in some areas due to collection for meat and for production of betel-nut lime.

Destructive fishing methods

Destructive fishing methods include any techniques that significantly damage habitats in the process of removing target species. Classic examples are: dynamite fishing, cyanide fishing and net fishing on reefs. In Indonesia, dynamite and cyanide fishing continue to be among the greatest threats to coral reef ecosystems. However, in PNG, a strong awareness campaign about the damaging effects of dynamite fishing, as well as strict laws prohibiting its use has managed to effectively reduce dynamite fishing throughout most PNG communities. Many PNG coastal communities also have a strong stance against the use of cyanide and other poisons on the reef.

Coral mining/collection

Coral harvesting or mining has been identified as a major factor contributing to reef degradation worldwide. Coral is harvested for a number of uses, including construction materials (such as road base, seawalls, and buildings), the aquarium trade, the curio trade and for the production of lime used in cement or in the chewing of betel nut. The main environmental affect associated with unregulated coral harvesting is a decreased live coral cover and the resulting decrease in available habitats for numerous reef organisms. In a number of studies, this decreased live coral cover has been directly linked to a decline in reef fish abundance and biomass. The removal of coral colonies may also lead to a reduction in the overall structural stability of the reef. The economic costs of coral mining can include loss of coastal property from coastal erosion (including damage to buildings and roads) and the subsequent need for implementation of coastal stabilization techniques. Other costs include foregone tourism revenue and decreased fishery yield. Despite the serious economic and environmental consequences of coral mining, it remains a prominent source of income for many communities throughout the developing world.

Currently, the two major uses of corals in PNG are for construction and for the production of betel nut lime. Although few communities use corals as house building materials, corals are often used in island communities for the construction of retaining walls to combat

erosion. The use of corals for production of betel -nut lime is widespread throughout PNG. Betel-nut is consumed by an estimated 88% of the PNG's population and a although some of the lime consumed is derived from mangrove shells, and other marine products, an overwhelming proportion of the lime consumed is derived from corals or other coral reef organisms, such as giant clams. In addition, the harvesting of coral for the aquarium trade is planned for some regions in the near future.

Coral Bleaching

As will be discussed in later lectures, most corals are a composed of a close association between a living animal (coral polyp) and unicellular algae (zooxanthellae). These algae live symbiotically within the polyp, using sunlight to produce energy for the polyp, whilst the polyp provides nutrients to the algae and a residence for the algae within the polyp tissue. It is the algae which gives the coral most of its colour. Therefore, when this relationship breaks down and the algae are expelled from the polyp into the water column, the coral colony turns white, resulting in what we know as "bleached" corals. Often, the coral tissue will stay intact and alive for some time, and take on a bright white or fluorescent appearance. Depending upon the health of the coral and the prevailing environmental conditions, the polyps can sometimes regain the zooxanthellae from the water column and return to full health. However, if conditions are not met, the corals soon die as they cannot meet their energy demands by feeding on their own.

Bleaching can be caused by a number of factors, including: decreased salinity of coastal waters from freshwater runoff, high UV light levels and higher than normal water temperatures (generally greater than 1^{0}C above the average maximum yearly sea temperatures), or a combination of these factors. The primary cause of the widespread bleaching events seen in 1998 appears to be higher than normal water temperatures (above average maximum temperatures at each location) (Figure 1). These warm water events are usually associated with changes in the earth's weather patterns, particularly El Nino and La Nina oscillations in water currents. In recent history, massive bleaching events and warm water anomalies have almost always overlapped, with at least 70% of cases of recent massive bleaching being explained by warm water events. However, sometimes the relationship is not as simple, and a combination of warm water and high levels of light, due to calm, clear waters, appears o have been responsible.

The most extensive recorded coral mortalities have all been within the last twenty years. Warm water events in 1998 caused the most extensive coral mortality seen to date, with corals being bleached in almost every corner of the globe. During this event, up to 90% of some reefs died, such as in the Seychelles. Many reefs hit by the 1998 bleaching have still not recovered.

Projected increases in sea temperatures over the next 100 years predict dire circumstances for coral reefs (Figure 2). Whilst the bleaching thresholds are currently being exceeded every few years, predictions indicate that thresholds will be exceeded every year by the year 2050. By the year 2100, average yearly temperatures are likely to exceed bleaching thresholds. The question still under debate is whether corals can adapt to these temperature increases in time.

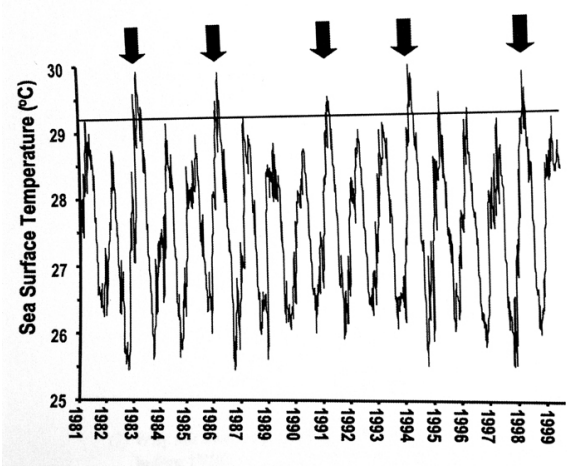


Figure 1: Weekly sea surface temperature data for Tahiti. Arrows indicate bleaching events reported in the literature. Horizontal line indicates the minimum temperature above which bleaching events occur (threshold temperature). (Hoegh-Guldberg 1999).

Although bleaching is threat to coral reefs that we may not have much control over, it is important that we still consider bleaching in marine conservation planning. Since bleaching is often patchy – some reefs will be bleached while other reef systems may escape bleaching entirely, incorporating areas with "resiliency" to bleaching into plans for protected area management plans is an optimal strategy.

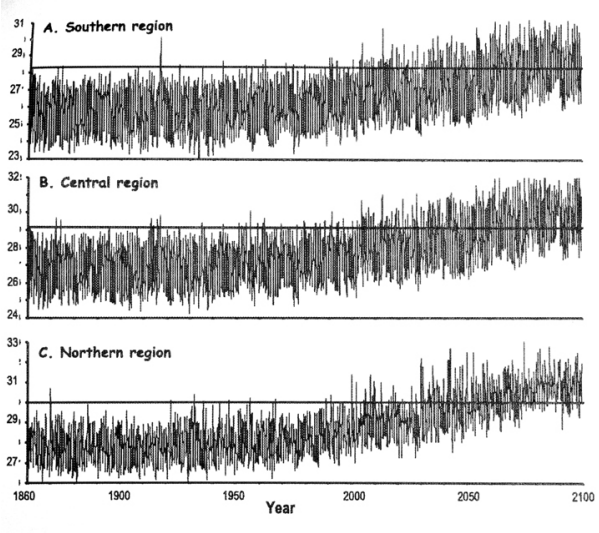


Figure 2: Sea surface temperature from the past 140 years and predicted over the next 100 years on the Great Barrier Reef, generated by the global coupled atmosphere-ocean-ice model. Horizontal lines indicate bleaching thresholds at each location. (Hoegh-Guldberg 1999)

However, we still have only limited information about what constitutes a "resilient" reef. Research is currently underway by a number of scientists to determine the key factors that determine why some reefs bleach while others do not. Some of the factors proposed to date are: proximity of reefs to cool water upwellings, magnitude of currents present at a site, local levels of plankton supply to corals, the strains of symbiotic algae that inhabit the corals, and the previous bleaching history of the area. Incorporating "bleaching resilient" reefs into management strategies may help to ensure that some reefs will remain to replenish those destroyed by bleaching. However, we are still a long way from developing accurate models to determine which reefs to choose.

Deforestation

One of the major factors influencing inshore coral reef systems in the tropics is the impacts of large-scale logging activities. Deforestation has been responsible for an increased load of sediment in freshwater runoff which ultimately makes its way down river systems and ends up on fringing reefs. The large amount of rainfall received in many parts of the tropics during monsoonal seasons magnifies this problem. While some corals can cope with heavy sediment loads in the water column, the majority of corals are ill-equipped for such loads and end up being literally smothered by sediments. In Papua New Guinea there are concerns about the increase in palm oil and copra plantations in coastal areas and the impacts this may have on the condition of reef ecosystems.

Pollution

Pollution can be described as the introduction by humans of any substances that decrease the quality of the natural environment. These may include toxic chemicals, fertilisers, sewage and solid waste. Papua New Guinea is fortunate to have generally much lower levels of pollution than neighbouring countries such as Indonesia. However, impacts of pollution to reefs is noticeable in some parts of PNG. Among the greatest pollution threats currently in PNG are raw sewage and solid waste. Traditionally, many coastal communities have been built out over the water, sometimes right on top of fringing coral reefs. In some of the larger villages, e.g. Tubuseria near Port Moresby, the amount of raw sewage ending up on reefs has caused irreparable damage to the fringing reef communities. Solid waste, especially plastics, is also a major problem in many coastal communities. The introduction of plastic bags without a proper waste disposal system has plagued inshore marine ecosystems in recent decades. These plastics take years to break down in the marine environment and can cause the smothering and death of corals and other organisms.

LECTURE 1.3: INTRODUCTION TO MARINE CONSERVATION

This course has been designed to provide you with some basic training in understanding and measuring the impacts of major threats facing tropical marine ecosystems, as well the skills necessary to implement, monitor and adapt management strategies for the conservation or sustainable use of marine resources.

Humans have been exploiting resources of the marine environment since early prehistoric times, probably with little impact. However, in recent centuries, rapid increases in human populations coupled with technological advances that have dramatically improved the efficiencies of fishing methods have meant that the world's oceans are under immense pressure. Not too many decades ago, the oceans were still considered to be an

inexhaustible pool of resources. Marine environments were also considered to be disposal sites for our waste products - anything dumped in the ocean simply disappeared. However, the continuing collapse of fisheries the world over, as well as measurable evidence of pollution in almost every marine habitat imaginable shows that these beliefs are far from true.

The oceans are important to our existence in many ways. They provide a large proportion of the world's protein requirements, as well as places for tourist and recreational activities. Most importantly, oceanic processes provide a life support system critical to key functions of the earth's biosphere. Without functioning marine ecosystems, life on this planet would be very different indeed. However, we face major challenges ahead in order to maintain the functional intactness and viability of marine ecosystems. As marine scientists, we have an important role to play in monitoring the health of these systems and developing ways in which to combat the wide range of threats humans impose so that marine ecosystems may continue to thrive into the future.

Goals of marine conservation and management

Ecosystem functions are the result of assemblages of plants and animals interacting with each other and with the physical environment. Marine conservation and management attempts to regulate our use of ecosystems so that we can benefit from them while at the same time modifying our impacts on them so that basic ecosystem functions are preserved. Unless essential ecosystem functions are maintained, our use of them will not be sustainable. When this happens, continued development will be hampered and may even stop.

Two other characteristics of ecosystems or groups of ecosystems, that are important to conservation practitioners concerns their resilience and biological diversity, or biodiversity. Biodiversity can be thought of in terms of 3 levels:

- Ecosystem diversity: the variety and frequency of occurrence of different ecosystems;
- Species diversity: the frequency of occurrence of different species;
- Genetic diversity: the frequency of occurrence and diversity of different genes and/or genomes within species. This includes the variation both within a population of species and between populations of that species.

Why is biodiversity important from the point of view of conservation and ecosystem management? To put it simply:

- the more diverse the assemblage of ecosystems in a large area, the greater the chance that some will survive a significant perturbation in the area;
- the more species represented in a given ecosystem, the better the chance of survival of the system if the populations of some species are perturbed; and
- the higher the level of genetic diversity within a population, the better its chances of undergoing the evolutionary changes necessary to adapt to changing conditions.

Loss of diversity at any of the three levels decreases the probability of recovery after a significant disturbance, or adaptation to changing conditions. The degree to which a system can recover from such a disturbance is a measure of its resilience**.** Systems with low resilience are less likely to recover than systems with high resilience. Systems with high levels of biological diversity are more likely to have a higher level of resilience than systems with less biological diversity.

As an integral component of the natural world, people have always interacted with, and transformed, ecosystems in a variety of ways to take advantage of the goods and services provided by ecosystems. Some of the functions, goods and services provided by ecosystems are listed in Figure 3.

Social choices, including the need to survive, determine what ecosystems are managed for, and how they are managed. Throughout human history this has been the case. Many of the social choices have, however, been the result of *ad hoc*, incremental actions rather than having been based on forward planning. This has often led to the full or partial loss of ecosystem functions and resource depletion. The nature of human disturbance to an ecosystem will determine the extent to which ecosystem

Ecosystem	Functions and services	Benefits and goods
Wetlands	· groundwater recharge and discharge	· medicinal and biomedical products
	· flood control	· water supply
	· water quality and quantity	· pollution clean-up
	· water purification	· fish nurseries and fisheries products
	· sediment/toxicant/ nutrient retention	· forage products
		· agricultural products
		· transport
Mangroves	· storm protection	· aesthetic and recreational values
	· provision and renewal of nutrients	· historical and cultural values
	· sediment accumulation	· fish nurseries and fisheries products
Coral Reefs	· coastal protection	· construction material
	· sand production	· genetic resources
		· global heritage
		· educational and scientific interest
		· fisheries products
Oceans	· global climate regulation	· fisheries products

Figure 3: Ecosystem functions, goods and services. Adapted from Cesar (1996).

integrity is lost. Ecosystem management must promote the beneficial use of the system without contributing to its degradation—use it but don't lose it.

Options for management

Many options exist for the conservation and management of marine resources. The biological, social and economic diversity of marine resources, selection of assessment methods, and impacts of human activities to species, habitats and ecosystems means there are many different and sometimes conflicting objectives in marine conservation and management. The objective may be to protect habitat and species of conservation concern, or to ensure the economic and social well being of future generations.

Several technical measures exist for management of marine resources and fisheries. Technical measures restrict the size of fish species that are caught or landed and the gear used. Gear restrictions such as the size of mesh in traps and nets, can control the minimum size at which fish species are caught. Size restrictions can specify a minimum size limit to allow fish to reach maturity or a maximum limit to allow larger fish to spawn. Within the context of fisheries management in PNG, gear restrictions are easier to enforce than size limits. It's simple to see when someone is using a gill net or dynamite fishing and this can be enforced within the traditional, local level governance systems. Size limits, however, can be difficult to enforce as they would require patrols and manpower to visit landing areas to identify and measure fish.

Time and area closures can protect fished species at particular phases of their life-history. Examples are protection of juvenile habitat or spawning areas. Habitat protection can be achieved using protected areas. Time closures can protect stocks until their production increases. Area closures may redistribute fishing effort and increase fishing costs without reducing mortality. Time and area closures have been most effective when combined with other measures such as catch and effort controls.

Marine reserves are areas of the sea where fishing is not allowed. They provide refuges where targeted species can recover and habitats impacted by fishing can regenerate. The idea of marine reserves as fisheries management tools has emerged with observation of incidental fisheries benefits from reserves established for conservation objectives. Marine reserves are predicted to benefit adjacent fisheries through two mechanisms: net emigration of adults and juveniles across borders, or 'spillover', and export of pelagic eggs and larvae. Inside reserves, populations increase in size, and individuals live longer, grow larger and develop increased reproductive potential. Enhanced production of eggs and larvae inside reserves is predicted to lead to net export and increased settlement

of juvenile animals outside the boundaries. Using marine reserves for fisheries management is controversial. Critics argue that most commercial species are too mobile to benefit, that marine reserves are only appropriate in very specific cases (usually small-scale tropical fisheries) and that it is too risky to implement them on a larger scale until we have more and stronger experimental proof of their efficacy. Fishers worry that reducing fishing grounds will decrease catches and increase traveling time. They are also cynical about the levels of compliance to closed-area regulations that can realistically be expected. Until recently, most insights into reserve function came from theoretical research. However, empirical evidence is increasing and demonstrations of

effects outside reserve boundaries are emerging from a wide range of habitats and fisheries.

Management and enforcement are more effective when managers and fishers work together. Co-management means that fishers and the government share responsibility for management of the fishery. This helps to minimize conflicts and allow fishers to indicate when certain regulations may be inappropriate. Co-management has worked best when a fishery is under the control of the fishers, such as in Individual Transferable Quotas, Co-operatives and property rights and customary tenure regimes. Co-management is emerging as a good fisheries management tool in many fisheries, including in the Pacific and Latin America. However, it is unrealistic to expect that co-management will solve all management problems. Fisheries management may still require reductions in catches and effort and this makes it hard to please everyone.

Traditional management is based on use rights and access to a property. The exclusive rights to the resource are enforced by the right of a community to prevent poaching. Exclusive rights are thought to motivate sustainable use and avoid the race to fishing and 'tragedy of the commons' found in open-access systems. These systems, when intact, are usually well enforced with high compliance and self-policed by the fishers themselves. Thus, there is a sense that the fate of the resource is under the control of the local community. Traditional management systems are usually not 'no-take' and may be subject to periodic harvest. In addition, traditional management regimes rely on the existence of strong governance and marine tenure. In many areas, traditional management has eroded and the resilience of such regimes in the face of increasing population, urbanization, migration, resource depletion and the conversion to a cash economy remains in doubt.

Biological factors

Consideration of management options requires an understanding of both the social and ecological setting. Biological or ecological factors to consider in development and implementation of conservation and management can be summarized as:

- Representation of all distinct natural communities within conservation landscapes and protected area networks
- Maintenance of ecological and evolutionary processes that create and sustain biodiversity
- Maintenance of viable populations of species
- Conservation of blocks of natural habitat that are large enough to be resilient to large-scale stochastic and deterministic disturbances as well as to long-term changes

These criteria are often cited as the foundations of the science of conservation biology. Representation ensures that the full range of habitat types and communities is included. Habitats are often the first critical unit or layer in setting conservation priorities, since species rely on various habitats for their life-history stages. Representation also includes conserving species diversity included endemics or species particularly vulnerable to extirpation or extinction. In addition, maintaining populations of species that are large enough to reproduce and replenish successfully is vital to conservation and management. The recent focus on fish spawning aggregations is an example of protecting the critical and vulnerable reproductive stage of many reef fish to ensure that they have the chance to maximize reproductive output. Conserving large areas is a response to threats such as climate change or over-exploitation, which can affect large areas of habitat or fish stocks, respectively. A network of marine reserves can act as a insurance system in the face of large scale disturbance and ensure that some refuge areas remain healthy.

Socioeconomic factors

The need to consider the human dimension is particularly acute in marine conservation and management. Management measures focus on changing or restricting behaviour and understanding how management measures impact (or the 'cost') stakeholders and communities is critical in achieving compliance and successful management. To date, the majority of research and literature on marine reserves has focused on natural science, with largely anecdotal social scientific references and few rigorous projects or programs evaluating the complexities of socioeconomic social scientific aspects of marine reserves. As with any policy or management decision, decisions regarding marine reserves always involve tradeoffs between the natural and human environments.

Both must be adequately described and analyzed and integrated for sound decision-making processes in management to occur. This is particularly true in developing countries, where the majority of the population may rely on natural resources for subsistence and cash.

Socioeconomic variables that are examined in most studies included dependence on coastal resources, governance of coastal resources, occupational diversity and mobility, and perceptions of what can affect and improve fishery resources.

Understanding governance, institutions and processes that are responsible for decision making is a critical first step in understanding the social context for conservation and management. Components of this includes the capacity of these institutions, their funding sources, jurisdiction, management strategies and implementation approaches, as well as the nature of their interactions with the public and with other institutions (such as churches).

Studying resource use patterns addresses the ways stakeholders use resources in time and space and may include extractive, such as harvesting fish or invertebrates, and non extractive uses such as boating and diving for recreation. Baseline data on human resource use will provide the context for understanding interactions and trade-offs among uses and users.

Understanding attitudes, perceptions and beliefs of resource users covers the underlying motivations that may influence human preferences, choices and actions. It examines the factors that shape human behavior and how these behaviors affect and are affected by resource availability. Priority topics may include stakeholders' social and cultural attitudes, values, beliefs, traditional knowledge, perceptions, and preferences related to management issues.

LECTURE 1.4: INTRODUCTION TO FISHERIES MANAGEMENT

No matter which fishing method is used, fishers and their gear interact with the habitat to some degree, for example lost fishing lines, pots and traps landing on benthic fauna and nets dragging across the seabed. The impact of fishing gear with the environment disturbs the habitat directly – physical disturbance – and the methods of fishing for bottom dwelling species affect the seabed habitat to some degree. In this section we will focus on the direct and indirect affects of fishing on coral reefs and associated ecosystems.

Fishing reduces the abundance of target fishes on tropical reefs. These fish have different roles on the reef ecosystem. The parrotfish are herbivores that graze algae and erode the reef structure. Others feed on invertebrates such as urchins and crown-of-thorns starfish. Studies in Kenya and Jamaica have shown how changes in the fish community can determine rates of bioerosion.

Surveys on Kenyan reefs have shown that fished species like triggerfish feed on urchins. ON many Kenyan reefs, fishing has depleted populations of urchin predators and the abundance and behaviour of urchins has changed in response. Urchins live in low numbers in crevices that are enlarged by their grazing and abrasive spines. On heavily fished reefs, reduced predation has lead to an increase in their numbers. At low predation pressure, urchins are found on exposed areas of reef rather than in crevices. Here they are able to out compete other herbivores and erode the reef, leading to the competitive exclusion of herbivorous fish. The continued bioerosion of the area by urchins has reduced coral recruitment and the erosion of the reef has led to an associated decrease in fish biomass.

In Jamaica, the primary urchin species is eaten by triggerfish and wrasses. Changes in the density and grazing pressure exerted by the urchin can regulate the abundance of corals and algae. When herbivorous fish such as parrotfish are abundant, they graze algae and prevent them from growing over the corals. However, if herbivorous fish are fished to low abundance and urchin are scarce then overall grazing pressure will be low and algae biomass will increase dramatically. This effect was demonstrated when there was a mass mortality of urchins throughout the Caribbean, including many areas that were heavily fished. Algal biomass increased rapidly, preventing coral recruitment and growth and causing a phase shift to an algal dominated reef.

Fish capture devices and markets

Modern, industrialised fishing has grown from the methods and systems used in artisanal fisheries. In this section we focus on the main fishing techniques used by industrialised fleets capturing the bulk of the catch in oceanic fisheries, and on the techniques used by artisanal fishermen in coastal waters. The general principles are the same, but the size of the gear, the tools used for the capture and handling, the vessels, equipment for navigation and fish finding, and the catches and costs involved are so different that they are separated below (see also Figure 4).

Marine capture fisheries now yield over 86 million tonnes per year, with a first sale value of around US$50 billion. Although there are approximately 17 000 marine fish species, 50% of fish catches are composed of just 20 species. Around 3.5 million fishing vessels are in use world wide and most continental shelf seas to depths of 200 m are heavily fished. Target species are generally decreasing in abundance, but the high efficiency of modern fishing makes catching them economically worthwhile.

Small scale and artisanal fisheries working from the shore in small canoes and boats account for 25% of the global catch and more than 40% of the catch for human consumption. The modern industrialised fisheries of the developed world contrast highly with the subsistence fisheries in poorer countries were fish are a vital source of protein and fishing may provide the only source of income.

Artisanal Fisheries: fisherman generally relying on his skill by himself or with the help of family members or a few companions; generally small-scale and dependant on local resources.

Industrialised Fishing: The main fishing methods in industrialised fisheries are show in Figure 1. Pure seines capture fish shoals by surrounding them with a huge net. Trawls filter water at a speed higher than the fish can swim. In long lining, fish are attracted by odour of baits that they swallow and get hooked. Gill nets form invisible net walls that the fish swim into and get gilled or become tangled. Each of these methods relies on highly specialised techniques and fish detection systems.

Purse seining

For example, modern purse seining is reliant on detection and location of fish shoals by hydro-acoustic instruments, such as sonar. Tuna purse seine is conducted by large vessels (larger than 60m) with large nets in tropical and subtropical oceans. Tuna are caught made in free swimming schools or when associated with natural and artificial floating objects (e.g. Fish attracting devices – FAD). In the east Pacific, tuna are caught in association with dolphin herds. The dolphin herds are visible on the surface and are encircled by the seine net, usually capturing large tuna that are underneath the dolphins. Fishers attempt to release the dolphins by submerging a portion of the net allowing the dolphins to swim and jump over the net. However, dolphins often become entangled in the net and drown. In 1992, about 60 000 dolphins were killed due to the tuna purse seine fishery in the eastern Pacific. The tuna purse seining fishery has been under increasing pressure to change the fishing operation to prevent accidental killing of dolphins.

Trawling

Trawling occurs at depths from 20 – 2000 m across all ocean basins. A bottom trawl is a rather heavy system of two steel doors to open the trawl and with enough weight to keep the trawl in contact with the bottom during the tow. Bottom trawl configurations and operations are dependent on the type of species targeted and the bottom composition. Once fish are pushed to the back of the net, the selectivity of the trawl bag then occurs as small fish pass through the mesh while larger fish are unable to escape. Most bottom trawl fisheries are regulated by mesh size and design in the bag of the trawl. It is also possible to use rigid grids installed in the net which gives a sharper and more efficient selection than mesh alone. In the fine meshed shrimp trawl fisheries, by-catch has been a major problem. There are estimates of by-catch to shrimp ratios of 5:1 in temperate waters and 20:1 in tropical waters. There are several by-catch reduction devices that can be used in tropical shrimp trawling, such as in the northern Australia prawn fishery. In addition, there has been considerable focus on the physical impact of bottom trawl gears on the bottom. On fragile bottom types, the impact of bottom trawling can be devastating and permanent. Pelagic species

are also caught by pelagic trawling, conducted mainly on species that occur in large shoals and aggregations.

Longlining

The rigging of long lines depends on the target species, fishing conditions and regulations of the country. Modern pelagic long lines are made of monofilament mainline with branch lines attached to the mainline by metal snaps. A long line may also be anchored to the bottom with a system of floats and sinkers. Pelagic long lines target tuna world wide. Bigeye and Yellowfin are caught across the Pacific Ocean and inter-tropical ocean regions. A variety of bait types are used, such as sardines and squid. Baiting is automated in large industrial fleets and manual baiting is common in coastal and artisanal fisheries. The capture process is based on the behaviour of the fish detecting the odour trail that is dispersed by the water current. More than 30 species can be caught by pelagic long lines and the question of untargeted species being caught is a major concern, especially for sharks. Long lining mostly targets high priced species like tuna. Landing top quality tuna for the sashimi market in Japan can bring wholesale prices of more than US$200 per kilogram. However, the majority of catch goes to less lucrative markets, such as tuna used for canning (sold for less than US$1 per kilogram). Long lining has several advantages over other methods, including high quality fish caught live, no impact to seabed, and limited juvenile catch.

Gill netting

Gill netting is one of the oldest and most wide spread fishing gears. Nets are now made of synthetic fibres and are designed to be transparent and invisible to the fish. Gill nets are passive gear, the fish itself moving into the net head-on and trying to push through the opening. Small fish can pass through, but larger fish with a size just bigger than the mesh size become caught. Very large fish become entangled or escape capture. Gill nets are highly selective for size classes of the target fish species, but by-catch of sea birds, marine mammals and marine turtles can be very high in certain fisheries. Gill nets can continue to 'fish' for many years after having been lost. This so called 'ghost fishing' can have serious negative effects on commercial fisheries, benthic habitat and the fish community.

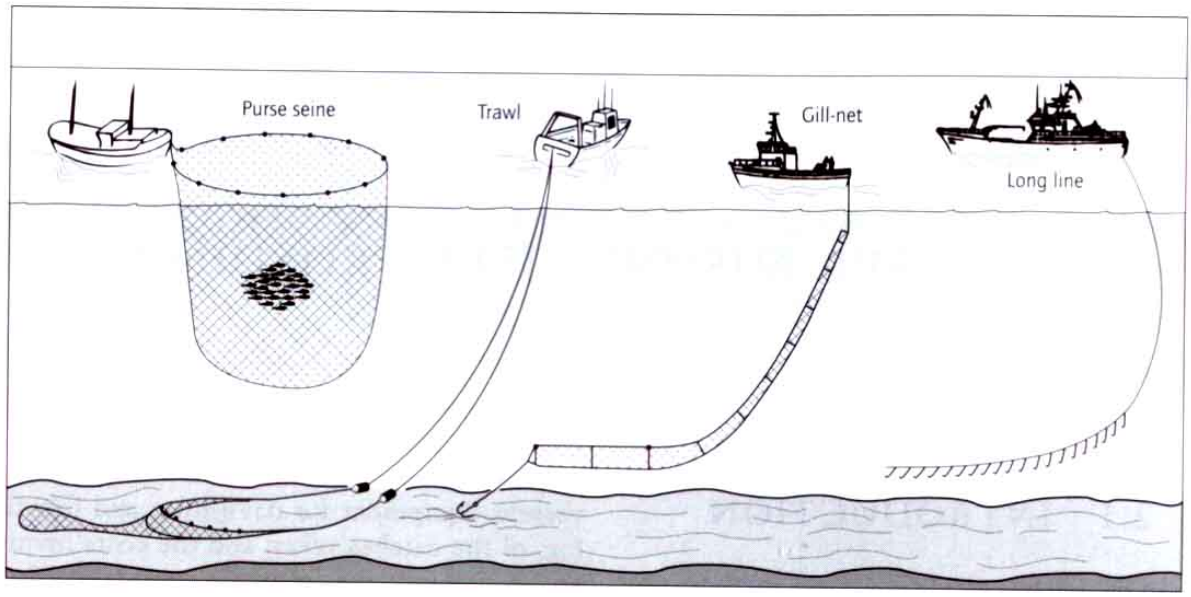


Figure 4: Main fish capture techniques, from left to right: purse seine, trawl, gill net and longline.

Artisanal fishing

Artisanal fisheries use several of the fishing methods described above, but are different by being less fuel, vessel and capital (money invested) dependent than industrialised fishing methods. Many small scale artisanal fisheries do not require vessels or energy consuming operations and have remained unchanged for centuries. Others are in rapid development and may only be called artisanal because of the still limited range and small scale of fishing effort.

An important characteristic of small scale artisanal fisheries are the high number of people involved world wide, resulting in a huge diversity of capture methods related to different resources, seasons and environments.

The range of examples of artisanal methods is vast and a few are described here. The use of spears is among the most ancient forms of fishing still used today. There are a number of single and multiple tipped designs for catching fish in shallow lagoons and coastal areas. For coral reef fisheries the main gears used are hook and line, nets, spearing and traps. Nets are usually set up just off the reef and fish are driven into them. Pole and line fishing for tuna is common along ocean fronts were pelagic species gather near the surface and feed on prey species. By using aggregating devices, fishers use live bait to attract the tuna schools towards the fishing boat. This induces a feeding frenzy and tuna will bite at any bright and moving object. At this point fishers lower bare or baited hooks in the mass of tuna. As the fishers strike into fish, the fish are propelled out of the water and onto the deck of the vessel. This is a common method for both artisanal and commercial skipjack fishing in Solomon Islands and Papua New Guinea. Both naturally (e.g. plant derivatives) and artificially (e.g. cyanide) derived products are used as fish poisons, to catch fish for human consumption or the aquarium trade. Diving is another common method used in artisanal fisheries. Generally, the species targeted have a high value, such as sea cucumber for Beche-de-mer, pearl oysters or seahorses. While there is little by-catch from diving, there can be damage to the habitat and fragile organisms like corals. There is also considerable danger to the diver, especially with the use of compressed air systems. It is a highly efficient method that can quickly deplete entire populations of organisms. Blast fishing is prevalent in poorer regions of the world. Bombs are made from explosives such as dynamite and detonated using home made fuses. Catch rates can be very high, but this method is indiscriminate, killing all sizes of fish, invertebrates and the corals. It can lead to the total destruction of local habitats.

Research problems in artisanal fisheries

Considering how large artisanal fisheries are world wide, engaging over 80% of all fishermen, there is a critical lack of data and scientific literature in artisanal fisheries compared with industrialised fisheries. Most of the literature is semi-anthropological or socioeconomic, with descriptive accounts of capturing methods and species compositions. However, there are several specialised agencies that focus on fisheries research in developing countries, such as the World Fish Centre and the FAO.

Many coastal ecosystems are only accessible and suited to artisanal fisheries, such as shallow lagoons and estuaries. Yet in many areas, both artisanal and industrialised fishing are in direct competition, often leading to conflict and artisanal fisheries are struggling to survive against the pressures of modernised capture techniques and overexploitation. For example in Senegal, Africa the artisanal pelagic fishery has been catching over 200 000 tonnes of sardines per year, competing directly with the industrial fishery. The sardines are caught by small purse seines and gill nets from wooden canoes with outboard engines. All fishing operations are preformed manually by a crew of 12-18 people. These fisheries in West Africa are all based on traditional wooden canoes, modified with the addition of an outboard engine and better fish storage. The design tends to remain the same and often fishermen resist changes in design. In most of these fisheries, the catch is processed to fishmeal, and the price is dependent on the global market if fishmeal. Therefore, some crises in artisanal fisheries can be caused by the global market.

Artisanal fisheries are usually associated with developing countries and often perceived as traditional and antiquated, poorly equipped subsistence activity. Many attempts to ‘modernise’ artisanal fisheries have failed due to the fact that the changes from traditional practices have not been taken up and accepted by fishers. Several studies show that smaller-scale technology are more socially and economically efficient and acceptable. In addition they are a requirement for community-based management, which relies on participation of fishers in decision making.

From gear to management

Fishing methods are associated with selectivity, and selectivity, or the impact of fishing on an ecosystem, is a fundamental component of fisheries management. There is a great deal of research effort focusing on the efficiency and selectivity of fishing gears. Recent developments are pushed by world and market opinions, leading to gear that allow turtles to escape from shrimp trawls, that reduce catching of marine mammals, and decrease the by-catch in shrimp and other specialised fisheries.

Mesh size and gear restrictions are the most easily applied and widely used management regulations. Many countries have legislation which bans certain harmful gear and mesh sizes with the aim of protecting their fisheries resources. Most of these laws apply to both industrialised and artisanal fisheries. However, selectivity is more of a problem for large-scale modern fisheries, which on average dump 45% of their catch, while small-scale artisanal fisheries throw away on average only 5%, despite operating in more diverse environments and with many more species. The survival of small-scale fisheries is challenged and often overwhelmed by modernisation, driven by increased investment, centralisation and the influence of global markets. Many management measures, such as total allowable catch and quotas favour large-scale fisheries, which have greater catching capacity. Unfortunately, in many countries, these regulations undermine the livelihood of small-scale fisheries working often working outside the global markets.

There is an urgent need to remedy the lack of quantitative data and information on small-scale fisheries. It is particularly important to establish the selectivity of the various gears and their impact on the ecosystem. Faced with the often complicated and diverse operating conditions of the artisanal fisheries, the national and international focus in small-scale fisheries seems concentrated on implementing management, such as total allowable catch. However, without fundamental research, these management measures may face the same failures as many previous attempts to modernise artisanal fisheries.

Fisheries in Papua New Guinea

The coral reef fisheries of Papua New Guinea (PNG) are mostly subsistence and artisanal (fisherman generally relying on his skill by himself or with the help of family members or a few companions), with fisheries methods generally traditional, using simple technology. The artisanal fishery is well established with approximately 116,000 people involved in small-scale fisheries in 1990. PNG reef artisanal fisheries exploit a wide variety of species, including finfish, coastal pelagic fish and sea cucumbers, crustaceans and molluscs, providing nearly all of the fish supply to domestic fish markets. Like the subsistence fishery, the artisanal fishery lacks fishery data, expect for one or two locations or where discontinuous data sets are available. Statistics on catches for export are available, however, these catch statistics are only a small percentage (probably less than 20%) of the total artisanal catch. Data from 1997-1998 show that approximately 1000t of reef and coastal species were exported in 1997, jumping to over 2000t by 1998. Sea cucumber (beche-de-mer) make up the largest component of the export (Figure 5). Reef finfish make up a small component of the artisanal export, but the catch went from 34t in 1997 to 92t in 1998. Beche-de-mer showed a steady increase from 8t in 1983 to 680t in 1998. Trochus exports went from a high of 346t in 1990 to 28 in 1998. The catch composition of the artisanal reef fishery differs throughout PNG (Figure 5). This is likely due to a variety of factors including different habitats, seasonal differences in fish presence and abundance, and different fishing techniques. For many people in remote areas, purchases made by local fishing companies offer inhabitants the only source of income. Unfortunately this often leads to over-harvesting of marine resources. The impact and pressure exerted on these resources is likely to increase in the future given the burgeoning population of PNG, the increasing desire for cash, and the decline in traditional income sources such as copra.

Fishing gear and species vulnerability to gears

Four different types of gear have been identified for the Port Moresby artisanal fishery. These include hand line with hook, spear (both surface and diving), gillnet and trolling. The use of this

gear is consistent with other areas of PNG, such as Huon Gulf, Manus Island and Tigak Islands. Typically, hand line catches were dominated by predatory species from the grouper, snapper, emperor and trevally families. Nets and spear usually caught parrotfish, rabbitfish and needlefish. Trolls usually caught reef associated pelagics.

Fishing methods and associated impacts

The fishing methods used in PNG are mostly low technology and traditional. Apart from possible reductions in fish stocks, impacts to reefs from these methods can include physical disturbance through trampling, anchor damage, breaking the reef to collect sedentary animals, net entanglement, and the use of traditional or modern poisons.

Beche-de-mer

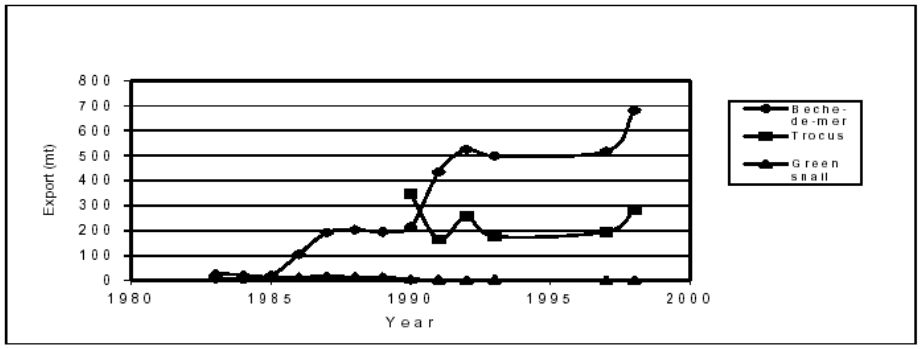
20 species of sea cucumber are commercially harvested in PNG, with *H. scabra* the most economically important species. Several studies and stock assessments across PNG indicate that overfishing has occurred in most areas where beche-de-mer have been harvested. For example, in West New Britain shallow areas were depleted of large, high value sea cucumbers. In Milne Bay Province, a stock assessment conducted in 2000, recorded an overall density (21.24/ha) lower than those for comparable fisheries in Torres Strait and northern Great Barrier Reef and similar to depleted fisheries in Timor. The beche-de-mer fishery in Milne Bay Province is changing from a low-volume, high-value fishery to a high-volume, low-value fishery. The depletion of high-value species has resulted in a shift to harvesting low-value species, as in New Ireland Province (Figure 5). Further surveys provide an indication of further depletion and unsustainable fishing pressure (Figures 6-8).

Trochus

Localised overharvest and unsustainable exploitation of Trochus is reported for Manus Province. The CPUE dropped from 30.1 kg/ fishing trip in 1987 to 13.1 kg/fishing trip in 1990 with concurred increase in fishing pressure over the same period. In addition, Trochus are reported to be depleted in West New Britain Province.

Figure 5: Summary of export quantities of reef fisheries resources exported in 1997 and 1998. (Source: PNG National Fisheries Authority database).

Fish Resource	Species	Common name	Kilograms		Total exports (metric tonnes (t))	
			1997	1998	1997	1998
Beche-de-mer	*Actinopyga echeites*	deep water red	16.40	4	**517.47**	**680.95**
	Actinopyga lecanora	stone fish	22,515.10	45,034.80		
	Actinopyga mauritiana	surf fish	25,802.70	32886.75		
	Actinopyga miliaris	black fish	22,712.90	18,814.80		
	Bohadschia argus	tiger fish	30,594.90	46,944.95		
	Bohadschia graeffei	flower fish	458.00	329.00		
	Bohadschia marmorata	chalk fish	15,728.00	14,691.90		
	Bohadschia vitiensis	brown sand fish	112,745.50	98,893.30		
	Holothuria atra	lolly fish	71,258.50	72,477.30		
	Holothuria edulis	pink fish	25,540.90	12,085.20		
	Holothuria fuscogilva	whiteteat fish	22,814.90	75,677.40		
	Holothuria fuscopunctata	elephant trunk fish	12,454.00	28,226.00		
	Holothuria leucospilota	snake fish	24,662.00	29,334.50		
	Holothuria nobilis	blackteat fish	16,574.20	23,231.05		
	Holothuria scabra	sand fish	38,287.90	53,900.30		
	Stichopus chloronotus	green fish	12,264.30	19,523.15		
	Stichopus variegatus	curry fish	19,155.20	26,255.45		
	Thelenota ananas	prickly red fish	10,094.80	22,395.55		
	Thelenota anax	giant beche-de-mer		870.00		
	Unspecified bechdemer	Unspecified	33,790.75	59,370.45		
Finfish	*Cephalopolis spp.(2)*	rock cods	1,751.25		**34.29**	**92.02**
	Cheilinus undulatus	dmaori wrasse	7,959.25	3,254.50		
	Unspecified wrasses	Unspecified wrasses	1,351.00	394.00		
	Cromileptes altivelis	Barramundi cod		6.00		
	Elagatis bippinulata	rainbow runner		1,000.00		
	Epinephelus lanceolatus	Grouper	5,000.00			
	Epinephelus polyphekadion	Camouflage cod	231.00			
	Epinephelus spp.(3+)	Groupers	1,000.50			
	Epinephelus spp.	reef cods		1,636.75		
	Epinephelus tauvina	reef cod	60.00			
	Lutjanus rivulatus	maori sea perch	200.00			
	Lutjanus spp.(2)	reef snappers	650.00			
	Plectropomus areolatus	polka dot coral trout	79.00			
	Plectropomus leopardus	coral trout	5,524.75	8,327.00		
	Plectropomus oligacanthus	high fin coral trout	153.00			
	Plectropomus spp.(2)	coral trouts	1,552.00			
	Mackerel spp.	Mackerel		73,296.50		
	Scomberomorus commerson	spanish mackerel	814.21	26.00		
	Synanceia verrucosa	stone fish	7,962.00	1,063.00		
	mixed reef fishes	unspecified reef fishes		3,019.05		
Lobster	*Panulirus sp.1*	bamboo crayfish	80.00		**105.99**	**114.01**
	Panulirus sp.2	Crayfish	4,355.00	7,880.00		
	Panulirus ornatus	spiny lobster	65,643.68	54,789.00		
	Panulirus penicillatus	tropical rock lobster	35,913.06	50,803.20		
	Panulirus spp.	tropical spiny lobster		540.00		
Shark fin	Carcharhinidae	deep water blue shark	8,258.90	73,859.20	**8.26**	**73.86**
Shark meat	Carcharhinidae	shark – unspecified	87,150.00	792,955.00	**87.15**	**792.96**
Mollusc	*Tridacna spp, Hippopus hippopus*	giant clams	26,650.00	13,560.00	**243.48**	**333.05**
	Turbo marmoratus	green snail	1,050.00	1,120.00		
	Pinctada maxima, P. margaritifer	mother of pearl	17,377.00	26,025.50		
	Trochus niloticus	Trochus	194,869.50	281,589.50		
		Blacklip	3,537.00	10,565.00		
	Cephalopods	Cuttlefish		104.00		
		Squid		85.00		
Grand Total			**996,643.05**	**2,086,844.05**	**996.64**	**2086.9**



← *Figure 6: Beche-de-mer, Trochus and Green Snail exports in PNG.*

Species	Percent by dry weight		
	1988	1989	1990
H. scabra	100	89.1	11.9
T. ananas		7.4	0.9
H. fuscogilva		3.5	0.6
A. miliaris			2.9
H. atra			43.6
H. nobilis			8.9
S. variegatus			0.6
A. mauritiana			30.5

↑ *Figure 7: Change in species composition of the catch in the New Ireland Beche-de-mer fishery between 1988 - 1990 (from Tenakanai 1991). Note 1990 data is for January to May only.*

Green snails

In general, reports from across PNG suggest overexploitation of green snails. For example, in a three year monitoring program in New Ireland revealed that green snails were recorded in a few areas, although there are reports from the 1940s and 1950s that green snail were collected anywhere in the province. Low numbers or absence of green snails are reported for Madang, Manus, Tigak Islands, New Ireland, Djaul Island, and many others.

Giant clams

Giant clams are a major fishery group in the Pacific Ocean. The large size of individual animals, their shallow water habitat, and their longevity means the species can be rapidly fished out in local areas. This has happened in many parts of PNG due to local harvest and poaching by overseas fishers. A stock assessment of commercially important clam species in Milne Bay Province, found that stock levels are very low and have been heavily depleted across the province.

↓ *Figure 8: Densities of beche-de-mer species per transect (400m2) for 1993, 1997 and 1999. Source: Anas et al. (2000).*

Species	1993	1997	1999
H. scabra	10.9	1.11	0.44
S. atra	14.92	11.14	8.5
S. chloronotus	0.76	0.65	0.98
S. variegatus	3.76	1.03	0.8
B. vitiensis	1.06	0.06	0.27
A. miliaris	1.01	0.03	0.28
H. agus	0.17	0.06	0.18
A. echinites	No data	0.03	0.21

Family	Percent composition of catch							
	Port Moresby			Huon Gulf			Tigak Islands	New Ireland Province
	1986	1986	1997	1992	1992	1997	1980-81	1994
Scombridae	10.1	4	36.86			34.75	2.7	
Carangidae	8.3	7.8	11.6	23		19.38	14	5.6
Lutjanidae	4.7	5.1	10.1	19	23.24	18.08	13.3	18.3
Lethrinidae	29.3	31.8	6.8	6.4	11.13	4.44	10.4	4.9
Belonidae	5.2	5.4	6.4			5.25	<1.0	
Acanthuridae	6.8	7.3	5.7			0.89	4.7	
Siganidae	5.5	6	3.6			1.17	1.3	
Serranidae	2.5	2.7	2.7	5.1	8	4.04	9.1	4.6
Scaridae	5.2	5.6	1.5	1.9		<1	8.1	6.5
Chanidae	<1	<1	<1			<1	2.3	
Haemulidae	3.9	4.2	<1	2.5		<1	3.3	3.2
Mugilidae	4	4.4	<1			1.41	21.2	
Mullidae	4.5	4.8	<1	3.4		<1	<1.0	
Sphyraenidae			<1			7.23		
Hemiramphidae			<1			<1		

↑ *Figure 9: Percent catch composition of some artisanal reef fin-fish fisheries in PNG. Source: Anas et al. (2000).*

Lobsters

There is little data on lobster fisheries in PNG. The most economically important species is the ornate rock lobster (*Panulirus ornatus*). The crayfish species currently being harvested in Brooker Island, Milne Bay Province, include the double-spined ornate lobster (*Panulirus penicillatus*), the spiny lobster (*P. ornatus*), the painted coral lobster (*P. versicolor*), and the long -legged spiny lobster (*P. longipes*). The first two species are the most commonly exploited. Brooker Islanders capture crayfish by spearing them while free diving on the reef slope and crest. Collections are sometimes made at night with the aid of underwater torches (flashlights). A total of 7,105 crayfish were harvested by Brooker Islanders during the recorded period of January 1998–September 1999. A local fishing company purchased the entire amount at a total value of 11,372 kina.

Sharks

Sharks are caught as bycatch of the commercial off-shore fishery and by traditional fishers. Sharks are common bycatch of both longline and purse seine tuna fishery. In the longline fishery, fishing gears are often modified to target sharks under the pretence of tuna fishing because shark commands a higher price than tuna. Commercial shark fishing operated in the Gulf of Papua commencing in 1980 until 1993. During the operation, a decrease in CPUE was observed and it was suggested that the resource was becoming fully exploited (catches decreased from about 2mt/day in December 1980 to about 0.8t /day in late 1982). During the period of September 1998 to October 1999, sharks comprised a minor part of the overall fish harvest on Brooker Island. Two specialist hunters were active at this time on the island. During a recorded two-month period (June–July 1999), one of these hunters caught a total of 39 sharks. This catch included black-tip reef sharks *(Carcharhinus melanopterus)*, lemon sharks *(Megaprion acutidens)*, white-tip reef sharks (*Triaenodon obesus*), gray reef sharks *(Carcharhinus amblyrhynchos)*, tiger sharks *(Galeocerdo cuvier)*, hammerheads (*Sphyrna* spp.), and various other unidentified sharks.

Reef fin-fishes (Artisanal)

Several studies from artisanal fishing grounds near Port Moresby and other areas have noted evidence of over-fishing, mostly around large coastal centers with high population concentrations. A WCS study to examine the ecosystem and social effects of a range of coral reef management strategies in Papua New Guinea and Indonesia showed that average fish size was negatively related to the number of fishing households and to sites with higher population densities (Figure 10). A larger average size of fish was found in Purdy Islands (remote reefs in PNG), with lower population and assumed fishing pressure, than in southern PNG. This illustrates the possibility that certain areas in PNG may be over-fished, although further research, such as changes in species catch composition and target species size frequency distribution, needs to be conducted.

Live reef fish trade

The introduction of the live reef fish fishery to PNG in 1990 has brought mixed blessings. Because of the high value of live reef fish, fishermen could substantially increase the value of their catch. The trade also brought in a new set of problems in the form of destructive fishing methods using cyanide and the targeting of spawning aggregations. The confirmed use of cyanide and deliberate targeting of spawning aggregation sites in the live reef food fishery in PNG has been a concern to government agencies and other stakeholders. Extensive reviews of the trade are available on the demand end of the trade, but limited information is available in the supply end of the market. Annual harvests of live reef fish in PNG have ranged from a reported low of under 2t in 1993 to a reported high of over 35t in 1997. The relatively low yield of the fishery can be

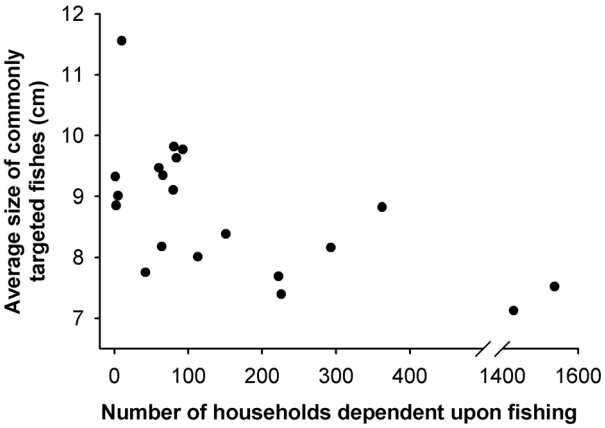


Figure 10: Average size of targeted reef fish under different levels of fishing pressure in Indonesia and PNG Source: WCS Asia-Pacific Coral Reef Program.

partially attributed to the need to negotiate access to reef areas owned by a large number of coastal and island communities. Also government intervention through the introduction of the moratorium on licences from 1997 has kept the fishery under check. Handlines and traps are the two methods most commonly used in the trade. Fish kept in the fishing vessel or in anchored cages are fed with schooling pelagics caught by spear and net. Target species for the trade appear to be mainly the maori wrasse and groupers, particularly coral trout and barramundi cod. The live reef fish trade has had both positive and negative impacts to communities. In some areas it has served to strengthen traditional tenure systems and bring awareness and understanding of resource use. However, most of the operations have had serious negative social impacts, such

as conflict between clans over fishing grounds and royalties. Under the Fisheries Management Act, 1998 all live fish operators in PNG are required to obtain licenses from the National Fisheries Authority, which bans the use of cyanide and hookah diving. However, enforcement of these conditions has been very difficult. The introduction of a comprehensive fishery management plan under which all live fish operations will be strictly regulated with the involvement of the provinces and the traditional resource owners/communities is urgently needed.

Further reading

Anas, A., Kumoru, L., and Lokani, P. (2000) Status of coral reef fisheries – statistics, fishing gears and impacts. In: *The Status of Coral Reefs in Papua New Guinea*, ed. Munday, P.L. Global Coral Reef Monitoring Network and Australian Institute of Marine Science, pp. 23-36.

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LECTURE 1.5: APPROACHES AND TOOLS FOR SUSTAINABLE FISHERIES MANAGEMENT

Introduction

So far this section has dealt with the status of fisheries in Papua New Guinea, the diversity of fishing gears, ownership issues and economics, and the impacts of fishing on target species populations, marine communities and whole ecosystems. We have also examined ways in which we can gather data on the fishery to try to improve the way in which it is operated and managed. Governments, managers and communities decide to manage a fishery when the consequences of having an unmanaged fishery are undesirable. We learned in previous sections that having an unregulated fishery is undesirable because of the impacts it can have on the species of concern, the ecosystem and the livelihoods of the people that depend upon the fishery. When fishing pressure is only light, the fishery may be able to sustain the extraction of target species or the limited damage to habitats. However, few places exist today where fishing pressure is that light. PNG is still considered by many to be lightly fished, however, it appears that in many places and many fisheries within PNG, fishing pressure is high enough to have caused a decline stocks, reduction in livelihoods, and in some places, alteration or damage to habitats. In PNG, the commercial pressures on valuable species such as tuna, beche de mer and live reef fish are certainly high enough to cause declines if left unmanaged.

This section deals with the multitude of tools that are available for implementing fisheries management. It is not intended to provide single solutions to problems, but instead to provide a description of the range of fishery management options available and how to assess which ones are most appropriate for the fishery of concern. Similar to conservation strategies discussed earlier, good fisheries management strategies require clear objectives, sound scientific advice and appropriate and enforceable management actions. There are a diverse range of biological and economic objectives, each of which may require a different approach to management. It is important to identify these objectives clearly in order to design management strategies that are best suited to meeting these goals.

Biological objectives

- Protect stocks from over-exploitation, which would otherwise jeopardize future production and catch rates
- Rebuild stocks that are already depleted
- Protecting species or habitats of special concern

Economic objectives

- Maximising the income of fishermen
- Maximising the country's GDP
- Maximising the availability of food for consumers

Social objectives

- Increasing employment
- Maintaining cultural values
- Maintaining stability of coastal communities

Political objectives

Avoiding conflict between competing fishers, villages or companies

Choosing the "right" solution(s)

Once your management objectives are clearly defined, it is important to take into account as many factors as possible that will be affected by the type of management strategies that you could potentially implement. You should look at all the potential management solutions available that are culturally, biologically and economically appropriate, and try to understand how different factors will be affected by that management policy. For example: How will implementing a temporal closure on the beche de mer fishery affect the populations of each species of beche de mer, the livelihoods of fishermen and exporters, market demands and price fluctuations etc. There are many examples of management strategies that have been implemented in other parts of the world to draw upon, however, in most cases we should be using these as lessons learned, rather than hard and fast solutions. An investigation by FAO into the management of the world's fisheries found that 57 out of 80 fisheries studied were either fully or overexploited, despite having management in place (FAO 1994). Examining what has gone wrong in other fisheries can give managers a head start on what NOT to do in their fishery. It can be very costly to try to reinvent the wheel, especially if that wheel doesn't work in the first place.

Management Options

There are a range of management options available, and most fisheries benefit from the implementation of more than one strategy. The table below (Figure 11) summarises the most common management strategies available to fishery managers. The majority of regimes encountered will fall under these groupings.

Catch Controls	Effort Controls	Technical Measures
Total allowable catches (TAC)	Limited licenses	Size and sex limits
Individual quotas (IQ)	Effort quotas	Time and area closures
Catch limits	Gear or vessel restriction	

Figure 11: Common management strategies for fisheries (Jennings et al. 2001).

1) Catch Controls

Catch controls are among the most widely used management technique. Catch controls are designed to limit the amount of total fish taken out of the fishery, usually on an annual or seasonal basis. Limits on the total catch set for the fishery is called the Total Allowable Catch (TAC). This total catch may also be divided up between individuals, vessels or companies, called Individual Quotas (IQs). When individual quotas are able to be sold or exchanged among individuals or companies, they become Individual Transferable Quotas (ITQs). An advantage to catch controls is that the catch limit can be reassessed regularly and the new limit adjusted based on previous catches and/or stock assessments. TACs have been used for several years in the beche de mer fishery in PNG.

Total allowable catches - TACs are among the most widely used fishery management techniques, and when they are enforced properly and based on sound scientific data, are a good way of sustainably managing the fishery. However, TACs have a number of inherent problems. Because there is one overall total catch, there is often a race between fishers to get the greatest proportion of that catch before the fishery is closed. In addition, the quality of the catch is lower, because fishers simply want to take whatever they can as quickly as possible, shorter fishing seasons and fishing in undesirable and often dangerous conditions. TAC can also often result in a flooding of the market at the time of harvest (e.g. beginning of the year), and a shortage of supply at other times of the year.

Individual Quotas – IQs divide the TAC into allocations for each individual, vessels or company. This system is similar to an overall TAC, however, each individual or company is guaranteed a share of the market. This gets around the problem of fishers "racing" to secure a share of the catch quota as in TACs. It also allows fishers to catch their quota at leisure throughout the season or year, without having to go out fishing in adverse conditions, just so that they can compete with others. This approach results in a higher catch quality, since fishers have more time and are economically encouraged to catch the best grade or product. However, by the same token, fishers may discard catch that doesn't meet their requirements, favouring to fill their quota with more prized catches. This can result in a lot of unwanted waste and by-catch in the fishery, and the real catch level (which

includes that sold and that discarded) may far exceed the total catch the managers were basing decisions on.

The way that IQs are initially allocated can also cause problems. Usually some measure of activity in the fishery is used as a guide for how IQs are divided up between individuals or companies. For example, a company that has caught 20 tonnes of product per year for the last two years might be given a license for twice as high an IQ than a company that has always only caught 10 tonnes per year for the last two years, even though previously this company caught far more. These types of allocations usually cause major conflicts between resource users. IQs are also very difficult to enforce, since catches have to be monitored on a much wider scale. If these quotas are not enforced properly, the system reverts back to a race again, similar to overall TACs.

Individual Transferable Quotas – ITQs are the same as IQs, however, when one company/ individual cannot catch all of their quota, they can transfer or sell this to another fisher. This results in a more efficient fishery since the TAC is more often approached.

2) Effort Controls

Effort controls attempt to restrict the amount of product taken out of the fishery by reducing the number of fishers/boats/gears/time spent in the fishery. The overall logic is that by reducing the amount of fishing effort, fishing mortality will be reduced, resulting in a more sustainable fishery. However, the amount of reduction in fishing mortality caused by a reduction in fishing effort is hard to predict, because we do not know how fishers will change their behaviour in response to restrictions in fishing effort. For example, if the length of net that fishers are allowed to use is halved, the fishers may simply spend twice as long fishing, resulting in no overall change in actual fishing effort, and hence, fishing mortality. When trying to manage a fishery that is effort controlled, we do not know with any certainty how the management restrictions will affect the overall catch.

3) Technical measures

Technical measures restrict the size of target species, the sex of fished species, the gear used to catch those species or the time or place that fishing may occur.

Size Restrictions: The size of individuals that are caught in the fishery may be controlled by Minimum Landing Sizes (MLS). Having size restrictions in place allows for fish to grow larger before they are caught in the fishery, thereby allowing for greater chance of reproductive success. Minimum size limits are usually based on the age at which fish mature. For example, the size where at least 50% of the population has had a chance to mature and reproduce. More recently, an upper size limit has been used in fisheries, to allow for the large, reproducing adults to avoid capture in the fishery, thereby greatly improving the reproductive success of the population. Sometimes where fish change sex at a larger size, lower and upper size limits will protect both the males and the females of the species.

In all cases, these measures will only work where the catches can be properly monitored and the allowable catches enforced.

Size limits have limitations where undersized animals cannot be returned safely to the sea. For example, if fishers are using spear-guns to catch crayfish, they are not able to return undersized animals to the sea in good condition. In addition, size restrictions are extremely hard to enforce. They require a large awareness program to inform fishers of the regulations, and a large effort on the part of enforcement personnel to inspect and regulate the fishery. This system of management is very difficult to properly enforce in PNG. Examples of cases where size restrictions have been trialled in Papua New Guinea include the crayfish fishery and beche de mer fishery (market driven).

Sex restriction: Where the animals can be easily sexed by sight, it may be useful to use to enforce sex restrictions on the catch. These restrictions usually apply to mature or egg-bearing females, particularly in crustaceans, for example, mud crabs. It is hypothesised that by protecting these females, the reproductive effort and subsequent recruitment rates will be increased. Again, these restrictions are difficult to enforce and are only applicable to a small suite of species.

Gear restrictions: This includes the restriction of gears or sizes of gears in order to alleviate pressure on certain target species. For example, the size of mesh in fishing nets may be restricted to be above a certain size to allow small fish to escape, with a similar end result to size restrictions. There may be some unwanted consequences however in multi-specific fisheries, for example, the capturing of larger animals that were previously able to avoid nets.

Time and Area Closures: These systems of management are put in place to protect target species at a specific phase in their life history or area of importance. Area closures are often put in place for the protection of nursery sites and spawning grounds. MPAs or No-Take Zones are special types of area closures that were covered in earlier chapters. The major problem associated with area closures is that they may not enhance fisheries, but rather redistribute fishing effort to other areas, which may be unsustainable. For this reason, area restrictions are most useful when combined with other management techniques, such as effort or gear restrictions.

Time (temporal) closures may be put in place during a particularly important time during species life histories, such as the spawning season, so that fishers do not target the spawning aggregations. Temporal closures may also be useful to allow a fishery stock to grow larger and be of more commercial value. Temporal closures have the inherent problem that they may cause a sudden rush to fish when the area is opened again to fishing. This may cause a rapid depletion of the resource and a flood of the market.

Enforcement and Compliance Issues: No management strategy is going to be successful without proper enforcement and compliance from the fishing community. Modelling a fishery and assuming 100% compliance with regulations is dangerous. Unfortunately, however, this is the case in the majority of fisheries throughout the world. Unfortunately, compliance and enforcement issues are a much greater problem than many people realise. Most developing countries have insufficient resources for proper awareness programs and enforcement of regulations. Compounding this problem is the fact that many coastal communities in developing countries are completely reliant upon marine resources for their livelihood. Asking these people to follow management regulations may result in undue economic hardship. Even in developed countries with a good budget for enforcement patrols, compliance with regulations can be poor if the fishers do not agree with the management plan, or if the benefits of breaking regulations outweigh the costs of getting caught. In order to maintain good compliance with regulations, fishers need incentives to comply with management that outweigh the economic loss and hardship they have to endure from the regulations in place. This may include financially offsetting the costs of regulation of the fishery for several years until fishers start to benefit from regulations, or showing fishers the benefits of similar management regulations in other areas.

Feedback and Adaptive Management

Whatever types of management are adopted, they will only be successful if regularly assessed, evaluated and adapted. Good adaptive management requires a continual feedback of solid data on all variables associated with the fishery, including what is happening to the target species, fisher livelihoods, changes in gears and methods, and changes in market structure. All of this information needs to be properly analysed and assessed and revisions made to management regulations.

CHAPTER 2: REEF MACRO-INVERTEBRATES

LECTURE 2.1: INTRODUCTION TO REEF MACRO-INVERTEBRATES

Introduction:

Macro-invertebrates are an important component of tropical fisheries. Invertebrates may contribute less to global fisheries catches than do vertebrates in terms of overall weight, but they often comprise the major part of fisheries catches in terms of monetary value. Macro-invertebrates also play important ecological roles in tropical ecosystem processes, such as filter feeding and cycling algae and detritus. Macro-invertebrates are conspicuous inhabitants of coral reefs and are often the focus of conservation and management programs. Reef macro-invertebrates that may be of interest to conservationists and managers can be broken into three broad categories: 1) Invertebrates that are important to fisheries 2) Invertebrates that are harmful to marine habitats, and 3) Invertebrates that indicate major ecological shifts in ecosystems.

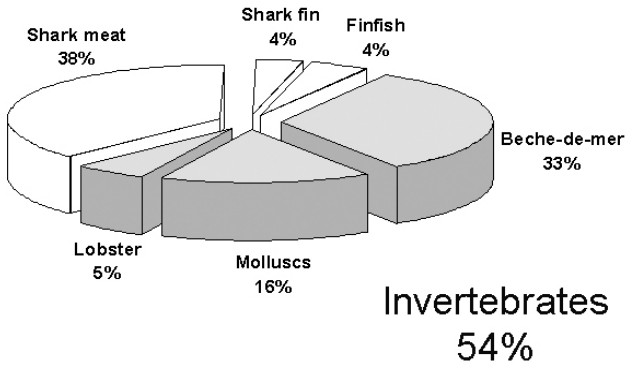


Figure 12: Composition of inshore fisheries exports in Papua New Guinea 1998 (PNG National Fisheries Authority Records)

The majority of invertebrates that are important to reef fisheries come from three phyla: the molluscs, crustaceans, and echinoderms. In PNG, these groups form 54% the total fisheries export for inshore fisheries – more than finfish and sharks combined! The major target invertebrates in PNG (Figure 12) include:

- Beche de mer
- Trochus
- Giant clams
- Lobster

Beche de mer

Beche de mer, or sea cucumbers (Phylum Echinodermata, Class Holothuroidea), are currently the most important inshore invertebrate fisheries export in PNG. Beche de mer is the name given to the dried product made from sea cucumbers that is sold to overseas markets. In 2000, beche de mer was worth between 4 and 70 Kina per kilogram of dried product for local collectors (*PNG National Fisheries Authority Records*). There are around 1200 species of sea cucumbers throughout the world, occupying a range of marine habitats from coral reefs to seagrass and sandy and rubble habitats. Out of these approximately 20 species are targeted in tropical fisheries, all within the two families – Holothuridae and Stichopodidae. Methods of collection include snorkel, SCUBA, Hookah, or weighted hook techniques. Very little, if any, beche de mer is consumed by PNG coastal communities. Although many locals are engaged in the fishery, they sell their catch to central or roving buyers, who then export it to markets located primarily in Asia.

Although some sea cucumbers are filter feeders, the majority of species feed on sediments using sticky tentacles. They are thought to be selective of certain particle sizes of sediment so as to maximise the intake of nutrient rich particles for food. From these sediments they appear to gain most of their nutrients from micro-algae, bacteria and detritus. They appear to have several important roles on reefs, including bioturbation (disturbance or turning over of sediments), reducing sediment stratification (layering), increasing oxygen in sediments, increasing productivity in the surface layers of sediments, releasing nutrients from the sediments into the water, and keeping micro-algal biomass in check (Uthicke 2001).

We know very little of sea cucumber life histories, however, recent studies suggest that sea cucumbers are very susceptible to overfishing (Uthicke & Benzie 2001). Uthicke & Benzie (2003) suggest that some species on the

Great Barrier Reef may live for up to 30 years, taking 5-7 years to become mature and as much as 5 years to reach a saleable size. Although there have been a number of management plans designed to improve the sustainability of the beche de mer fishery, most of these have failed, with the end result being that the stocks are managed in a "boom-bust" manner. Stocks are normally fished down until the fishery is unviable, then collectors wait for the stocks to recover again. However, as a result of their life histories, many stocks do not recover properly and some species appear to have become locally extinct due to fishing pressure (Uthicke 2001). There is no clear indication of what would happen if sea cucumbers were removed from reefs completely (Uthicke & Benzie 2001), however, that appears to be the fate facing many reefs in the Indo-Pacific as sea cucumber becomes more and more valuable. The biology and management of sea cucumbers will be discussed in further detail in the next lecture.

Trochus

Trochus, or "topshells", are a mollusc of the family Trochidae, Phylum Mollusca. *Trochus* are fished as a source of mother-of pearl for buttons and jewellery, and are also collected for the curio trade. The main species fished is *Trochus niloticus*. This species has formed a significant source of income in Pacific Islands since the early 1900's. Originally *Trochus* were restricted to reefs of the East Indian and Western Pacific Oceans only, but they have since been introduced to a number of locations further east to provide fisheries resources (Figure 13). *Trochus* are collected by reef walking or on snorkel, and the shells are sold to exporters who ship to Japan, Taiwan and the Philippines.

Trochus are found mainly in shallow water (3m to 6m) on reef flats and crests, especially in surge zones where there is an abundance of hard, flat substrate to feed, combined with grooves and spurs to shelter. *Trochus* are herbivorous and feed primarily on turf algae within these zones. They are moderately long-lived (10-14 years) and take around 2 to 3 years to mature. There has been some research into the sustainable yields for trochus, using large-scale depletion experiments.

In PNG, *Trochus* form the second largest export by weight (>300 tonnes per year; *National Fisheries Authority Records 2000*). The main problem with *Trochus* management has been that the total allowable catch (TAC) is very difficult to determine due to limited data on stock size and life histories. Minimum size limits may work as a management tool, however, there is a need a stronger scientific basis for setting size limits (ie: site-specific reproductive data). Traditional management has been adapted and used to manage *Trochus* stocks in some communities in the Western Pacific and has been shown to have positive impacts on the fishery (Evans et al. 1997).

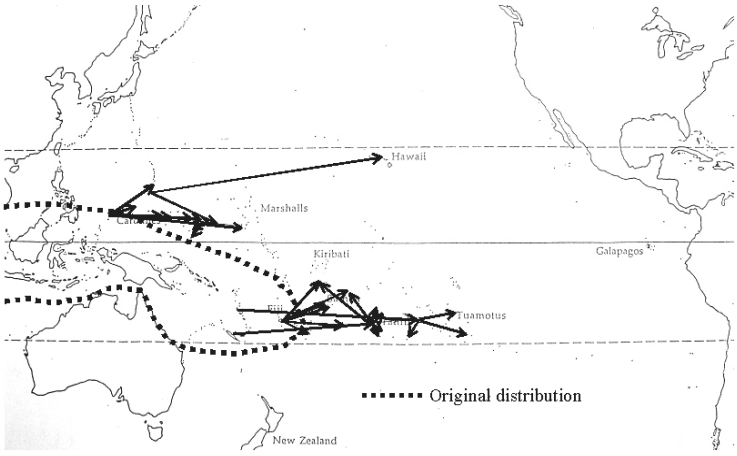


Figure 13: Original distribution of Trochus niloticus and location of transplantations during the 1900's.

Lobsters/Crayfish

Lobsters comprise a large part of fisheries catches worldwide, and are the third most important inshore invertebrate export from PNG, with more than 100 tonnes exported per year (*National Fisheries Authority Records 2000*). Lobsters also form an important component of subsistence fisheries in coastal communities. There are three main species of crayfish caught in tropical fisheries, all within the Family Palinuridae: *Panulirus ornatus, Panulirus versicolor* and *Panulirus longipes.* The most commonly targeted of these is the ornate rock lobster (*P. ornatus*). Lobster are collected by hand or with spears using snorkel, SCUBA and Hookah. Stocks have been reported by communities and buyers to have declined and decreased in average size in high population areas and near central buyers (e.g. Port Moresby, Kavieng and Manus – WCS

unpublished data).

Most species of lobster have widespread distributions, and live in shallow waters down to depths of greater than 200m. Lobsters live in caves or crevices and emerge at night to feed. They have a herbivorous to omnivorous diet. Stocks of *P. ornatus* from the Great Barrier Reef and Torres Strait have been found to migrate to the northern GBR and to the eastern Gulf of Papua to breed. These migrations have long been targeted in both PNG and northern Australian fisheries (Dennis et al. 2001). Recently the fishery has been closed during the breeding season (November to February) to provide a sanctuary for this highly susceptible life stage.

Giant Clams

Giant clams are bivalves (Phylum Mollusca), belonging to two genera – *Tridacna and Hippopus*. Within these two genera are six species: *Tridacna gigas, T. derasa, T. squamosa, T. maxima, T. crocea, Hippopus hippopus.* Clams are collected by reef walking and on snorkel. Some species (e.g. *T. gigas*) are free-living and are easily collected by hand. Others grow within the reef substrate (e.g. *T. crocea*) and are pried from the reef with crow-bars or similar objects. All six species are targeted in the fishery in PNG. A limited amount of clam meat is exported (around 25 tonnes annually in PNG, *National Fisheries Authority Records*), however, large quantities of clam meat are eaten by coastal communities and the shells are often used for the production of lime to be chewed with betel-nut. Giant clams have also been increasingly reported to be poached by foreign fishing vessels for overseas export (WCS unpublished data).

Giant clams occur in shallow waters of reefs and lagoons to depths of around 15m. All giant clams share the characteristic of having symbiotic algae living within the mantel tissue (zooxanthellae). Clams are filter feeders, obtaining nutrients from planktonic algae and other organisms. Some of these nutrients are passed on to the symbiotic algae, which in turn provide energy to the clams through photosynthesis. Giant clams can filter enormous quantities of water, and are thought to play an important role in maintaining water quality on reefs. Little is known of the ecosystem impacts of removal of large quantities of clams from reefs.

Some species may be already locally extinct in parts of the Pacific (e.g. *T. gigas*). There is an urgent need to encourage communities to use alternative, more sustainable sources of betel-nut lime. Some of the rarer or extirpated species should have immediate bans on collection to have any hope of recovery. There is also the possibility of supplementing natural clam stocks with aquaculture, a technique which has been successful in the Solomon Islands (Bell 1999).

Invertebrates that threaten coral reef habitats

Corallivorous snails

Corallivorous snails feed on living coral tissue. The most common of these snails belong to two genera: *Drupella* and *Coralophila.* They can target several different growth forms of coral, but are mainly found on branching coral and massive colonies. Corallivorous snails are normally present on healthy reefs in relatively low abundance. However, occasionally corallivorous snails form outbreaks or plagues and destroy large areas of living coral in a short period of time. There has been some research into the population dynamics of these snails (Cumming 2000), however, the cause of outbreaks is still largely unknown. In PNG, there has only been one documented outbreak – in Milne Bay in the late 1980's (Munday et al. 2000).

Crown of Thorns Starfish

Crown of thorns starfish (COTS) were mentioned in the preceding lecture and won't be covered in detail again here. COTS feed on live coral tissue, targeting primarily branching acroporid corals, but they also target other coral life-forms when branching corals are unavailable. COTS usually occur in relatively low numbers on reefs, but can occasionally occur in large outbreaks, which are capable of decimating reefs within a matter of weeks. PNG has not suffered any major outbreaks, however, the GBR has seen a number of outbreaks in recent decades, sparking a large research program to identify the cause of this problem. However, despite the large amount of research, there are no clear links between human activities and COTS

outbreaks. It is still unclear whether these plagues are caused by human factors, or whether they are natural.

Indicators of environmental/ ecological change

Boring organisms

Boring organisms are species that burrow into the reef substrate or reef matrix. They mainly include polychaete worms, sponges and bivalves. These organisms use the reef matrix for anchorage and protection, but gain their nutrients through filter feeding. It is thought that because these organisms feed on organic matter and plankton in the water column, that they may indicate the level of nutrients in the water, and therefore the degree of water quality (Kiene 1997). In recent years, however, studies have found that this relationship is fairly weak and unpredictable, and only applicable to certain species (Pari et al. 2002). Few researchers nowadays include the monitoring of boring organisms in research programs.

Sea Urchins

Sea urchins are spiny herbivorous animals belonging to the Class Echinoidea, Phylum Echinodermata. Sea urchins are generally cryptic by day, hiding under ledges or in surge channels, and emerging at night to feed. Urchins are important grazers on turf algae and are also important as bioeroders of dead corals and the reef substratum, scraping the surface of reef with their radula when feeding.

Sea urchins have been reported to increase in abundance when their predators (e.g. triggerfish) are removed through overfishing (McClanahan 2000). Sea urchins may also increase in density in response to the removal of their main competitors for algae – herbivorous fishes (Hughes 1994). In extreme cases, sea urchins have virtually replaced herbivorous fishes as the dominant grazer of turf algae on reefs. In this case it is difficult for herbivorous fishes to become re-established because urchins remove much of the standing biomass of algae, leaving nothing for the fishes (Hughes 1994).

In a famous case study reported from Jamaican reefs in the Caribbean (Hughes 1994), sea urchins were thought to have become the dominant grazing herbivore on reefs due to overfishing of competitors and predators. However, a pathogen (disease) went right through the sea urchin population, virtually wiping them out and leaving few grazing herbivores remaining on the reef. Within a short period of time, algae took over reefs and smothered corals. Live coral cover was reduced from around 60% to 10% within a decade. Twenty years later, reefs are still recovering from this catastrophe.

Measuring changes in sea urchin densities may provide a good indication of changes in the reef ecosystem due to fishing, or due to the exclusion of fishing, such as inside marine protected areas (MPAs). Carreiro-Silva & McClanahan (2001) showed that where fishing had been successfully reduced within a marine protected area in Kenya, an increase in sea urchin predators resulted, followed by a reduction in sea urchin abundance. The reduction in sea urchins inside the MPA has also coincided with in an increased growth of corals within the MPA.

Survey techniques for reef macro-invertebrates:

A range of simple survey techniques are available to examine populations of macro-invertebrate on reefs. The most suitable techniques to use will depend largely on the size, rarity and movement patterns of the species in question.

Small quadrats: Small quadrats, (e.g. 1m x 1m squares made from PVC pipe) are useful for sampling small invertebrates, including corallivorous snails, boring organisms, and sea urchins. These organisms usually occur in high densities and can often be more easily counted within small areas, such as small quadrats, than larger belt transects.

Belt transects: These are areas surveyed either side of tape measures laid out on the reef. Fairly narrow transects of either 1m or 2m in width by 50-200m long are most commonly used for surveying less abundant, or larger invertebrates, such as giant clams, sea cucumbers and certain species of sea urchins. Narrow width transect have been shown to produce best results, while increasing the with of transects (e.g. to 5m) has been found to greatly decrease the accuracy of

surveys due to the difficulty in recording cryptic species that were further from the observer (WCS unpublished data).

Area searches of large quadrats: Larger quadrats (e.g. 20m x 20m) are often useful for species which are relatively cryptic, but widely dispersed. However, it is easy to accidentally double-count animals and overestimate abundances. To avoid this, individuals should be marked once counted, or alternatively, quadrats should be searched in an organised manner (e.g. zig-zagging up and down 1m belts) to avoid recounting individuals.

Size-frequency versus density only estimates: Similar to fish surveys, gathering information on size frequencies of target invertebrate species can sometimes reveal patterns much more easily, rapidly and precisely than using simple density data alone (WCS unpublished data). Most invertebrates are relatively immobile and are easy to gather size information on. Below is an illustrative guide to measurements of some common invertebrates targeted in fisheries.

Petersen mark-recapture: For species that are easily tagged, relatively mobile and mix thoroughly throughout the rest of the population, simple mark-recapture methods may be used to get fairly accurate estimates of population densities. These methods are based on the simple principle that if you mark a known number of individuals and release them into population, then after a given time recapture a number of individuals, you can work out the overall population size in an area. This is estimated by calculating the proportion of individuals recaptured with tags, compared to those without tags, multiplied by the total number of tagged individuals released: $N = T_i \times U_R / T_R$

Where:

N = estimated population size,
T_i = number of individuals tagged and released
U_R = number of untagged individuals recaptured
T_R = number of tagged individuals recaptured

This method has many assumptions that are rarely met. For example, that tagging does not influence the mortality of individuals, and that individuals mix thoroughly within the population, that there is no tag loss, and that the chance of recapture of tagged individuals is the same as untagged individuals. However, despite these problems, mark-recapture techniques still often provide some of the best density estimates for certain species, such as trochus.

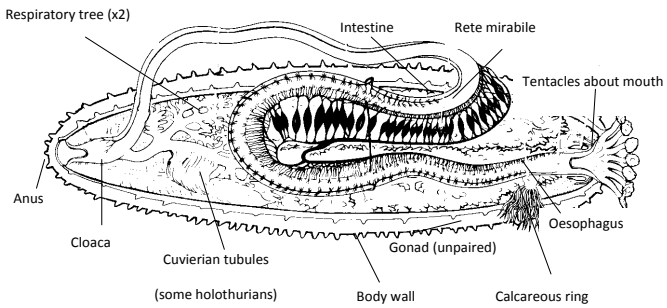
LECTURE 2.2: SEA CUCUMBER BIOLOGY AND TAXONOMY

From Forbes *et al* (1999)

Sea Cucumbers (Holothuroidea or holothurians) comprise one of the five classes of the phylum ECHINODERMATA and consist of 25 families, 200 genera and 1400 species worldwide. Fundamental division of the phylum is based on the general body plan. As with all members of the Echinodermata they display a pentaradial body design, based around the mouth, with rings of nervous, haemal and water vascular systems running the length of the body. The pentaradial body plan of the holothurians has become horizontal rather than vertical as in the other echinoderm groups. The anatomical systems (nervous, haemal and water vascular) are organised into five major trunks running the length of the body. These trunks (ambulacra) are often mirrored externally by tracks of tube feet, which are the external and locomotory part to the water vascular system. Due to the horizontal mode of life adopted by many species within the group the body has become elongated and cylindrical with numerous sensory papillae resulting in the common name “sea cucumber”. Figure 14 illustrates the general holothurian body plan.

Surrounding the mouth internally is the calcareous ring, consisting of a series of five calcareous plates, which protect the ring of vital

Figure 14: Anatomy of a Holothurian. Diagrammatic Representation (after Cannon and Silver, 1986)



tissues. The distinctive shape of these plates is used as a taxonomic feature to separate genera within the family *Holothuriidae.*

Arranged around the mouth externally are modified tube feet, which can be retracted. These serve primarily for food collection. Different feeding modes have therefore given rise to a variety of tentacle forms. Tentacle structure is therefore used as a taxonomic feature in division of the class into the orders Aspidochirotida and Dendrochirotida. The order Dendrochirotida are suspension feeders, often found with their body buried in the sediment and their highly branched feeding tentacles projecting into the water column. The order Aspidochirotida contains the largest and most conspicuous holothurians. They ingest sand and digest some of the associated organic materials.

The orders Apodida and Molpadida lack tube feet apart from the specialised feeding tentacles. Food is passed into the mouth and into the intestine, which terminates posteriorly in the cloaca. The gut lies in a fluid filled coelomic cavity. Gonads (ovaries or testes) lie in one or two tufts at the anterior of the body and open anteriorly. The respiratory tree, which is responsible for gas exchange, lies in the posterior of the body and opens to the cloaca. Lying along the gut is the rete mirabile, a network of fine haemal tissue and is responsible for the transport of nutrients and metabolites. In some holothurians a cluster of white tubules, the cuvierian tubules, lie posteriorly near the cloaca through which they may be ejected in defence. These become very adhesive on contact with water.

The body wall has powerful radial and longitudinal muscles. Unlike the other classes within the phylum, in most of the holothurians the skeletal structure (test) has been reduced to microscopic calcareous structures known as spicules. In the order Dactylochirotida this has remained complete. Classification of the orders into genus and species largely relies on the examination of the microscopic spicules found in the body wall. These can take on a variety of shapes from simple rods and tables in the genus *Stichopus,* to the buttons of some *Holothuria* species to the elaborate anchors and plates of the *Synaptidae.*

Holothurians are dioecious, although some are hermaphrodites. A number of species brood their young either externally amongst their tentacles or in external brood pouches, some internally in the gonad or coelom. The most common form of reproduction however is by broadcast of gametes. Sexes are usually indistinguishable except for brooding females. Asexual reproduction is known in some species.

LECTURE 2.3: SEA CUCUMBER FISHERIES AND BECHE-DE-MER

From Conand (1999)

Holothurian fisheries are mostly based on around thirty species amongst the thousand existing. Sea cucumbers are consumed, either raw, boiled or pickled, or processed in a dried form, beche-de-mer. In Japan and Korea, the body wall and viscera of sea cucumbers are eaten raw or pickled. The most important sea cucumber product, however, is the dried body wall, which is marketed as beche-de-mer (trepang or hai-som), throughout tropical regions. Beche-de-mer fisheries have a long history, as the Chinese have sought sea cucumbers for a thousand years or more in India, Indonesia and the Philippines. During the 18th and 19th centuries, traders gathered them in a wider area. These fisheries are still poorly documented and, in many cases, not well managed.

The whole "Holothurian Fishery System" is complex (Conand 1990, Conand and Byrne 1993). There are at least five levels between the resource on the sea-floor and the plate of the consumer (e.g. middleman, exporter, importer). At each level, different actors may intervene. Numerous interactions take place at each level and between the levels. The commercial sea-cucumbers are harvested according to the main geographical areas. In general, more interest has been given to the biology of the species targeted in traditional fisheries than in more recent ones. Despite the abundance and large size of these animals and their importance in benthic communities, little information is published on their population biology compared with other living marine resources. The different commercial species share a few characteristics : 1) - abundance in shallow waters; 2) - large size of the specimens; 3) - thickness and quality of their body wall; 4) - absence of Cuvierian tubules

(or not easily rejected). From these characteristics, and the information from the markets, it has been possible to grade the species into four categories, grade 1 being the highest and grade 4 corresponding to the lowest one, which is generally not profitable to fish.

The fisheries can be divided according to the geographical area and the species harvested. Tropical fisheries tend to be multispecific whereas temperate fisheries are generally monospecific. Traditional tropical fisheries in the Western-Pacific and Indian Oceans produce a dry product; recently, some countries have started exploitation on the Eastern-Pacific coasts. Temperate fisheries for fresh or frozen product were long limited to the North-Western Pacific Ocean and there are now more countries showing interest.

Tropical fisheries in the Indian and Western Pacific produce a dry product and are divided into two main regions: the Western Central Pacific and Indian Ocean. The Western Central Pacific is the main producing region in the world with large countries and Pacific Islands.

Indonesia is now the major world producer and exporter of beche-de-mer product. From the national statistics, production has been around 4,700 t/year since 1987 (which corresponds to more than 47,000 t fished, as statistics generally refer to processed products), but from other sources (FAO catches, FAO export data, pooled markets data) it appears that they are probably around 2,600 t/year. Local consumption by Chinese people in Indonesia is not evaluated, but probably does not exceed a few hundred metric tons. Production appears to be regularly increasing since 1988-89, as in other countries. More than twelve species of sea cucumbers are processed by traditional Indonesian methods which may include two unusual features, soaking in salt before boiling and incisions on the body wall for larger species. These practices give an unusual appearance to the processed product and probably result in a lower quality and less valuable product. There is very little information on the sea cucumber fishery in The Philippines, although it is considered as the second largest producer in the world, with catches of around 2,000 t (dry weight) per year, which seems to show a slight decrease since 1992.

In Malaysia the situation is complex, as the country appears simultaneously to be a producer, exporter, importer, and consumer and as the product figures are presented within different categories (live, fresh or chilled and frozen) (Baine and Forbes 1998).

Papua New Guinea (from NFA information literature)

There is an active fishery in Papua New Guinea. Species harvested include the sandfish (*Holothuria scabra*), black teatfish (*Holothuria nobilis*), Greenfish (*Stichopus cloronotus)* and prickly redfish (*Thelenota ananas*). In terms of landing price, sandfish can fetch around 70 Kina/kg, the prickly redfish, 33 Kina/kg. Sea cucumbers are caught by wading on reef tops or by diving. Hookah and scuba is prohibited in PNG, as is fishing at night when sea cucumbers spawn.

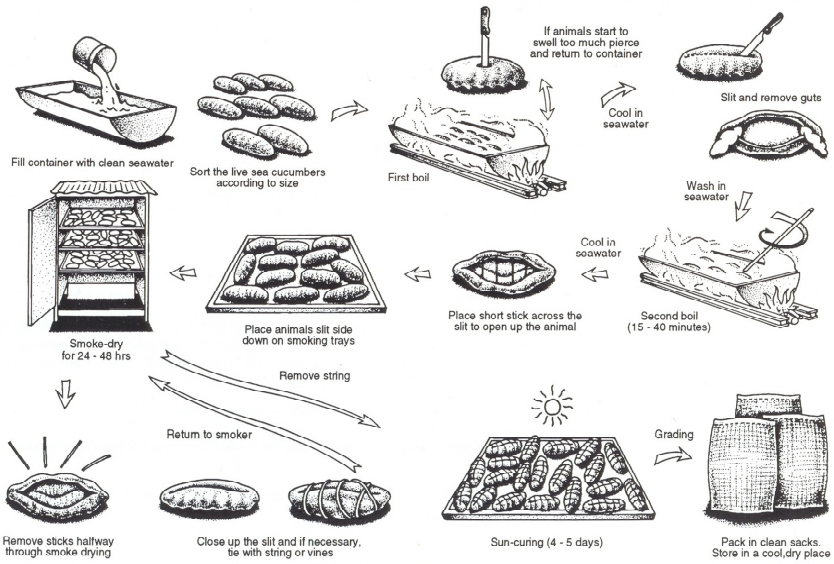


Figure 15: Beche-de-mer processing (after SPC 1994)

Processing (Figure 15) involves gutting, boiling, scrubbing, and sun-drying or smoking. Methods

vary from group to group and location to location. Processing is important in terms of meeting buyer requirements for the international market. A general approach to processing is attached as Figure 2. This applies regionally.

In PNG, there are differences in processing for different species. Once processed there is a normal procedure to follow in preparing beche-de-mer for export. This includes:

- Completion of a packing list (species, grade, weight)
- Preparation of a commercial invoice
- Completion of a certificate of fitness to export
- Obtain NNFA approval. If approved the product is inspected.

The majority of beche-de-mer is exported to the Asian markets. Large quantities are exported to Singapore and Hong Kong (2 main beche-de-mer markets).

IN PNG, the beche-de-mer fishery is governed by the beche-de-mer Fishery Management Plan. Management measures include:

- Open to PNG citizens only
- Closed from 1 October – 15 January
- Prohibition of hookah, scuba and lights
- Provincial TAC (Total Allowable Catch) allocations
- Closure of fishery when TAC is reached
- Minimum sizes are set for live and dry specimens (17 species). For example, for sandfish the minimum live size is 22cm and dry size is 10cm. For prickly redfish, the equivalents are 25cm and 15cm.
- Licences are required for storage and export
- NFA to be provided with monthly summaries of their purchases.

Management

(from Baine 1994)

Adams (1993) presents South Pacific Commission (SPC) recommendations regarding the management of individual South Pacific holothurian fisheries. These recommendations are suggested by Adams (1993) as a basis for possible general principles for beche-de-mer fisheries management. The following list takes these recommendations and presents them in general terms:

- Undertake baseline surveys, where possible; establish permanent population survey sites; establish monitoring programmes to collect data on fisheries and exports;
- Encourage communities in the regulation of their fisheries; provide exclusive rights to local fishers;
- Limit entry to fisheries; reduce fishing effort on overfished areas; suspend fishing and export activities to allow recovery of resources; suspend harvesting during breeding seasons; rotational harvesting; provide closed seasons; establish marine reserves for the provision of broodstock; discourage, and possibly prohibit, night fishing for nocturnal species;
- Prohibit scuba diving and hookah to alleviate pressure on deeper water spawning stocks; implement minimum size limits (MSLs) to prevent early removal of potential spawning stock; consider quotas as a management measure to encourage selective harvesting of larger, more valuable specimens;
- Restriction of number of export businesses and introduction of export quotas;
- Education and instruction in improved processing techniques; and
- Establishment of sea ranching programmes.

Figure 16 summarises the types of management tools that have been employed in some sea cucumber fisheries. This list does not represent current management regimes but merely gives an indication of the range of options that have been historically applied in different countries. More common measures relate to closures, quotas and export restrictions. As can be seen, a variety of management options have been employed in different combinations, or at different times. This is common in many fisheries. In Papua New Guinea, for example, under the National beche-de-mer Fishery Management Plan, there is a combination of access restrictions, closures, Total Allowable Catches (TACs), Minimum Size Limits (MSLs) for 17 species, and storage and export licences (Desurmont 2003). On the other hand, the only regulations reported for New Caledonia are self imposed by fishers and include harvesting seasons and size limits (Anon 1993). It should also be noted that 30% of the countries in Table 5 have reported no regulations.

When reviewing available information on holothurian fisheries, however, there are a

number of readily identifiable general issues that should concern us:

- There are many countries that have no regulations in place or if they do, a lack of funds and manpower for monitoring and enforcement is seen as a common problem (Adams 1992, Baine and Choo 1999, Jimmy 1996, Martinez 2001, Trianni 2002);
- There is little in the literature that provides information on the success or failure of management initiatives, mainly as a result of relatively recent imposition of regulations and management measures and the lack of any baseline data for comparison;
- Many problems, such as the lack of basic ecological information, lack of education and awareness programmes, combined records of species caught and uncertainty as to the origin of catch (Baine and Choo 1999, Rasolofonirina and Conand 1998, Samyn 2000), all impede the adoption of effective management tools;
- The growing economic importance of this resource and resulting community dependencies will affect acceptance and adherence to regulations and lead to internal disputes e.g. over territory (Kinch 2002, Martinez 2001); and
- Each fishery has different characteristics and there is potentially little to learn from monitoring the imposition of regulations in another fishery.

In more direct terms the following are offered as main causes for concern in many holothurian fisheries:

- information on holothurian biology and ecology is lacking, as are basic stock assessments;
- holothurian products are in high demand, with holothurian fisheries potentially quite lucrative to fishers, particularly in the provision of stable livelihoods;
- holothurian fisheries and trade routes are complex and existing statistics do not inspire confidence when trying to estimate catches;
- management in most instances has been reactive to dwindling stocks presumably

Figure 16: Management tools employed in sea cucumber fisheries, by country (and source)

Country	Closure, area limitation	Gear limitation	Quota or TAC	Limited access, permits	Export permits	Size limits	Export restrictions	Closed seasons	Storage licences	Voluntary	No management	Source
Australia	x	x	x	x								Beumer 1992; Uthicke and Benzie 2000
Ecuador	x		x					x				Martinez 2001
Fiji						x	x					Adams 1992
Indonesia											x	Bruckner et al. 2002
Kenya											x	Samyn 2000
Madagascar											x	Irwing 1994
Malaysia											x	Baine and Choo 1999;
Mexico	x					x		x				Castro 1995
Mozambique	x											Abdulla 1998
N Caledonia										X		Anon 1993
N Zealand			x									Morgan and Archer 1999
N Mariana Is	x				x		x					Trianni 2002
PNG	x	x	x	x	x	x	x	x	x			Desurmont 2003; Kinch 2002
Solomon Is										X		Holland 1994
Thailand											x	Bussarawit and Thongtham 1999
Tonga		x				x	x	x				Anon 1996
Tuvalu											x	Belhadjali 1997
USA			x									Bradbury 1997; Woodby and Larson 1996
Vanuatu			x				x					Jimmy 1996
Venezuela				x								Rodrigues and Marques Pauls 1996

because of overfishing, with associated difficulties in measuring the effectiveness of management measures;
- enforcement of regulations and monitoring is a problem particularly in areas which are geographically isolated and in countries lacking financial and human resources; and
- there is a lack of education and awareness programmes.

There have perhaps been two major consequences in the past decade as a result of these main problems and the slow progress in addressing them. Firstly, there has been increased interest in holothurian rearing and restocking, in an attempt to perhaps deflect effort away from wild resources in the future and/or to mediate for the social impact of dwindling wild resources. Secondly, CITES (Convention on International Trade and Endangered Species) has become involved.

There are many problems with the current status and management of holothurian fishery resources. These problems include a lack of information on the population dynamics of exploited species (including taxonomic difficulties), a lack of reliable fishery and trade statistics, illegal activities, a lack of effective regulations, and low state level prioritisation of this resource with associated knock-on effects on monitoring and enforcement. This final problem is one to take particular note of, as many countries do not view holothurians as a high priority resource, despite their ecological role and economic importance to small communities. One must also take into consideration any possible lack of interest from fishers and traders, with considerable evidence of widespread "boom and bust" fishing activities in reaction to current high market demands. This, however, can also be linked to a lack of educational awareness programmes. It is difficult to identify general approaches to the problems facing holothurian fisheries, as each fishery is unique and very dependent upon political factors within specific states.

Over the last two decades, the global exploitation of sea cucumbers has reached such high levels and raised such concern that a United States call, with multi-Party support, has been made to consider the listing of the families Holothuridae and Stichopodidae in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Bruckner et al. 2003). However one views the input of CITES, be it positively or negatively, be it through the eyes of a conservationist, producer, importer, exporter, consumer, processor or fisher, the involvement of CITES is now a reality and reflects some international concerns at the current status of sea cucumber populations and approaches to their management and trade.

The involvement of CITES is one new approach to the problems facing holothurian resources. It has a true international dimension, and is an approach that needs consideration. An Appendix II classification refers to species that are not necessarily threatened with extinction now, but that may become so unless trade is closely controlled. International trade in Appendix II species may be authorised by the granting of an export permit or re-export certificate. No import permit is necessary. Permits or certificates should only be granted if the relevant authorities are satisfied that certain conditions are met, and that trade will not be detrimental to the survival of the species in the wild.

Such a measure does have its positive aspects, particularly in the provision of an international face to future management and trade in these species. It offers a watchful eye and would promote more international co-operation on sea cucumber fisheries management as well as more effective country and even fisheries specific monitoring and control.

There is a need, however, for countries to be willing and able to implement such a listing. There will always be the problem of illegal fishing and trade, but this could also be exacerbated by any CITES classification when viewed suspiciously by members of the beche-de-mer industry. This problem would be exacerbated even further with a lack of state resources to enforce management measures, coupled with political and other socio-economic issues that may be unique to any given state. It is also difficult to see where CITES can help in unravelling the complexities of fisheries and trade in these species.

There is much to be addressed in taking this route. Bruckner et al. (2003) identifies a number of general areas that need to be examined when considering the appropriateness

of CITES, namely taxonomic uncertainties within the families, the ability to distinguish taxa in the form they are traded, the adequacy of biological information for making non-detriment findings, the ability to make legal acquisition findings, and research needs. Each of these has its own extensive array of issues. To follow this route is a considerable undertaking and will require extensive international discussions and co-operation. It may well provide the necessary impetus for stronger action from the scientific community on many of the basic issues underlying holothurian resource management. On the other hand the potential impact on local communities and economies must be thoroughly understood. It will be interesting and informative to observe the progress and impact of the Appendix II listing of *Hippocampus spp*. (seahorses), which came into effect on 15 May 2004.

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CHAPTER 3: FISHERIES BIOLOGY

LECTURE 3.1 INTRODUCTION TO FISHERIES BIOLOGY

Fisheries biology and fisheries management are not the same thing. Fisheries science and biology are multidisciplinary subjects, combining animal behaviour, ecology, and population dynamics with environmental processes to predict how fish populations will respond to fishing mortality. The results of fisheries science and biology inform fisheries management, such that policies and practices are implemented to meet objectives by various stakeholders, from fishers to consumers to conservationists.

Biologists were first to draw attention to the problem of over-fishing. Fisheries science took its form from 1890 onwards, relying on a mix of zoology and statistics. The original objective of fisheries science was to support management to obtain the 'best result' or greatest sustainable yield. The search for this single biologically based objective came to dominate fisheries science and management. It is now recognised that there are many reasons to manage a fisheries and that most of them are not to do with yield maximisation. The old view that we should sustain the highest catch possible does not hold. It is not sufficiently precautionary and ignores other objectives, such as biological, economic, recreational and social/cultural.

It is best to begin with a simple model of fish populations. One of the earliest models was proposed in 1931 by E.S. Russel and is know as 'Russel's Axiom' (Fig 1). The biomass of a fish population changes from year to year and Russels Axiom shows the major causes of this change and summarises the basics of fish population dynamics. Self-contained breeding populations are referred to as stocks. Stocks are the basic unit of fisheries biology. For example, a species like blue fin tuna (*Thunnus maaccoyi*) probably consists of a single stock, because it only spawns in one known location. In contrast, there may be at least three separate stocks of herring in the North Sea, each with a different spawning ground. Stock size can be measured by the total number of fish, but more usually it is measured by biomass, which is the total weight of fish.

Stock biomass can increase for two reasons:

- Recruitment: new fish entering the stock by the process of reproduction
- Growth: individual fish getting fatter

Stock biomass can decrease for two reasons:

- Natural mortality: fish die of natural causes such as being eaten or disease
- Catch of the fishery: what man takes from the stock as catch or yield

Figure 17 assumes that there is no immigration of fish into or out of the stock and that the habitat remains healthy and available for all stages of the life cycle of the fish. For example, the loss of a nursery habitat could decrease stock size and potential catch from that stock.

The job of the fisheries biologist is to measure:

- stock size
- recruitment
- growth
- natural mortality

Then to give advice and recommendations to managers on sustainable and best level of catch scientists try and measure the stock size by carrying out research surveys. They can use the same type of gear as the fishery (hook and line, trawl) for the survey and/or they can use methods different from the fishery (underwater visual census). The objective is to get a good idea of numbers of fish and how old they are. Surveys can be expensive and can usually only cover a small part of the stock. How this measure related to the whole stock, which can be very large, is always a problem.

Collecting catch and fishing effort from the fishery itself is another approach. This can be relatively simple and inexpensive, such as by issuing logbooks or carrying out fish market surveys. Here the scientists have to study the fishers (e.g. were, how, when, why and how hard they fish) as well as the fish stock itself. A critical outcome of such surveys is that the scientists come to appreciate the knowledge and experience of the fishers and these links are essential for future long term management of the fishery. With fish stocks often so large across time and space, and research budgets

tight, the fishing community itself has a large role to play in providing information and in decision making. Indeed, co-management of fisheries is emerging as a key approach to fisheries management in the South Pacific. Catch rates of fishers are often used as a proxy for stock size or fish abundance. This is often referred to as catch per unit effort (CPUE). CPUE is not necessarily a good indicator of stock size due to the complexity in the relationship between fishing effort and fishing mortality and changing fishing practices over time (e.g. more efficient fishing gear or technology).

Another critical aspect of fisheries biology is to determine the age of a fish. If you know how old fish were, you can also measure how long or how heavy they were and measure the growth rate. You can also look at the number of fish in each age class which can tell you about the mortality rate (what are the chances of surviving to be five years old?) and recruitment rates (how many fish enter the one year age class each

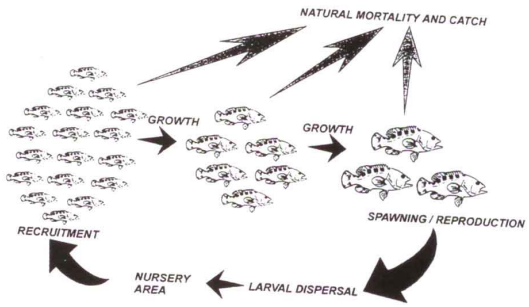


Figure 17: Russel's Axiom of fish population dynamics

year?). Figure 18 shows how the numbers of fish per age class can tell you if a stock is over-fished. Notice the changing shape of the graph from no fishing to over-fished.

Using samples of fish to determine the growth and mortality rates assumes that you have a fairly representative sample of fish from your stock. That is if you sampled your stock with a certain kind of fishing gear, you need to be aware of how efficiently the gear samples the different ages and sizes of fish and you allow for gear selectivity to correct for any bias in the sample. For example, if you sampled a stock of mullet (*Mugil cephalus*) along a coast using a net, the mesh size may select for a certain size range and allow smaller individuals to escape through the mesh. This would bias understanding of the age classes.

Knowledge of maximum age a fish can, on average, reach in a previously unfished stock is a good indication of the potential sustainable yield of a stock. For example, if you had to decide on what the sustainable yield from a 100,000 ton stock of tropical anchovies, with a maximum age of one year, you may be quite confident that the fishery could sustain 10,000 tons per year. On the other hand, you may not be so confident that a fishery could take 10,000 tons per year from a 100,000 ton stock of orange roughy, with a maximum age of over 100 years. The maximum age or longevity in an unfished stock gives a good indication of the rate of natural mortality. Fish stocks with a high rate of natural mortality, such as the anchovies in the above example, will be potentially more productive (higher rate of growth and recruitment) than those with low rates of natural mortality.

With measurements of stock size, recruitment, growth and mortality, you can calculate what level of catch is sustainable. A manager will want to know if the stock is overexploited, underexploited or being exploited in a sustainable fashion. The fisheries biologist gives advice on appropriate levels of fishing (how many fishers, how much effort, how much catch) and/or the size of fish at first capture. Since wild populations of fish are naturally dynamic and there is a good deal of uncertainty in biological estimates the fisheries biologist will provide a range of options to the fisheries manager.

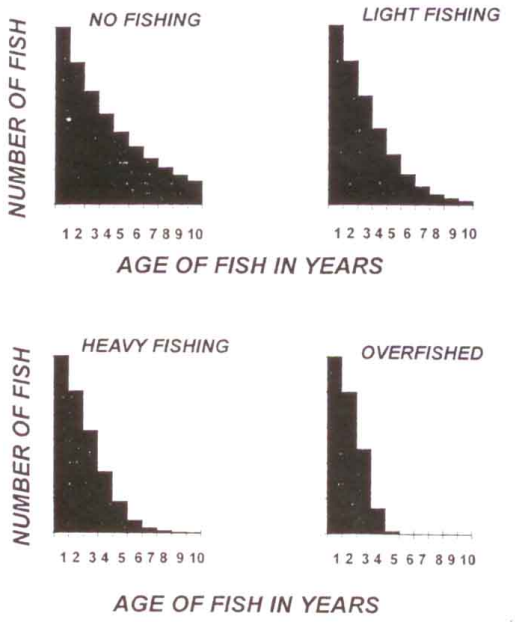
Fishing effects on fish populations and communities

Behaviour and life histories

Not all species are equally vulnerable to fishing. Apart from the fact that gear with a large mesh size will only catch larger individuals, vulnerability is determined by behaviour and life history. Behaviour determines the susceptibility to fishing gear and thus the mortality. Life history determines how a population responds to various levels of fishing pressure and mortality.

Behaviour

The ways that fish swim, shoal, feed and migrate can affect their vulnerability to fishing. Fish shoal because this increases their feeding and foraging and helps them to avoid predators.



↑ *Figure 18: Age structure of fish predicted under different pressures.*

However, fishers can take advantage of shoaling behaviour because whole schools can be surrounded with seine nets. This means that fishing can be profitable even if the overall population is low since many fish can be captured at once. In traditional artisanal reef fisheries, fishers have extensive knowledge of spawning behaviour of target species and fished within spawning aggregations.

The ability of a fish to avoid nets depends on swimming speeds. Smaller fish cannot stay ahead of a trawl net and are more likely to be caught. Net makers have taken advantage of various responses by species to an advancing trawl to develop by-catch reduction methods to increase the survival of non-target species. Understanding differences in behaviour of shrimp and by-catch provided the basis for designing nets that reduce turtle death. Turtle excluding devices have a large opening at the top of the net through which the turtle can escape, with relatively few shrimp lost through the opening.

Migrations of fish are well known to fishers who often catch fish at bottlenecks in migration routes. Many of these fisheries no longer exist because of over-fishing in predictable spots where fish aggregate in time and space. Fish habitat preference will also affect their vulnerability to fishing. Flatfish living on sandy bottoms are easy to catch compared to eels that live in rocks and crevices. Many pelagic fish aggregate around floating objects and fishers use these as focal areas for trawling or netting. Fishers now construct fish aggregating devices (FADs) to attract pelagic fish.

Life history

Fish species have a range of life history traits that may leave them vulnerable to fishing or allow them to sustain fishing mortality. As a result, some fish stocks have collapsed while others have flourished. Theoretical and empirical data suggest that large, slow growing and late maturing species suffer the greatest population declines due to fishing, because these traits are associated with low population increase. For example, slow growing skates and rays have often decreased in abundance following exploitation. This is because of their advanced age at maturity and low fecundity (number if eggs per unit of body mass). Conversely, species with short life spans and rapid population growth, which mature early and reproduce in large quantities, may be fished sustainably at young ages and high pressure.

Age and size structure

Fishing is size selective because the meshes of nets or other methods allow smaller individuals to escape. As a result, fishing can change the size and age structure of a population, with body size and age decreasing with increasing fishing mortality. This in turn can affect other aspects of life history, such as reproduction. With smaller individuals common, the egg production may fall because smaller fish produce fewer eggs. Figure 19 shows the size frequency of bump head parrotfish at two sites in Solomon Islands. Kalikoqu is in Roviana Lagoon with a population of approximately 12 000 people. Tetepare Island is the largest uninhabited island in the South Pacific with a lower fishing pressure than Kalikoqu. At Kalikoqu, bump head parrotfish were 28.5–102.0 cm in length, while at Tetepare the range was 59.0–111.5 cm and the mean lengths (62.7 cm [SD 14.0] and 89.5 cm [SD 15.8], respectively) were significantly different (ANOVA, $p<0.0001$). This example shows that fishing mortality is having a significant effect on the size and age structure of bump head parrotfish, with a smaller average size in an area with higher fishing mortality.

Reproduction

Size selective fishing can also change the sex ratios of fished populations. Coral reef fish families contain many hermaphroditic species, were species function as both sexes either simultaneously or sequentially. In most hermaphrodites that are fished, sex change occurs at a critical size and as such, the larger sex will not be replaced quickly. For example, the grouper (Epinephelinae) are protogynous hermaphrodites, going from female first to male later in life once they reach a large size. Fishing has biased the sex ratio by taking out the larger males. Thus, the proportion of male gag grouper in the Gulf of Mexico fell from 17% to 2% during a 10 year period of intensive fishing on spawning aggregations. The loss of males may lead to reduced fertilisation of females and subsequent recruitment failure. These effects have barely been examined.

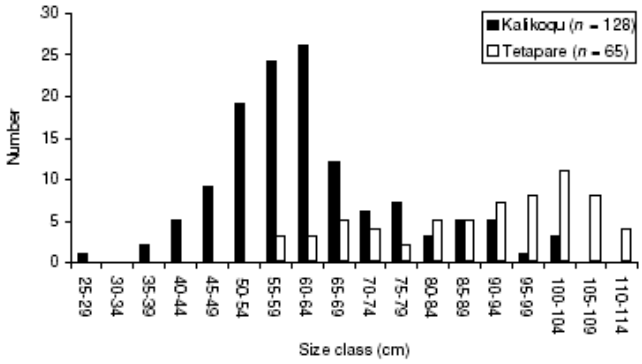


Figure 19: Size frequency distribution of bump head parrotfish speared in Kalikoqu and Tetepare Island passage and outer reefs (Source: Aswani and Hamilton, 2004).

Changes in the size and age of fish can have serious effects on reproductive output. The relative fecundity of fishes increases with body size and so a population has a greater fecundity when composed of larger rather than smaller individuals. There are also potential genetic effects to fishing mortality. In experimental systems, selective harvesting has led to genetic change, such as removal of larger individuals selected for slower growth. However, it is often difficult to detect heritable responses to exploitation and there is a need to record losses of genetic intraspecific diversity and deciding how to protect it.

Community effects

Extinction is the permanent loss of a species, while extirpation is the local loss of stocks or sub-populations. Fishing has extirpated many species. There include the giant clam and the bump head parrotfish, both highly vulnerable to fishing because of ease of capture. The Banggai cardinalfish is collected for the aquarium trade and may be approaching extinction in the wild even though it now thrives in captivity. Factors that make a species vulnerable to extirpation by fishing are limited distributions, dependence on specific habitats, slow life histories and accessibility to fishers. For major target species, the chance of extinction is very low because economic extinction will occur first, provided that the species is not increasing in value as it becomes scarce. However this does not help if a species is vulnerable as by-catch. Thus several species of skate that can only tolerate moderate fishing mortality due to their slow life history are suffering high fishing mortality as by-catch in the cod fishery.

Diversity

In addition, patterns of fish diversity can be modified by fishing. Comparisons of fished and un-fished areas on coral reefs have shown that species richness (number of species) is higher in the un-fished areas. However, local reductions in species richness are not always followed by a clear decrease in yield. This may be due to the idea that some species are redundant. The loss of one or two grouper species on a reef, where 15 or more are abundant is unlikely to lead to detectable changes in total yield. However, this is not true for all species and families. Indeed, the bump head parrotfish occupies a unique role as a keystone species in coral reef processes, largely responsible for bioerosion on outer shelf reef habitats.

Community structure

Fish communities pass through a series of structural changes as they are increasingly fished. At first larger individuals of all target species decrease in abundance and form a smaller proportion of the total abundance. Eventually, the whole community may be dominated by smaller individuals and smaller species. Since fish communities are often

difficult to study, changes in community structure are taken from changes in catches. Changes in catches often show the same pattern. For example on Fijian reefs subject to high fishing pressure, larger species were less abundant than on lightly fished reefs.

Changes in abundance are also reflected in trends in trophic structure (each step in the food chain). In general, species with fast life histories feed at lower trophic levels. On intensively fished reefs, fish biomass is dominated by herbivores, while invertebrate feeders and piscivores dominate on lightly fished reefs. Studies in the relationship between trophic structure and fishing intensity have revealed that fish communities can change very quickly in response to fishing. Even low levels of fishing are enough to cause dramatic changes in the trophic structure of fish communities. This pattern is also reflected in global fishing statistics. Thus the trophic level of marine catches fell between 1950 and 1993 as fishers 'fished down the food chain'.

Competition and interaction

Predator-prey relationships play an important structuring role in aquatic ecosystems, but most evidence suggests that removal or increase of one species which eats another does not have a dramatic and predictable impact on ecological processes. On a scale of kilometres to tens of kilometres on coral reefs, decreases in abundance of piscivorous target species (such as snapper) from fishing were not associated with corresponding increases in the abundance of their prey. This may be due to the diversity and size distribution of the biota on coral reefs. In species rich coral reefs there are many size variations within fish groupings and a wide variety of life history traits and feeding strategies. As a result, the overall effect of piscivores on their prey can be large, although the impact of any individual species or small group of species is minor. This differs greatly with other ecosystems such as lakes, were few keystone species dominate the biomass within a trophic group

LECTURE 3.2: REPRODUCTION IN FISHES

Adapted from CFMDP Fisheries Management Training Manual

Size at first maturity

To understand the reasons behind controls or regulations on fisheries activities, it is important to understand the reproductive characteristics of fish. Fish are like humans in that they have to reach a certain age and size before they are physically mature enough to start breeding. The size and age will differ for different species, even for quite similar species. Scientists can study the reproductive characteristics of a particular species and estimate at what size, on average, that species will start reproducing. This is called size at first maturity. These estimates are what many minimum size regulations are based on.

For example, scientists have studied some of the fish species important to the live reef food fish (LRFF) trade and estimated the size, measured by length, each species needs to reach before it is mature enough to first reproduce.

On average, the Hump Head Maori Wrasse (*Cheilinus undulatus*) first starts reproducing when it is around 42 cm in length (Figure 20). The squaretail coral trout (*Plectropomus areolatus*) first starts reproducing at around 33 cm in length.

A 35 cm Maori Wrasse or a 25 cm squaretail coral trout would still be immature and will not have had a chance to reproduce.

Unfortunately, there are many species that have not yet been studied, especially non-commercial fish and invertebrates.

Many fish produce thousands or millions of eggs each time they breed, although very few of these actually make it through to maturity. Allowing each species to reach its size at first maturity before catching it at least gives it a chance to reproduce and contribute to the continued growth of the population. Catching it before it is mature enough to reproduce means that individual will never add to the population. Imagine an island population of humans where every year the youths go away to study and never return. Eventually the population would be reduced to elderly people and very young children and, if the situation continued the population would eventually disappear because there would be nobody left to reproduce. This is

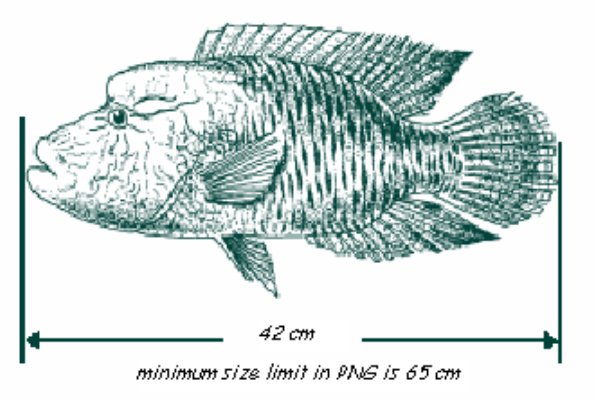


Figure 20: Size at first maturity for Cheilinus undulatus, the maori wrasse.

the effect we have on a fish population when we continually take out young individuals before they have reproduced – eventually the adults remaining are too few to maintain the population and that fish stock slowly disappears.

One area where fish differ from humans is that, often, the larger and older the individual is, the more young it is able to produce. Once a young female fish has reached breeding age, the number of eggs it produces is often related to her size – larger individuals produce many more eggs than smaller ones.

For some species for example, if a female fish is allowed to double in size, the number of eggs she produces will increase **eight** times. Another study concluded that one large 12.5 kg grouper or snapper would produce the same number of healthy eggs as 212 fish of the same species weighing 1.1 kg each (and weighing, in total, 233 kg!) (Figures 20-21).

Maximum size regulations take advantage of this characteristic by protecting the large, most productive breeding adults of a population.

Once the animal has reached its species particular size and age to start breeding it is ready to spawn, often at a particular time of the year or moon phase when all the other breeding individuals of that species are also ready. Many fish and invertebrates reproduce in a similar way – at spawning time the animals release sperm and eggs directly into the water where they mix. If the mixing is successful the eggs become fertilised and develop into larvae, a tiny, swimming form of the animal.

Reproductive methods

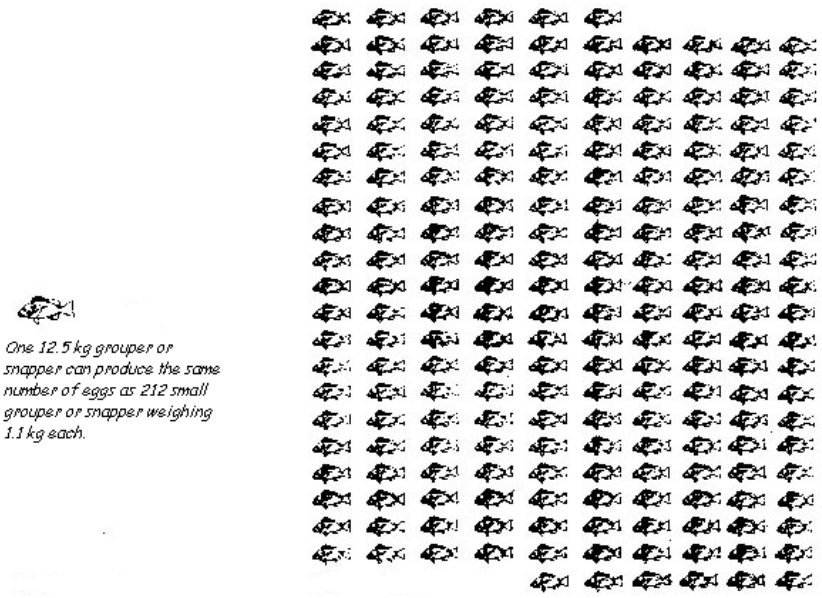
Fish and sharks have three methods of reproduction – classified depending on how they care for their eggs. These three terms apply to both (a) where embryos undergo development (i.e. inside the mother or outside in an egg), and (b) how parents provide nutrition for their embryos.

- Oviparity - lay undeveloped eggs, external fertilisation (90% of bony fish) or internal fertilisation (some sharks and rays), no nutrition apart from yolk.
- Ovoviviparity - internal development of the eggs without direct nourishment from mother (only yolk), eggs hatch and develop inside the mother, advanced at birth (most sharks and rays) or larval birth (some rockfish).
- Viviparity - internal development of eggs with direct nourishment from the mother, fully advanced at birth.

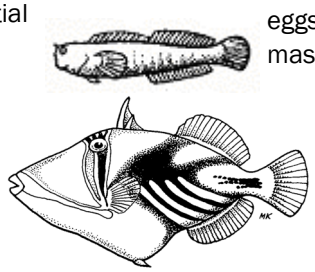
Advantages and disadvantages of oviparity

We will mostly be looking at the first method, oviparity, as that is how the majority of fish and marine invertebrates reproduce. Some of the advantages of this method are:

Figure 21: Relative egg production in different sizes of groupers and snappers.

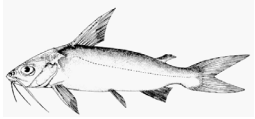


- The eggs are "inexpensive" to produce – meaning the parent doesn't have to supply nutrients to a developing egg or embryo. The energy saved by not supplying eggs or embryos can therefore be put into producing many eggs –the adult produces many offspring, which are broadcast into the plankton to drift with tide and currents.
- When the offspring settle out of the plankton, they may be in totally new environments, allowing for a greater potential area for the young to survive in, and more potential spread of the species.
- As the eggs are in the water, they do not dry out (don't need a protective coating or shell like reptile or bird eggs).



Oviparity also comes with its disadvantages:

- When born, the fish must first go through a larval stage for growth before they transform into the adult stage. In this larval stage, they must fend for themselves in obtaining food and avoiding predation.
- They may not find a suitable environment when they settle out of the plankton column.
- The survival of individual eggs is very low, so millions of eggs must be produced in order for the species to ensure enough make it through to adulthood.



Reproductive methods of marine fish

Demersal eggs that produce pelagic larvae

Some species produce nests of small demersal eggs (on the ocean floor) that hatch larvae that float at the surface with tides and currents. Parental care of the nests until the eggs hatch is almost always present. Potential predation on these nests, especially those that are exposed to the open reef is always great.

Clownfish and other damsels, dottybacks, grammas, gobies, blennies, and triggerfish are among the reef fish that spawn demersal eggs.

Mouth brooders that produce demersal postlarvae or juveniles

Sea catfish (Ariidae) carry relatively small numbers of fertilised eggs in their mouth until they hatch. They continue to carry the young entirely through early development and the resulting postlarvae or juvenile immediately assumes life on the sea floor after leaving the parent. The catfish brood mass will contain only 15 to 170 fertilised eggs. The male carries the eggs and the number of eggs in the brood mass is dependent on the size of the male – the larger the fish, the larger the mouth and the more eggs can be carried. Brooding lasts from 4 to 6 weeks, during which time the male doesn't feed.

Mouth brooding has the advantage, like pelagic spawning fish, of not having to prepare or guard a nest site, and also an advantage similar to the nest makers, of protection during the very vulnerable egg and early embryonic stages.

Mouth brooders that produce pelagic larvae

Other mouth brooders produce relatively small eggs that result in pelagic larvae. Mouth brooders that carry relatively small eggs that result in pelagic larvae have the advantages of a secure brooding method, production of a relatively large number of eggs per spawn, larvae that are well developed at hatching, and broad distribution of young in through dispersal in the plankton.

The male is always the brooding parent in marine mouth brooders. Although the eggs are kept in the oral cavity of the male, they are still exposed to, and oxygenated by, the marine waters that pass through the mouth and gills of the male.

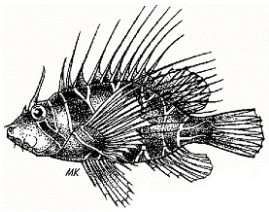
Only the jawfishes (Opistognathidae) and the cardinalfishes (Apogonidae) are small egg, mouth brooding reef fish that produce pelagic larvae.

Pelagic eggs rafted, or attached, and floating

Some species, scorpionfish, lionfish, frogfish and angler fish, produce pelagic eggs that are bound to each other in a dense gelatinous medium, and others, flying fish, produce eggs that have long tendrils that catch around floating weed and debris and keep the egg afloat. The eggs are usually kept together in the raft or nest until hatching and then the larvae become pelagic and are dispersed by the currents.

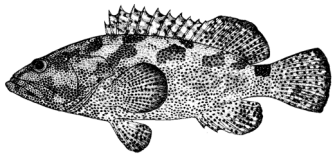
Pelagic eggs that produce pelagic larvae

By far the most common reproductive method among tropical marine fish is the production of vast numbers of small, externally fertilized pelagic eggs that hatch small pelagic larvae. There is no parental care of the embryo, larvae or juvenile. Many species spawn on almost a daily basis during the optimum spawning periods of the year so a vast number of eggs are produced to make up for the lack of parental care.



Large fish produce many eggs per spawn, perhaps over a million for the large groupers, while small fish may produce only 300 to 500 per spawn.

Productiveness of a species, however, although strongly influenced by the production of an average female, is dependent on the number of females producing eggs. A very abundant species of small fish can produce more eggs than a rare species of large fish.

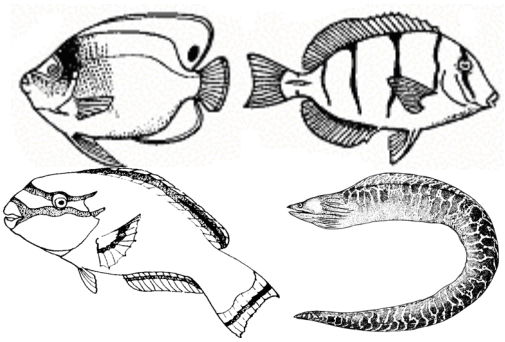


Typically, tropical pelagic eggs hatch in 20 to 24 hours after spawning, the larvae require about 72 hours to develop eyes, gut, and fins before beginning to feed. The larval stage extends from 21 to 40 days depending on species, temperature, available food and possibly a suitable environment for juvenile survival. Settlement of the post larvae or juvenile may occur in a shallow nursery area or on or near the offshore reef environment.

Angelfish, surgeonfish, parrotfish, groupers, moray eels, snappers, grunts, mullets, reef drums, porgies, wrasses, and many other species spawn pelagic eggs.

Spawning behaviour in marine fish

Production of gametes (eggs and sperm), is not a simple matter. It would be pointless for individuals of any species to simply shed eggs and sperm and hope that they meet somewhere in the ocean. Even sessile species (organisms attached to place that can not move or have very limited powers of movement) that produce millions of gametes like oysters, clams and corals have



elaborate timing (moon phases) and communication (pheromones) methods to insure that the gametes are released at the same time in the same areas, thus ensuring fertilisation of many eggs.

Pheromones are chemical substances secreted by an animal that convey information and stimulate behavioural responses.

Mobile species, on the other hand, can come together and coordinate the release of sperm and eggs. They have to be sure of many things before they can spare the expense of egg and sperm release.

Spawning systems are adapted to all other aspects and behaviour of that particular species. Small species that are adapted to specific sites by feeding behaviour (such as cleaner wrasse), or are very territorial because of a relationship with another species, or are dependent on reef cover for protection from predation, tend to form

pairs or small harems.

Clownfish, for example, are territorial because of their relationship with a particular sea anemone. This means they live in a defined area and their spawning behaviour reflects this. Clownfish establish pairs that can remain intact for many years. Some species of gobies, blennies, hawkfish, and rabbitfish also form stable pairs.

Some species of fish form spawning **harems** – a single male spawns repeatedly with several females, perhaps up to dozen, and the entire harem occupies the same general area of the reef. The male protects his territory, and its resident females, from other males that may be passing through or that occupy adjacent territories. Angelfish in the genus *Holocanthus* commonly form spawning harems, one male will be dominant and control an area of several hundred square feet of reef structure with 3 to 6 smaller females in residence. Some species that lay demersal eggs, such as triggerfish and puffers, form harems as do some pelagic egg producers such as angelfish, wrasses, and parrotfish.

Other species form pairs only for the immediate spawning and different pairs may form each day or even at different times on the same day. This is known as promiscuous (many partners) spawning. Many damselfish spawn in this manner with the male establishing a territory, courting many females, and spawning in turn with each female on the same nest site. The male defends his nest site but does not maintain an established harem of specific females. The females may spawn with several males at various nest sites over the spawning season.

Some species - wrasses, groupers, tangs, snappers, and jacks, for example - spawn in schools or aggregations.

Spawning aggregations

This type of spawning behaviour is unique, in that the fish migrate to a particular site at a specific time just for the purpose of spawning. Once at the site, a place and time that favours the distribution and survival of the spawn, intensive spawning occurs over a relatively brief period, and the spawning aggregation then disperses, often back to reef sites they previously occupied before spawning time. The defining characteristics of this category are migration to the spawning site and the rapid and intense spawning activity. Some species of grouper travel to prominent reef sites year after year and engage in this type of spawning behaviour.

These species form schools only when it comes time to mate. Spawning aggregations typically form during specific seasons, moon phases and times of day. The fish will form a large school and release their eggs and sperm in mass quantities. As many as 10,000 fish will gather during some aggregations, and often several different species aggregate simultaneously at the same site. Releasing a massive onslaught of fertilised eggs in the water may have advantages over a solitary egg, because a massive onslaught may be enough to overwhelm the egg predators. The predators will eat as many as they can, but some eggs will inevitably survive. Spawning aggregations also help ensure individuals of a species have more chance of finding another individual to mate with – instinctively they know that many other individuals of their own species will be gathered in a particular spot at a certain time, so they don't have to rely on finding them by chance in the vast ocean.

LECTURE 3.3: REEF FISH TAXONOMY AND TROPHIC ROLES

This lecture will comprise 2 parts:

- An introduction to fish identification and trophic biology of reef fish.
- A laboratory exercise on the structural features of fish and an introduction to meristics using fresh fish samples purchased from the markets.

Laboratory exercise:

The majority of reef fish conservation and research will require you to occasionally identify fish at the species level, whether you are identifying the species of groupers in a spawning aggregation you are monitoring, recording fish catch data to determine whether fisheries have improved from management efforts, or keying out a fish you suspect is a new species. This laboratory exercise will provide a broad overview on how to identify fishes. It is not designed to give you a species level knowledge of all reef fishes immediately – this would take years - but it will instead provide you with some skills and hints to assist you in identifying and gradually learning reef fish species in the future.

Students will work in pairs and each pair will be provided with a sample of 2 – 4 fish to work on. The

objective of this lab will be to:

1. Understand some of the key characteristics of common PNG reef fishes
2. Learn some of the key body measurements used to distinguish reef fish species (meristics) and gather fisheries catch data.

Working in pairs and using the data sheet provided, determine the body measurements and meristic formulas for at least one fish each. Use the notes in Figure 22 as a reference and you will also be given instructions during the lab on how to derive meristic formulas and gather body measurement data.

■ **IDENTIFICATION AND DESCRIPTION OF STRUCTURAL FEATURES**

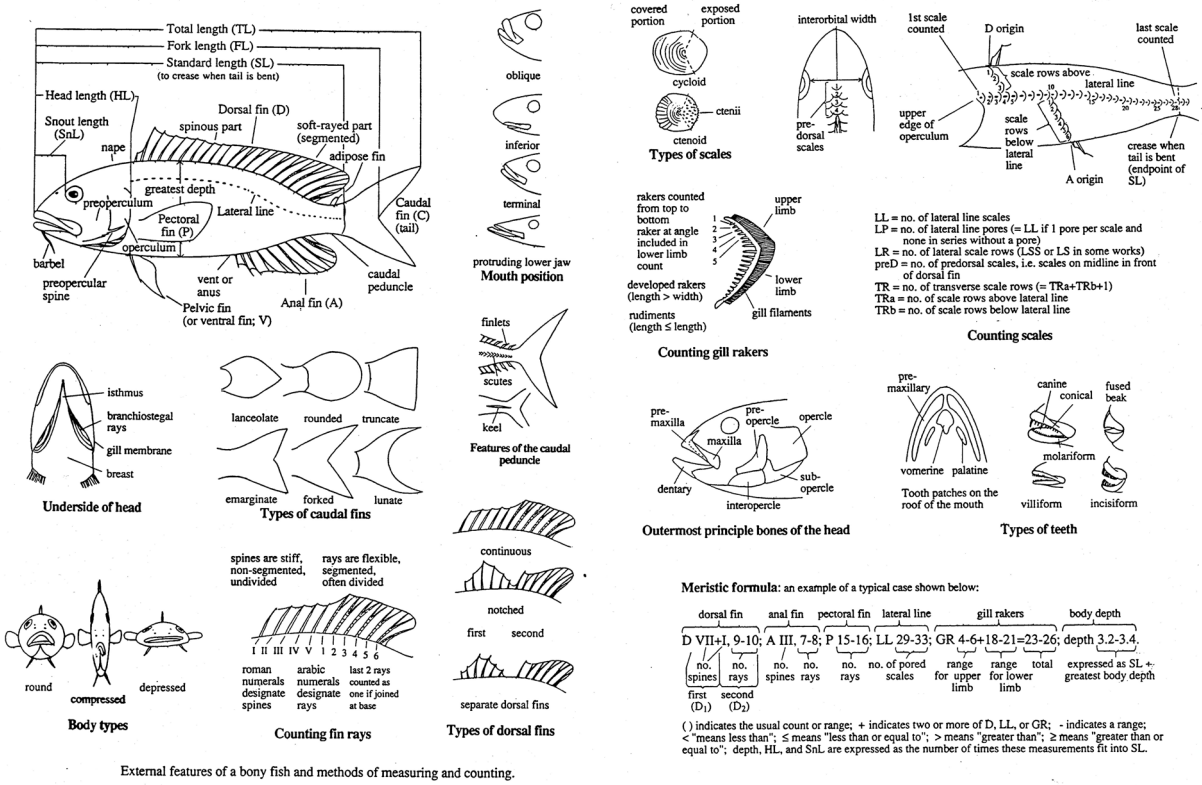
Head: Identify the pre-opercular and opercular margins - smooth or serrate; check for presence of pre-opercular or opercular spines; note number and position of nostrils; note the condition of the gill membranes, are these free from one another and the throat; check for external sensory features on the head or snout; note and describe the characteristics of the teeth using microscopic examinations where necessary; describe the form and setting of the teeth with reference to the laboratory handouts; are the teeth of the upper jaw present on both the premaxillary and maxillary bones; where possible check the buccal cavity for the form and position of teeth on the premaxillary, vomerine and palatine bones; check to see if the teeth are uniseriate or in villiform bands.

Note the form of the gill rakers; although the number of gill rakers may be diagnostic they will not be counted in this laboratory

Body and squamation:
Identify the lateral line scales; does the lateral line extend the length of the body, is it incomplete stopping short of the base of the caudal fin or interrupted terminating and then recommencing after a gap; the lateral line count commences at the first scale touching the shoulder girdle at the upper end of the gill opening and ends with the last scale at the caudal fin base; the scales above and below the lateral line are counted from the origin of the first dorsal or anal fin along the oblique scale row but not including the lateral line scale; the predorsal scale count is the number of scales on the mid-line from the origin of the first dorsal fin to the occiput. The scales are either cycloid or ctenoid; cycloid scales are smooth but the rear margin of ctenoid scales has small tooth-like serrations. In some families, the posterior lateral line scales from scutes, others have scutes along the midventral line.

Fin counts:
These must differentiate between spines and flexible rays and expressed in terms of standard formulae; and abbreviation for the fin, the number of spines (Roman numerals) and rays (Arabic numbers). If the spinous and soft rays of the fins are continuous, the counts are separated by a comma; if separate, a plus sign (+) separates the counts, e.g. D IX + 16. Conventions for counting fins are shown in the accompanying diagrams.

Figure 22: From Bellwood, D.R., 2000 Tropical Ichthyology Course Handbook, James Cook University, Townsville



External features of a bony fish and methods of measuring and counting.

CHAPTER 4: SEAGRASSES

LECTURE 4.1: BACKGROUND

Seagrasses are specialized marine flowering plants that have adapted to the nearshore environment of most of the world's continents. Seagrasses form an ecological group and not a taxonomical group. Most are entirely marine although some species cannot reproduce unless emergent at low tide. Some seagrasses can survive in a range of conditions encompassing fresh water, estuarine, marine, or hypersaline. There are relatively few species globally (about 60) and these are grouped into just 13 Genera and 5 Families.

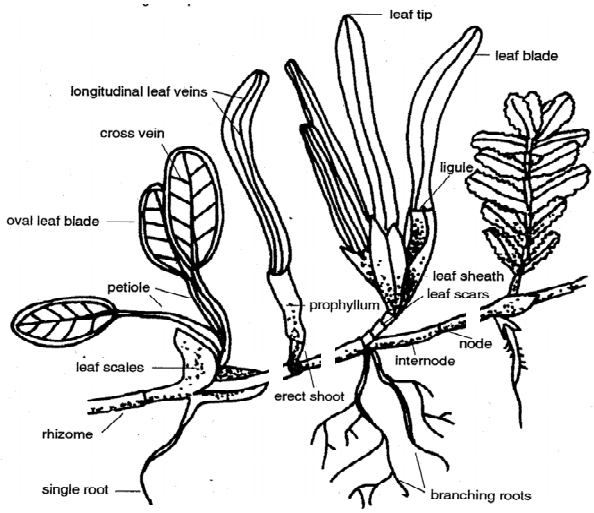
The families in which the seagrasses are incorporated belong to the Division Magnoliophyta (Angiosperms), Class Liliopsida (Monocotyledons), but have been arranged within this class in various ways. The Hydrocharitaceae have always been recognized as a distinct family. However, the taxonomy at a subfamily level has not yet been resolved (see Kuo & den Hartog 2001).

Early taxonomic studies on seagrasses were carried out in Europe by botanists who were interested in aquatic plants as a whole, the Helobiae, or by phycologists who were primarily interested in the algal epiphytes on seagrasses. Linnaeus (1753) was the first to designate a scientific name for the most well-known seagrass species, *Zostera marina*. He was followed by other scientists who provided new genus names and described new species of seagrasses. Ascherson, however, was the first to produce a monographic compilation of all that was known about seagrass classification and distribution. He updated his work continually, and in 1906 published a modern review on the taxonomy and geographical distribution of seagrasses in the form of a monograph, in which he recognized 32 species in 8 genera worldwide (Ascherson 1906).

The monograph entitled 'The Sea-Grasses of the World' by den Hartog (1970) is by far the most complete taxonomic work on seagrasses with species descriptions, notes on ecology and distribution of each species and genus as well as keys for identification including drawings and distribution maps. den Hartog (1970) recognized 47 species (with 4 subspecies) in 12 genera, arranged within 2 families (Potamogetonaceae and Hydrocharitaceae). Since then, a few taxonomic works have been carried out on certain groups of seagrasses including descriptions of new species. Based on den Hartog's monograph (1970) and more recent taxonomic works, currently 60 species of seagrass in 12 genera are recognized. It is anticipated that the number of species will change in the near future, as new highly advanced techniques for taxonomic research have become available, such as the molecular approach. Further, new diving techniques may lead to the discovery of new species in deep-water habitats, and finally there are still many stretches of coast that are still unexplored.

Traditionally, the characters used in classifying flowering plants are the reproductive structures, e.g., petals, sepals, stamens, fruits and seeds (figure 23). However, flowers and fruits of most seagrasses are not often collected and therefore identification of seagrass species and genera is more or less dependent on vegetative characteristics, such as blade width, blade tips, vein numbers, fibre distributions, epidermal cells, characteristics of the roots and rhizomes, etc. Some of these vegetative characters may show considerable variation, e.g., the leaf tips. Nevertheless, if used in conjunction with other features, this character can be valuable taxonomically.

Figure 23: Composite illustration demonstrating morphological features used to distinguish main seagrass taxonomic groups. from Lanyon (1986)



Leaf:

Tip: Can be rounded or pointed. Tips are easily damaged, so young leaves are best to observe Figure 24).

Veins: Used by the plant to transport water, nutrients and photosynthetic products. The pattern, direction and placement of veins in the leaf blade are used for Identification.

- cross-vein: perpendicular to the length of the leaf
- parallel-vein: along the length of the leaf
- mid-vein: prominent central vein
- Intramarginal-vein: around inside edge of leaf

Edges: The edges of the leaf can be either serrated, smooth or in-rolled

Sheath: A modification of the leaf base that protects the newly developing tissue. The sheath can entirely circle the vertical stem or rhizome (continuous) or not (non-continuous); fully or partly cover the developing leaves and be flattened or rounded. Once the leaf has died, persistent sheaths may remain as fibres or bristles.

Attachment: The leaf can attach directly to the rhizome, where the base of the leaf attachment clasps the rhizome, from a vertical stem or from a stalk (petiole) e.g. Halophila ovalis.

Stem

The vertical stem, found in some species, is the upright axis of the plant from which leaves arise. The remnants of leaf attachment are seen as scars.

Rhizome

The horizontal axis of the seagrass plant, usually in sediment. It is formed in segments, with leaves or vertical stem arising from the joins of the segments, the nodes. Sections between the nodes are called internodes. Rhizomes can be fragile, thick and starchy or feel almost woody and may have scars where leaves were attached.

Root

Underground tissues that grow from the node, important for nutrient uptake and stabilisation of plants. The size and thickness of roots and presence of root hairs (very fine projections) are used for identification.

The following key (Figure 25) is designed and arranged to identify all known seagrass species in the western Pacific. Seagrasses can be identified by using vegetative (rarely reproductive) morphological characters, usually two or three.

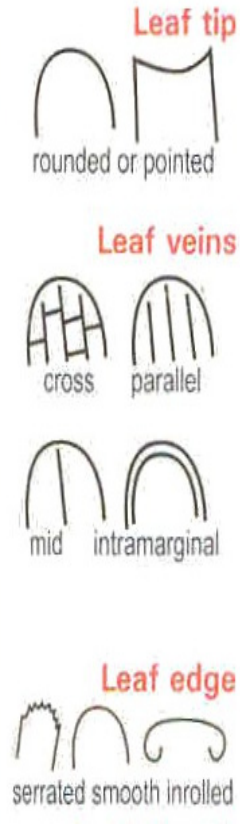


Figure 24: Features of seagrass leaves.

SEAGRASSES OF THE WESTERN PACIFIC

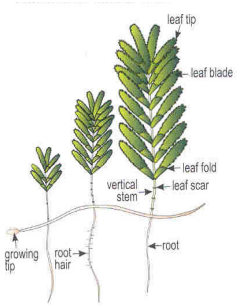
Leaves cylindrical

Syringodium isoetifolium

- Leaf tip pointed
- Leaves contain air cavities
- Inflorescence a “cyme”

Leaves oval to oblong

obvious vertical stem with more than 2 leaves



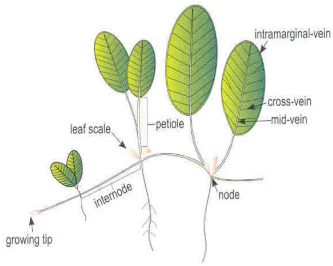
Halophila spinulosa

- leaves arranged opposite in pairs
- leaf margin serrated

Halophila tricostata

- leaves arranged in clusters of 3, at a node on vertical stem
- leaf margin serrated
- leaf clusters do not lie flat

leaves with petioles, in pairs



Halophila ovalis

- cross veins more than 10 pairs
- leaf margins smooth
- no leaf hairs
- separate male & female plants

Halophila decipiens

- leaf margins serrated
- fine hairs on both sides of leaf blade
- male & female flowers on same plant

Halophila minor

- Leaf less than 5mm wide
- cross veins up to 10 pairs
- leaf margins smooth
- no leaf hairs
- separate male & female plants

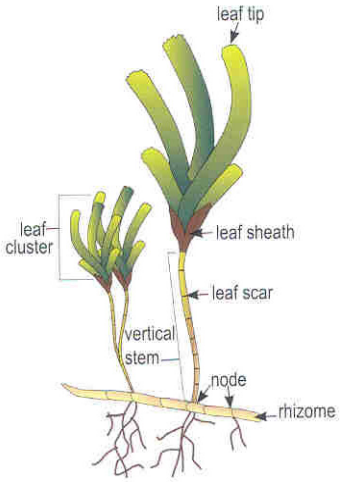
Halophila capricorni

- leaf margins serrated
- fine hairs on one side of leaf blade
- separate male & female plants

↑→ *Figure 25: Adapted from Waycott, M, McMahon, K, Mellors, J., Calladine, A., and Kleine, D (2004) A guide to tropical seagrasses in the Indo-West Pacific. (James Cook University Townsville) 72pp.*

Leaves strap-like

Leaves can arise from vertical stem



Thalassia hemprichii

- Leaf with obvious red flecks, 1-2mm long
- Leaf tip rounded may be slightly serrated
- Leaf often distinctly curved
- Distant scars on rhizome

Cymodocea serrulata

- Leaf tip rounded with serrated edge
- Leaf sheath broadly flat and triangular, not fibrous
- Leaf sheath scars not continuous around upright stem

Cymodocea rotundata

- Leaf tip rounded with smooth edge
- Leaf sheath not obviously flattened
- Leaf sheath scars continuous around upright stem

Halodule uninervis

- Leaf tip tri-dentate or pointed, not rounded
- Leaf with 3 distinct parallel- veins, sheaths fibrous
- Rhizome usually white with small black fibres at the nodes

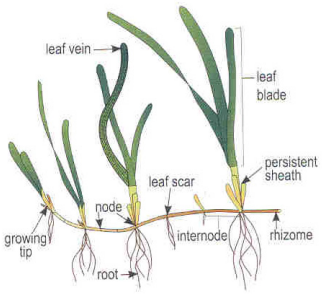
Halodule pinifolia

- Leaf tip rounded
- Leaf with 3 distinct parallel- veins, sheaths fibrous
- Rhizome usually white with small black fibres at the nodes

Thalassodendron ciliatum

- distinct upright stem
- clusters of curved leaves (>5 mm wide), margins serrated
- stem and rhizome woody

Leaves always arise directly from rhizome



Enhalus acoroides

- large plant, leaves >30 cm long, >1 cm wide
- inrolled edges of leaves
- long, black bristles protruding from thick rhizome

Zostera capricorni

- leaf with 3-5 parallel-veins
- cross-veins form boxes
- leaf tip smooth and rounded, may be dark point at tip
- rhizome usually brown or yellow in younger parts

LECTURE 4.2: SEAGRASSES OF PAPUA NEW GUINEA

Seagrass meadows are an important marine habitat of Papua New Guinea coastlines. Seagrasses are a functional grouping referring to vascular flowering plants which grow fully submerged and rooted in soft bottom estuarine and marine environments.

In the last few decades, seagrass meadows have received greater attention with the recognition of their importance in stabilising coastal sediments, providing food and shelter for diverse organisms, as a nursery ground for fish and invertebrates of commercial and artisanal fisheries importance, as carbon dioxide sinks and oxygen producers, and for nutrient trapping and recycling. Seagrass are rated the 3rd most valuable ecosystem globally (on a per hectare basis) and the average global value for their nutrient cycling services and the raw product they provide has been estimated at 1994US$19,004 ha^{-1} yr^{-1} (Costanza *et al.* 1997). This value would be significantly greater if the habitat/refugia and food production services of seagrasses were included.

Seagrasses are also food for the endangered green sea turtle (*Chelonia mydas*) and dugong (*Dugong dugon*) (Lanyon *et al.* 1989), which are found throughout the PNG region, and used by traditional PNG communities for food and ceremonial use. Tropical seagrasses are also important in their interactions with mangroves and coral reefs. All these systems exert a stabilizing effect on the environment, resulting in important physical and biological support for the other communities. Seagrasses slow water movement, causing suspended sediment to fall out, and thereby benefiting corals by reducing sediment loads in the water.

Nutrient availability is one of the major factors determining seagrass presence across PNG. Seagrasses frequently grow on intertidal reef platforms and mud flats influenced by pulses of sediment laden, nutrient rich freshwater, resulting from high volume seasonal summer rainfall (Carruthers *et al.* 2002). Cyclones and severe storms or wind waves also influence seagrass distribution to varying degrees. On reef platforms and in lagoons the presence of water pooling at low tide prevents drying out and enables seagrass to survive tropical summer temperatures. Often, the sediments are unstable and their depth on the reef platforms can be very shallow, restricting growth and distribution. Most PNG species are found in water less than 10m deep and meadows may be monospecific or consist of multispecies communities, with up to 10 species present at a single location.

The earliest records of seagrasses in the PNG region come from Salamaua in the Huon Gulf in 1890 (den Hartog 1970). However apart from these early collections, the majority of study on seagrasses in PNG did not occur until after the mid 1970's. It is generally agreed that there are 13 seagrass species present in PNG (Short *et al.* 2001). Seagrass species diversity is highest in the southern part of the country (adjacent to Torres Strait) and declines towards the east. The highest number of species reported is 13 from Daru (Johnstone 1979), followed by Motupore Island (Bootless Inlet) and the Fly Islands each with 10 species (Brouns & Heijs 1985; Johnstone 1978a 1978b). No species are considered endemic to PNG and none are listed as threatened or endangered.

Seagrass communities in PNG grow on fringing reefs, in protected bays and on the protected side of barrier reefs and islands. Major seagrass meadows occur around Manus Island, in the coastal bays surrounding Wewak and Port Moresby, on the island reef complexes of Milne Bay province and on the reef platforms surrounding the Tigak Islands and Kavieng. Seagrass meadows are also a significant feature at several other localities (eg. Rabaul, Kimbe) and scattered areas of seagrasses line much of the coastline of NG mainland (eg. Madang, Morobe and Western provinces) and the offshore islands (including Lihir and Mussau). Areas of the coast were seagrasses do not exist are either steep slopes exposed to oceanic swells or along the 500km of gulf coast east of Daru, a possible consequence of high silt loads and large volumes of fresh water in the run off from the Fly and Purari Rivers (Johnstone 1979).

Seagrass zonation appears fairly similar across PNG (Johnstone 1982) and seems to be determined by comparable biotic and abiotic parameters. From intertidal to subtidal, the zonation pattern of seagrasses generally begin with a zone of 1 or 2 species (mostly *Halodule uninervis, H. pinifolia* or *Halophila minor*). Subsequently, in the lower eulittoral zone, other seagrass species join in a mixed seagrass meadow generally dominated by *Cymodocea rotundata, Halodule uninervis* and *Thalassia hemprichii*, with isolated patches of *Halophila ovalis.* In the upper sublittoral zone, the mixed seagrass meadow is dominated by

T. hemprichii and *Enhalus acoroides*, with isolated patches of *Syringodium isoetifolium, C. serrulata* and *H. uninervis*. This zone is generally the most abundant and usually constitutes the bulk of the meadows throughout PNG. The lower edge of the meadow consists of a combination or 2-4 species when a reef plateau is present or monospecific *H. decipiens* or *H. spinulosa* at the deepest depths on the sublittoral sandy slopes. The remaining species are less common and not widely distributed. Monospecific patches of *Thalassodendron ciliatum* have been reported to occur on coral rubble banks in 6-8m depth on the deeper edges of the reef slopes on Manus, Kavieng and the Fly Islands. *Zostera capricorni* has only been reported from Daru (Johnstone 1982) and is one of the most northern locations for the species in the western Pacific.

Local conditions may often determine which seagrass species are present. Extensive mixed seagrass meadows are the dominant community type in the bays, harbours and sheltered capes along the coasts of the NG mainland and the islands of New Britain and New Ireland (Den Hartog 1970, Brouns & Heijs 1985, Heijs & Brouns 1986, Johnstone 1982). These extensive seagrass meadows are dominated by *T. hemprichii* and/or *E. acoroides*, with up to another 10 species present to varying degrees. *H. decipiens* meadows sometimes occur in the deeper areas and meadows of *E. acoroides* border the gentle sloping mangrove fringes in the more protected bays and the shallow lagoons surrounding Kavieng.

Throughout the rest of the PNG archipelago, most seagrass occurs in shallow lagoons adjacent to large islands, or on the reef platforms and leeward shores of small vegetated cays/islands of the Solomon and Bismarck Seas. A survey in 2001 of seagrasses in the Milne Bay province found that seagrass mainly occurred on the tops of the reefs and shoals with reef flats, and cover was generally low in regions without large islands (eg. Louisiade and Bwanabwana regions). Some of the most abundant seagrass meadows in the Bismarck Sea occur on the reef plateaus on the eastern and northern coastlines of Seeadler Harbour (Manus Island) (Heijs & Brouns 1986). These communities are dominated by colonizing and intermediate species, such as *T. hemprichii C. rotundata* and *H. uninervis* which can survive a moderate level of disturbance. *E. acoroides* occurs in protected small bays or behind the reef crest on the sublittoral reef flat, as it has low resistance to perturbation (Walker *et al.* 1999).

Smaller islands are generally characterised by relatively small fringing reef platforms, such as Niolam Island (Lihir group) where the mean extent of inter-tidal habitat is approximately 81m from shore to reef crest (D Dennis CSIRO pers comm). Seagrass communities in these cases, are restricted to locations with shallow fringing reef-flat with lagoons (0-2 m depth). Most inter-tidal seagrass communities are dominated by *C. rotundata* and *T. hemprichii*; with small quantities of H. ovalis (D Dennis CSIRO pers comm). *E. acoroides* dominates the intertidal reef flats on the protected sides of islands (eg. Duke of York, Nanuk and Talele Islands) and in the bays and harbours protected from oceanic swells (eg. Luise Harbour, Malie Harbour, Lakakot Bay, Londolovit Bay) (D Dennis CSIRO pers comm, S Foale ANU pers comm).

The total area of seagrasses world-wide is estimate to be at least 177,000 sq km (Spalding *et al.* 2003). The total area of seagrass meadows in PNG however is unknown, as no broad scale mapping exercise has been conducted (Coles *et al.* 2003). This is because mapping in tropical systems is generally from field observations as remotely sensed data (satellite and aerial imagery) is generally ineffective for detecting tropical seagrasses of low biomass and/or in turbid water (McKenzie *et al.* 2001b). Some estimation could be possible using a simple modeling approach, based on the high likelihood that between 4-5% of almost all shallow water areas of reef and continental slope within the depth range of most seagrasses (less than 10 metres below MSL) would have at least a sparse seagrass cover. This however, has not been attempted. The closest attempt so far is a new dataset prepared by the United Nations Environment Programme World Conservation Monitoring Centre (http://stort.unep-wcmc.org/maps). These maps however should be interpreted with caution as they have been migrated to GIS based on literature review and outreach to expert knowledge. Much of the information is from only a few localities and is generally historic (eg. Wewak, Manus, Kavieng, Rabaul, Port Moresby).

There are also many anecdotal reports of extensive un-mapped seagrass meadows covering the reef flats and shallow lagoons around the Fullerborne region, Cape Gloucester, Stettin Bay (Kimbe Bay), Mussau Island, Heina - Ninigo Islands, and along the perimeter of the sea corridor between Buka and Bougainville. Recent mapping initiatives in Milne

Bay province (T Skewes CSIRO pers comm) and the Lihir group (D Dennis CSIRO pers comm) are a major step forward. In 2001, a survey by CSIRO and CI estimated 11,717 ha of seagrass in the Milne Bay area (J Kinch CI pers comm). Such efforts will serve as important baselines against which future changes can be assessed.

Tropical seagrass meadows are known to fluctuate seasonally and between years (Mellors *et al*. 1993, McKenzie 1994, McKenzie *et al.* 1996), however losses have been reported from most parts of the world, sometimes from natural causes such as cyclones and floods (Poiner *et al.* 1989, Preen *et al.* 1995, Campbell & McKenzie 2004). More commonly, loss has resulted from human activities such as dredging, land reclamation, industrial runoff, oil spills or changes in land use and agricultural runoff (Short and Wyllie-Echeverria 1996).

The major changes in PNG seagrass meadows would have occurred post World War Two and are related to coastal development, agricultural land use, or population growth. In general though there is insufficient information and no long-term studies from which to draw direct conclusions on historic trends. Munro (1999) does report that 2000 year old mollusc shell middens in PNG have basically the same composition as present day harvests suggesting indirectly that the habitats including seagrass habits and their faunal communities are stable and any changes occurring are either short term or the result of localised impacts.

These localised impacts are likely to be from soil erosion related to coastal agriculture (palm oil plantations), land clearing (logging and mining), bush fires and from the discharge of mine tailings. For example, there are unconfirmed reports of losses due to mining operations in Luise Harbour (Lihir) where the seagrass has declined significantly compared to before the mine (M. Macintyre ANU pers comm). Other effects include sewage discharge, industrial pollution and overfishing. Most of these impacts can be managed with appropriate environmental guidelines, however climate change and associated increase in storm activity, water temperature and/or sea level rise has the potential to damage seagrasses in the region or to influence their distribution. Sea level rise and increased storm activity could lead to large seagrasses losses.

To provide an early warning of change, scientific and community-based (Seagrass-Watch) long-term monitoring sites have been established as part of the Global Seagrass Monitoring Network (www.SeagrassNet.org, www.seagrasswatch.org Short *et al.* 2002, McKenzie *et al.* 2001a). Sites are monitored quarterly in Kavieng, Tigak Islands and Madang, and the program hopes to expand to include other regions of PNG. By working with both scientists and local communities, it is hoped that many anthropogenic impacts on seagrass meadows which are continuing to destroy or degrade these coastal ecosystems and decrease their yield of natural resources can be avoided.

LECTURE 4.3: MONITORING A SEAGRASS MEADOW

Environment monitoring programs provide coastal managers with information and assist them to make decisions with greater confidence. Seagrasses are often at the downstream end of catchments, receiving runoff from a range of agricultural, urban and industrial land-uses.

Seagrass communities are generally susceptible to changes in water quality and environmental quality that make them a useful indicator of environmental health. Several factors are important for the persistence of healthy seagrass meadows, these include: sediment quality and depth; water quality (temperature, salinity, clarity); current and hydrodynamic processes; and species interactions (e.g., epiphytes and grazers). Seagrass generally respond in a typical manner that allows them to be measured and monitored. In reporting on the health of seagrasses it is important to consider the type of factors that can effect growth and survival. Factors include:

- increased turbidity reduces light penetration through the water, interfering with photosynthesis and limiting the depth range of seagrass;
- increased nutrient loads encourages algal blooms and epiphytic algae to grow to a point where it smothers or shade seagrasses, thereby reducing photosynthetic capacity;
- increased sedimentation can smother seagrass or interferes with photosynthesis;
- herbicides can kill seagrass and some chemicals (e.g., pesticides) can kill associated macrofauna;
- boating activity (propellers, mooring, anchors) can physically damage seagrass meadows, from shredding leaves to complete removal;
- storms, floods and wave action can rip out patches of seagrasses.

A simple method for monitoring seagrass resources is used in the Seagrass-Watch program. This method uses 50m by 50m sites established within representative intertidal meadows to monitor seagrass condition. The number and position of sites can be used to investigate natural and anthropogenic impacts.

Seagrass-Watch is the largest community-based seagrass monitoring program in the world. The Seagrass-Watch monitoring program was established in 1998 as an initiative of the Queensland Department of Primary Industries and Fisheries (QDPI&F). Seagrass-Watch has expanded to the Indo and western Pacific, with volunteers in Micronesia, Palau, Japan, Philippines, Malaysia, Indonesia, Papua New Guinea, Solomon Islands and Fiji. Monitoring is now occurring at approximately 150 sites.

This program monitors the seasonal dynamics of seagrass meadows, the relationships between seagrass condition and climate change and the loss and recovery of seagrass meadows and provides an early warning of change. It involves local community groups assisting in mapping and monitoring seagrass habitats vital for fisheries, turtles and dugongs. Local community volunteers are trained by QDPI&F in the application of methods for scientifically rigorous assessment of seagrass resources. The sampling design and the parameters were developed in collaboration with the community and research scientists.

Monitoring sites are selected in consultation with community volunteers, management agencies, local government, and seagrass researchers. Seagrass-Watch monitoring is coupled where possible with existing environmental monitoring programs (e.g. seagrass depth range, water quality and beach profile) to increase the ability to identify causes for change. The monitoring is conducted using a nested design at three scales: transect (metres), sites (kilometres) and locations (10s kilometres) (Figure 26). Monitoring sites are established in areas of a.) relatively high usage, b). where usage may be high in the near future and c.) in comparable 'control' sites where current and predicted usage is low and likely to remain low. Generally, three sites are established at each location. At each site, three parallel 50 m transects (each 25 m apart) are established, the middle transect is permanently marked. The seagrass habitats along each transect are assessed by visual observation. At each transect, eleven quadrats are sampled (1 quadrat every 5 m) for seagrass cover and species composition, every three or six months, depending on site access and availability of volunteers. Quadrats are photographed to ensure standardisation/calibration of observers and to provide a permanent record.

To learn more about the program, visit www.seagrasswatch.org

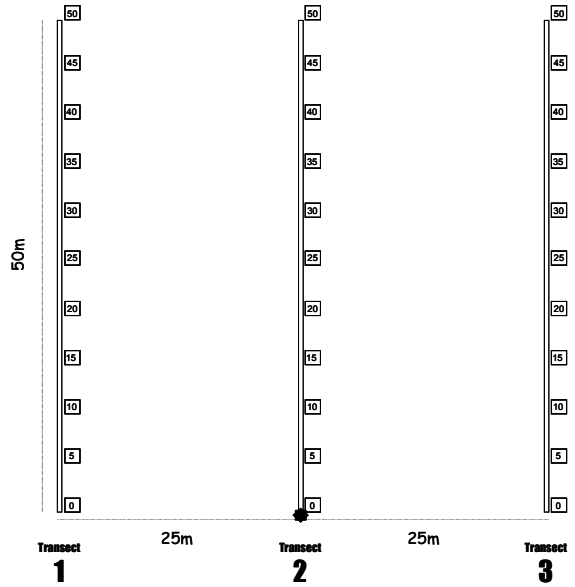


Figure 26: Layout of a seagrass watch site.

Seagrass-Watch Monitoring Summary

Source: McKenzie, L.J., Campbell, S.J. & Roder, C.A. (2001) Seagrass-Watch: Manual for Mapping & Monitoring Seagrass Resources by Community (citizen) volunteers. (QFS, NFC, Cairns) 100pp

Site layout Pre-monitoring preparation

Make a Timetable

Create a timetable of times of departure and arrival back, and what the objective of the day is and what is to be achieved on the day. Give a copy of this to all volunteers involved in advance so they can make their arrangements to get to the site on time. List on this timetable what the volunteers need to bring.

Have a Contact Person

Arrange to have a reliable contact person to raise the alert if you and the team are not back at a specified or reasonable time.

Safety

- Assess the risks before monitoring - check weather, tides, time of day, etc.
- Use your instincts - if you do not feel safe then abandon sampling.
- Do not put yourself or others at risk.
- Wear appropriate clothing and footwear.
- Be sun-smart.
- Adult supervision is required if children are involved
- Be aware of dangerous marine animals.
- Have a first aid kit on site or nearby
- Take a mobile phone or marine radio

Necessary equipment and materials

- 3x 50metre fibreglass measuring tapes
- 6x 50cm plastic tent pegs
- Compass
- 1x standard (50cm x 50cm) quadrat
- Magnifying glass
- 3x Monitoring datasheets
- Clipboard, pencils & 30 cm ruler
- Camera & film
- Quadrat photo labeler
- Percent cover standard sheet
- Seagrass identification sheets

Quarterly sampling

Within the 50m by 50m site, lay out the three 50m transects parallel to each other, 25m apart and perpendicular to shore (see site layout). Within each of the quadrats, complete the following steps:

Step 1. Take a Photograph of the quadrat

- Photographs are taken at the 5m, 25m and 45m quadrats along each transect, or at quadrats of interest. First place the photo quadrat labeler beside the quadrat with the correct code on it.
- Take the photograph from as vertical as possible, to include the entire quadrat frame, quadrat label and tape measure. Try to avoid any shadows or patches of reflection off any water in the field of view. Check the photo taken box on the datasheet for that quadrat.

Step 2. Describe sediment composition

- Dig your fingers into the top centimetre of the substrate and feel the texture. Describe the sediment, by noting the grain size in order of dominance (e.g., Sand, Fine sand, Fine sand/ Mud).

Step 3. Estimate seagrass percent cover

- Estimate the total % cover of seagrass within the quadrat – use the percent cover photo standards as a guide.

Step 4. Estimate seagrass species composition

- Identify the species of seagrass within the quadrat and determine the percent contribution of each species to the cover (must total 100%). Use seagrass species identification keys provided.

Quadrat code = site + transect+quadrat

e.g., PN1225 = Poona site 1, transect 2, 25m quadrat

Step 5. Measure canopy height

- Measure canopy height of the seagrass ignoring the tallest 20% of leaves. Measure from the sediment to the leaf tip of at least 5 shoots.

Step 7. Estimate algae percent cover

- Estimate % cover of algae in the quadrat. Algae are seaweeds that may cover or overlie the seagrass blades. Use “Algal percentage cover photo guide”.

Step 8. Estimate epiphyte percent cover

- Epiphytes are algae attached to seagrass blades and often give the blade a furry appearance. First estimate how much of the blade surface is covered, and then how many of the blades in the quadrat are covered (e.g., if 20% of the blades are each 50% covered by epiphytes, then quadrat epiphyte cover is 10%).

Step 9. Describe other features and ID/ count of macrofauna

- Note and count any other features which may be of interest (eg. number of shellfish, sea cucumbers, sea urchins, evidence of turtle feeding).

Step 10. Take a voucher seagrass specimen if required

- Seagrass samples should be placed inside a labeled plastic bag with seawater and a waterproof label. Select a representative specimen of the species and ensure that you have all the plant part including the rhizomes

and roots. Collect plants with fruits and flowers structures if possible.

At completion of monitoring

Step 1. Check data sheets are filled in fully

- Ensure that your name, the date and site/ quadrat details are clearly recorded on the datasheet. Also record the number of other observers assisting.

Step 2. Remove equipment from site

- Remove all tent pegs and roll up the tape measures. If the tape measures are covered in sand or mud, roll them back up in water.

Step 3. Wash & pack gear

- Rinse all tapes, pegs and quadrats with freshwater and let them dry.
- Review supplies for next quarterly sampling and request new materials
- Store gear for next quarterly sampling

Step 4. Press any voucher seagrass specimens if collected

- The voucher specimen should be pressed as soon as possible after collection. Do not refrigerate longer than 2 days, press the sample as soon as possible.
- Allow to dry in a dry/warm/dark place for a minimum of two weeks. For best results, replace the newspaper after 2-3 days.

Step 5. Submit all data

- Data can be entered from a downloadable spreadsheet (www.seagrasswatch.org) and emailed
- Mail original datasheets, photos and herbarium sheet.

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LECTURE 4.4: MANAGING SEAGRASS RESOURCES

Threats to seagrass habitats

Destruction or loss of seagrasses have been reported from most parts of the world, often from natural causes, e.g., "wasting disease" or high energy storms. However, destruction commonly has resulted from human activities, e.g., as a consequence of eutrophication or land reclamation and changes in land use. Increases in dredge and fill, construction on the shoreline, damage associated with commercial overexploitation of coastal resources, and recreational boating activities along with anthropogenic nutrient and sediment loading have dramatically reduced seagrass distribution in some part of the world Anthropogenic impacts on seagrass meadows continue to destroy or degrade coastal ecosystems and decrease seagrass functions and values, including their contribution to fisheries. It is possible global climate change will have a major impact. Efforts are being made toward rehabilitation of seagrass habitat in some parts of the world: transplantation, improvement of water quality, restrictions on boating activity, fishing and aquaculture, and protection of existing habitat through law and environmental policy.

Management

Seagrasses do not exist in nature as a separate ecological component from other marine plants and are often closely linked to other community types. In the tropics the associations are likely to be complex interactions with mangrove communities and coral reef systems. In temperate waters, algae beds, salt marshes, bivalve reefs, and epiphytic plant communities are closely associated with areas of seagrass. Many management actions to protect seagrasses have their genesis in the protection of wider ecological systems or are designed to protect the overall biodiversity of the marine environment.

Seagrasses are also food for several marine mammal species and turtles, some of which (such as the dugong Dugong dugon) are listed as threatened or vulnerable to extinction in the IUCN Red List (IUCN 2000). Seagrasses are habitat for juvenile fish and crustaceans that in many parts of the world form the basis of economically valuable subsistence and/or commercial fisheries. The need to manage fisheries in a sustainable way has itself become a motivating factor for the protection of

seagrasses.

Coastal management decision making is complex, and much of the information on approaches and methods exists only in policy and legal documents that are not readily available. There may also be local or regional Government authorities having control over smaller jurisdictions with other regulations and policies that may apply. Many parts of South East Asia and the Pacific Island nations have complex issues of land ownership and coastal sea rights. These are sometimes overlaid partially by arrangements put in place by colonising powers during and after World War II, leaving the nature and strength of protective arrangements open for debate.

Both Australia and the United States have developed historically as Federations of States with the result that coastal issues can fall under State or Federal legislation depending on the issue or its extent. In contrast, in Europe and much of South East Asia, central Governments are more involved. Intercountry agreements in these areas such as the UNEP Strategic Action Plan for the South China Sea and the Mediterranean Countries Barcelona Convention (http://www.unep.org/) are required to manage marine issues that encompass more than one country.

Approaches to protecting seagrass tend to be location specific or at least nation specific (there is no international legislation directly for seagrasses as such that we know of) and depend to a large extent on the tools available in law and in the cultural approach of the community. There is, however, a global acceptance through international conventions (RAMSAR Convention; the Convention on Migratory Species of Wild Animals; and the Convention on Biodiversity) of the need for a set of standardised data/information on the location and values of seagrasses on which to base arguments for universal and more consistent seagrass protection.

Six precursors to successful management of coastal seagrasses are:

- Important fish habitat is known and mapped
- Habitat monitoring is occurring
- Adjacent catchment/watershed impacts and other threats are managed
- Some level of public goodwill/support is present
- Legal powers exist hat are robust to challenge
- There is effective enforcement and punishment if damage occurs

The key element is a knowledge base of the seagrass resource that needs to be protected and how stable/variable that resource is. It is also important to know if possible any areas that are of special value to the ecosystems that support coastal fisheries and inshore productivity. It is important as well that this information is readily available to decision makers in Governments in a form that can be easily understood.

LECTURE 4.5: MAPPING SEAGRASS DISTRIBUTION

Information on seagrass distribution is a necessary prerequisite to managing seagrass resources. The first step is to provide baseline maps that document the current extent, diversity and condition of the seagrasses. The next step is to establish monitoring programs designed to detect disturbance at an early stage, and to distinguish such disturbance from natural variation in the meadows.

To make informed management decisions, coastal managers need maps containing information on the characteristics of seagrass resources such as where species of seagrasses occur and in what proportions and quantities, how seagrasses respond to human induced changes, and whether damaged meadows can be repaired or rehabilitated. Knowledge of the extent of natural changes in seagrass meadows is also important so that human impacts can be separated from normal background variation (Lee Long et al. 1996b). Changes can occur in the location, areal extent, shape or depth of a meadow, but changes in biomass, species composition, growth and productivity, flora and fauna associated with the meadow, may also occur with, or without a distributional change (Lee Long et al. 1996b). Seagrass resources can be mapped using a range of approaches from in situ observation to remote sensing. The choice of technique is scale and site dependent, and may include a range of approaches.

McKenzie et al (2001b) provided a decision tree to facilitate the formulation of a survey/mapping strategy.

Generally, an area can be mapped from a field survey using a grid pattern or a combination of transects and spots. When mapping a region of relatively homogenous coastline between 10 and 100 km long, it is recommended that transects should be no further than 500-1000 m apart. For

What is the size of the region or locality to be mapped?	
Less than 1 hectare	**1**
1 hectare to 1 km^2	**2**
1 km^2 to 100 km^2	**3**
Greater than 100 km^2	**4**
1. Fine/Micro-scale (Scale 1:100 1cm = 1m)	
Intertidal	aerial photos, *in situ* observer
Shallow subtidal (<10m)	*in situ* diver, benthic grab
Deepwater (>10m)	SCUBA, real time towed video camera
2. Meso-scale (Scale 1:10,000 1cm = 100m)	
Intertidal	aerial photos, *in situ* observer, digital multispectral video
Shallow subtidal (<10m)	*in situ* diver, benthic grab
Deepwater (>10m)	SCUBA, real time towed video camera
3. Macro-scale (Scale 1:250,000 1cm = 250 m)	
Intertidal	aerial photos, satellite
Shallow subtidal (<10m)	satellite & real time towed video camera
Deepwater (>10m)	real time towed video camera
4. Broad-scale (Scale 1:1,000,000 1cm = 10 km)	
Intertidal	satellite, aerial photography
Shallow subtidal (<10m)	satellite, aerial photography & real time towed video camera
Deepwater (>10m)	real time towed video camera

Figure 27: A decision tree. The data capture methods used to map the distribution of seagrass meadows vary according to the information required and the spatial extent

regions between 1 and 10km, it is recommended to use transects 100-500m apart and for localities less than 1km, 50-100m apart is recommended. This however may change depending on the complexity of the regional coastline, i.e., more complex, then more transects required (Figure 27).

When mapping, ground truthing observations need to be taken at regular intervals (usually 50 to 100m apart). The location of each observation is referred to a point, and the intervals they are taken at may vary depending on the topography. When ground truthing a point, there are a variety of techniques that can be used depending on resources available and water depth (free dives, grabs, remote video, *etc*). A point can vary in size depending on the extent of the region being mapped. In most cases a point can be defined as an area encompassing a 5m radius. Observations recorded at a point should ideally include some measure of abundance and species composition.

Intertidal field survey

The objective of the field survey is to determine the edges/boundaries of any seagrass meadow and record information on species present, % cover, sediment type, and depth (if subtidal). Field surveys are also essential if using remote methods like aerial photographs to evaluate image signatures observed, or examine areas where the imagery does not provide information (e.g., such as in areas of heavy turbidity), and produce reference information for later accuracy assessment.

General field procedure

You will need:

- Hand held compass or portable Geographic Positioning System (GPS) unit
- Standard 50 centimetre x 50 centimetre quadrat.
- Seagrass identification and percent cover sheets (see Appendix)
- Clipboard with pre-printed data sheets (see Appendix) and pencils.
- Suitable field clothing & footwear (e.g., hat, dive booties, etc)
- Aerial photographs or marine charts (if available) of the locality
- Plastic bags - for seagrass samples with waterproof labels
- Weatherproof camera (optional)

First, define the extent of the study area. Check the tides to help you plan when is the easiest time to do the mapping, e.g., spring low is best for intertidal meadows. If mapping can be conducted at low tide when the seagrass meadow is exposed, the boundaries of meadows can be mapped by walking around the perimeter of each meadow with single position fixes recorded every 10-20metres

depending on size of the area and time available. An important element of the mapping process is to find the inner (near to the beach) and outer (towards the open sea) edges of the seagrass meadow. To survey an area quickly, it is possible to work from a hovercraft or helicopter.

Alternatively, an area can be mapped using a grid pattern or a combination of transects and points. Estimate distances along transects and between points, rather than using a tape measure.

The number of mapping points you survey will be entirely up to you. If you need to accurately map an area, then intensive surveying (sample lots of mapping points) is recommend. It is also beneficial to try to get a good spread of mapping points over the area, as some of the changes in the seagrass meadow will not necessarily be obvious.

Field survey point measures

- Step 1. Use a GPS to record the geographic position of the point
- Step 2. Record general information such as: observer, location (e.g., name of bay), date, time and water depth if not exposed
- Step 3. Describe sediment composition by noting the grain size in order of dominance (e.g., Sand, Fine sand, Fine sand/Mud)
- Step 4. Record % seagrass cover/abundance and composition from within 3 haphazardly tossed 50cm x 50cm quadrat (use the percent cover photo standards as a guide (Appendix II)
- Step 5. Estimate algae percent cover
- Step 6. Describe other features and ID/count of macrofauna
- Step 7. Take a photograph from every 10th mapping point (not essential)
- Step 8. Collect a voucher specimen of each new seagrass species encountered

Creating the map

The simplest way to map a seagrass meadow is to draw the boundaries on a paper marine chart from the GPS positions of the ground truth points. The problem with this type of mapping however is that the final map is in a format that does not allow manipulation and transformation. A paper map is permanent, which makes it difficult for future seagrass mapping studies to be compared, queried and analysed. If resources are available, it is recommend that the data be transferred to a digital format and a Geographic Information System (GIS) be used.

GIS are software systems of highly accurate digital maps that can be overlaid to reveal relationships that might not otherwise be detected on traditional paper maps. Digitally-stored cartographic databases can be altered much quicker than hard copies and shared data can be standardised. The key element of a GIS is the separation of differing data sets into thematic layers. GIS software provides the functions and tools needed to store, analyse, and display geographic information. Two of the most common GIS packages are ArcGIS and MapInfo. Mapping seagrass meadows with a GIS can help to identify emergent patterns or relationships in geographically referenced data. For further reading on the application of GIS to aquatic botany, see Lehmann and Lachavanne (1997).

Boundaries of meadows can be determined based on the positions of survey points and the presence of seagrass, coupled with depth contours and other information from aerial photograph interpretation. Errors that to be considered when interpreting GIS maps include those associated with digitising and rectifying the aerial photograph onto the basemap and those associated with GPS fixes for survey points.

In certain cases seagrass meadows form very distinct edges that remain consistent over many growing seasons. However, in other cases the seagrass tends to grade from dense continuous cover to zero cover over a continuum that includes small patches and shoots of decreasing density. Boundary edges in patchy beds derived from aerial imagery or direct observation are vulnerable to interpreter variation. Given the uncertainty surrounding the determination of meadow edges it is suggested that each mapping effort include its own determination as to what it considers seagrass habitat based on the purpose of the mapping (Lee Long *et al.* 1996a, McKenzie *et al.* 1996, 1998, 2001b).

The final map can be presented on screen and in hard copy. The final maps need a clear legend describing the features highlighted, a scale, and a source. The maps are best accompanied by metadata. Metadata is information about the data and not to be confused with a summary of the data. Metadata describes data source, data reliability, conditions of use, limits on interpretation and use-by date, and usually includes the correct form of citation to be used for acknowledging the data source. It holds information about the quality of the data. The project metadata for all spatial data

should have some statement about the accuracy of a map product. The Australian New Zealand Land Information Council has a very useful guide for metadata (http://www.anzlic.org.au/).

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CHAPTER 5: CORALS

LECTURE 5.1. INTRODUCTION TO CORAL REEFS, THEIR ECOLOGY AND FORMATION.

Coral reefs are amongst the oldest of ecosystems, dating back some 400 million years. However, the corals which formed these ancient reefs have long been extinct and the reefs they created are now submerged some 120 metres below current sea levels. Modern reefs are in fact only about 2.5 million years old, and the corals we see on modern coral reefs mostly evolved in the Palaeocene and Eocene (37-67mya).

Today, coral reefs are found throughout tropical shallow waters along the shores of islands and continents. The reef matrix, built from the dead skeletons of reef-building corals, and the many organisms which are associated with it represents one of the most diverse ecosystems on the planet rivaled only by the diversity seen in tropical rainforests. While rainforests are purported to contain more species than coral reefs, coral reefs contain far more different phyla.

Coral biology

The immense structure of coral reefs is created primarily, by the humble coral polyp. Before going on to look at the formation of reefs and the nature of reef ecosystems, it is appropriate that we first examine the structure and anatomy of these simple organisms. Put simply, the coral polyp is a bag of full of gonads, sitting inside a skeletal cup.

Colonial Structure: The success of coral polyps (in terms of the abundance of corals) is attributed, in part, to their colonial strategy. Although individual polyps are theoretically capable of living entirely on their own (and indeed some corals do exist as solitary polyps), they often form colonies comprising numerous polyps living as a single entity. The advantages of being a colonial organism are numerous (e.g. virtual immortality, lower chance of mortality, increased maximum size). The colony is formed by cloning, so all polyps within the colony are genetically identical. While each polyp is capable of feeding and reproducing, the polyps tend to function for the common good of the entire colony. In some situations, this co-operation has evolved to such an extent that polyps are differentiated to suit a particular function (this is rare amongst the reef-building corals, but common in soft corals)

Coral reproduction: Equally important in the success of corals is their immense reproductive capabilities. A coral polyp can be viewed as a bag full of gonads, and at certain times of the year approximately 1/3 of the corals biomass is comprised of gonads. Not all the gametes that are released by corals will survive to become reproductively mature corals. In fact only 5-15% of gametes are successfully fertilised, of the fertilised zygotes perhaps only 10% will survive the larval phase, and less than 1% will recruit successfully to a coral reef.

Of the recruits that are successful, most will settle on or near their natal reef. A small percentage will get swept along by ocean currents to neighboring reefs, and the occasional coral may even ‘raft’ across the breadth of entire oceans to colonize new areas or interbreed with otherwise isolated populations.

Even after a coral settles on a bare patch of reef and begins to grow there is a long way to go before reaching maturity. The mortality rate of newly settled coral appears to be in the order of 85%, depending on where on the reef the coral settles. Mortality is caused by mostly incidental predation by herbivorous fish, but they may also be smothered by sediments, or shaded by larger corals and therefore have limited light (necessary for photosynthesis). When the juvenile coral is very small it does not yet have the advantages of larger colonial organisms, and is very susceptible to mortality. Once the coral reaches a size around 10cm in diameter there is then only a very low chance of mortality (ie a type 3 survivorship curve).

Calcification: Perhaps, the most important aspect of a corals biology is the production of the calcium carbonate skeleton which is left as a lasting legacy, long after the coral has died. The skeletons of dead corals form the building blocks of the reef. However, not all corals contribute to reef growth. Some corals, called soft corals (and we will get into the taxonomic distinction of these groups later) have skeletons comprised of loose spicules which separate and are dispersed after the coral dies. These spicules contribute to the coral sediment which is important for in-filling between hard-coral skeletons, but do

not contribute directly to reef growth. Other corals incorporate calcium carbonate sediment into their skeletons by ingesting the sand, and so do not produce any carbonate. However many species of hard corals precipitate calcium from the sea water to construct hard skeletons. The rate at which these corals can construct their skeletons, determines their growth rate. Not surprisingly the corals which grow fastest contribute most to reef growth. While some corals grow very fast and can reach massive sizes, others grow relatively slowly and never get very big. Differences between these corals can be directly related to their method of acquiring nutrients for growth.

Hermatypic & non-hermatypic corals: Corals which contribute most to reef growth, often form close associations with zooxanthellate algae. These corals are called hermatypic corals and comprise the main reef-building species. The zooxanthellate algae live within the tissues of the coral and gain energy through photosynthesis, and 94-98% of all organic carbon produced by zooxanthellae leaks out of the cells to be used as food by the coral. Because of the extra energy provided by the zooxanthellae, hermatypic corals are able to deposit their limestone skeletons 2-3 times faster, than possible without zooxanthellae.

Non-hermatypic corals are the hard corals which do not support zooxanthellae and have to rely exclusively on heterotrophy to obtain their nutrition. These corals grow much more slowly than the hermatypic corals, and are also much less common.

Habitat requirements of corals: Corals can grow in a wide variety of environments, but they only form reefs in optimal habitats, where the rate of calcification can exceed the rate at which coral skeletons are eroded away by the action of the sea and eroding organisms.

Basic habitat requirements of the corals are:

- Shallow water: Although various types of corals can be found from the water's surface to depths of 19,700 ft. (6,000 m), reef- building corals are generally found at depths of less than 150 ft (46 m), where sunlight penetrates. This is because reef- building corals have a symbiotic relationship with a type of microscopic algae which rely on sunlight for photosynthesis.
- Clear waters: Reefs tend to grow faster in clear water. Clear water allows light to reach the symbiotic algae living within the coral polyp's tissue. Many scientists believe that the algae, called zooxanthellae, promote polyp calcification.
- Warm water: Reef-building corals require warm ocean temperatures (68 to 82 F, or 20 to 28 C). Warm water flows mainly along the eastern shores of major land masses. Precipitation of calcium from the water is necessary to form a coral polyp's skeleton. This precipitation occurs when water temperature and salinity are high and carbon dioxide concentrations are low. These conditions are typical of shallow, warm tropical waters.
- Water movement: Reef development is generally more abundant in areas that are subject to strong wave action. Waves carry food, nutrients, and oxygen to the reef; distribute coral larvae; and prevent sediment from settling on corals.
- Hard substrate: most corals grow on a hard substrate.

Reef formation

Cementing the reef: Coral reefs are formed by the calcium carbonate that is accreted by hermatypic (zooxanthellate) corals, and then remains in place after the corals die. However, to build a reef you need some sort of cement to hold the reef together. The cement for the reef is provided by coralline algae.

Coralline algae: Coralline algae are not immediately apparent when you look at a reef, but they are in fact extremely common. The most common forms of coralline algae are a pinkish colour and if you look closely, you'll see most of the reef is covered with coralline algae. The coralline algae grow over the skeletons of dead corals and in doing so cements them in place.

After the corals and coralline algae have combined to form a wall of calcium carbonate there is often a build up of sediment in behind the wall (called in-filling). The coralline algae will also grow amongst the sediments effectively incorporating them into the reef. Through the combination of coral growth, in-filling and cementing by coralline algae the calcium carbonate basis of reefs can rapidly extend both upwards and sideways.

Reef Growth: Reef growth is a continual process, as corals grow ever larger, more corals die-off, more sediment is collected and the whole system is stabilised by coralline algae. However, there is a limit to how high the reef can extend, because corals can't live out of water. If corals recruit to shallow reefs and grow upwards, the upper part of

the colony will eventually die because it has too much exposure during low tide. As a result, all mature coral reefs throughout the world are at approximately the same height relative to the sea-level. This level is usually the mean low water level (the average height of the low tides), though it can be higher in areas where air temperatures are lower, or where water levels are maintained at low tide e.g. on some atolls.

Because coral reefs cannot extend above a certain level, you can well imagine that the height of reefs can change with changes in the sea level over geological time. Currently we are facing a period of increasing sea-level. With the melting of the polar ice-caps the sea-level is expected to rise at a rate of approximate 2cm per decade, and so reefs can also extend upwards at this rate. It is possible that if the sea-level increases too rapidly the modern day coral reefs may not be able to keep up and will eventually drown, because coral can't survive in the ocean depths any better than they can out of water.

Even when the vertical growth of coral reefs is limited, corals can continue to grow horizontally.

Reef types: While the process of reef growth is fairly similar throughout the world, there are considerable differences in the types of reefs that are formed. Generally, reefs can be categorised as Fringing reefs, Barrier Reefs, or Atolls. These categories relate to the origins of different reefs

- Fringing reefs are the most recently formed reefs, formed in shallow waters of continental coastlines and islands.
- Barrier reefs (e.g. the Great Barrier Reef) are reefs formed along the submerged margins of continental shelves, established at a previous much lower sea level. When they were first formed these reefs would have been growing as fringing reef of mainland Australia, then as the sea level rose isolated patches of the reef were able to keep pace with the rate of sea level rise. Barrier Reefs may result in considerable accumulation of coral rubble to form new islands called coral cays.
- Atolls are formed when coral grows around the margins of volcanic islands, and the volcano then subsides or is submerged leaving a ring of coral reef.

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LECTURE 5.2. DISTURBANCE AND RECOVERY OF CORAL COMMUNITIES.

Coral reef ecosystems are very sensitive and susceptible to disturbance, both from human activities and natural disturbance events.

Natural vs Anthropogenic Disturbances

Despite what we may think natural disturbances can have severe effects on coral reef ecosystems, but the vast majority of decreases in coral cover and general colony health have been linked to anthropogenic influences (Figure 28). Management of reef ecosystems tends to focus only on anthropogenic influences, but it is not always clear whether disturbances are caused or exacerbated by human activities (e.g. in cases of coral bleaching, and outbreaks of Crown-of-thorns starfish).

Natural Disturbances	Anthropogenic (human induced) Disturbances
Cyclones and wave damage	Anchor damage & fin damage
Natural predators	Fishing and collecting
Rain and freshwater runoff	Pollution/ contamination
Competition	Eutrophication
Dessication	Sedimentation
Outbreaks of crown-of-thorns starfish	Introduced Pests
	Global warming

Figure 28: Disturbances to coral communities.

Major Impacts

Global warming: Global warming is generally considered as the single greatest threat to modern coral reefs. Issues regarding global warming has direct relevance to coral reefs because reefs are likely to be threatened by increased sea-surface temperatures both because coral will bleach and also sea levels will rise and drown coral reefs. Human activities that affect global warming are generally removed from reef ecosystems and so the regulation of such practices is not the role of reef managers. However, research on coral reefs (coral cores, bleaching) is providing considerable evidence that global warming is both real and of considerable concern.

Crown-of-thorns outbreaks: The coral eating starfish, *Acanthaster planci* is native to Indo-Pacific coral reefs, but has the potential to cause extreme and widespread destruction of coral reefs. Although the effects of these starfish are well known, it is not known whether outbreaks of crown-of-thorns starfish are a natural phenomenon. Previously, it has been argued the outbreaks occurred because the giant triton (a natural predator of crown-of-thorns starfish) had been over-fished, or the input of nutrients increased the survivorship of starfish larvae. Neither of these arguments have overwhelming support from scientists, but still it is possible that human activities have increased the frequency or intensity of outbreaks of crown-of-thorns starfish. In order to prevent starfish from devastating popular tourist destinations, starfish are killed in localized regions. However, it will never be feasible to kill all starfish across the entire reef and it is still questionable whether this would be the best practice even if it was feasible.

Fishing and collecting: Fishing has a direct impact on populations of target species, but some fishing practices such as trawling cause other impacts not directly related to the capture of target species (eg. habitat destruction, pollution etc). It is the aim of management, not to prevent fishing, but ensure that fishing practices are sustainable (ie. will not result in the eventual demise of target species).

Pollution/ contamination: Shipping and related activities poses potentially disastrous water quality problems for the Great Barrier Reef. Of most concern is the threat of a major oil spill, but there is also the potential for other ship-sourced pollution. Even though the Great Barrier Reef has never witnessed a major oil spill, the Great Barrier Reef Management Authority is at the fore-front of international research into the best procedure for the clean-up of oil spills.

Eutrophication/ sedimentation: The Great Barrier Reef ecosystem is very dependant on the maintenance of high water quality. Most tropical marine ecosystems grow best in conditions of low nutrients (particularly phosphorus and nitrogen), and so it is important to prevent excessive nutrients entering the reef ecosystem (eutrophication). It is obvious that we are having a considerable effect on the water quality in the Great Barrier Reef: Sediment and nutrient input from terrestrial discharge has increased fourfold since the introduction of coastal land-use (primarily farming). These days river discharge comprises 39% of nitrogen input and 52% of phosphorus input to the Great Barrier Reef. Reduction in the nutrient loads entering the Marine Park from coastal catchment is seen as one of the primary issues facing the management authorities.

Introduced pests: Another potential impact caused by shipping activities is the introduction of feral organisms from other oceans, through the expulsion of ballast water. No introduced pests have yet caused problems on coral reefs (though introduced starfish are threatening southern Abalone fisheries), but reef wide monitoring is being undertaken to recognise the introduction of any feral organisms.

Anchor damage & fin damage: Corals are clearly amongst the most important elements in coral reef ecosystems: they provide the structural framework of the reef, contribute primarily to reef growth, and also provide food for numerous reef organisms. Despite the ability of corals to form massive reefs, the individual coral colonies are particularly susceptible to physical damage. Boat anchors cause considerable physical damage to corals, particularly in rough weather when the anchor chain drags back and forth across the reef. Considerable coral damage is also occurs by fin damage and accidental breakage by snorkellers and divers. To avoid impacts from anchors, permanent moorings are deployed in areas of heavy use. Only education and training can reduce the impacts of divers.

Global warming

The issue of global warming is one of the most widely debated topics of the modern era. While many scientists are of the view that global warming is a real phenomenon and poses a serious threat to all the world's ecosystems, there are others who think that global warming is either natural or non-existent. It is true that the Earth goes through a constant cycle of warming and cooling (hence the recurrent ice-ages) and at present we are in a warming period. However, there is also considerable evidence that the actions of humans have increased the rate at which the world is warming. Two of the largest groups addressing the issue of global warming are the United States National Coalition on Climate Change Policy (who have named themselves the "Cooler Heads"), who argue that global warming is science fiction (Figure 29). On the other hand, the United States National Oceanic and Atmospheric Administration (NOAA) consider global warming to be of serious concern.

National Coalition on Climate Change Policy	National Oceanic and Atmospheric Administration
www.globalwarming.org	www.ncdc.noaa.gov/ol/climate/globalwaring.html
"Global air temperatures show an increase of about 0.45°C over the last century, and this maybe no more than normal climatic variation"	"Global warming is not a uniform phenomenon, while some areas will heat up, others will cool. Warming has been greatest in most highly populated regions (N. America and Europe)"
"98% of total greenhouse gases are natural (eg. water vapour and CO_2), & man-made emissions have had no more than a minuscule impact on climate"	Human activity has greatly increased the concentration of CO_2 (mostly from combustion of coal and oil), and by 2050 concentrations of these gases will be double that of pre-industrial levels. Moreover, there have been steady increases in the concentrations of Methane, Nitrous oxide and Chlorofluorocarbons (all of which contribute to global warming).
"Projections of future climate changes are uncertain. Although some computer models predict warming in the next century, these models are very limited"	Predicted climate change have proved correct up to this point, and by all predictions the mean atmospheric temperature will increase by 1-3.5°C over the next century (an unprecedented rate of climate change)
"The idea that global warming would melt ice caps and flood coastal cities seems to be mere science fiction"	Polar ice-caps are shrinking at a phenomenal rate and combined with expansion of oceans through warming, the sea-level is rising by 1-2mm/year.

Figure 29: Views of global warming held by the National coalition on climate change policy and the National Oceanic and Atmospheric Administration (NOAA).

Global warming is a natural phenomenon caused by heating of the earths core. However, human activities are leading to an increase in Greenhouse gases and minor ancillary heating in the production of energy which contributes to increases in atmospheric temperatures. It is expected that the rate of global warming will continue to accelerate over the next few centuries, and even now it seems the current rate of climate change (increases of 1-2°C per century) is much greater than at any time in geological past.

Effects of Global Warming: The effects of climate change will vary around the globe. Temperature rises are expected to be greater towards the Poles than near the Equator, and over land than at sea. While rainfall is expected to increase in some areas and decrease in others, likely changes in rainfall for particular regions are still highly uncertain.

Already, the effects of global warming are starting to be seen through an increased incidence of El nino events. There are also other signs of global warming, such as accelerated rise in the mean sea-level and increased occurrence of coral bleaching.

CORAL BLEACHING

Coral bleaching is the whitening of coral colonies due to the loss of symbiotic zooxanthellae from the tissues of polyps. This loss exposes the white calcium carbonate skeletons of the coral colony. Corals naturally loose 0.1% of their zooxanthellae during processes of regulation and replacement. However, adverse changes in a coral's environment can cause an increase in the number of zooxanthellae lost. There are a number of stresses or environmental changes that may cause bleaching including disease, excess shade, increased levels of ultraviolet radiation, sedimentation, pollution, salinity changes, and increased temperatures.

Minor bleaching of corals is very common (see most mushroom corals have some sign of bleaching) and is usually of little consequence for corals, because most corals can continue to feed themselves until they can restore a suitable crop of zooxanthellae. However, when bleaching is particularly intense or last for an extended period then the coral is very likely to die. Even if the coral doesn't die directly from the bleaching, they will produce far fewer gametes than they otherwise might have, and bleached corals are also far more susceptible to disease.

Most evidence currently indicates that elevated temperature is the cause of mass bleaching events that are becoming increasingly apparent. Corals tolerate a narrow temperature range between 25 degrees Celsius and 29 degrees Celsius depending on location. Corals bleach in response to prolonged temperature change and not due to rapidly

fluctuating temperatures. It has been widely shown that reef-building corals on healthy coral reefs are living very close to their upper thermal limit, and accelerated increases in mean sea surface temperatures are likely to result in more frequent and/or more intense bleaching events.

Bleaching (and even mass-bleaching) is not a new phenomenon, and mass bleaching events have been recorded as far back as the 1970's. It is apparent however, from the records that are being kept that bleaching is appearing to be ever more widespread, and also the bleaching events are increasing in intensity.

With predicted increases of 1-2^{o}C in average atmospheric temperature over the next century it is suggested that mass-bleaching will eventually become an annual event, and even if not all the corals die, they are unlikely to produce any viable offspring (there is evidence that the production of gametes, fertilisation success and larval survival are affected by increased temperature even more than the adult corals), which will spell disaster for coral reefs and the end of coral reefs as we know them.

Combined with increasing sea-level, global warming represents the greatest single threat to coral reefs. Even if man was to cease all activities that contribute to global warming, it is anticipated that there are already sufficient concentrations of green-house gases in the atmosphere to cause accelerated global warming over the next 50-100 years. The only hope for corals is if they can ADAPT to increasing sea-surface temperatures, such that at least some coral can continue to grow and breed even in waters 1-2^{o}C above current temperatures. Some people believe that this **IS** possible, though there is still a lot of work to do before we know the real future of coral reefs.

Replenishment of coral populations

The recovery of scleractinian coral communities after major disturbances can occur in one of two different ways:-

- Growth and recovery of remnant corals
- Recruitment by corals spawned on upstream reefs

Where there has been complete coral devastation, reefs must rely on settlement and subsequent growth of new recruits. In such cases, recovery may be very slow (up to 20 years) especially where reefs are very isolated (and must rely on low and unpredictable recruitment). Recovery from disturbances is much quicker where remnant corals persist, and then grow to immediately increase live coral cover.

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LECTURE 5.3. INTERACTIONS BETWEEN CORALS AND OTHER REEF ORGANISMS.

The coral reef ecosystem (by definition) incorporates all animals that live on and around the reef matrix, including various fish, reptiles, mammals, birds and numerous different invertebrates. If we compare the reef ecosystem with that of other ecosystems we will see firstly, and most obviously that coral reef ecosystems are very diverse. In terms, of corals there are approximately 2,500 species worldwide. In addition there are over 3,000 species of reef fish, and 6,000 species of non-coralline anthozoans (e.g. jellyfish) as well as many other invertebrate and vertebrate species. Unlike other high diversity ecosystems (such as rainforests), the species diversity is readily apparent, as the numerous reef fish swim in full view and the numerous different coloured corals cover the substrate.

Coral reef ecosystems are also incredibly productive, which is surprising considering that coastal waters are usually very unproductive. The explanation for this is that there are many and varied sources of primary productivity in reef ecosystems (including zooxanthellae in corals and clams, as well as phytoplankton, turf algae and macro-algae). The contribution of primary productivity from these various sources varies through time and between locations. This primary productivity gives rise to numerous primary and secondary consumers.

Given the high diversity and density of organisms, it is not surprising that reef ecosystems exhibit very complex trophic dynamics (food webs). In fact, the

trophic dynamics of reef ecosystems is so complex it is not yet fully understood, and significant energetic pathways are still being found. If we consider the length of food chains, or the number of different trophic levels in different ecosystems, it is very apparent that there are a large number of links in the food chains of reef ecosystems. Terrestrial food chains often include only three levels (primary producer, primary consumer, secondary consumer), and the average number of links is less than four. Current research in reef ecosystems has shown that it is common to have as many as eight links in reef based food chains, and the average is around six. Having a large number of trophic links has advantages and disadvantages. The large number of links is believed to increase the stability of the system, but at the same time particular species may have a disproportionate impact on the entire ecosystem. Scleractinian corals, for example, are essential to the existence of coral reef ecosystems, not only because they "build" reefs, but also because they provide food and other resources to many coral reef organisms. As a consequence, large -scale reductions in scleractinian coral cover (e.g., following mass-bleaching events) can have profound and far-reaching effects on coral reef ecosystems.

Corals as Food and Habitat

There has been considerable research showing a significant correlation between the abundance of scleractinian corals and the abundance and diversity of coral reef fishes. This relationship suggests (but does not prove) that many reef fish are highly dependent upon corals. For some reef fish (e.g. certain butterflyfish, wrasses and leather-jackets) scleractinian corals represent an essential food source. Moreover, many reef fish rely on corals for habitat. For example, there are many damselfish and gobies that live exclusively within the branches of live coral colonies. Even fishes that do not rely directly on corals for shelter, benefit greatly from the habitat structure that live corals provide.

Given their reliance on corals, it is not surprising that disturbances to coral communities (e.g. coral bleaching and outbreaks of *Acanthaster planci*) often have devastating effects on other reef associated organisms, such as coral reef fishes. Among those fishes with the greatest reliance on scleractinian corals are the coral-feeding butterflyfish. Approximately one half of all butterflyfish feed almost exclusively on scleractinian coral and are therefore, adversely affected by declines in live coral cover. For this reason, butterflyfish are often considered to be "indicators" of coral reef condition. That is, when coral cover declines, you'd expect a decline in butterflyfish abundance. However, it is important to note that not all butterflyfish are equally reliant on scleractinian corals. In fact, some species do not eat any live coral and may actually increase in abundance following some coral disturbances.

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LECTURE 5.4: TECHNIQUES FOR SAMPLING CORAL COMMUNITIES.

Line Intercept Transects

The most common technique used to sample coral communities is the line intercept transect, providing data on percent cover and relative abundance of different groups of organisms. The line intercept transect method is used to estimate proportional cover of sessile, benthic organisms by calculating the fraction of the total length of the line that is intercepted by each taxa (this technique does not provide an estimate of actual density, because the area sampled is effectively zero). The line intercept transect technique was adapted from terrestrial plant ecology, and works well to sample sessile benthic flora and fauna, and provides a very rapid and efficient method for documenting coral cover and community composition of reef benthos.

There are alternative techniques for sampling coral communities (e.g. belt transects, photo-quadrats, permanent quadrats) which may be used depending on the specific aims of the research. Generally, these techniques provide more information about the coral community (e.g. the size of coral colonies, the number and proximity of colonies) than can be extracted using the line intercept transect method. However, there is an almost universal trade-off

between the amount of information that is gathered from each individual transect versus the size and number of replicate transects that can be sampled within a given time period.

Choosing the most appropriate sampling unit requires several important considerations:

Information required—eg. specific spatial arrangement vs simple densities)

The size of the study organism—the sampling unit needs to be at least an order of magnitude bigger than the study organism (ie. it is no good trying to sample elephants with a 1-metre quadrat)

The abundance of the study organism—the sampling unit needs to be sufficiently large to get reasonable estimates of abundance (it is good to aim for >10 and <50 organisms per unit sampled)

Boundary effects—the sampling unit must be used in such a way to maximise accuracy in estimating the amount of area sampled, and use rigorous protocols to decide on the inclusion of organisms along the edge of the sampling unit

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LECTURE 5.5: DIVERSITY AND CLASSIFICATION OF SCLERACTINIAN CORALS.

Scleractinain corals are a highly diverse group of organisms, with over 800 extant species. However, very few people are capable of recognising all coral species. Distinguishing between coral species requires both detailed information on corallite structure (often involving the use of a microscope) and gross morphology (e.g. growth form, colour etc).

Functional Groups

Scientists rely on distinguishing different species as means of separating organisms with different characteristics (e.g., different habitat requirement, different life-histories etc.). However, some species may have very similar characteristics, such that they are "ecologically equivalent". These species may then be placed into "functional groups" when documenting the abundance and/ or distribution of different organisms. Scleractinian corals are often placed into "functional groups" based on their growth form (e.g. branching vs tabular vs massive), and there is considerable research that shows that most corals with a particular growth form share many ecological characteristics. For example, massive corals grow much more slowly than branching corals, but massive corals are much more resistant to physical disturbances, compared to branching corals.

By using growth forms (rather than taxonomic classifications) it is possible to gain important insights into the ecology and functionality of reef communities, without needing a strong taxonomic knowledge of scleractinian corals. However, there are cases where it is important to classify corals to taxonomic groups (e.g., when documenting coral diversity) and it is always useful to record the species, genus or family of coral, if possible.

Growth Forms

Growth forms used to classify scleractinian corals group together many different species and often span different genera and families. Massive corals, for example, can include species from the families Poritidae, Faviidae, Mussidae and even the Acroporidae.

The major growth forms used to classify scleractinian corals include:

1. Branching Corals – Tree-like corals with many separate branches (can be further divided into arborescent, digitate, corymbose, and tabular), mostly *Acropora* spp.

2. Massive Corals – Large hemispherical colonies, e.g. *Porites* spp.

3. Columnar Corals – Colonies formed of vertical pillars with very little branching, e.g. *Isopora* spp.

4. Encrusting Corals – Thin flat colonies growing over the substrate, e.g. *Montipora* spp.

5. Foliaceous Corals – Colonies comprised of thin flat plates, often forming a whorl, e.g. *Turbinaria* spp.

6. Free-living Corals – Individual polyps or coral colonies that are not attached to the substrate, mainly mushroom corals (family Fungidae).

Further reading

Jackson, J. B. C. (1979). Morphological strategies of sessile animals. Pp 499-555 In: G. Larwood and B. R. Rosen (Eds) Biology and systematics of colonial organisms. London, Academic Press.

Veron J.E.N. (1986). Corals of Australia and the Indo -Pacific. University of Haiwaii Press, Honolulu.

Family	Genus	No. Spp
Acroporidae	Acropora	169
	Montipora	73
	Astreopora	12
	Anacropora	7
Astrocoeniidae	Stylocoeniella	3
	Stephanocoenia	1
	Paulastrea	1
	Madracis	8
Pocilloporidae	Pocillopora	17
	Seriatopora	6
	Stylophora	7
Poritidae	Porites	52
	Goniopora	24
	Alveopora	14
	Poritipora	1
	Stylaraea	1
Fungiidae	Fungia	18
	Cycloseris	10
	Cantharellus	3
	Heliofungia	1
	Ctenactis	3
	Herpolitha	2
	Polyphyllia	2
	Sandolitha	3
	Halomitra	3
	Zoopilus	1
	Lithophyllon	3
	Podabacia	4
	Diaseris	2
Oculinidae	Galaxea	7
	Oculina	5
	Simplastrea	1
	Schizoculina	2
Meandrinidae	Meandrina	2
	Ctenella	1
	Dichocoenia	1
	Dendrogyra	1
	Gyrosmilia	1
	Montigyra	1
	Eusmilia	1
Agariciidae	Agaricia	7
	Pavona	14
	Leptoseris	15
	Coeloseris	1
	Gardineroseris	1
	Pachyseris	5
Merulinidae	Hydonophora	6
	Merulina	3
	Paraclavarina	1
	Boninastrea	1
	Scapophyllia	1
Faviidae	Favia	22
	Favites	14
	Goniastrea	13
	Platygyra	11

Family	Genus	No. Spp
	Echinopora	12
	Montastrea	10
	Cyphastrea	8
	Leptastrea	7
	Caulastrea	5
	Plesiastrea	2
	Oulastrea	1
	Diploastrea	1
	Leptoria	2
	Moseleya	1
	Barabattoia	2
	Australogyra	1
	Oulophyllia	3
	Diploria	3
	Colpophyllia	1
	Parasimplastrea	1
	Solenastrea	2
	Cladacora	2
	Erythrastrea	1
	Manicina	1
Mussidae	Acanthastrea	12
	Lobophyllia	9
	Symphyllia	7
	Scolymia	3
	Cyanaria	1
	Blastomussa	2
	Micromussa	3
	Mussismilia	3
	Isophyllia	2
	Mussa	1
	Mycetophyllia	5
	Astralomussa	1
	Indophyllia	1
Pectiniidae	Echinophyllia	8
	Pectinia	9
	Oxypora	5
	Mycedium	5
	Echinomorpha	1
Siderastreidae	Pseudosideatrea	1
	Horastrea	1
	Anomastrea	1
	Siderastrea	5
	Psammacora	12
	Coscinaraea	8
Euphyllidae	Euphyllia	8
	Physogyra	1
	Plerogyra	3
	Catalaphyllia	1
	Nemenzophyllia	1
Dendrophylliidae	Turbinaria	11
	Duncanopsammia	1
	Balanophyllia	1
	Heteropsammia	2
Caryophyllidae	Heterocyanthus	1
Trachyphylliidae	Trachyphyllia	1
Rhizangiidae	Astrangia	1

CHAPTER 6: MANGROVES

LECTURE 6.1: BIOLOGY AND ECOLOGY OF MANGROVES

What are Mangroves?

Mangroves ecosystems are the main vegetation type that occur in the protected inter tidal areas along the coastlines of tropical and sub tropical countries. Inter tidal mean the environment is constantly influenced by the tidal regime of a given area. Inter tidal areas are harsh environment, with settings ranging from high rainfall to dry, high temperature to low, high to low freshwater input, soils that are pure clay, mixes with sand or silt, sandy, coral rubble or rocky, lacking in oxygen, changes in the salinity of the water column and the soil.

These variations in the chemical and physical factors in the inter tidal zone produces a gradient and influence the mangrove ecosystems to display the extreme variations in the plant composition, forest structure and growth rates.

Distribution and biodiversity

General distribution in Papua New Guinea

The Fly and the Sepik river deltas have the largest areas of mangrove forest, while all coastal provinces have varying forest areas and species composition.

Global distribution

This is categorized into 6 major regions as shown on the diagram. The global biodiversity distribution on the tropical and sub tropical regions of the world is directly proportional to the temperature and rainfall regimes of each region. Generally, as we move away from the tropical areas or the equator the biological diversity declines. The area including Indonesia, PNG and Australia has the largest number of mangrove species. Indonesia leads by 45 and PNG is only second with 44. Figure 30 gives an indication of the area as species distribution around the world.

A country with a very large area of mangrove does not mean it has a large number of species; a small area of mangroves can have a large number of species. Compare in this case Brazil and PNG. A large area of mangroves with one or a few species is known as a strand.

Country	No of species		Area in km^2
Pakistan	4		1,683
Japan (only Okinaw)	11	*	75
India	28		5,370
Malaysia	36		6,424
Indonesia	45	*	45,421
Papua New Guinea	44	*	5,399
Australia (Northern)	37	*	9,695
Solomon islands	22		No data
(Vanuatu)	15		16
Fiji	9	*	517
Tonga	8		3
New Zealand	1	*	287
Columbia	11		4,975
Panama	11	*	17,008
Brazil	7		13,340
USA	6		1,990
Mexico	5		9,328

Figure 30:Species diversity verses Area. Orange shaded countries are centres of global biodiversity.

General biology

Mangroves are generally a group of marine plants. They basically occur between the terrestrial environment and the marine habitat. The Inter tidal zone is a harsh environment and exhibit a few of the following. The chemical and physical composition of the soil is very variable; the substrate is anaerobic, tidal flooding clears the forest floor from seed establishment and the lack of fresh water for the general survival. Being at the sea front, they are exposed to strong winds and wave action that can readily erode them. The specialized adaptive features of mangroves enable them to overcome and survive the extreme harsh environmental conditions in the intertidal zone.

Specialised adaptive features

Oxygen requirement

The anaerobic nature of the soils on which they grow have enabled they to develop aerial roots so that they can utilize atmospheric oxygen in contrast to their terrestrial relatives. The aerial roots for breathing come in a variety of from and may be

characteristic to the specific genera or species. The aerial roots have lenticels or breathing pore. The lenticels occur on the aerial roots, on twig, on the stem and on the seed or hypocotyls. Species that do not have aerial roots have lenticels on the twigs and stem. Examples of this are featured in *Aegiceras corniculatum* and *Excoecaria agallocha*. Certain species can display both aerial and non-aerial roots depending on where they grow in relation to the amount of oxygen in the soil. An example of this is *Avicennia marina*. This can be seen on Motupore near the start of the nature train where *Avicennia marina* grows on the sandy substrate lacking the aerial roots. The genus *Rhizophora* has lenticels on the fruits (hypocotyls).

Figure 31 provides examples of mangrove species with their typical/common root type. You are to sketch the root type in the space provided. (some species may have a combination).

Root type	Functions	Example in the species
Pneumatophores	Arial- Breathing Under substrate components- Anchorage and Nutrition	*Sonneratia alba, Sonneratia caseolaris, Xylocarpus moluccensis, Avicennia eucalipiffolia, Avicennia rumphiana, Avicennia officinalis*
Stilt-roots	Breathing Anchorage Nutrition	*Rhizophora stylosa, Rhizophora apiculata, Rhizophora lamarckii, Rhizophora mucronata*
Knee roots	Breathing Under substrate for anchorage and nutrition	*Bruguiera gymnorrhiza Bruguiera cylindrica, Bruguiera parviflora, Bruguiera sexangula*
Planks roots	Breathing Under substrate – For Anchorage & nutrition	*Xylocarpus granatum, Xylocarpus moluccensis*
Buttress	Breathing Anchorage - Under substrate for nutrition	*Bruguiera gymnorrhiza, Bruguiera cylindrica, Bruguiera parviflora, Bruguiera sexangula, Ceriops decandra, Ceriops tagal, Heritiera littoralis, Xylocarpus granatum. Xylocarpus moluccensis*
Normal No specialized aerial roots	Breathing, Anchorage, Nutrition Aegiceras corniculatum, Excoecaria agallocha (have lenticels on the stem or trunk)	*Aegiceras corniculatum, Excoecaria agallocha, Lumnitzera, Racemosa, Nypa fruticans, Osbornia octodonta, Pemphis acidula Scyphiphora hydrophyllacea, Xylocarpus rumphii*

Figure 31: Root types in mangroves. The spaces under each category in column one is for you to sketch the root type.

Fresh water requirement – Salt secretion and accumulation

In response to the lack of fresh water in the inter tidal zone, mangroves developed salt secretion glands in the leaves. The slat secreting glands in the leaves enable the mangroves to take in salt water, get rid of the salt and utilize the fresh water component for its daily requirements. Take a close look at the leaf surfaces and you should be able to see salt crystals. If there are no salt crystals there will be a moist area, taste the moisture on the leaf surface and it should be salty. The moisture is from the crystals that have melted to clear the pores for the continued salt excretion. The amount of salt secreting glands in the leaves depends on the growth zone.. There are two categories or salt regulatory mechanism. The salt secretors and salt accumulators. These mechanisms include salt secreting glands in leaves, accumulation of salt in the older leaves, when they drop off the salt is lost, some species accumulate salt in the roots while many add an extra activity by tilting the angles of their leaves to minimize heat and evapo-transpiration. Such mechanisms have allowed mangroves to be evergreen and productive year around except a few species that are deciduous.

Due to the evergreen nature the mangrove ecosystem is one of the most productive ecosystems on earth. Primary production through photosynthesis is non-stop year round, continuously making oxygen available to flora and fauna, including humans. The continuous production of leaf litter allows the detritus foot chain to be continues, making available nutrients and chemical requirements for other animals and plants.

Growth, dispersal and establishment characteristics of mangrove fruits and seeds

Vivipary

The common mangrove genera *Rhizophora* have developed special features in the seeds/hypocotyl to avoid being washed away on dropping to the forest floor. The seeds / hypocotyls are fully developed with shoot development while still attached to the parent plant. This is Vivipary or being viviparous.

The development of unique structures on the seed/ hypocotyl such as the sharply pointed tip, enables the establishment in the substrate when dispersed. The plunging into the substrate prevent the possibility of being washed or swept away by tides and currents.

The club/softball pat shape i.e. larger at the tip and narrowing to the shoot end provides natural buoyancy. The enables the hypocotyl to be upright (shoot up) and floating during dispersal, allowing the pointed tip to establish in suitable substrate and quickly produce roots. Prolonged periods of floating and the non-availability of suitable substrate will deny the growth of propagules.

Cripto vivipary

Mangrove species with seed coats, protecting the developing seeds are called crypto viviparous. The seeds are also fully developed with roots emerging, but are covered with a seed coat to prevent them from physical damage The seed coat splits while still hanging on the tree or breaks on falling impact to disperse the developed seeds. These crypto vivipary species are usually found at the landward zones or tidal creeks of mangrove forest. The exception is *Avicennia eucalyptofolia* which occurs in all zones. Examples of these are *Xylocarpus moluccensi* (*australiasicus*), *Xylocarpus rumphii*, *Avicennia eucalyptofolia*, *Avicennia rumphiana*, *Avicennia officinalis*.

Increased survival of these species is achieved by:

- The production of many seeds in a single fruit.
- The production of numerous individual fruits with individual seeds.

Normal fruits and fruits

The species with normal seeds like land plants include the following. *Excoecaria agallocha*, *Heritiera littoralis*, *Pemphis acidula, Scyphiphora hydrophyllacea*. *Sonneratia alba, Sonneratia caseolaris Aegiceras corniculatum Lumnitzera racemosa, Osbornia octodonta* and *Nypa fruticans* (wild sago palm) having the strongest seed coat, but can grow in a number of zones.

Phenology

Phenological studies involve knowing the time between flowering and fruiting, to fruit maturity and dispersal of the various species. This is important for the classification of mangroves species and particularly the collection of mature seeds for planting. Phenological data on the preliminary studies of the mangrove species that occur in the Bootless Bay area is presented later.

Various types of flowers, fruits and seeds in Mangrove species

Mangrove flowers, fruits and seeds come in a variety of colors, arrangement, shape and sizes. A number of examples are provided. You will only observe some in the field, depending on it's phenology Some are seasonal while others are continuous year round.

Mangrove ecology

Zonation

The specific adaptive features of Mangrove species you saw earlier with the preferred physical setting of the habitat should by now give you a picture of the likely growth habitats various families, genera or species prefer. This is known as zonation. The inter tidal zone can be divided to three main categories as shown in the diagram below.

- Sea front – submerged on most tides
- Middle – between sea shore and land – only submerged by medium and high tides
- Mangrove back – only covered by spring or very high tides.

The above distribution or zonation by mangrove correlated with the level of tidal flooding, duration of being submerged, soil, substrate type, amount of salt in the water, salt concentration in the soil/ substrate, amount of fresh water input, climate, the geomorphology and substrate/soil characteristics. This include pH and availability of air/oxygen in the soil. Aerobic and anaerobic.

Identifications of mangrove to the generic or species level

Unless you are an expert, the identification of mangroves utilizes a KEY. The key takes into account the structural arrangement of the leaves, flowers, roots and other features for identification. The easiest is the use of a colour pictorial guide.

An example of the taxonomic classification of a particular mangrove is as follows:

Division: Magnoliphyta (flowering plant)
Class: Magnoliopsida
Order: Rhizophorales
Family: Rhizophoraceae
Genus: Rhizophora
Species: stylosa
Scientific name: Rhizophora stylosa Griff.

Common name: Spider mangrove

The values of Mangroves and Mangrove Ecosystems

The value of mangroves and mangrove ecosystem can be put into two divisions. These are the direct and indirect values. The uses and values are environmental, economic and social. Some of this is outlined in Figure 32.

Value	Direct	Indirect	Environ-mental	Socio-economic
Human uses - food, timber, fire wood, crafts, medicine, aquaculture, charcoal, medical, furniture, dyes, shell fish and lime production, thatch, fencing, honey, woodchips and paper, boats and canoes	☺			☺
Coastal protection - erosion prevention, substrate stabilization, wind break i.e. Reduction of in the severity of coastal storms, wave and flood damage		◆	◆	◆
Buffer zone- protection of sea grasses and coral reefs through silt trapping - Protect coral reefs and sea grass beds i.e. Maintenance of coastal water quality		◆	◆	◆
Fisheries-Breeding and nursery grounds for many fishes and invertebrates and fishing ground for man i.e. Nursery and feeding grounds for commercial and artisanal fisheries	☺	◆	◆	◆
Habitat for other organisms - fishes, bats, birds, lizards, insects, other plants both benthic and pelagic		◆	◆	◆
Carbon trade - carbon sink, take in carbon dioxide and give out oxygen - ever green nature makes it a highly productive ecosystem year round	☺	◆	◆	◆
Litter production and bio chemical cycles - detritus cycle continues - ever green nature makes it a highly productive ecosystem year round		◆	◆	
Continual photosynthesis and primary food production		◆	◆	◆
Utilize for ecotourism				◆

Figure 32: The values of mangroves.

LECTURE 6.2: MANGROVES – THREATS, MANAGEMENT AND RESTORATION

How man degrades mangrove ecological systems

- Indiscriminate and unsustainable removal or harvesting, Removal for settlement
- Used as rubbish dumps – oil pollution from ships and spills, industries and silt from mining
- Construction of roads, causeways, wharves and jetties, seawall through or by removal of mangroves
- Land reclamation, construction for tourism facilities, poor drainage leading to increased soil salinity
- Pollution (types) – chemical spray in the Vietnam war, Siltation from roads and construction and agriculture near and up stream from mangroves, Human sewerage, urban and industrial effluents leading to oxygen demanding wastes, Agriculture – Discharge and spraying of pesticides and herbicides, heavy metals.
- Lack of educational awareness on the importance and the ecological functions
- Population pressure

Natural causes that degrade mangroves

- Sea level rise resulting from the green house effect and climate change
- Drought
- Storms, tsunamis, volcanic activity
- Soil erosion
- Diseases
- Natural die back

Educational awareness

Management of humans through educational awareness is the best tool for the conservation, sustainable use and management of mangroves and the mangrove ecosystem, the importance and the ecological functions

Restoration as a management tool – the mechanisms involved in replanting degraded or new areas

- Community involvement and participation leads to success with community based management such as size restrictions, taboos, harvestable amounts in an given period – size restrictions i.e. carapace length of mud crabs, female mullets with eggs, seasonal taboos
- Survey of the current status

Rational and or the objective (s) by the community for replanting or planting

►Fire wood ►Prevention of coastal erosion ►Prevention of riverbank erosion ►Wind break ►Timber for construction ►Buffer for silt prevention in order to control water quality of the coastal waters for the health of sea grass beds and coral reefs ►Aesthetic value ►Food certain species ►Habitat for other animals and plants marine, aquatic and terrestrial ►Degraded areas► New areas ►Seawalls stabilization ►Stabilization of reclaimed land

Conservation – steeps to take and the possibilities available

- Enforcement of guidelines, rules and policies
- Management of food resources
- Thinning of natural re-growth seedlings - practical

- Rotational harvesting 15-30years
- Control of activities up stream or in the catchments area
- Educational awareness

Surveys before any restoration activities

- Socioeconomic and biological surveys will help point out the problems faced by the community and allow for the most appropriate method to be applied.
- The standing stock, forest structure, species distribution, available of seedling or good propagates and wild seedlings.
- Depending on the community objective – carry out species site matching
- Explore the possible method of restocking – direct from seeds, from wild seedling and from nursery reared seedlings. – The costing and the advantages need to be highlighted
- Site preparation
- Planting
- Care and maintenance during and after planting – thinning, replace ones that are damaged or have died

Research and Monitoring the various techniques and application

Monitoring programs, and more specific environmental, ecological and socioeconomic monitoring are done to ensure the mangrove ecosystems are conserved and managed. Many environmental factors influence the distribution, diversity and productivity of mangrove ecosystems. Some of these include climate, geomorphology, tidal range, fresh water input, and soils characteristics. Any survey or research in mangroves need to take into account the environmental parameters and conditions existing at the site at the time of data collection. A variety of methods are available to study the environmental characteristics and community structure of mangrove ecosystems, at varying levels of details depending on the time, manpower and budget.

Study of mangrove community structure

Angle count cruising method

The instrument known as the relascope, that is similar to the one used by land surveyors (For details refer to English et al. 1994). This method estimates the basal stem density of mangrove trees per hectare. It is a plot less method, in that it does not sample a specific, known area of forest. A 360-degree turn is made and the trees that fall within the given scale are recorded.

Advantages	Disadvantages
Quick on a large area	Plot less and none permanent
Less time	Not often used
	Need measurements in DBH for confirmation

Transect line plots method (A practical plot / transect measurement)

This method provides a quantitative description of the species composition, community structure, and plant biomass of mangrove forest. Plots are established along a transect in any given areas or along the various zones or along the entire inter-tidal zone. This method can provide the information on changes in forest structure and growth to soil, climate and tidal hydrological factors. Permanent plots can are established for long term monitoring of changes in forest structure, biomass and growth over time.

Measurements of Girth at Breast Height (GBH) or Diameter at Breast Height (DBH) .The measurements of GBH or DBH assesses the density of species, basal area dominance of particular species and the probability (frequency) of occurrence of the various species along or throughout the plot.

Advantages	Disadvantages
1. Simple equipment - tape measure, transect line rope	1. Very time consuming
2. Establishment of permanent plots	2. Frequency measurements is a function of plot size lager plots = lager frequencies therefore frequency comparison can only be made between plots of similar size

Local topography and hydrology

This technique provides a description of the local topography with respect to tidal inundation (flooding) and drainage patterns. The water level at the peal of the tide is marked to determine the frequency and duration. This is important in determining the zonation, distribution and species composition of the mangrove forest.

In general the inter tidal zone can be divided into three main categories low, mid and high inter tidal areas or zones.

Primary Productivity in Mangrove forest

Measurements of light absorption by the forest canopy are used to estimate the leaf area, photosynthetic production or the rate of photosynthesis per unit area. This method is useful for comparison of different forest types, distribution and for monitoring forest change over time. This technique does not measure the net primary production.

Tidal Flooding /Inundation and Mangrove Soil studies

Soil characteristics directly influence mangrove productivity and structure. These methods deal with physical and chemical properties of soils, such as pH (hydrogen ion concentration), Eh (Redox potential), salinity, and particle size.

Mangrove soils are waterlogged and anaerobic. Part of the detritus food cycle takes place through the process called oxygen-reduction (redox). The redox potential (Eh) is the measurement of the reducing power.

Species composition and growth of mangroves is directly affected by the physical composition of mangrove soils. The proportions of clay, silt, and sand, together with the grain size, dictate the permeability of the soil to water, which influences soil salinity and water content. Nutrient status is also affected by the physical composition of the soil, with clay soils generally higher in nutrients than sandy soils.

pH acidity

The acidity influences the chemical transformation of most nutrients available to plants. Good soils have a ph vale of between 6 and 7, which is neutral. Lower than 6 are acidic. Acidic soils do not readily allow the transformation chemical nutrients to plants.

Salinity

Soil salinity affects the growth and zonation of mangrove forest. The majority of mangrove species grow best in low to moderate salinities (25ppt). Different species are able to tolerate different levels of soils salinity.

Other topics

- Phenological
- Biodiversity
- Ecological
- Monitoring – Actual surveys, aerial photos, remote sensing

Key to the identification of mangroves from the Bootless Bay area

1. Leaves simple, with only one blade on each petiole → 2

1. Leaves compound, with several leaflets on each petiole, leaflets pointed to ovate, tree, deciduous between June and July, seeds normal type, round guava like, Pheumatophores present → *Xylocarpus*

2. Leaves alternate, with only one being found at any one place on the twig → 3

2. Leaves opposite, with the leaves in pairs, one on each side of the twig →7

3. Leaves with a distinct notch at the tip, small tree or shrub, flowers white, small seeds less than 2cm in length and width →*Lumnitzera*

3. Leaves rounded or pointed at the tip → 4

4. Petiole longer than the leaf blade. Base of the petiole visibly clasping the twigs, when the Shrub leaf drops off a ring like scar is left on the twig no more than 1m tall, growth at sea front in strand or individuals on rock/gravel substrate, no pneumatophores, soft ball bat like stem, Flowers are green and when open has 5 white petals, the seed is less than 5cm long and less than 3mm wide, red brown when mature → *Aegialites annulata*

4. Petiole shorter than leaf blade. Petiole without a clasping base → 5

5. Leaves quite large, silvery on the underside, tree rough looking, buttresses roots, flowers purplish, normal green seeds in bunches turning brown at maturity, normally grow at the back of mangroves and along the edges of creek or river banks → *Heritiera littoralis*

5. Leaves smaller, underside is green, tree or shrub not rough looking → 6

6. Tree with milky sap on the stem or leaves, leaves green and turn to red in preparation to drop off

(deciduous), flowers yellow, seed 3 lobed green and turn to black when ripe, usually at the back of mangroves and along tidal banks, no pneumatophores → *Excoecaria agallocha*

6. Shrub or small tree no taller than 4meters, green leaves slightly curves on the underside, no pneumatophores, white flowers, seed small chilly or banana shaped, green and turn red brown at maturity → *Aegiceras corniculatum*

7. Simple small leaves that are notched at the tip, when crushed gives a strong pleasant smell. The petioles and twigs are reddish, small tree or shrub, no pneumatophores, bark thick woolly, flower small white, seed ice cream cone shaped less than 1.5cm, turns yellow brown when mature, growth usually on sandy or rocky soils at the sea front → *Osbornia octodonta*

7. Leaves rounded or pointed, petioles not red, no smell when crushed → 8

8. Buds at the very end of the twigs blunt → 9

8. Buds at the very end of the twigs long, flattened, pointed and slightly twisted → 11

9. Simple leaves dark green to yellowish-green and shiny above but more or less gray woolly below, the two sides of the leaves are distinct, pencil like Pneumatophores, widely distributed, all zones, small, yellow flowers, seed hairy/wool like and shaped like a heart, green to yellow in color, usually strand formation → Avicennia marina

9. Simple leaves, green with both side about the same → 10

10. Leaves not shiny, often thick and fleshy, rounded or ovate, flowers white, seed or fruit round sitting in a star shape 6 calyx cup, distinct network of Pneumatophores that are large like an upside down ice cream cone, covering a large area → *Sonneratia alba*

10. Leaves sticky and shiny when young. Petiole about 0.5cm long. Trees. Growth on mangrove back or along river banks. No Pneumatophores, flower small white, fruits no more than 1cm long and gear-like, green and turning brown when ripe → *Scyphiphora hydrophyllacea*

11. Tree with aerial prop roots, sea front, unopened flowers 2-16 on inflorescence bunch, white and hairy when opened, seeds vivipary, calyx 4-lobed, hypocotyls averaging 30 cm long, sharply pointed, most common at the sea front → *Rhizophora stylosa*

11. Tree with prop roots, sea front or at the back of the *R. stylosa* zone, flowers in pairs, yellow brown when un opened short stalk, hypocotyls blunt at the tip, average length 28cm. Slightly curved, calyx 4-lobed pointing up wards → *Rhizophora apiculata*

11. Tree with aerial prop roots, flowers from 1-2 (4) rare, hypocotyls up to 50 cm, the longest and biggest amongst the *Rhizophora*, sharply pointed → *Rhizophora mucronata*

11. Tree, extensive prop root system, sterile, rarely forming hypocotyls, flowers 2-4, back of mangroves and along river or tidal banks → *Rhizophora lamarckii*

11. Tree without prop roots, Calyx 5-16 lobes → 12

12. Shrub or small tree no more than 5m, Leaves yellowish green, rounded or slightly notched at the tip. Calyx 5- lobed, hypocotyls 10-20cm long, angled down the side, green but turn brown when mature, yellow seed collar when ripe, hypocotyls hang down, common at the mangrove back in strands and along tidal creeks → *Ceriops tagal*

12. Shrub or small tree, Leaves yellowish green, rounded or slightly notched at the tip Calyx 5- lobed, hypocotyls 10-20cm long, forms a smooth cylinder without ridges or angles → *Ceriops australis*

12. Shrub or small tree no more than 4m tall, leaves yellowish green, rounded or slightly notched at the tip. Calyx 5- lobed, hypocotyls 5- 12 cm long, pointing upright, seed collar red to yellow when ripe, usually form strands, back of mangroves → *Ceriops decandra.*

Glossary of terms

Axil: The place where the base of the leaf joins a twig or branch
Axillary: Arising from the axil
Apex of leaf: Tip of the leaf blade
Acute: Tapering to the tip of leaf see leaf apex type
Blade: Thin, flat part of the leaf
Buttress: Downward sloping radial projection from lower part of the tree trunk
Calyx: The outer envelope of the flower, ring like usually green just below the flower stalk
Compound: More than one see for leaves as in Xylocarpus or a coconut frond
Collar: The neck as in hypocotyls
Ecosystem: The complex of a biological community and its environment functioning as an ecological unit in nature, with exchange of matter and

energy amongst the members of the community and with the environment
Family: A group of related genera
Genus (Genera): A group of related species
Gland: A secreting surface or structure
Habitat: The kind of place or places where a plant or an animal lives
Hypocotyls: The part of the seed –see the family Rhizophoraceae
Inflorescence: The arrangement of flowers on the twig
Knee roots: See root types
Leaflet: One of the leaf of a compound leaf
Lenticel: A place on the root, stem, twig or seed containing air pores for breathing
Ovate: Egg-shaped in outline
Petal: Flower part –see flower structure
Petiole: The stalk of a leaf. See leaf structure
Phenology: Complex cycle in flowering-fruiting to seed maturity and seed dispersal in a given period of time
Plank roots: See root types
Pneumatophores: Roots that stick out of the soil and are adapted for breathing. They have many lenticels and are finger-like to knee type -- See root types
Shrub: A woody plant smaller than a tree
Simple: see leaf type
Species: A term for all the individuals of one kind that is able to inter breed
Stilt root: Also know as prop root sees root types
Sterile: Infertile, unable to produce seedlings
Substrate: Material on which plants grows. E.g. soil, rock, sand, mud and gravel
Viviparous: Germinating seed that is still attached to the plant as in the family Rhizophoraceae
Water-logged: The soil is waterlogged when all the spaces between soil grains are full of water and there is no air in the soil.

A sample data collection sheet
[For practical exercise on transect /plot measurements]

Location:							
Site:			Temp:			Soil Eh:	
Date:			Soil type:		Soil pH:		
Time:		Salinity (%):			Name of data collector:		

Transect No.	Plot No.	Tree species code	DBH (cm)	Sapling species code	DBH (cm)	Seedline species code	DBH (cm)
NB: Tree = D > 4 cm; Sapling = D < 4 cm, H > 1 m; Seedling = H < 1 m							

Figure 33: Sample data collection sheet

CHAPTER 7: SAMPLING DESIGN AND DATA ANALYSIS

This manual was adapted from manuals written in the past by U.L. Kaly, G.P. Jones and N. Molschaniwskyj for James Cook University of North Queensland, New Zealand Development Assistance (NZAID) and Forum Fisheries Agency (FFA), © Kaly, Jones & Moltschaniwskyj 1994, 1995,1996, 1997. Some of the case history data and examples are the intellectual property of Asian Development Bank, SPREP and the Tuvalu and Vanuatu Governments.

INTRODUCTION

Sampling and monitoring are central tools for the effective adaptive management of natural resources and ecosystems. Taken together with sound ecological information, sampling provides the basis from which strategies aimed at sustainable use of our natural resources and services (e.g. pollution attenuation) can be derived and assessed. A well-designed sampling / monitoring programme can:

- Identify existing conditions (usually termed baseline) in an area of focus. This may include stock assessments or the condition of ecosystems;
- Provide information on possible sources of problems (such as pollution, over exploitation, habitat destruction);
- Provide on-going information on changes in ecosystem health through time allowing for arrest of degradation; and
- Determine whether management strategies have been effective.

Although some resource and environmental monitoring is being carried out in PNG, it is often on an *ad hoc* basis, usually carried out to meet specific short-term objectives. There is a clear need for more strategic sampling and long term monitoring designed to meet the four objectives listed above for adaptive management of resources and ecosystems in the country. One of the many reasons that this work is only just beginning, has been a shortfall in technical expertise required to design and implement integrated sampling and monitoring programmes.

This part of the Marine Training Course has been designed to cover the most important aspects of the design of sampling and monitoring programmes, how to avoid traps and deal with, analyse and interpret the information that is collected. The work will include lectures, discussion, laboratory and field sessions over 5 days, and aims that at the end of the course you will be able to undertake surveys. The main topics we will cover include:

1. Introduction: Services you will be able to provide, skills you will need
2. Green's Rules for sampling designs
3. How to optimise sampling and monitoring designs
4. Data handling & storage
5. How to analyse the results of surveys (statistics)
6. How to present results.

EXPECTED BENEFITS AND OUTCOMES

By the end of this part of the course, you should be able to:

- Design and carry out a sampling or monitoring programme
- Adapt your knowledge to a range of marine habitats, resources and situations
- Store, examine, analyse and interpret data. Report the results to others; and
- Work with others similarly trained to carry out surveys in the future.

LECTURE OUTLINE

Lecture 7.1: Introduction to sampling and statistics
Lecture 7.2: Green's Rules for sampling designs
Guest Lecture: Case histories
Lecture 7.3: Introduction to statistics: The description of data
Lecture 7.4: Statistical distributions and knowing when means are different
Lecture 7.5: Optimising a seagrass sampling design
Lecture 7.6: Data Analysis
Lecture 7.7: Storing and presenting data

Working groups: Design a Sampling programme

On Day 4 of this module of the course you will be asked to separate into small working groups to use the information you learned during the first few lectures to design a monitoring programme. This exercise will centre on one of a range of case studies we provide, or on a programme you are already involved in or know about. This will give you practice in going through the steps to developing an appropriate design. Each group should work through the topics provided below as a guide to their discussion and then prepare to report back to the course with a 10 minute presentation showing how you solved the problem, and where you think more information is needed. The discussion should take you about 1.5 hours.

In designing your monitoring programme please consider the following topics.

1. What kind of study is this? Is it for resource assessment, environmental management, to test the effectiveness of a management action (e.g. marine reserve), is there to be repeated monitoring to examine changes over time?
2. What is the overall aim of your sampling / monitoring programme?
3. What are the specific questions you would set up for yourself? Hint: break the question up into all of the various factors you would set the design up to measure. Consider time, treatment (e.g. reserve vs. open access), habitats, sites & locations etc.
4. Looking at the map provided, and using your knowledge of the area (if you are dealing with a case you know), would you divide the area of interest into a number of ecologically distinct parts? Are there different kinds of broad ecosystems? What are they?
5. If you have divided your area into different parts, how would you go about sampling to characterise each? That is, how would you choose locations and sites and distribute your sampling effort?
6. How much replication would you use?
7. What kind of pilot work is required?
8. Construct a design tree for your monitoring programme (Hint: this is an important step that will help you to see the design and effort that will be required and should never be missed)
9. What measurements would you actually make? List them all and explain why you would make those measurements (Hint: how do they relate back to your original questions?)
10. Are there any special measures or species you would include because they are of ecological, social or economic importance?
11. How much work is involved? That is, is your design within the capabilities (time, resources, money) of the project? (Let's say you have roughly 20,000K per survey – this means you can't hire a huge vessel or take an endless amount of time. The point here is to keep it real).
12. How often would you repeat your sampling if it is a monitoring programme?
13. Check off all of Greens Rules. Are there any for which you need more information?

You may use the board or overhead projector facilities to illustrate your working group's points to the rest of the participants. By the end of this session, everyone will have had the chance to consider designs for a wide range of common project types.

Examples

(Figures 34-37)

Example 1: Assessment of the sea cucumber stock around New Hannover, New Ireland Province

Example 2: Effectiveness of a Marine Conservation Area at Motupore Island, National Capital District

Example 3: Adaptive management of *Trochus* resources in Madang Lagoon, Madang Province

Example 4: Long term monitoring of seagrass health and cover around Motupore, Lion and Loloata Islands, National Capital District

Example 5: Distribution and abundance of corals around Kimbe Bay, West New Britain Province.

Figure 34: Example 1 Assessment of the sea cucumber stock around New Hannover, New Ireland Province

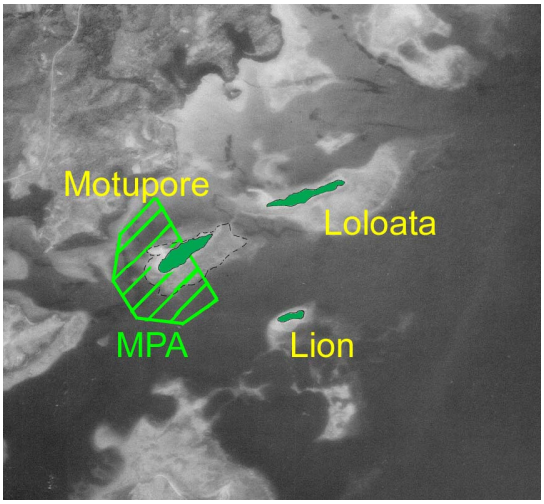


Figure 35: Example 2: Effectiveness of a Marine Conservation Area at Motupore Island, NCD

Figure 36: Example 3: Adaptive management of Trochus resources in Madang Lagoon, Madang

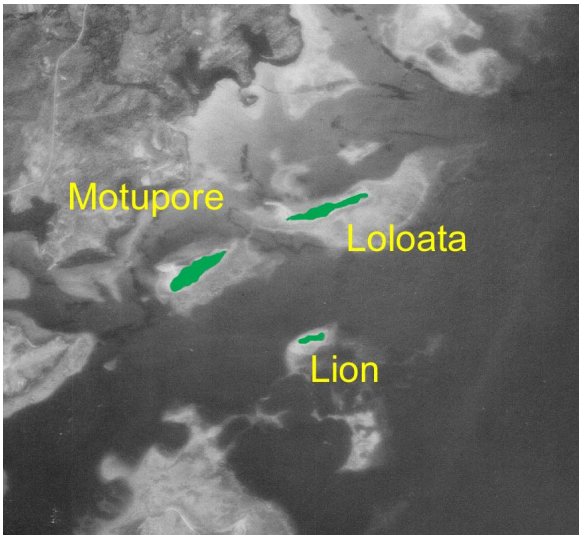


Figure 37: Example 4: Long term monitoring of seagrass health and cover around Motupore, Lion and Loloata Islands, NCD

LABORATORY NOTES

LABORATORY 7.1: USING EXCEL SPREADSHEETS

In this exercise we will create a spreadsheet to receive and analyse some data on fish abundances collected in the lagoons around Port Vila, Vanuatu, which are very similar to the species and habitats in PNG. In the process you will learn a lot about how to use the program, and be able then to construct your own databases for analysing future sampling / monitoring data.

IMPORTANT NOTE: Things you should type will appear in these notes in BOLD while keys to push appear as either ALT+ENTER to mean push these keys simultaneously, or ALT, ENTER meaning that they should be pushed one after the other. Mouse commands will be operated by clicking once or twice in quick succession (double click) on a screen symbol (or "icon"). Some mouse commands also use the right mouse button, instead of the usual left one. LHS = Left hand side; RHS = Right hand side.

These notes assume you are using Windows 2000 or later, and EXCEL 2000-2002.

1. Start Microsoft EXCEL

Click on Microsoft EXCEL from your START, PROGRAMS menu or double click its icon if you have a shortcut on your desktop.

2. About the worksheet

The worksheet that automatically appears before you has thousands of rows (labelled as numbers on LHS of the window) and 256 columns (labelled as letters on the top) – the number of rows and columns is limited in later versions of this program only by the available memory . On any worksheet the ACTIVE cell is the one surrounded by a dark border - this is the only cell that is available for data or formula input at any one time. Each cell is referred to by its co-ordinate address, e.g. cell A1 is the top left hand cell in the spreadsheet. Only a small part of a spreadsheet is visible on the screen at any one time, but you can easily scroll through to any part of it by the following methods:

(a) Use the cursor keys to move the active cell around. Try this now.

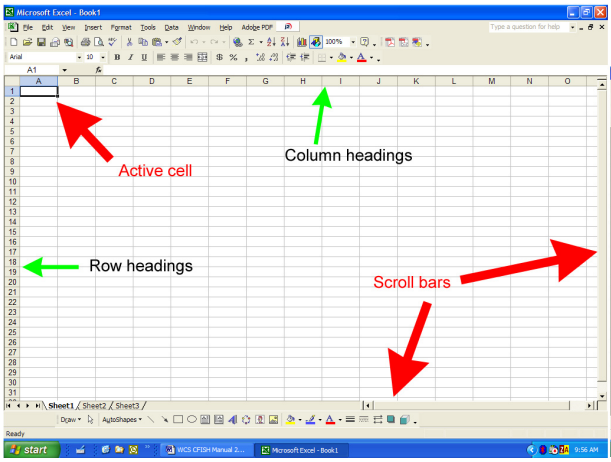
(b) Click the mouse pointer on the scroll arrow (the pale bar to the far right and bottom of the screen) that points to the direction you want to go.

(c) Click the mouse on the scroll box, hold the click down and move the box to the position you want to move to (the scroll bar is a relative indicator of where you are in a spreadsheet).

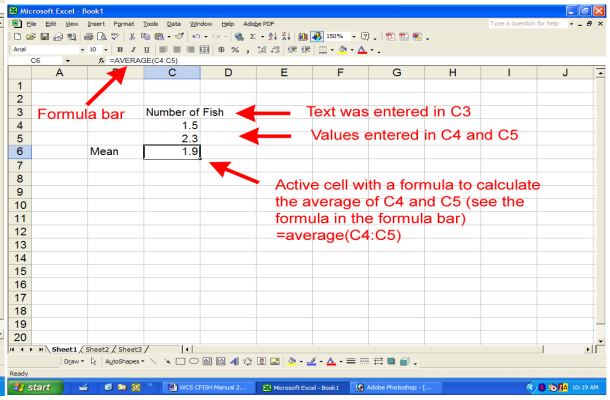
(d) Click within the scroll bar itself and the spreadsheet will move a window's worth at a time.

3. Entering text, formulae and data

All text, numbers and formulae are entered into cells. By entering values into some cells and formulae into others, we are able to do simple up to quite complex calculations. Additionally, once data have been entered into a sheet, small programs included in EXCEL can be used to calculate statistics. Before you enter information, you must first select the cell you are going to work with. Data in cells can be much longer than the cell shows, and appear in the formula bar at the top of the screen, the address of the current active cell is always displayed on the far LHS of the formula bar. The important point here is that all cells are capable of taking either text, numerical or formula information and can be referred to for doing calculations.



Select cell A1 by moving the mouse pointer (shaped



as a cross whilst inside the spreadsheet) into the cell and clicking once. Type: DATA SHEET FOR EXERCISE 1 - Fish survey Port Vila Lagoons, Vanuatu

Select cell A3 and type: DATE

Select cell B3 and type: LOCATION

Select cell C3 and type: SITE

Select cell D3 and type: HABITAT

Select cell E3 and type REPLICATE

Select cell F3 and type TOTAL

You can also automate your sheet so that it prints out the current date (and time if you like). This is useful when you want a hard copy of your data - it lets you keep track of which draft you are on because it constantly updates according to the computer's clock.

Select cell A2 and type: =now()

This is a formula function - we will deal with these in detail later. If the date and time are incorrect, you will have to reset the computer's clock using the windows control panel from the Windows Main Menu (click on Control Panel and then Date and Time - type in the correct date and time in the dialogue box that appears). If the date/time appears as ###### your column is not wide enough to display all of the text. Simply adjust the column widths - see section 5(b) of these notes to find out how.

If you make a mistake entering data into a cell you can:

(a) backspace within a cell

(b) move off the cell, and go back to it and start again as if it were empty, press return to make the data enter the cell, or simply move off it by clicking elsewhere or using the cursor keys.

(c) clear a cell of all by selecting it, choosing EDIT with the mouse, then CLEAR, then ALL, the cell is now back to empty. You can clear just the data (but keep the formatting) by selecting the cell and pushing DEL.

Save your data spreadsheet using the FILE, SAVE AS command in the menu. Use your name in the filename if you are going to keep it on the hard drive:

i.e. save as:

a:\Portvila fish data.xls

or

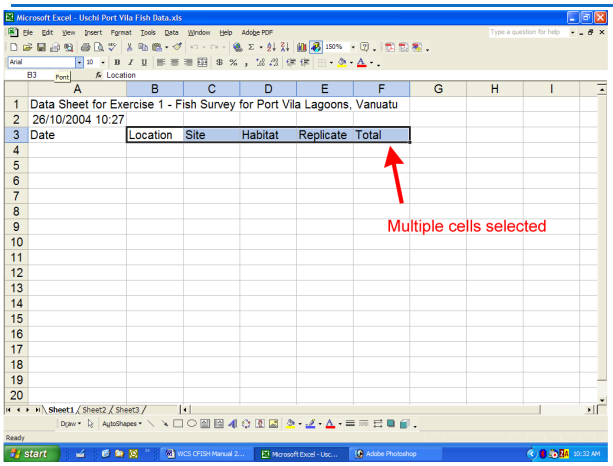
c:\yourname Portvila fish data.xls

We are going to use some real data collected from Ekasuvat, Emten, Eratap and Tapi Lagoons for learning how to use the spreadsheet and graphing functions in EXCEL. The data are fish counts collected during Jan/Feb 1998 from 16 sites (spread in the four lagoons) and two habitats. The habitats are mangrove fringe and sandy-bottom channel area. There were 5 replicate 5 minute timed counts of fish abundances using visual techniques surveyed at each combination of habitat and site. The counts included acanthurids, siganids, gerreids, mugilids, mullids, lethrinids and chaetodontids to a total of 81 species. These data on total abundances are provided for this exercise for the purpose of training - you should be able to apply the techniques you learn here to storage and analysis of the monitoring data you will be collecting, regardless of whether it is of fish, coral, sea cucumber, water quality or other information. You should enter the fish data now under the headings you set up in your spreadsheet, till the sheet looks like the one at the end of this section of the manual.

Please enter all data now. Save your data using the FILE, SAVE command, or by clicking with the mouse on the disk icon in the menu bar.

4. Selecting multiple cells

You can select multiple cells to move data around, format text etc. easily with the mouse. Click the mouse onto a cell on some corner of your intended selection. Holding the mouse button down, drag across the cells to be selected. Do not let the mouse button up until you have the selection right. If you make a mistake you will need to re-select or use the EDIT, UNDO command. Selected areas of the spreadsheet appear darker, except for the top left cell. You will need to select cells before you can copy and paste, delete, format, border or move the data they contain. That is, highlighting is your way of telling the program which cells are to be



manipulated before you tell it in what way you want them changed.

MOVING DATA: To move data you must first select it (i.e. highlight it). Then you can either:

(i) Use the cut and paste commands. Choose EDIT, CUT. A moving border appears around the cells you selected. You then select the top left hand cell of the destination for your data and choose EDIT, PASTE. You could also try using EDIT, PASTE SPECIAL which allows you to move over only the values, or formatting etc.

(ii) Use the drag and drop function. This is the easiest way to move cells around on your screen. Highlight the cells to be moved, then move your mouse pointer onto any border of the selected cells (except the bottom right where a small box appears). Click with the mouse and, holding the mouse button down, drag the whole selection across to wherever you want it, release the mouse button. All of the contents of the cells, including any formulae and formatting will have moved to the target position.

5. Formatting the spreadsheet

The formatting commands can be used to highlight specific bits of information, make entering data easier or can be used to make tables which can be printed out complete with boxes, shaded borders and different column or row widths. Formatting can also be used to control how the text appears, or to control add-ons for numbers such as $, % signs, number of significant figures, alignment of text and date/time.

Formatting text:

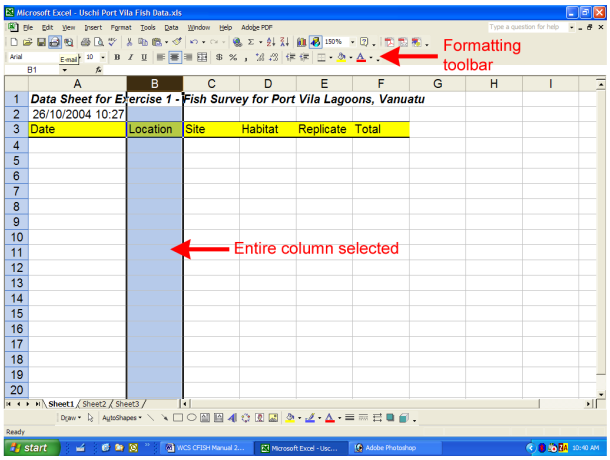
(a) FONTS: Select cell A1. Choose FORMAT, CELLS, FONT using the mouse. Click the box marked BOLD and ITALIC to format the title of your spreadsheet. Alternatively, simply select the cell and click on the formatting icons in your toolbars.

(b) COLUMN WIDTHS: Move your mouse marker to the cell label divider between A and B on the top of the spreadsheet. Click and hold the button as you drag the divider to the left and right to change the width of the column. Settle on an appropriate thickness for each column that allows you to read its contents comfortably.

(c) FORMATTING NUMBERS: Select the cell or multiple cells to be formatted, then choose FORMAT, CELLS, NUMBER and enter the number of decimal places as 2 to round the numbers to two values after the decimal point. If you only wish to display whole numbers, enter 0 instead.

(d) ALIGNMENT (e.g. centering) OF TEXT OR DATA: Select a column by clicking on the letter that labels it (e.g. column B etc...). Choose FORMAT, CELLS, ALIGNMENT, and then select how you want the text aligned either horizontally or vertically using the drop-down menus. Alternatively, you can simply click on the centre alignment icon in the formatting toolbar.

(e) BORDERS, BOXES AND SHADING: Make your table easier to read by selecting rows or columns of blank cells in the right places and filling them with shading. For example, select cells B3 to F3, choose FORMAT, CELLS, PATTERNS, and choose a shade. You can also choose a shade by clicking on the icon in the formatting toolbar. Line borders can be erected around individual cells or groups. Select cells A3 - F3 (remember, do this by selecting cell A3 and holding down the mouse button, drag the mouse over to cell F3 and then release the mouse button). Choose FORMAT, CELLS, BORDER, OUTLINE, or choose particular bordering options.



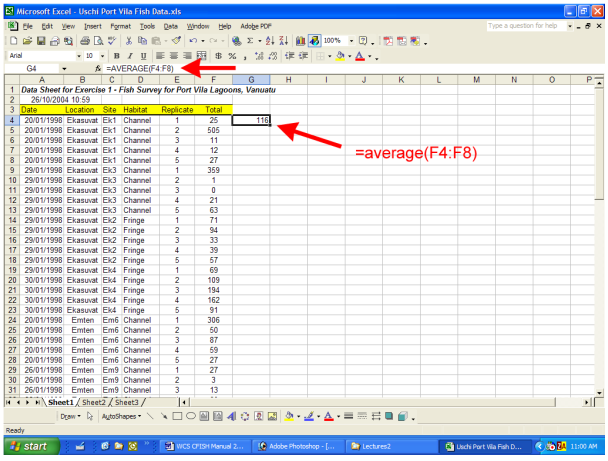
Spend some time now making your table easy to read.

(Hint: Many of the border and other formatting commands have been assigned icons in the menu bar. This means that you can access them very easily by simply selecting the cells and clicking on the icon. For example, **B** and *I* give you BOLD and ITALICISED text, A lets you change the colour of your text).

Save your data now.

6. Entering a formula

All data you will be collecting for surveys and monitoring will need to be summarised and analysed before you can interpret them. The EXCEL spreadsheet is a very powerful system for summarising the data. In this exercise, we will calculate the mean (average) number of fish recorded at each site and habitat, the standard deviation, and the standard error and then the mean and SE of fish counts summarised for all the lagoons at Vila so that we can compare them. We will also see how, once the formulae have been written into the spreadsheet, we can automate calculation of these values for a lot of data with ease.



A mathematical formula can be entered into a cell and told to draw information from any other part of the spreadsheet (or even another spreadsheet) to perform an operation. The way to bring in data from elsewhere is to refer to it by its cell identification (e.g. A3, B12, etc...). Alternatively, you can use any cell as a simple calculator. Try the following:

(a) CALCULATOR: select cell H1. type **= 5 + 5** The answer 10 will appear in the cell after you've pushed return or moved off the cell. Erase what you've just done in that cell, we don't want it in the spreadsheet: reselect cell H1, choose EDIT, CLEAR, ALL. Alternatively, just push DELETE.

(b) CALCULATING A MEAN (average): Select cell G4. type **= average(F4:F8)** In this case, after we push ENTER or move off cell G4, we will have calculated the average number of fish recorded in 5 timed counts censused in the channel habitat at Ekasuvat Site 1 (Ek1). Note: "average" is a built-in function and will calculate the average of the range of cells specified, without including blank cells. Therefore, when you enter the data, if you mean zero do not leave a cell blank, you will have to actually enter a zero. EXCEL reads F4:F8 to mean F4 to F8. There are alternatives:

(i) you could type **= average(F4, F5, F6, F7, F8)** which in this case would be the hard way to do the calculation, but in some cases may be worth it; or

(ii) type = average(F4:F8) to encompass a continuous range of cells (won't work if some numbers are in different places!; or

(iii) select cell E4 and type **= average (**then move your mouse to cell F4 and holding the button down, drag the dotted envelope which appears on the screen down to cell F8. Release your button and the range F4:F8 will have appeared in your formula. Simply close the formula off with a **)** and the formula will be entered. This is useful for very large sums and selections.

Calculate an overall mean for the whole survey in Cell F2.

(c) CALCULATING THE STANDARD DEVIATION: Select cell H4. Type the formula: **= STDEV(F4:F8)**

HINT: Label each new row with the calculations so that you know what they are. For example in Cell G3 type **Mean**, in Cell H3 type **SD** or **S**.

(d) CALCULATING THE STANDARD ERROR (SE): Select cell G3 and type the heading **SE**. In cell I4 type the formula: **= STDEV(F4:F8)/sqrt(count (F4:F8))** This, at first complicated-looking formula, calculates the SD for the range specified, and then divides it by the square-root of n (the number of observations). Alternatively you could have typed **= H4/sqrt(count(F4:F8))** because we already worked out the standard deviation S in cell H4!

Some of the functions built-in to excel include the following:

- STDEV() = sample standard deviation
- AVERAGE() = mean
- COUNT() = number of non-blank values in the specified range
- SQRT() = square root
- SUM() = sum of values in specified range
- ^2 = squared
- * = multiplied
- / = divided
- + = plus
- - = minus

(Hint: You can use the INSERT, FUNCTION command to bring up a dialogue box with all of the built-in functions - just select the one you want after first having selected a target cell for the calculation).

7. Copying data or formulae to save time with many calculations

You can copy the contents of cells from one cell address to another. In the case of formulae, copying translates cell references to the corresponding position for the recipient cell. That is, if a formula in cell G4 took data from cell F4 to F8, then copying the formula to cell G9 would translate the formula so that it would take the data from cell F9 to F13. This is property of EXCEL will make the rest of our analysis very efficient.

COPYING A CELL

Select cell G4, choose EDIT, COPY, a dotted envelope will appear around the cell. Then select cell G9 and choose EDIT, PASTE. The formula in cell G9 will now read =average(D9:D13) which is the appropriate calculation we would want in that cell ! That is, we now have automatically calculated the mean number of fish at Ek3, Channel.

COPYING MULTIPLE CELLS

Select cells G4 to I4 by clicking the mouse on G4, holding the button down, and dragging to I4. Choose EDIT, COPY. Now select cell G9 only. Choose EDIT, PASTE. The cells selected will appear and fill G9 to I9 with the appropriate formulae and results - check that this happened. Go ahead, now and select all cells from G4 to I4 and pasting them into cell E14 (this will give you mean, SD and SE for the next site and habitat). Go ahead and copy the formulae into the appropriate positions for all sites and habitats.

(Hint: You can speed up this process. After performing the first one, move to the next target cell, say G19 and push ALT, ENTER. This command simply repeats the very last operation you performed. It is not restricted just to the case of copying, but works for deleting, formatting and most other commands).

Note: The paste commands work between spreadsheets as well, so if you want a file to obtain data from another spreadsheet, even in another directory, you can (see the EXCEL help file, or ask for help during the training session).

8. Save your spreadsheet again !!

9. Do the EXCEL tutorial on spreadsheets

Your last task in this session of learning EXCEL is to go through the electronic tutorial in your own time. This is provided under the EXCEL HELP menu.

10. Quitting EXCEL

To end your session in EXCEL, make sure you have saved your latest version of the spreadsheet (if you forget, the program will actually remind you before it will close). Choose FILE, EXIT.

Examining fish count data in Excel

Figure 38 shows fish data from the Erakor lagoons EIA. Data are total number of fish (all families) recorded in 5 minute timed counts, collected in mangrove fringe & channel habitats. Note data are arranged in two groups of columns to save space. Please enter these data into your EXCEL spreadsheet as a continuous dataset arranged in 6 columns and 80 rows.

Date	Location	Site	Habitat	Rep	Fish	Date	Location	Site	Habitat	Rep	Fish
20-Jan-98	Ekasuvat	Ek1	Channel	1	25	24-Jan-98	Eratap	Er2	Channel	1	34
20-Jan-98	Ekasuvat	Ek1	Channel	2	505	24-Jan-98	Eratap	Er2	Channel	2	98
20-Jan-98	Ekasuvat	Ek1	Channel	3	11	24-Jan-98	Eratap	Er2	Channel	3	43
20-Jan-98	Ekasuvat	Ek1	Channel	4	12	24-Jan-98	Eratap	Er2	Channel	4	62
20-Jan-98	Ekasuvat	Ek1	Channel	5	27	24-Jan-98	Eratap	Er2	Channel	5	54
29-Jan-98	Ekasuvat	Ek3	Channel	1	359	24-Jan-98	Eratap	Er3	Channel	1	135
29-Jan-98	Ekasuvat	Ek3	Channel	2	1	24-Jan-98	Eratap	Er3	Channel	2	156
29-Jan-98	Ekasuvat	Ek3	Channel	3	0	24-Jan-98	Eratap	Er3	Channel	3	34
29-Jan-98	Ekasuvat	Ek3	Channel	4	21	24-Jan-98	Eratap	Er3	Channel	4	174
29-Jan-98	Ekasuvat	Ek3	Channel	5	63	24-Jan-98	Eratap	Er3	Channel	5	455
29-Jan-98	Ekasuvat	Ek2	Fringe	1	71	24-Jan-98	Eratap	Er4	Fringe	1	155
29-Jan-98	Ekasuvat	Ek2	Fringe	2	94	24-Jan-98	Eratap	Er4	Fringe	2	75
29-Jan-98	Ekasuvat	Ek2	Fringe	3	33	24-Jan-98	Eratap	Er4	Fringe	3	253
29-Jan-98	Ekasuvat	Ek2	Fringe	4	39	24-Jan-98	Eratap	Er4	Fringe	4	56
29-Jan-98	Ekasuvat	Ek2	Fringe	5	57	24-Jan-98	Eratap	Er4	Fringe	5	106
29-Jan-98	Ekasuvat	Ek4	Fringe	1	69	24-Jan-98	Eratap	Er5	Fringe	1	1009
30-Jan-98	Ekasuvat	Ek4	Fringe	2	109	24-Jan-98	Eratap	Er5	Fringe	2	411
30-Jan-98	Ekasuvat	Ek4	Fringe	3	194	24-Jan-98	Eratap	Er5	Fringe	3	218
30-Jan-98	Ekasuvat	Ek4	Fringe	4	162	24-Jan-98	Eratap	Er5	Fringe	4	205
30-Jan-98	Ekasuvat	Ek4	Fringe	5	91	24-Jan-98	Eratap	Er5	Fringe	5	75
20-Jan-98	Emten	Em6	Channel	1	306	31-Jan-98	Tapi Point	Tp5	Channel	1	111
20-Jan-98	Emten	Em6	Channel	2	50	31-Jan-98	Tapi Point	Tp5	Channel	2	105
20-Jan-98	Emten	Em6	Channel	3	87	31-Jan-98	Tapi Point	Tp5	Channel	3	3
20-Jan-98	Emten	Em6	Channel	4	59	31-Jan-98	Tapi Point	Tp5	Channel	4	283
20-Jan-98	Emten	Em6	Channel	5	27	31-Jan-98	Tapi Point	Tp5	Channel	5	46
26-Jan-98	Emten	Em9	Channel	1	27	02-Feb-98	Tapi Point	Tp6	Channel	1	44
26-Jan-98	Emten	Em9	Channel	2	3	02-Feb-98	Tapi Point	Tp6	Channel	2	55
26-Jan-98	Emten	Em9	Channel	3	13	02-Feb-98	Tapi Point	Tp6	Channel	3	265
26-Jan-98	Emten	Em9	Channel	4	60	02-Feb-98	Tapi Point	Tp6	Channel	4	71
26-Jan-98	Emten	Em9	Channel	5	11	02-Feb-98	Tapi Point	Tp6	Channel	5	92
20-Jan-98	Emten	Em7	Fringe	1	25	22-Jan-98	Tapi Point	Tp3	Fringe	1	88
20-Jan-98	Emten	Em7	Fringe	2	17	22-Jan-98	Tapi Point	Tp3	Fringe	2	33
20-Jan-98	Emten	Em7	Fringe	3	51	22-Jan-98	Tapi Point	Tp3	Fringe	3	134
20-Jan-98	Emten	Em7	Fringe	4	43	22-Jan-98	Tapi Point	Tp3	Fringe	4	452
20-Jan-98	Emten	Em7	Fringe	5	9	22-Jan-98	Tapi Point	Tp3	Fringe	5	217
26-Jan-98	Emten	Em4	Fringe	1	93	02-Feb-98	Tapi Point	Tp4	Fringe	1	26
26-Jan-98	Emten	Em4	Fringe	2	122	02-Feb-98	Tapi Point	Tp4	Fringe	2	61
26-Jan-98	Emten	Em4	Fringe	3	72	02-Feb-98	Tapi Point	Tp4	Fringe	3	53
26-Jan-98	Emten	Em4	Fringe	4	35	02-Feb-98	Tapi Point	Tp4	Fringe	4	152
26-Jan-98	Emten	Em4	Fringe	5	85	02-Feb-98	Tapi Point	Tp4	Fringe	5	61

← *Figure 38: Raw data from Vanuatu lagoons*

LABORATORY 7.2: GRAPHING WITH EXCEL

In this exercise we will produce some graphs to help with your interpretation of the fish data you entered during the first session. The techniques you will learn can, as above, then be applied to the results of any sampling / monitoring programme you are carrying out. In contrast to the last session on learning EXCEL, this time we will begin with the tutorial provided under the HELP menu of the program which will give you an overview of the graphing facilities. You should then proceed by working through these notes to obtain detailed information on producing some commonly-used scientific graphs.

REMINDER: Things you should type will appear in these notes in **BOLD** while keys to push appear as either ALT+ENTER to mean push these keys simultaneously, or ALT, ENTER meaning that they should be pushed one after the other. Mouse commands will be operated by clicking once or twice in quick

1. Start Microsoft EXCEL

Double-click the Microsoft EXCEL icon from the WINDOWS program manager

2. Load the spreadsheet that you were working on during the first session on EXCEL.

Choose FILE, OPEN and type:

a:\Portvila fish data.xls

or

c:\yourname Portvila fish data.xls

3. Separate the data for graphing

(a) Your mission with the fish data is to determine whether there are differences between and within lagoons around Port Vila in term of fish abundance. We have information collected from four sites in

each lagoon which we will plot as two separate graphs:

(1) A graph showing mean densities of fishes separated for each site and lagoon; and

(2) A graph showing mean densities of fishes for each lagoon (sites pooled).

The first graph highlights differences among sites within each lagoon, while the second highlights differences among the four lagoons. *What are the two questions I must have asked to want these two graphs?*

You have already calculated the means, SD and SE for all of the data. We now have to arrange the data into tables suitable for graphing. Being aware that a mean without any measure of variance (either as SD, S^2, SE, 95%CL etc..) is uninterpretable in science, we will concentrate on producing graphs of means with the standard errors (SE) you calculated during the last session.

(b) You will need to create a subset of the data (in table form) for each of the two graphs you will draw. You can do this using either of two methods:

You can either rearranging the cells carrying the information of means and SE into a table suitable for graphing; or

You can use the PIVOT TABLE function, which still needs some rearrangement before you can draw the graphs.

Reproduced below are the data tables and graphs for the two types of graphs to be drawn for the Port Vila Lagoons fish monitoring study to assist you with the form of the layout.

Graph type 1

For Graph type 1 the data table should look like shown in Figure 39. Note that a column has deliberately been left blank between the sites relating to each lagoon. This is to create separation in the graph to make the grouping of the data easier to read:

Here is a Figure caption that would be appropriate:

Figure 1: Mean densities of all species of fishes recorded at four sites in four lagoons around Port Vila, Vanuatu. Data are means of five replicate 5 minute timed counts done at each site, +/- SE. The terms Ek4, Em7 etc. refer to site numbers in each lagoon.

Graph type 2:

Figure 2: Mean densities of all species of fishes recorded in four lagoons around Port Vila, Vanuatu. Data are means of five replicate 5 minute timed counts done at each of four sites (sites pooled), +/- SE.

Method 1: Manual technique

The easiest way of rearranging the cells for the two graphs if you are going to use the means and SE's calculated earlier, is to use the drag and drop function. First, set up the titles by typing them into the cells somewhere to the right of the data table itself in your spreadsheet. Then, select cell G4 by clicking on it. When it has been selected, approach the cell with your mouse pointer till it changes from a white cross to an arrow. When you have the

	Ekasuvat					Emten					Eratap					Tapi Point			
	Ek1	Ek2	Ek3	Ek4		Em4	Em6	Em7	Em9		Er2	Er3	Er4	Er5		Tp3	Tp4	Tp5	Tp6
Mean	116	58.8	88.8	125		81.4	105.8	29	22.8		58.2	190.8	129	383.6		184.8	70.6	109.6	105.4
SE	97.3	11.07	68.51	23.11		14.21	50.96	7.874	10.07		11.03	70.35	35.23	165.3		73.29	21.34	47.7	40.71

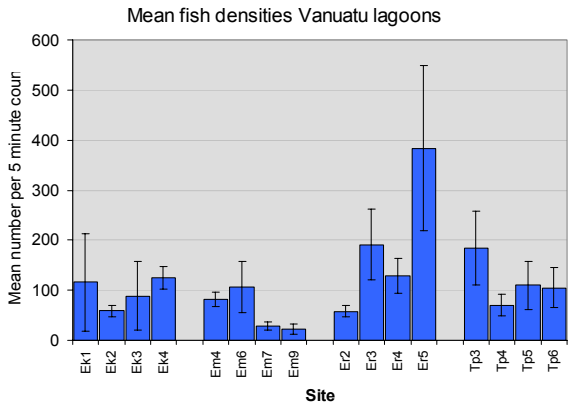


Figure 39: Layout of summarised data and the output of Graph type 1

	Ekasuvat	Emten	Eratap	Tapi Point
Mean	97.2	59.8	190.4	117.6
SE	28.5	14.8	50.4	24.6

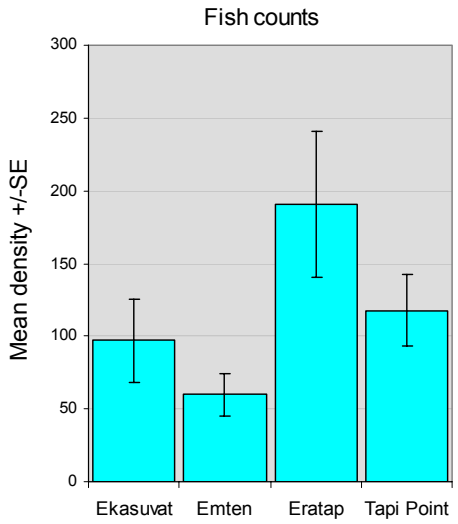


Figure 40: Data layout and form of graph type 2.

arrow, push and hold your left mouse button while you drag the cell over to the position you want in your table. Let the mouse button go and the mean will have been moved to the new position, whilst retaining its formula and value. Continue to do this with all the mean and SE values until your new table is complete (Figure 40).

Method 2: Pivot tables

Pivot tables are powerful tools for summarising and organising large amounts of data in Excel. Basically, they are built-in macros or programs designed to calculate means, SD (or other common methods of summarising data) which are then output in table format on your spreadsheet. From this table you can easily produce graphs to illustrate the important features of your data.

Step-by-step guide to using PivotTable Wizard:

Step 1: Select the entire dataset you wish to summarise: A3-F83

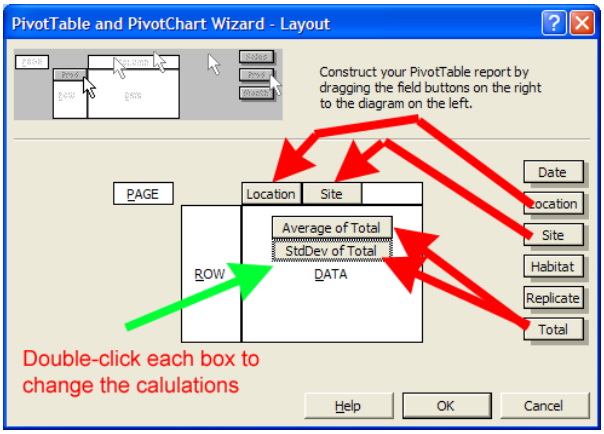
Step 2: From the MENU choose DATA, PIVOT TABLE & PIVOT CHART REPORT

Step 3: Choose MICROSOFT EXCEL LIST OR DATABASE, NEXT

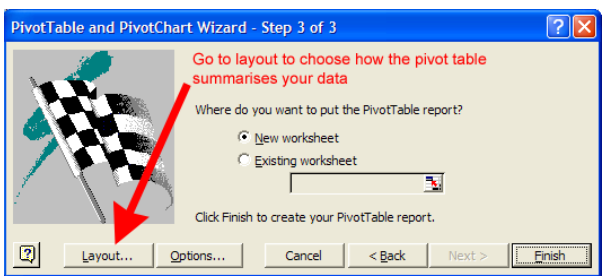
Step 4: The range for your data should already appear in the box because you pre-selected it before starting the PivotTable Wizard. If the range is wrong, or not in the dialogue box, add it manually now: type **$A$3:$F$83**, Choose NEXT

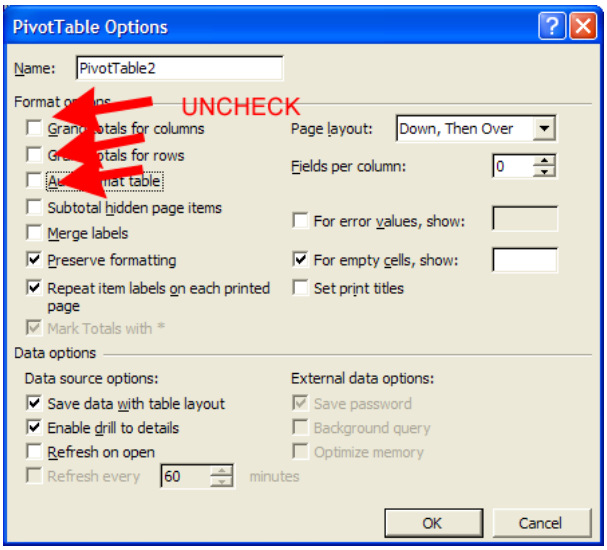
Step 5: Allow the results to be placed in a new worksheet – this will stay in the file you are currently working on, but not clutter up the sheet with the raw data. Click on LAYOUT.

Step 6: This is the step you will need to think about: How do you want your data organised? Basically, you need to drag items from the far right of your dialogue box into the waiting fields labelled row, column and data. Here, I would put LOCATION followed by SITE into the COLUMN



field. Then move TOTAL into the field labelled DATA. Click on the box LOCATION, and holding down the left mouse button, move it over to the COLUMN section of the table. Release your mouse. Go through the same procedure for the SITE and TOTAL boxes. You could then get



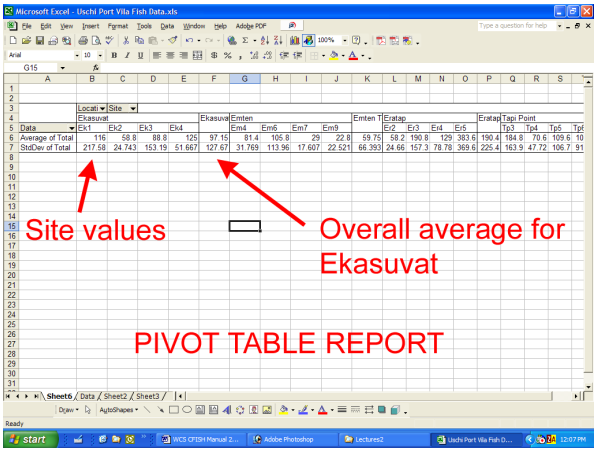


further subdivision of the means by moving other terms into the pivot table, but we will not do this here. When you have moved the TOTAL box into the central area called DATA, release the mouse, and you will see a new box called "Sum of TOTAL". Change this to average by double-clicking the Sum of TOTAL box and choosing AVERAGE in the PivotTable Field dialogue box that appears. Choose OK. Now drag TOTAL again into the DATA section of the table. Double click the new Sum of TOTAL box that appears and scroll down your Summarise by: list to choose STDDEV for standard deviation. Choose OK. Choose NEXT.

Step 7: Go back to the previous screen by pushing OK. Choose OPTIONS. Uncheck the GRAND TOTALS boxes and table formatting. Choose FINISH.

Updating your PivotTable.

If you change your data in any way (other than adding to it outside the range originally selected), you can update the PivotTable easily. Make your changes in the dataset. Then click your cursor anywhere in the PivotTable. Choose DATA, REFRESH DATA from the menu. The PivotTable will be instantly updated to reflect your changes.



You should now have a table (see below) which shows the mean and SD for the fish separately for the four lagoons and four sites per lagoon, with a bit of extra information on average per location which could be used for constructing your second table. Note however, you will have to convert your SD to SE, since Excel does not provide this option directly in the PivotTable.

Your two graphing tables will still have to be constructed from the pivot table. You can do this by typing, for example, "=B5" in cell B12 and copying cells across till the table is reproduced. Do the same for Mean and SE, but for SE, you will have to change the formula. SE=SD/√n. So in Cell B14 you need to put in a formula that says "=B7/SQRT(5)" where we draw the SD from B7 and divide it by the square-root of n=5 (replicates). Delete the 0 and values in cells F12-F14, K12-K14, P12-P14 and U12-U14 to provide the spacing for your graph. Copy to all other relevant cells.

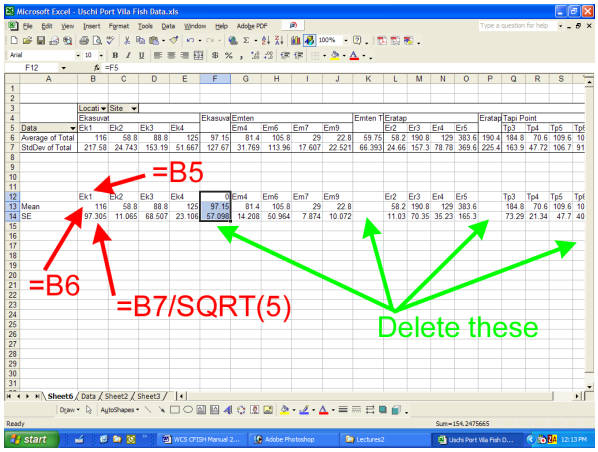
Use a similar procedure to create the table required for drawing Graph 2, taking the data instead from F6-F7, K6-K7, P6-P7 and U6-U7 etc.

Save your spreadsheet !

4. Drawing the graph

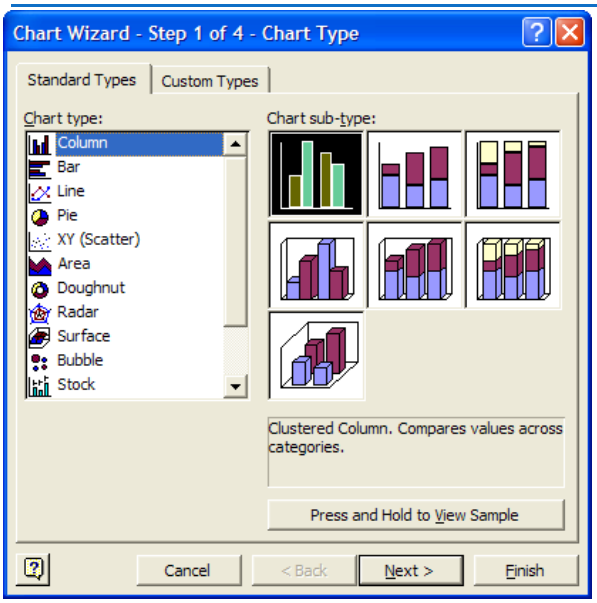
Select Cells B12 to T13 by clicking the mouse button on B12 and dragging the mouse to T13 before releasing the button. Make sure the area is actually selected (it will be dark except for the first cell which is reversed).

Click on the Chart Wizard icon (this is a small bar graph located in the menu bar). Choose COLUMN type for your graph, NEXT. A preview will appear of the graph you are constructing. Check the data range is correct and choose NEXT. Type in a chart



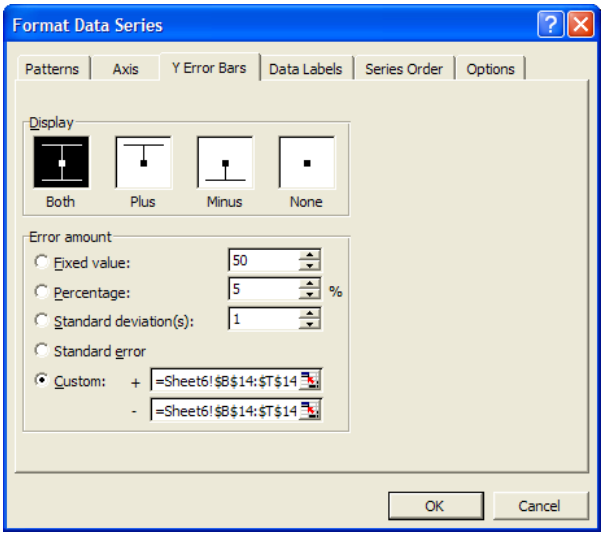
title and labels for the x and y axes. Choose NEXT. For Chart location, accept that it should be inserted into the current sheet, choose FINISH.

Now you will need to add error bars and perhaps enhance the graph a bit. Select the DATA SERIES by double-clicking in any data column on the graph (you should see a small box appear in every column). Click on Y ERROR BARS and Choose CUSTOM. Click in the + box and go back to the spreadsheet and select cells B14-T14 (the SE values which go with the means in Graph 1). Do the



same (exactly) for the - box (you need to display both the upper and lower SE around your mean). Do not click OK yet. Go to OPTIONS and change gap width from 150 to 10 so that the bars on the graph become thicker. Choose OK.

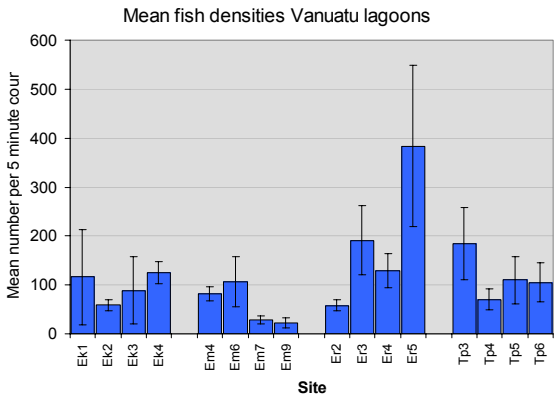
You can make other refinements like forcing axis labels to be vertical etc. Explore the menus available as required.



Repeat the procedure with the data for graph 2 and save your spreadsheet with graphs !

7. Quitting EXCEL

To end your session in EXCEL, make sure you have saved your latest version of everything (if you forget, the program will actually remind you before it will close). Choose FILE, EXIT.



Field / laboratory Exercise 7.3: Optimising designs - Precision

To detect possible differences among sites, times and treatments in a sampling / monitoring programme, we need to monitor indicators (biological and/or physical) and determine whether the values we obtain for them are truly different, or only differ because of sampling error (variation). That is, we need to see differences among our factors that are visible above "background noise". Sounds easy? Unfortunately it is only for the largest types of marine organisms found in very small populations that all individuals in the population can be counted to give an absolute measure of changes. For the remaining indicators such as fishes, corals, seagrasses, chemicals, sediments etc. some sort of sampling procedure is required. That is, measures will be made from small samples and we will use these to calculate the mean measure, along with some confidence limits for the estimate. The best way to do this cannot be known in advance. A **pilot survey** must be carried out to obtain some preliminary information about the distribution of individuals / other indicators in the study area in order to determine how best to characterise the 'population', and therefore detect changes over time. This information is used to determine the number of **replicates** required to ensure that the estimates are as accurate and precise as possible or required.

We are going to carry out a pilot survey in the seagrass beds around the station to:

- Test our survey methods
- Optimise our survey design so that we are putting enough effort into each survey to actually

be able to detect changes through time and/or from place to place.

To do this, we need to determine how many replicates we need to take at each site to detect a change in mean abundance or measure of a given magnitude. This information cannot (ever) be determined without a pilot study (see also Green's rules).

In pilot surveys, one arbitrarily takes a certain number of replicates to gather the information required to optimise the final survey design. From these initial replicates, estimates of **mean** values ($\bar{x}$) can be made (although at this stage it could be unreliable). You can also calculate the **standard deviation** among replicates and the **standard error**.

Reminder:

The Mean (average) = $\bar{x}$ = a summary measure that describes the population in a given place / time as defined by the study

Standard Deviation = SD = a measure of how much variation there is among replicate samples, given in the same units as the mean;

Standard Error = SE = is the SD of means repeatedly drawn from a population and a measure of how reliable our mean is. It depends on the standard deviation and the sample size

Sample Size = n = the number of replicates taken at any one place, site, time (the total number in the whole study is often called N).

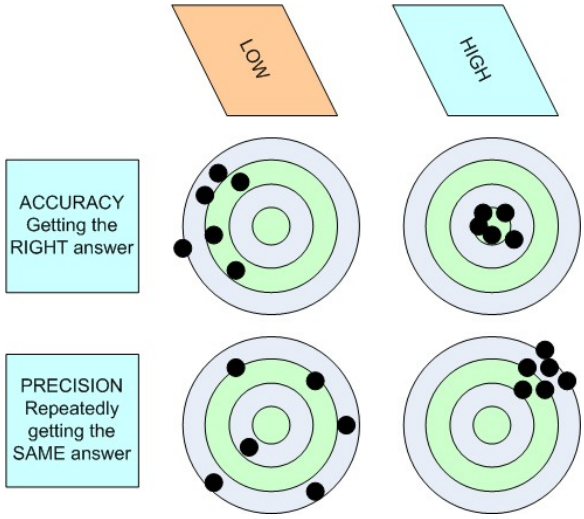
Factor = a variable we are specifically interested in. It may be a time, place or treatment around which the question is built and the survey design optimised.

Remember that the standard deviation is a measure of the spread among individual samples and should be relatively insensitive to changes in sample size (n). It is a property of 'patchiness' in the 'population' of values. It can change if we change the size of sampling units (think about why). The standard error is a measure of the variation among estimates of a mean, given a particular sample size (n). It is calculated as:

$$SE = \frac{SD}{\sqrt{n}} \quad \text{[equation 1]}$$

Unlike the standard deviation, the standard error is quite sensitive to changes in sample size (n). That is, for a given sampling situation, it gets smaller when the sample size increases. The good thing about this, is we can improve our estimate of mean density by increasing sample size.

Ideally we use the pilot survey to maximise the **accuracy** and **precision** of our estimates for a given sampling effort. These are slightly different things. The accuracy of an estimate of density is the closeness of our sample mean to the true value. That is, it is a property of the **mean** ($\bar{x}$). Unless you know the true value of the mean (μ), it is not always



possible to assess the accuracy of using any sampling method. However, differences among means will certainly indicate accuracy is dependent upon the factor in question. When counting very small organisms we usually underestimate by failing to count all the organisms present, hence, a larger mean is usually considered more accurate.

The precision of an estimate is dependent upon variation around our estimate of the mean. That is, it is a property of the **standard error**. The smaller the standard error relative to the mean, the more precise the estimate. More formally,

$$\text{Precision, } P = \frac{SE}{\bar{x}} \quad \text{[equation 2]}$$

It is very easy to calculate the number of replicates required to reach a desired level of precision for any sampling method. If you need to detect very small changes, high precision is required (e.g. P = 0.1). For most purposes, however, a precision of 0.2 or 0.3 (standard error 20 or 30% of the mean) is considered acceptable. All else being equal, the sampling regime will detect a 20 or 30% change in

mean density, which may be sufficient for heralding a change in the conditions of concern (factors) such as fish populations, seagrass cover etc.

Remember that: $P = SE / \bar{x}$

Then, $$P = \frac{SD}{\sqrt{N}} * \frac{1}{\bar{x}}$$ [equation 3]

For P=0.1, and using "$\bar{x}$ " and "s" from the pilot survey, you can calculate the required sample size by solving the above equation for "n". You can do the same for a precision of 0.2 or 0.3.

In the case of a survey we may need to sample in different regions and subsample each region with locations and each location with sites and each site with replicates, like this design tree (Figure 41):

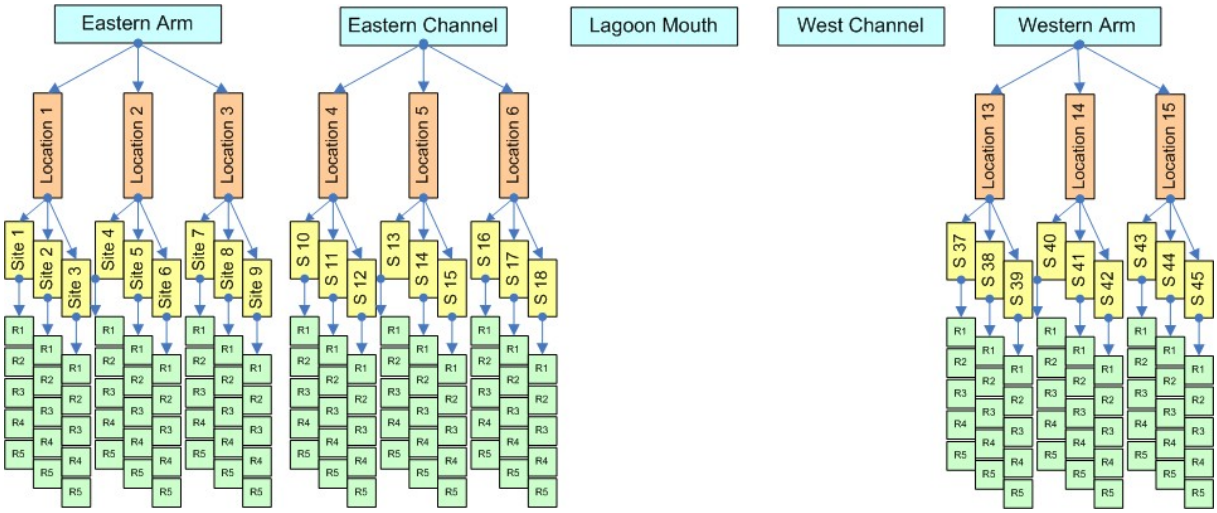


Figure 41: Design tree for a nested sampling design.

Approach

(1) Calculate the mean of your measures, SD, SE and Precision (P).

(2) Using the formula for precision (above) calculate the sample sizes required to get a precision of 0.1, 0.2 and 0.3 respectively for your measures (% seagrass cover and % epiphytes). Plot a graph of precision on y-axis versus number of replicates on the x-axis for each measure (for a rough example see Figure 42). How many replicates will you need to take for each variable to get a reasonable level of precision? Is the precision the same for each variable? How will you decide how many replicates to take?

(3) Make a table of the results for the means for each sampling variable, and the sample size required to get a precision of 0.2. How do you explain the differences among the different variables?

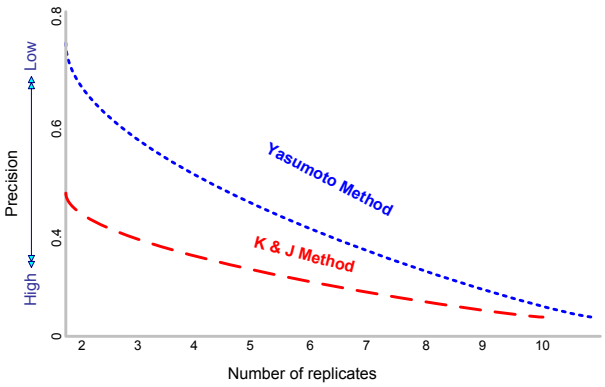
Fieldwork

You should work in pairs. Each pair should take a quadrat and slate and collect seagrass data in 10 replicate quadrats for each of three quadrat sizes (see below) thrown randomly around the area, within your maximum snorkelling depth. You will have to collect the data onto a slate and then transcribe them onto a datasheet when you are dry.

Place the quadrat on the seafloor over the top of the seagrasses and other bottom features. We will be collecting data from three different quadrat sizes:

Small: 30x30 cm – 4 crossed string points

Figure 42: Example of graph of precision versus number of replicates for two sampling variables. Note that they differ. In this case, it is best to optimise the design for the least precise measure. Which is the least precise measure on this graph?



Medium: 50x50 cm – 16 crossed string points
Large: 100 x 100 cm – 81 crossed string points (Figure 43).

Choose a corner of the quadrat that you will always use to start the smaller quadrat sizes (e.g. top left corner) and collect the data INDEPENDENTLY for each quadrat size. That is, 10 separate quadrats for each size per pair.

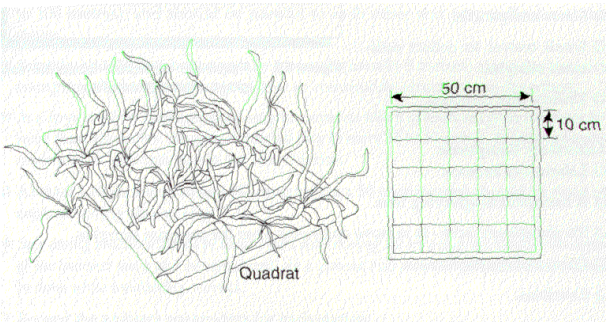


Figure 43: Quadrat design

Look under the crossed strings, recording what is under each. Line yourself up directly over the top of the crossed strings to do the quadrat. You will need to record the number of strings with each of the types of seagrass, algae, sponges, other sessile / benthic organisms, sand, mud, rocks and other features. These should add up to 81 crosses (100% of crosses available). Separately, you should record the number of crosses that had seagrasses covered by epiphytes. That will allow us to estimate the percent of seagrasses which are covered by epiphytes versus the percentage which is clear of epiphytes.

Laboratory / computer work

The aim of this practical exercise is to learn:

- What precision (p) is;
- The relationship between quadrat size and precision; and
- The relationship between number of replicates and precision.

Each participant should have collected their own data on seagrasses during the field session. We will be looking at the combined data as part of the lab to make some important points, but please do not share data until it is time to hand over precision values to other pairs.

Enter your data into an EXCEL sheet.

For each quadrat size calculate the mean percent cover of seagrasses and the percent with epiphytes and their standard errors. Using that information calculate the precision which is given by Formula in Equation 2. Draw a graph of the mean percent cover for each quadrat size for your data only (i.e. not the group's data). What does it tell you? Can you pick a best quadrat size from this?

For each quadrat size calculate the mean precision and the standard error by stealing the precision values calculated by other pairs. The mean and standard error for each quadrat size will be based on n readings of precision (one from each pair in the group). On a graph, plot mean precision ±S.E. against quadrat size. The quadrat size with the smallest precision value would be the best to use in sampling seagrasses around Motupore.

Precision of your estimate of the mean is also determined by the number of quadrats (see Formula below). As the number of replicates increases, the precision improves (P gets smaller). Using the mean percent cover and SE estimated with the best quadrat size, determine the number of

FORMULA BOX

To calculate the number of replicates needed to obtain a precision of 0.5 to 0.001 you would need to rearrange the following two formulas to make n the subject. Here is the proof:

1. $P = \frac{SE}{\bar{x}}$

2. $SE = \frac{s}{\sqrt{n}}$

Therefore: $P = \frac{S/\sqrt{n}}{\bar{x}}$

$P * \bar{x} = S/\sqrt{n}$

$(P * \bar{x})^2 = S^2/n$

$n = \frac{S^2}{(P * \bar{x})^2}$

$n = (S/(P * \bar{x}))^2$

The EXCEL formula is: n = (S/(P*$\bar{x}$))^2
(enter the cell references for S, P and $\bar{x}$).

replicates required to get a precision of 0.5, 0.2, 0.1, 0.05, 0.01 and 0.001. What is the relationship between number of replicates and precision? Hint: draw a graph with number of quadrats on the x-axis and precision on the y.

Note: As precision (P) gets smaller you have a more precise estimate (need fewer replicates). As P gets larger you have a less precise estimate (need more replicates).

LABORATORY 7.4: STORING AND REPORTING YOUR RESULTS

Storing data

So far, we have been concentrating on learning how to use EXCEL to enter our data, format, manipulate and analyse it. We have not yet discussed HOW the data should be arranged for long term storage and ease of use. One of the biggest traps people fall into is in poor organisation of their data. The numbers have all been entered into sheets, but they may be poorly labelled so that when you or someone else looks at them later it is not clear what they are, where they came from, or what they are measures of ! This is an extremely common mistake and leads to loss to expensive data and historical information. Data should also be organised so that they can most easily be used for analyses either in EXCEL, or other statistical packages. Further, the data you may collect on someone else's behalf has to be readable by them.

Pay attention to:

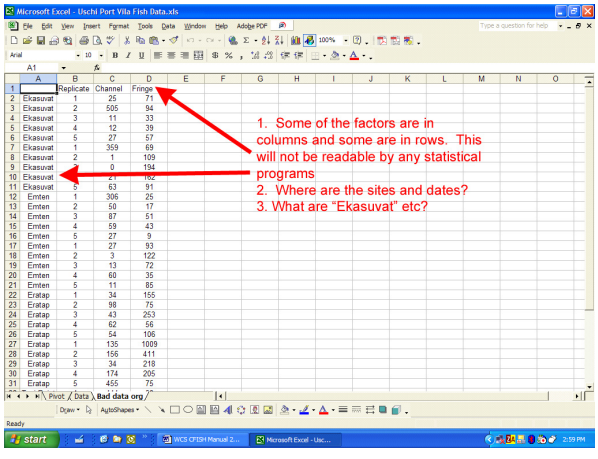
- Headings with dates
- Labeling of all data – without exceptions
- Recording all the details (latitude / longitude, who did the work, etc)
- Use one row per sample (quadrat, transect, water sample etc)
- Include a column for all factors (times, sites, treatments) recording the level of each factor for each row (independent variables)
- If more than one variable is recorded for each sampling unit, add columns on the RHS and continue the information within the row (dependent variables)

In this screen-shot, the data from Vanuatu have been stored badly by someone on the team (no names !). Although all of the values for the fish counts are there, he missed out labelling the sites (so we only know which lagoon the data came from), and someone from outside will not know that Ekasuvat, Emten, Eratap and Tapi are lagoons ! There are no dates, no survey number, and the factor of HABITAT has been put in separate columns so cannot be analysed (EXCEL and other statistical programs will treat these not as factors, but different variables (e.g. species) in the design.

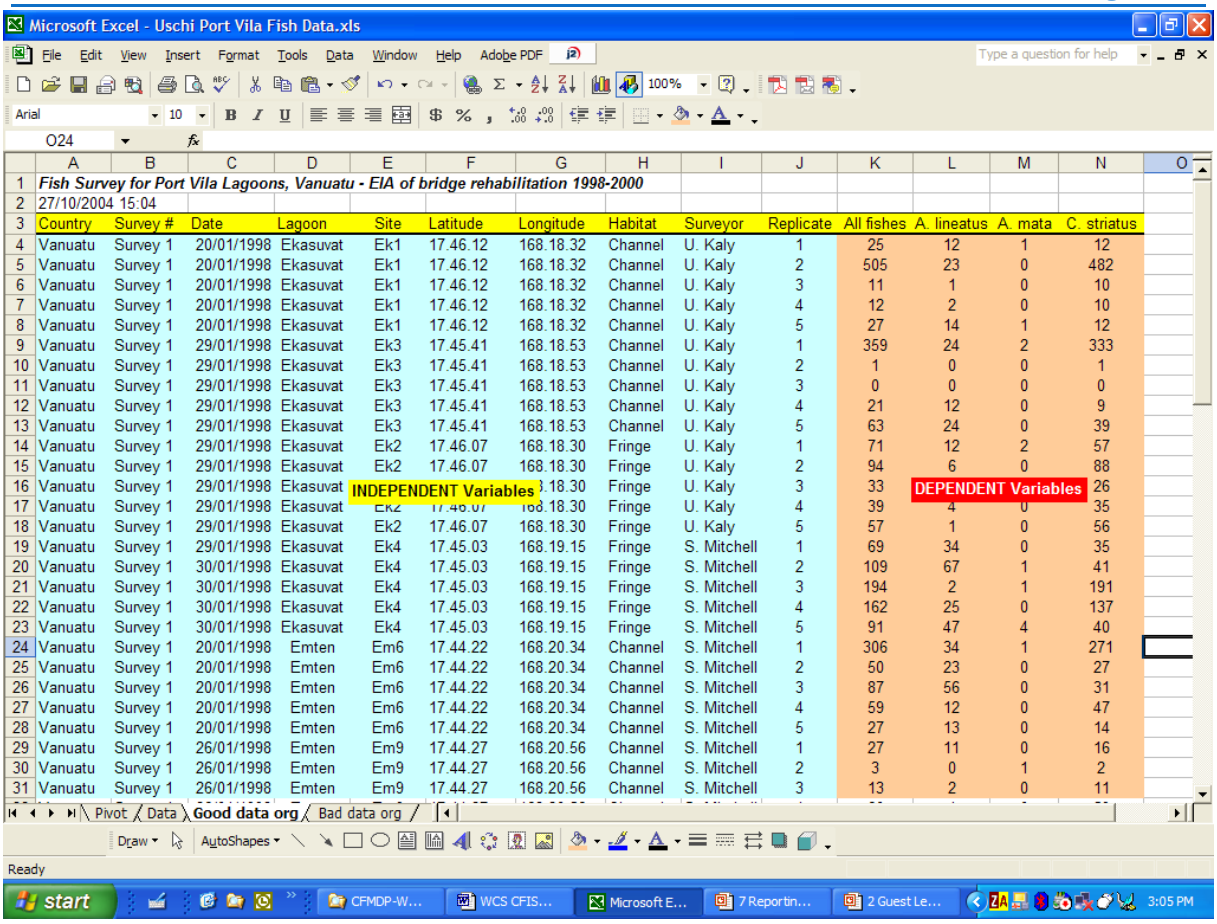
The best way to store data for the long term is to list ALL of the factors and values in such a way that each ROW represents ONE quadrat, transect, core or whatever. That is, ALL of the information you could possibly collect for a single replicate, including all the species etc in one row.

In Figure 44 the data have been properly stored for the long term. Although it is not necessary for the individual survey to put in the country name, it does make using the data later a whole lot easier, particularly if they are picked up for use in larger datasets. You will notice that there is a column for EVERY factor that relates to collecting the data for each timed transect (independent variables). That is, in Row 4, we have all the information needed to locate the counts done on all species of fishes, including which replicate it was, who did the count (me), what habitat, the latitude and longitude (sometimes separately for each replicate), site, lagoon, date of the count, which survey it was done for (there were 3 done in this study) and the country.

You should now go ahead and arrange the seagrass data in the same way. Open the file you were



working on and add all the columns you would need, their proper headings and a heading for the sheet that will ensure no one ever gets lost using these data – including YOU.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	*Fish Survey for Port Vila Lagoons, Vanuatu - EIA of bridge rehabilitation 1998-2000*													
2	27/10/2004 15:04													
3	Country	Survey #	Date	Lagoon	Site	Latitude	Longitude	Habitat	Surveyor	Replicate	All fishes	A. lineatus	A. mata	C. striatus
4	Vanuatu	Survey 1	20/01/1998	Ekasuvat	Ek1	17.46.12	168.18.32	Channel	U. Kaly	1	25	12	1	12
5	Vanuatu	Survey 1	20/01/1998	Ekasuvat	Ek1	17.46.12	168.18.32	Channel	U. Kaly	2	505	23	0	482
6	Vanuatu	Survey 1	20/01/1998	Ekasuvat	Ek1	17.46.12	168.18.32	Channel	U. Kaly	3	11	1	0	10
7	Vanuatu	Survey 1	20/01/1998	Ekasuvat	Ek1	17.46.12	168.18.32	Channel	U. Kaly	4	12	2	0	10
8	Vanuatu	Survey 1	20/01/1998	Ekasuvat	Ek1	17.46.12	168.18.32	Channel	U. Kaly	5	27	14	1	12
9	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek3	17.45.41	168.18.53	Channel	U. Kaly	1	359	24	2	333
10	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek3	17.45.41	168.18.53	Channel	U. Kaly	2	1	0	0	1
11	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek3	17.45.41	168.18.53	Channel	U. Kaly	3	0	0	0	0
12	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek3	17.45.41	168.18.53	Channel	U. Kaly	4	21	12	0	9
13	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek3	17.45.41	168.18.53	Channel	U. Kaly	5	63	24	0	39
14	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek2	17.46.07	168.18.30	Fringe	U. Kaly	1	71	12	2	57
15	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek2	17.46.07	168.18.30	Fringe	U. Kaly	2	94	6	0	88
16	Vanuatu	Survey 1	29/01/1998	Ekasuvat	INDEPENDENT Variables			Fringe	U. Kaly	3	33	DEPENDENT Variables		26
17	Vanuatu	Survey 1	29/01/1998	Ekasuvat				Fringe	U. Kaly	4	39			35
18	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek2	17.46.07	168.18.30	Fringe	U. Kaly	5	57	1	0	56
19	Vanuatu	Survey 1	29/01/1998	Ekasuvat	Ek4	17.45.03	168.19.15	Fringe	S. Mitchell	1	69	34	0	35
20	Vanuatu	Survey 1	30/01/1998	Ekasuvat	Ek4	17.45.03	168.19.15	Fringe	S. Mitchell	2	109	67	1	41
21	Vanuatu	Survey 1	30/01/1998	Ekasuvat	Ek4	17.45.03	168.19.15	Fringe	S. Mitchell	3	194	2	1	191
22	Vanuatu	Survey 1	30/01/1998	Ekasuvat	Ek4	17.45.03	168.19.15	Fringe	S. Mitchell	4	162	25	0	137
23	Vanuatu	Survey 1	30/01/1998	Ekasuvat	Ek4	17.45.03	168.19.15	Fringe	S. Mitchell	5	91	47	4	40
24	Vanuatu	Survey 1	20/01/1998	Emten	Em6	17.44.22	168.20.34	Channel	S. Mitchell	1	306	34	1	271
25	Vanuatu	Survey 1	20/01/1998	Emten	Em6	17.44.22	168.20.34	Channel	S. Mitchell	2	50	23	0	27
26	Vanuatu	Survey 1	20/01/1998	Emten	Em6	17.44.22	168.20.34	Channel	S. Mitchell	3	87	56	0	31
27	Vanuatu	Survey 1	20/01/1998	Emten	Em6	17.44.22	168.20.34	Channel	S. Mitchell	4	59	12	0	47
28	Vanuatu	Survey 1	20/01/1998	Emten	Em6	17.44.22	168.20.34	Channel	S. Mitchell	5	27	13	0	14
29	Vanuatu	Survey 1	26/01/1998	Emten	Em9	17.44.27	168.20.56	Channel	S. Mitchell	1	27	11	0	16
30	Vanuatu	Survey 1	26/01/1998	Emten	Em9	17.44.27	168.20.56	Channel	S. Mitchell	2	3	0	1	2
31	Vanuatu	Survey 1	26/01/1998	Emten	Em9	17.44.27	168.20.56	Channel	S. Mitchell	3	13	2	0	11

Figure 44: Good data layout for spreadsheet storage.

Reporting results

The information you collect from the field will need to be stored and simplified so that you can use it to examine what the data are telling you and communicate your results to others. Later in the course there will be a session on writing a full scientific report. In this part of the course, we are going to concentrate on the art of the QUICK REPORT CARD. That is, a short report format you can use to keep your results up to date and tell people where you are when they ask. This is not the same as a full scientific report, but will put you in a good position to be able to produce one.

You have already stored two sets of data (the Vanuatu data and the seagrass pilot data) and done some graphing in EXCEL. In this exercise, we are going to automate a PRECISION REPORT in an EXCEL spreadsheet so that you can quickly and easily analyse future pilot data and optimise your designs. The layout and graphs we will use can give us an "at-a-glance" look at how much effort we will need at the level of replication to get good precision. Once you have written this sheet, copy it to a floppy disk for later use after the course is over (Figure 45).

Here are some things you need to consider for making your optimisation calculator and short report:

- What do you need to show with your data?
- What graphs, analyses and other information would you need to calculate / graph to see the results?

Open your seagrass data file. Arrange the data and calculations in a way that shows how all the calculations follow each other and lets you draw the graphs you will need. Here is an example from Fanga'uta Lagoon in Tonga. Note the formulae written in column H. These ensure you always know how the contents of cells were calculated. They would not be shown in a report, even a short one, but they may be needed by your client in an electronic copy. Make sure they are clear.

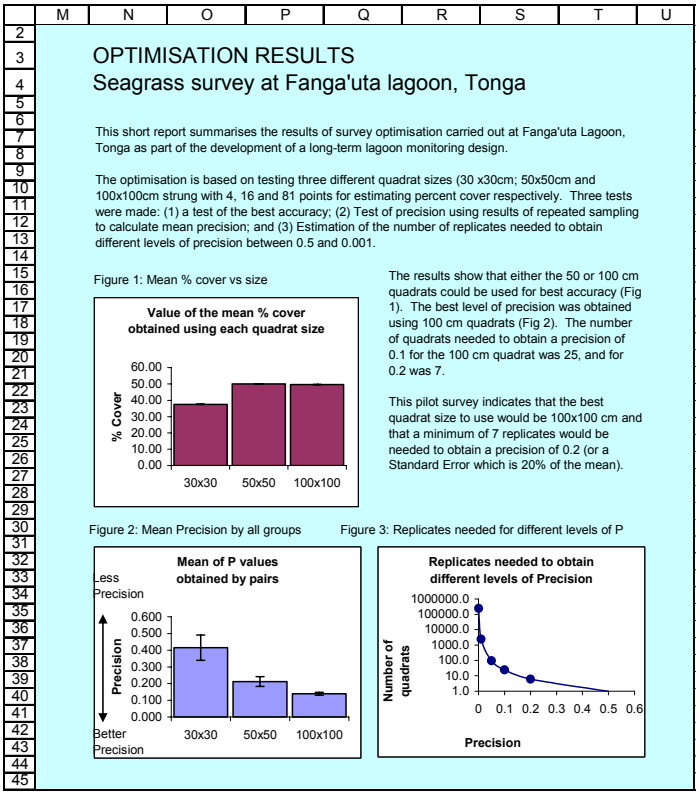
Next, draw the graphs you will need to determine which quadrat size is best for the task at hand (Figure 46). NOTE: The data used here are from Tonga – yours may be very different (it would be surprising if they were not !). Place the graphs

somewhere on your sheet away from the calculations, and put some shading around them to show the extent of the report card. Next, add some text boxes in which you will write a very quick explanation of the purpose of the pilot survey, the methods used and results obtained. Remember you don't have to write everything, just a summary. Full details are to be provided in the full scientific report.

	A	B	C	D	E	F	G	H
1	OPTIMISING SEAGRASS DATA - Total cover by all seagrasses							
2								
3		#/4	#/16	#/81	%	%	%	
4	Replicate	30x30	50x50	100x100	30x30	50x50	100x100	
5	1	1	5	59	25	31.25	72.84	=D5/81%
6	2	0	12	34	0	75.00	41.98	
7	3	3	3	23	75	18.75	28.40	
8	4	0	13	60	0	81.25	74.07	
9	5	1	7	45	25	43.75	55.56	
10	6	4	10	25	100	62.50	30.86	
11	7	2	4	18	50	25.00	22.22	
12	8	3	8	71	75	50.00	87.65	
13	9	1	12	52	25	75.00	64.20	
14	10	0	6	15	0	37.50	18.52	
15								
16					30x30	50x50	100x100	
17	Mean				37.50	50.00	49.63	=AVERAGE(G5:G14)
18	SD				35.84	22.44	24.52	=STDEV(G5:G14)
19	SE				11.33	7.10	7.75	=G17/SQRT(10)
20	P				0.30	0.14	0.16	=G18/G17
21								
22	PRECISION FROM ALL OF THE TEAM							
23								
24	Group 1				0.30	0.14	0.16	
25	Group 2				0.29	0.23	0.12	
26	Group 3				0.46	0.28	0.13	
27	Group 4				0.61	0.2	0.15	
28								
29					30x30	50x50	100x100	
30	Mean P				0.416	0.213	0.139	=AVERAGE(G23:G26)
31	SE				0.075	0.029	0.008	=STDEV(G23:G26)/SQRT(4)
32								
33								
34					P required	n needed		
35					0.5	1.0		=(G18/(E35*F35))^2
36	In my case, 100x100 was the best quadrat				0.2	6.1		
37	size, so I will optimise number of quadrats				0.1	24.4		
38	for the 100x100 size (yours might be				0.05	97.6		
39	different - why?)				0.01	2440.5		
40					0.001	244053.4		
41								

Figure 45: Spreadsheet set up to calculate precision.

Figure 46: Example of a report card.



8. Recommended Reading

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Sokal, R.R. & F.J. Rohlf. 1981. Biometry. 2nd Edition. Freeman & Co., NY. 859pp

Underwood A.J. 1991. Beyond BACI: Experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Aust. J. Mar. Fresh. Res.*

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Underwood A.J. 1992. Beyond BACI: The detection of environmental impacts on populations in the real, but variable, world. *J. Exp. Mar. Biol. Ecol.*
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9. Terms Used

95% Confidence Limit = The confidence intervals for specific statistics (e.g., means, or regression lines) give us a range of values around the statistic where the "true" (population) statistic can be expected to be located (with 95% certainty).

ANOVA = Analysis of variance. The purpose of analysis of variance (ANOVA) is to test for significant differences between means by comparing (i.e., analysing) variances.

Correlation is a measure of the relation between two or more variables. Correlation coefficients can range from -1.00 to +1.00. The value of -1.00 represents a perfect negative correlation while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents a lack of correlation.

Geometric Mean is a summary statistic useful when the measurement scale is not linear; it is computed as: G = (x1 *x2 *...*xn)1/n; where n is the sample size.

Harmonic Mean is a summary statistic used in analyses of frequency data; it is computed as: H = n * 1/S(1/xi), where n is the sample size.

Histograms (the term was first used by Pearson, 1895) present a graphical representation of the frequency distribution of the selected variable(s) in which the columns are drawn over the class intervals and the heights of the columns are proportional to the class frequencies.

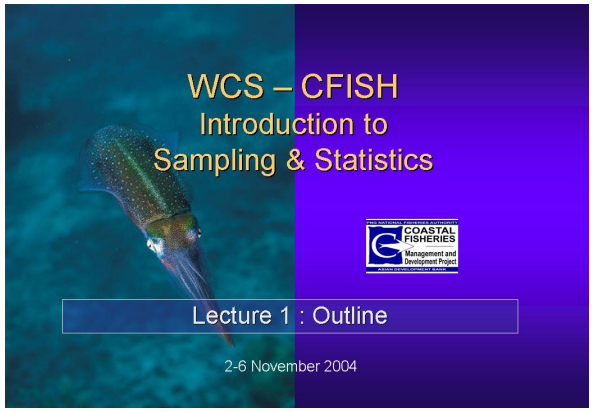
Mean is a particularly informative measure of the "central tendency" of the variable if it is reported along with its confidence intervals. Usually we are interested in statistics (such as the mean) from our sample only to the extent to which they are informative about the population. The larger the sample size, the more reliable its mean. The larger the variation of data values, the less reliable the mean.

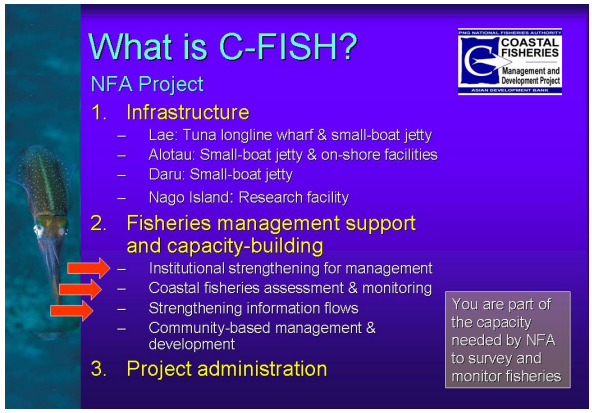
Median = A measure of central tendency (the term first used by Galton, 1882) of a sample is the value for which one-half (50%) of the observations (when ranked) will lie above that value and one-half will lie below that value. When the number of values in the sample is even, the median is computed as the average of the two middle values.

Mode = A measure of central tendency, the mode (the term first used by Pearson, 1895) of a sample is the value which occurs most frequently in the sample.

Nonparametric methods were developed to be used in cases when the researcher does not know the parameters of the distribution of the variable of interest in the population (hence the name nonparametric). In more technical terms, nonparametric methods do not rely on the estimation of parameters (such as the mean or the standard deviation) describing the distribution of the variable of interest in the population. Therefore, these methods are also sometimes (and more appropriately) called parameter-free methods or distribution-free methods.

Lecture 7.5: Introduction to Sampling & Statistics





This module: Introduction to Sampling & Statistics

1. Introduction: Services you provide, skills you will need
2. Green's Rules for sampling designs
3. Optimising designs
4. Data handling & storage
5. Analysing results of surveys (Statistics)
6. Presenting results

Lecture 1: Sampling / monitoring → describing distribution & abundance

- Needed for fisheries stock assessment & management, control of environmental impacts, or basic research
- We need to know 3 things:
  - WHERE organisms are (distribution)
  - HOW organisms are distributed (patchy or clumped, random throughout their range, or respond to some feature
  - How MANY there are → How many can we safely take?
- Both of these can vary through TIME and SPACE

In summary….

- Sampling – obtaining information about something using a small subset to characterise it
- Monitoring – repeated sampling designed to detect changes through time
- Distribution – where animals / plants are
- Abundance – how many there are

Services you will be able to provide

- Identification of a range of organisms
- Field methods for surveying fishes, benthic invertebrates / corals, mangroves, seagrasses, fish markets
- Appreciation of sustainable management
- Logical design of sampling programmes
- Handling & storing data
- Simple analysis of data
- Simple reports that describe results
- Organising and doing a sampling / monitoring project

Why a special course for MARINE?

- Life-cycle with dispersive larval phase
- Numbers of juveniles & adults vary through space and time unpredictably
- Many moderately abundant and rare species - what do we monitor?
- The environment poses logistic problems for sampling (..if only we had gills…)
- Many habitats are fragmented, but connected through larval dispersal - this requires special consideration (compare with terrestrial mammals)
- Marine environments subject to catastrophic and unpredictable disturbances (cyclones, floods, climate change).

Skills you will need

1. Ability to focus on and clearly state the question/problem to be examined
2. Knowledge of logical framework which will assist in the correct, methodical solving of problems
3. Knowledge of principles of sampling and monitoring
4. Knowledge of simple statistics
5. Ability to collect field information, store, handle, analyse, interpret results.
6. Ability to assimilate other people's results to enhance your own findings (what was found in the past?)
7. Ability to communicate results to the outside world (NFA, others) with reports, seminars?

LECTURE 7.6: GREEN'S RULES

Introduction to Sampling & Statistics

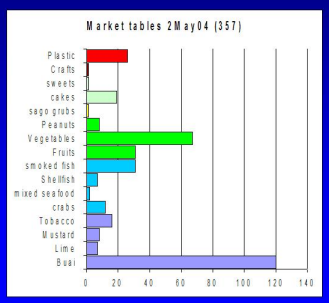
COASTAL FISHERIES Initiative and Management and Development Project

Lecture 2 : Green's Rules

Introduction to Sampling & Statistics

- Introduction: Services you provide, skills you will need
- Green's Rules for sampling designs
- Optimising designs
- Data handling & storage
- Analysing results of surveys (Statistics)
- Presenting results

How did we get this outcome?



- What are the traps?
- Can we go wrong?
- How do we ensure results are dependable and the decisions we make on them will not be wrong?

3

Green's Rules

- The 10 Commandments of sampling / monitoring design
- Get these right and its VERY hard to go wrong

The 10 commandments of sampling & monitoring design

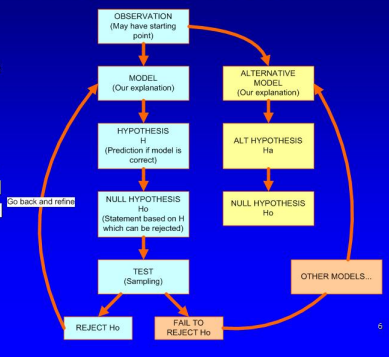
1. Frame the question
2. Replicate
3. Randomise
4. Use Controls
5. Pilot surveys
6. Verify sampling techniques
7. Stratify your sampling
8. Optimise design
9. Test your assumptions
10. Accept your results !

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons. 257 pp

5

1. Frame the question

- Hypothesise
- Be able to state concisely to someone else what question you are asking.
- Your results will only be as good as your initial conception of the problem.



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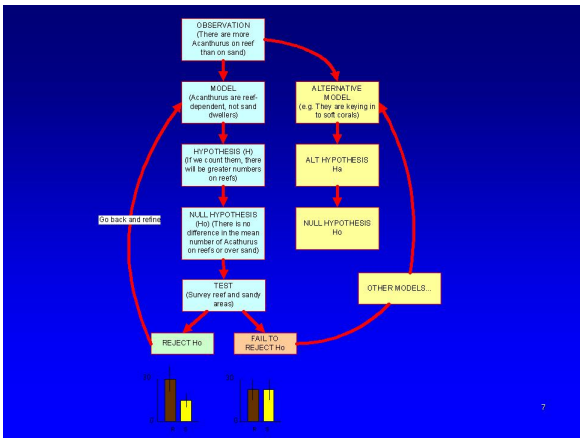


7

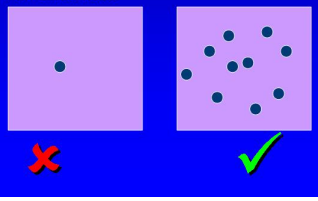
Features of deductive arguments

- The hypothesis is proposed based on your model and must be TESTABLE
- It is a prediction based on the model
- You cannot use data to propose an hypothesis and then use those same original data to test it !
- To test an hypothesis, we need a null hypothesis which is a logical OPPOSITE to the Hypothesis
- It is used to disprove all possibilities other than the prediction of interest
- This is followed by a test or experiment

8

2. Replicate, replicate, replicate

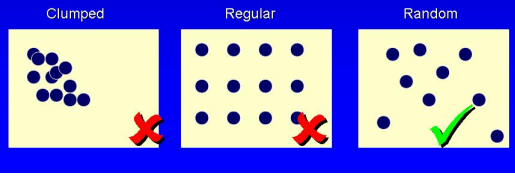
- Take replicate samples within each combination of time, location, and any other controlled variable. Differences "among" can only be demonstrated by comparison with differences "within"



9

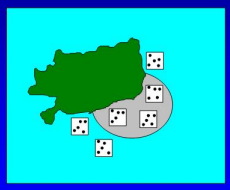
3. Randomise sampling

- Take an equal number of randomly allocated replicate samples for each combination of controlled variables.
- Putting samples in "representative" or "typical" places is ***not*** random sampling



4. Use controls

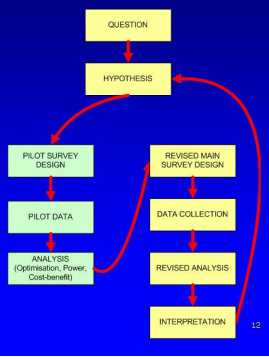
- To test whether a condition has an effect, collect samples both where the condition is present and where the condition is absent but all else is the same.
- An effect can only be demonstrated by comparison with a control



11

5. Pilot surveys

- Carry out some preliminary sampling to provide a basis for evaluation of sampling design and statistical analysis options.
- Those who skip this step because they do not have enough time usually end up losing time, money and reputation.



12

6. Verify techniques (accuracy)

- Verify that your sampling device or method is sampling the population you think you are sampling, and with equal and adequate efficiency over the entire range of sampling conditions to be encountered.
- Variation in efficiency of sampling from area to area biases among-area comparisons.

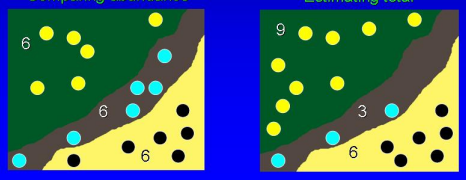
13

7. Stratify

- If the area to be sampled has a large-scale environmental pattern, break the area up into relatively homogeneous (similar) sub-areas (= stratification).
- If you are estimating the total abundance over the entire area, make the allocation of sampling effort proportional to the size of each sub-area and the variance attributable to each.

SIMPLE
Comparing abundance

PROPORTIONAL
Estimating total

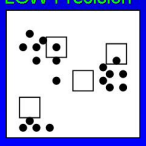


14

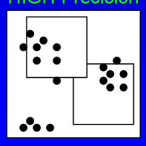
8. Optimise sampling unit (precision)

- Verify that your sample unit size is appropriate to the size, density, and spatial distribution of the organisms you are sampling.
- Then estimate the number of replicate samples required to obtain the precision (= standard error : mean ratio) you want

LOW Precision

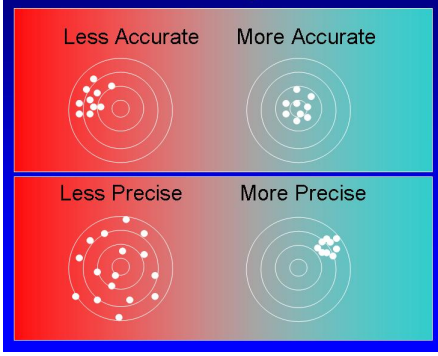


HIGH Precision



15

Accuracy ≠ Precision



Hitting the RIGHT target

Repeatedly hitting the SAME target

16

9. Test assumptions of the statistics you use

- Not too important when means and SE (standard errors) being used graphically.
- Test your data to determine whether the error variation is homogeneous, normally distributed, and independent of the mean.
- If it is not, as will be the case for most field data, then you can:
  - (a) appropriately transform the data
  - (b) use a distribution-free (non parametric) procedure
  - (c) use an appropriate sequential sampling design, or
  - (d) test against simulated Ho data.

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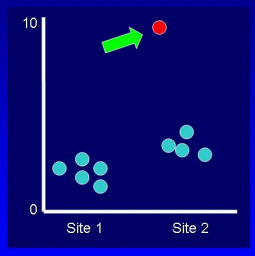
10. Accept your results !

- There is no such thing as an outlier
- Having chosen the best statistical method to test your hypothesis, stick with the result.
- An unexpected or undesired result is not a valid reason for rejecting the method and hunting for a "better" one



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Typical sampling / monitoring designs

- Define the factors of interest
  - Time (once, or repeated)
  - Habitats (reef, seagrass, shallow, deep, nearshore, offshore etc.)
  - Sites and locations (Province, island, N/S/E/W)
- Use these to define the question Green's Rule 1
- There are 2 kinds of factors:
  - Fixed (you / client defines them) Time, habitats
  - Random (included so that results are general) Sites

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Here is a simple valid monitoring programme with time as a factor of interest

The data you would collect for this would be:

Time → / Replicate ↓	1	2	3
	$x_{1,1}$	$x_{2,1}$	$x_{3,1}$
	$x_{1,2}$	$x_{2,2}$	$x_{3,2}$
	$x_{1,3}$	$x_{2,3}$	$x_{3,3}$
	$x_{1,4}$	$x_{2,4}$	$x_{3,4}$
	$x_{1,5}$	$x_{2,5}$	$x_{3,5}$

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LECTURE 7.7: CASE STUDIES

Introduction to Sampling & Statistics

COASTAL FISHERIES Management and Development Project

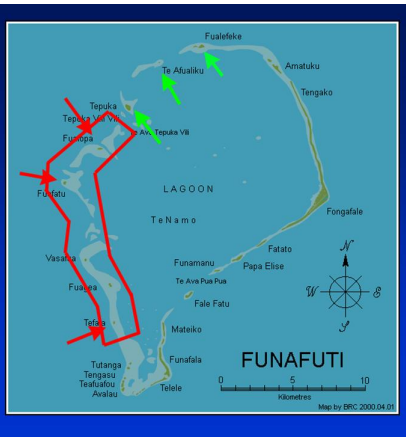
Special Lecture: case studies

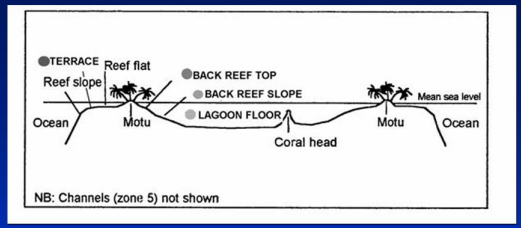
Examples of sampling & monitoring programmes

1. Funafuti conservation area, Tuvalu
2. Erakor Lagoons, Vanuatu

Funafuti conservation area

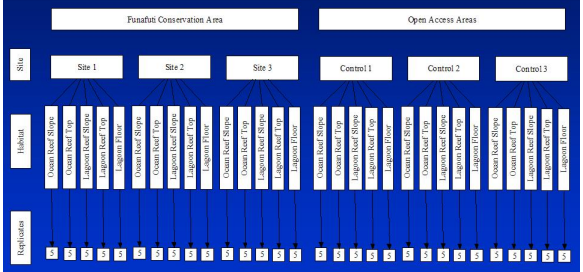
- What were the questions?
  - to establish a baseline and identify any existing patterns of distribution of marine resources in and outside the conservation area
  - to observe changes through time
  - to determine whether the conservation area 'works'





INDICATORS:
- 5 families of fishes
- Food fishes
- Corals & algae
- Other invertebrates

What was the design?



2 surveys

Treatment	Site	Code	Date(s) Survey 1	Date(s) Survey 2	Latitude S	Longitude E
Control 1	Fualifeke	C1	4/11/97	22/1/99	08°25.970'	179°07.357'
		C1-T	16/11/97	6/4/99	08°25.518'	179°07.106'
Control 2	Afualiku	C2	3/11/97, 18/11/97	16/3/99,22/3/99	08°26.283'	179°05.481'
		C2-T	18/11/97	6/4/99	08°26.053'	179°05.720'
Control 3	Tepuka	C3	29/10/97	17/3/99	08°28.099'	179°04.904'
		C3-T	11/11/97	23/3/99	08°27.229'	179°04.242'
Reserve 1	Fualopa	R1	30/10/97	18/1/99	08°29.742'	179°03.967'
		R1-T	10/11/97	19/3/99	08°29.318'	179°03.288'
Reserve 2	Fuafatu	R2	2/11/97	15/3/99	08°30.886'	179°02.626'
		R2-T	17/11/97	26/3/99	08°30.238'	179°02.169'
Reserve 3	Tefala	R3	5/11/97	20/1/99	08°36.092'	179°04.460'
		R3-T	13/11/97	25/3/99	08°35.822'	179°03.958'

What was measured?

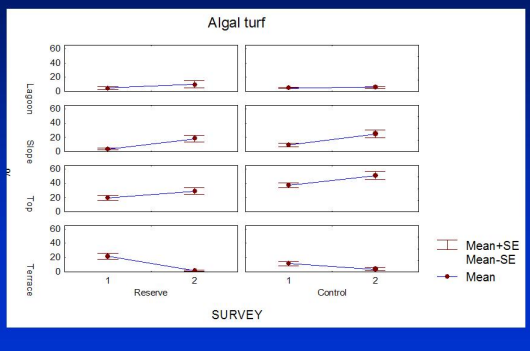
Table 1: Summary of transect methods to be used for surveying the main groups of indicator organisms.

ORGANISM	METHOD	REPLICATES*	TEAM MEMBERS
3 families of Fishes	30m x 10m belt transects	7	Uschi Kaly, Samasone Sauni, Niko Apinelu
Food fishes	5 minute timed counts	10	Karim Belhadjali, Uschi Kaly, Tolue Niu
Corals & algae	30m PIT transects with 100 observation points	7	Claudia Ludescher, Luka Teiti, Uschi Kaly
Invertebrates	30m x 2m transects	7	Teleke Peleti Lauti, Sepola Maatusi

What were the results?

- Only 2 surveys so far
- Results interesting, but would have expected best results after 5 years
- Signs of poaching
- Once the project stopped, so did the monitoring

Plots used



Foodfishes

Species		Lagoon	Slope	Top	Terrace
Acanthurus nigricaudus	Pone uli		↑		
Mulloidichthys vanicolensis	Kaivete				
Mulloides flavolineatus	Kaivete	↓			
Naso lituratus	Manini lakau, Uma lei		↑		
Monotaxis grandoculus		↑	↑		
Lutjanus gibbus	Taea		↑		
Gnathodentex aureolineatus					
Acanthurus lineatus	Ponelolo			↑	
Acanthurus nigricans	Pone uli				↑
Ctenochaetus striatus	Mailo			↓	
Acathurus triostegus	Manini		↓	↓	
Scarus sordidus	Ulafi	↑		↓	
Spratelloides delicatulus		↓	↓	↑	
Diversity of foodfishes		↑		↓	↑
Total number of foodfishes		↓	↓		

5 families of fishes

Species		Lagoon	Slope	Top	Terrace
Thalassoma amblycephalum	Kiole		↑	↑	↑
Ctenochaetus hawaiiensis	Maito				
Acanthurus nigricans	Pone uli				
Ctenochaetus striatus	Maito			↓	
Thalassoma quinquivittatum	Kiole		↑	↑	↑
Diversity of fishes		↑		↓	↑
Total number of fishes			↑	↑	↑

Corals, algae, physical

Species		Lagoon	Slope	Top	Terrace
Dictyosphaeria	Limu		↑		
Peyssonelia	Limu			↓	
Halimeda	Limu	↓			
Microdictyon	Limu		↑	↑	
Acropora nobilis	Kamu		↑		
Rubble	Kikili		↑	↑	
Sand	One	↑	↓		
Algal turf	Limu				
Coralline paint	Limu			↓	↓
Diversity of hard corals	Kamu			↓	↑
Total cover by hard corals	Kamu				↑
Diversity of algae	Limu		↑	↓	
Total cover by algae	Limu		↑		

Overall

Results are promising, but needed more time

Group	Increase #	Increase %	Decrease #	Decrease %	No Change #	No Change %	# Tests
Foodfishes	11	18	10	17	39	65	60
Transect fishes	11	39	2	7	15	54	28
Corals & Algae	11	21	7	13	34	65	52
Totals	**33**	**24%**	**19**	**14%**	**88**	**63%**	**140**

Good and bad points

GOOD:

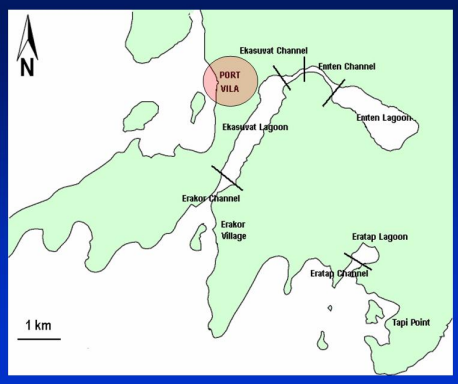
- Well-designed
- All of data collected for first 2 surveys
- Potential for effective management of lagoon resources

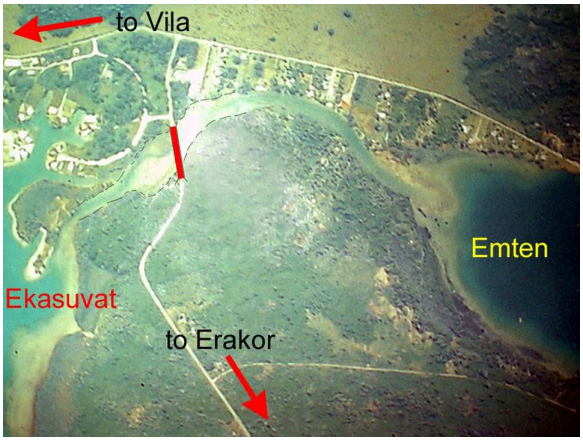
BAD:

- Team not experienced, so data a bit weak
- No further surveys
- Expect count & biomass ↑ in 5-10 years

Erakor lagoons, Vila

- What were the main questions?
  - Are there differences in water quality between Ekasuvat and Emten lagoons?
  - Are there any patterns within lagoons?
  - Has the water quality changed through time?
  - Can we identify problem areas for management?

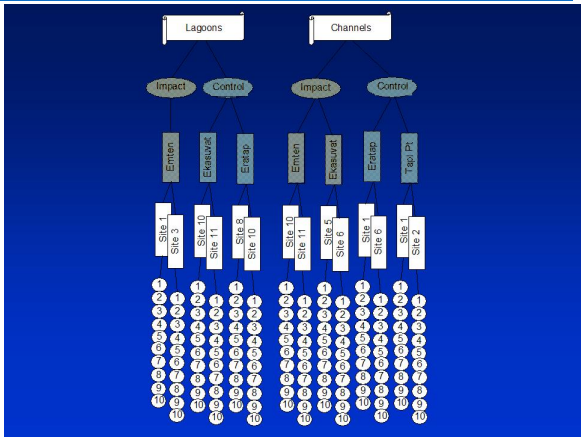




What was the design?

TABLE 1: LAGOON AND CHANNEL LOCATIONS AND SITES SURVEYED IN THIS STUDY (SEE ALSO MAPS 1-4).

Ecosystem	Treatment	Location	Sites
Lagoons	Impact	Emten Lagoon	Sites 4, 6-7, 9-11
	Controls	Ekasuvat Lagoon	Sites 7-10
		Eratap Lagoon	Sites 7-12
Channel areas	Impacts	Emten Channel	Sites 1-3, 5, 8, 12-16
		Ekasuvat Channel	Sites 1-6
	Controls	Eratap Channel	Sites 1-6
		Tapi Point Channel	Sites 1-6

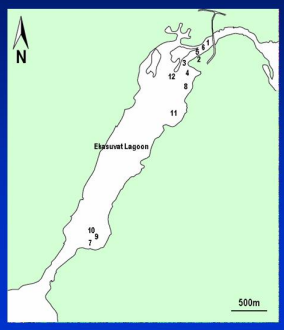


What was measured? (Seagrasses, shellfish, fishes)

TABLE 1: SUMMARY OF SURVEYS UNDERTAKEN AND METHODS USED.

Habitat	Location		Survey type	Method	Replicates
Seagrass beds dominated by Thalassia	Lagoons & Channels	Emten, Ekasuvat, Eratap, Tapi	Seagrass surveys	1m² quadrat	10
Cockle beds	Lagoons	Emten	Cockle surveys	1m² quadrat	10
Mangrove fringes	Lagoons & Channels	Emten, Ekasuvat, Eratap, Tapi	Timed fish counts	5 minute count	5
Main passages	Channels	Emten, Ekasuvat, Eratap, Tapi	Timed fish counts	5 minute count	5
Sandy areas near beaches	Lagoons	Emten, Ekasuvat, Eratap	Seines	15m x 1.5m seine net	5

Seagrasses, fish, shellfish

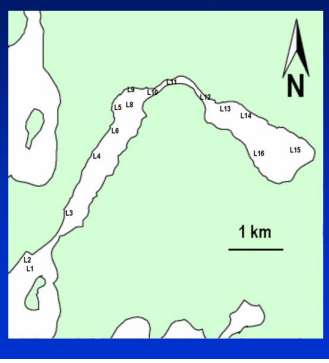


Water quality

TABLE 1: SITES SAMPLED AND VARIABLES MEASURED IN THE ERAKOR LAGOONS ON 26TH JANUARY 1998 BY STEVE ROGERS OF GEOLOGY, MINES AND WATER RESOURCES.

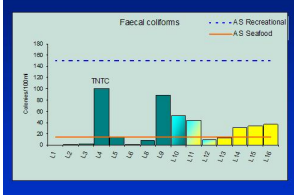
Location	Site	Latitude	Longitude	Variables measured at all sites
Erakor Bay	L1	17.46.12	168.18.32	Conductivity (mS/cm)
	L2	17.46.07	168.18.30	Temperature
Ekasuvat Lagoon	L3	17.45.41	168.18.53	Clarity (m)
	L4	17.45.03	168.19.15	NH_3
	L5	17.44.30	168.19.28	NO_3
	L6	17.44.46	168.19.27	PO_3
	L8	17.44.30	168.19.35	COD
	L9	17.44.15	168.19.41	Total coliforms
Ekasuvat Channel	L10	17.44.20	168.19.57	Faecal coliforms
Emten Channel	L11	17.44.16	168.20.05	
	L12	17.44.18	168.20.21	
Emten Lagoon	L13	17.44.22	168.20.34	
	L14	17.44.27	168.20.56	
	L15	17.44.56	168.21.31	
	L16	17.45.04	168.21.08	

Water quality

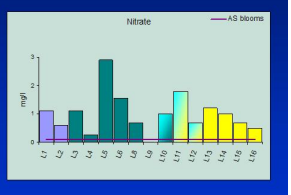


What were the results?

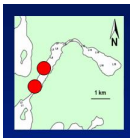
Water Quality Patterns within Ekasuvat



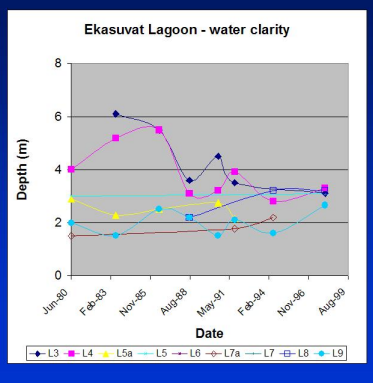
Faecal coliforms



Nitrates



Changes in water clarity through time (a range of surveys)



Good and bad points

- Shows that lagoons have degraded through time
- Suggests some causes (e.g. resort sewers and reduced flows)
- Shows condition of lagoons and resources
- Shows patterns in lagoons
- Shows lagoons are in need of management
- Data through time collected by lots of people using different techniques
- Inadequate replication for time data (2)

LECTURE 7.8: THE DESCRIPTION OF DATA

Introduction to Sampling & Statistics

Lecture 3 : Statistics: the description of data

or…."Variance is your friend"

Introduction to Sampling & Statistics

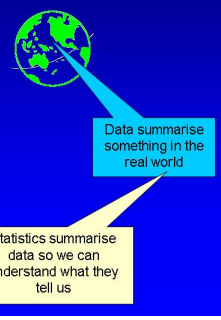
- Introduction: Services you provide, skills you will need
- Green's Rules for sampling designs
- Optimising designs
- Data handling & storage
- Analysing results of surveys (Statistics)
- Presenting results

Topics:

1. The mean / average – what is it?
2. What is an estimate of error? variance? Two meanings… (and why is variance my friend???)
3. Deriving SD or S (the standard deviation)
4. What is SE (the standard error)?

Starting at the beginning…

- Datum = singular
- Data = plural
- If data describe / summarise the real world, statistics describe / summarise the data
- Statistics are descriptive properties of data
- The first point to know is that "statistics" are a matter of convention. There are many ways to describe data, what we will see are the agreed methods that people usually use.



Some definitions not to confuse…

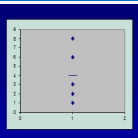
- Variables are things that we measure, control, or manipulate in research. For example, the salinity of water, number of fish, size of trees.
- Usually we try to summarise measurements of variables. This leads to parameters and statistics.
- Parameters are the true values of the summary information of your data. e.g. True mean μ (Greek "mu").
- Statistics are our estimates of the value of parameters. e.g. mean $\bar{X}$ (or average)

More definitions….

- These two terms, parameter and statistic, depend on your definition of the population of interest.
- e.g. the people in this room; or the people in this country, or any other frame of reference (now you see why Green's Rule 1).
- Examples of parameters and statistics:

Parameters:	Statistics:
μ (true mean)	$\bar{x}$ (sample or estimated mean)
σ (true standard deviation)	s (sample standard deviation)
σ^2 (true variance)	s^2 (sample variance)
TRUE	ESTIMATED

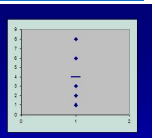
Your first mission:



Find a way of describing, using a single number, the following data: 1, 3, 8, 6, 2

- We could:
  1. Pick the highest value, saying the readings do not exceed that (max)
  2. Pick the middle most value (median)
  3. Pick the most common value (mode)
  4. sum values and divide by the number of values, n (mean)
  5. multiply values / n (geometric mean)

The mean: $\bar{x}$



For numbers 1,3,8,6,2

This is the statistical term for average

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \ldots . x_i + \ldots . x_n}{n}$$

where:

n = number of samples or replicates

i = the ith replicate in the series from 1 to n

It can also be written as:

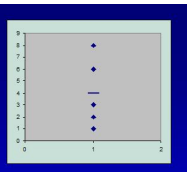
$$\bar{x} = \frac{\Sigma x_i}{n} = 4$$

More about the mean

- The mean is a particularly informative SUMMARY STATISTIC (or parameter, if you know the true value): that is, it summarises the data.
- It is a measure of the "central tendency" of the variable if it is reported along with its confidence intervals = errors.
- Usually we are interested in statistics (such as the mean) from our sample only to the extent to which they are informative about the population.
- The larger the sample size, the more reliable its mean. The larger the variation of data values, the less reliable the mean
- NEVER report a mean without some confidence intervals (more later)

Your second mission:

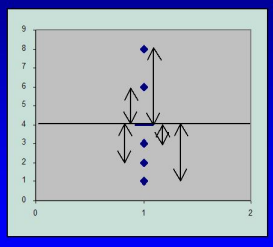
How could we describe the location and spread of these values?



1. we could use the normal coordinate system and describe each point in relation to the x-axis
2. we could describe the distance of each point from one selected point
3. we could describe the distance of each point from the mean

The standard deviation (error around a mean)

- SD or S
- σ if a parameter
- a measure of the location or spread of each replicate in relation to the mean
- How would we measure the spread of values around the mean?



What is error? Have we done a bad job?

- No. There are many types of "error / deviation / variance"
- In statistics, errors are mathematical descriptions of deviation from the mean and include:
  - "Errors" due to your mistakes
  - "Errors" due to the equipment
  - "Errors" due to specific genetics and life experienced by an organism
  - "Errors" due to which treatment your variable is in (e.g. fish in impact vs control)
  - "Errors" due to arm of the lagoon, depth etc.

Measuring spread

- we could add all of the deviations
  - but negative values mixed with positive ones would cancel out the deviations
  - and this could result in a larger number if we have more points
- we need a method that is not affected by these two problems….

So what are our options?

- Using absolute value
- Squaring the deviations ✓

- But then, we still have the problem of a larger SD with more replicates
- So we average the deviations over df (a measure of the number of data points) ✓

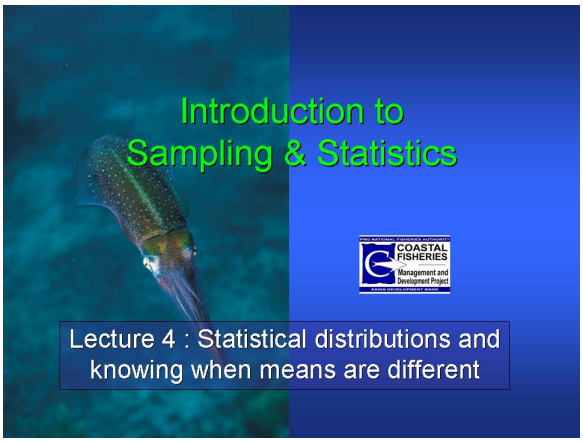
…and what are degrees of freedom?

- When we compare means, we do so with n-1 df.
- df differ from n in that they describes the number of unique pieces of information that are needed to describe the raw numbers.
- If we know the mean, we only need n-1 numbers to pin down the whole system.

So to describe our data properly…

- People often use a mean
- Expressed +/- SD (NEVER WITHOUT)
- Sometimes SD comes in other related forms
  - 95% confidence limits
  - Standard Error (SE) or
  - variance (S^2)

LECTURE 7.9: DISTRIBUTIONS



Introduction to Sampling & Statistics

- Introduction: Services you provide, skills you will need
- Green's Rules for sampling & experiments
- Optimising designs
- Data handling & storage
- Analysing results of surveys (Statistics)
- Presenting results

2

Distributions
Look at this simple data set:

6	x_1
13	x_2
0	x_3
12	x_4
0	x_5
5	n

MEAN $\bar{x} = 6.2 = \frac{\Sigma x_i}{n}$

VARIANCE (spread)

$S^2 = 6.3 = \frac{\Sigma (x_i - \bar{x})^2}{(n-1)}$

STANDARD DEVIATION

$SD \text{ or } S = 2.5 = \sqrt{S^2}$

STANDARD ERROR

$SE = 1.1 = S / \sqrt{n}$

HINT: You never need these formulae – they are in EXCEL

The population of values this sample came from is:

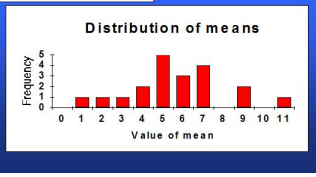
1	3	0	4	5	4	3	2	7	14
0	4	0	7	9	4	0	3	14	17
12	7	6	9	12	5	2	1	2	9
15	11	7	12	8	3	3	0	0	8
16	12	18	10	5	0	0	1	5	6
5	7	10	19	3	1	0	2	4	7
7	2	2	21	13	0	7	0	3	0
2	1	2	8	14	8	5	4	0	1
3	0	4	0	23	16	12	15	7	3
16	7	5	1	19	15	14	16	12	5

This population of cells has a $\mu = 6.6$ and a $\sigma = 5.8$
That is TRUE mean and TRUE SD

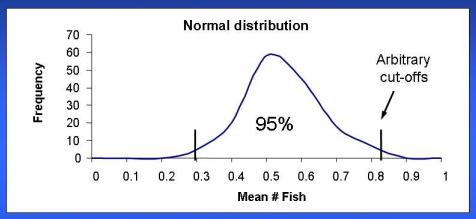
If we take 20 samples, each of 5 replicates from this population….

	$\bar{x}$	S		$\bar{x}$	S
Run 1	6.2	6.3	Run 11	1.8	4
Run 2	5.4	4.4	Run 12	3.4	4.2
Run 3	9	7.6	Run 13	6.4	4.6
Run 4	2.4	3	Run 14	5	3.4
Run 5	7.4	3.8	Run 15	11	6.5
Run 6	6.4	7.4	Run 16	7	8.2
Run 7	4.4	4.3	Run 17	9.4	9.9
Run 8	5.2	4.5	Run 18	7.8	6.2
Run 9	5.6	5.2	Run 19	4.4	3.6
Run 10	7.8	6.8	Run 20	5.4	4.1

We would get the following DISTRIBUTION of means

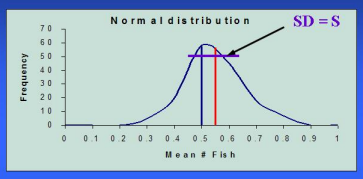


The area under the distribution curve = 100% of observations



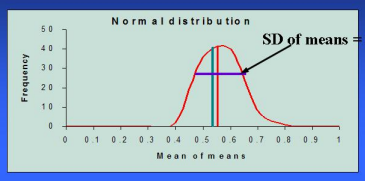
- 95% of the distribution (of the observed means) lie between 0.30 and 0.83
- 5% lies outside in the "tails"
- If we take another sample and get a mean of 0.25, we would say that it is unlikely that it comes from this distribution (<5% chance)

Distribution of sample means



•This is a distribution of mean values obtained in 165 replicate random fish counts (with 5 counts per replicate)
•Mean of the groups of samples $\bar{x}$ = 0.50
•True mean μ = 0.55

Distribution of the means of means



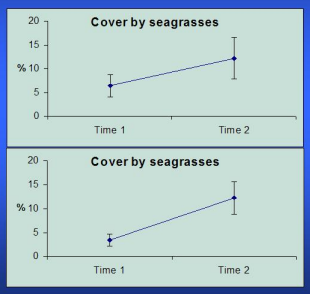
- This is a distribution of mean values obtained in 84 replicate random samples of means (with 5 means per replicate)
- Mean of the means of samples $\bar{x}$ = 0.54
- True mean μ = 0.55

$SE = s/\sqrt{n}$

Reality check…..

- So far we have only described what samples of numbers look like for:
  - means of samples taken of a variable
  - means of groups of means calculated from those samples
- This shows the relationship between $\bar{x}$ μ, SD and SE
- But what happens if we want to compare means with one another?

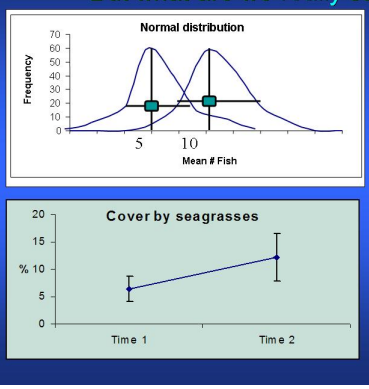
What are we doing when we compare two means on a graph?



Top graph:
You would say means cannot be distinguished

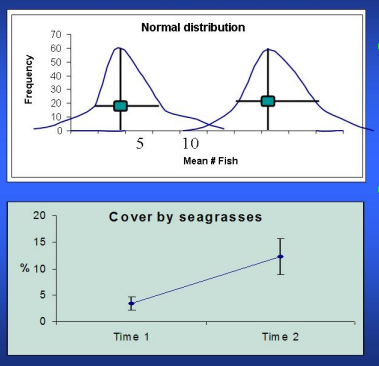
Bottom graph:
Means are different

But what are we really saying?



- If we turn the lower graph on its side…
- In this case, there is overlap in the SE's and the means are close together
- We conclude that the two samples come from the same population

When the means are different



- In this case, there is no overlap in the SE's and the means are far apart
- We conclude that the two samples come from different populations

Distributional statistics

- In monitoring, sampling and experiments we often use these stats
- They assume that we have an underlying normal distribution
- That is, that the data represent some mean value with some variation distributed in the shape of a normal curve
- This gives us the ability to compare means relatively easily, though there are costs if the assumptions are not met

LECTURE 7.10: OPTIMISING DATA

Introduction to Sampling & Statistics

COASTAL FISHERIES Management and Development Project

Lecture 5 : Optimising a seagrass sampling design

Introduction to Sampling & Statistics

- Introduction: Services you provide, skills you will need
- Green's Rules for sampling & experiments
- Optimising designs
- Data handling & storage
- Analysing results of surveys (Statistics)
- Presenting results

Focusing on Green's Rule 8: Precision

1. Why do we need to optimise designs? Type I and Type II errors
2. Optimising your designs by looking at Precision

Aims:

➔Gain experience in doing seagrass surveys in clear water

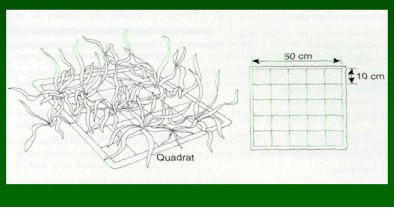
➔Assess yourself for the deepest working depth on snorkel

➔Get pilot data for optimising sampling designs and handling data (lab session)

Seagrasses & epiphytes

Quadrats - e.g. 1m^2 or transects 100 points

- Gridded to allow for estimation of % cover
  - seagrasses
  - epiphytes



Self-assessment: workable scientific snorkelling

- Work out your own comfortable working depth
- Tell this to your team
- Collect seagrass data WITHIN your limits

Why do we need to optimise designs? Type I and Type II errors

- Type I error is getting too many significant results. That is we Reject H_o too often
- Type II error is failing to reject H_o when it should have been (i.e. too many non-significant results)

The truth

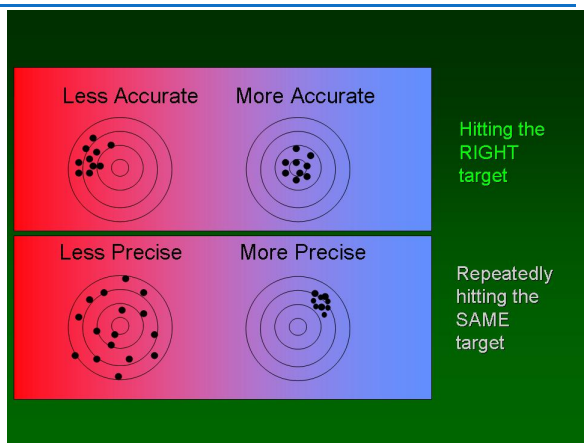
What you see	Ho is true	Ho is false
Fail to reject Ho	✓	Type II error
Reject Ho	Type I error	✓

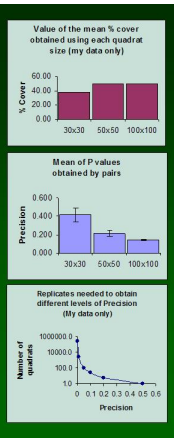
Optimising your designs using precision (P)

- Precision is the SE : $\bar{x}$ ratio
- $P = \frac{SE}{\bar{x}}$
- S or SD (standard deviation) and S^2 (variance) are estimates of some true value that is absolute for a population (average deviations)
- SE (standard error) varies with the amount of sampling effort = $S/\sqrt{n}$, so as we put in more effort, we get a better (smaller) SE

Characteristics of P

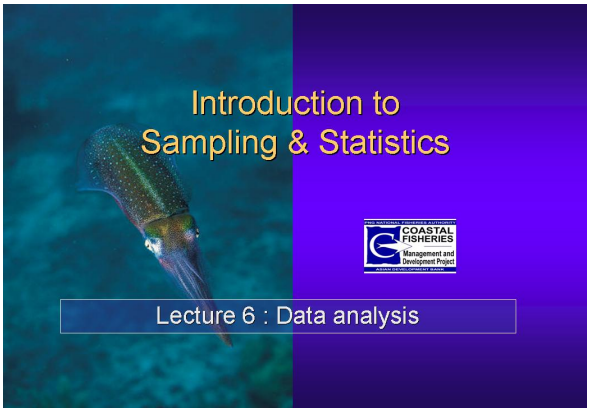
- Rule of thumb: $P \leq 0.1$
- i.e. SE should be 10% of mean or less
- Our concerns with the mean are about getting accuracy - i.e. the RIGHT answer
- Precision is about getting the SAME answer repeatedly
- Both SE and P are sensitive to:
  - size of sampling unit
  - number of replicates
  - suitability of sampling gear
  - all other forms of errors





- TOP: Accuracy: This plot of means shows that our estimate of the mean can differ.
- MIDDLE: Precision: was best for the 100x100 quad
- BOTTOM: If we want P=0.1, we will need 24 replicates. If we wanted precision of P=0.01 we would need 2,440 !!

LECTURE: 7.11 DATA ANALYSIS



This module: Introduction to Sampling & Statistics

1. Introduction: Services you provide, skills you will need
2. Green's Rules for sampling designs
3. Optimising designs
4. Data handling & storage
5. Analysing results of surveys (Statistics)
6. Presenting results

What Statistics should we use?

- It depends on your question…But in fact should be part of the initial planning (do not leave it as a surprise for later)
- The main basic types:
  - 1. Descriptive Statistics
  - 2. Inferential / Deductive Statistics
- The main approaches:
  - A. Parametric
  - B. Non-parametric

1. Descriptive Statistics

- Organise, summarise, describe measures
- No predictions or inferences are made of population parameters
- No hypothesis-testing
- Mean $\bar{x}$, mode, median, range, SD, SE, 95%CL, CV, skewness, kurtosis, frequency distributions

2. Inferential / Deductive Statistics

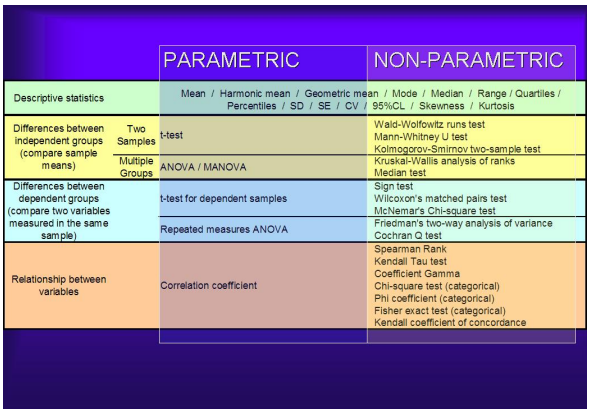
- Used to infer or predict population parameters from sample measures, based on probability theory
- T-tests, ANOVA, MANOVA, χ^2, Correlation, Regression

A. Parametric Statistics

- Oldest
- Make strict assumptions which may not always be true. Require data to be normally distributed and to have homogeneous variances
- Used only with actual observations (not ranks or categorical)
- Compare means and variances
- Counts must usually be transformed. Same for derived data (%, proportions, indices)

B. Non-parametric Statistics

- More recent methods
- Best for small sample size (<100)
- Not based on strict assumptions. Do not require normality or homogeneity
- May be more suitable for processing biological data
- Often simpler to use mathematically
- Can use with actual observations, ranks or categories
- Compare medians
- Can be used with counts or derived data (proportions, indices)



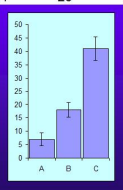
		PARAMETRIC	NON-PARAMETRIC
Descriptive statistics		Mean / Harmonic mean / Geometric mean / Mode / Median / Range / Quartiles / Percentiles / SD / SE / CV / 95%CL / Skewness / Kurtosis	
Differences between independent groups (compare sample means)	Two Samples	t-test	Wald-Wolfowitz runs test Mann-Whitney U test Kolmogorov-Smirnov two-sample test
	Multiple Groups	ANOVA / MANOVA	Kruskal-Wallis analysis of ranks Median test
Differences between dependent groups (compare two variables measured in the same sample)		t-test for dependent samples	Sign test Wilcoxon's matched pairs test McNemar's Chi-square test
		Repeated measures ANOVA	Friedman's two-way analysis of variance Cochran Q test
Relationship between variables		Correlation coefficient	Spearman Rank Kendall Tau test Coefficient Gamma Chi-square test (categorical) Phi coefficient (categorical) Fisher exact test (categorical) Kendall coefficient of concordance

What is the secret?

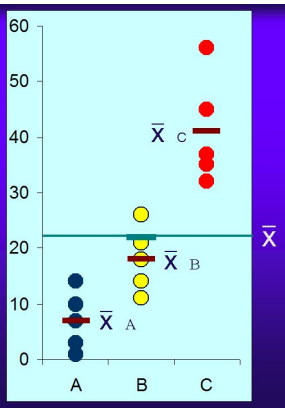
Stats are about measuring the variation within groups and comparing it with variation between groups. If the variation between groups is visible above the background (within), we see a difference.

1-F ANOVA

A	B	C
1	11	45
3	21	32
7	18	37
10	14	56
14	26	35

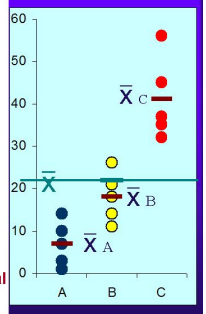


Mean +/- SE



Source of variation	Formula	What signal it estimates
Among treatments	$\frac{\Sigma (\bar{x}_i - \bar{x})^2}{a-1}$	$A_i + \varepsilon$
Residual (error)	$\frac{\Sigma\Sigma (x_{ij} - \bar{x}_i)^2}{a(n-1)}$	ε
Total	$\frac{\Sigma\Sigma (x_{ij} - \bar{x})^2}{an-1}$	

QUESTION: How would you isolate the signal from Factor A (the factor of interest)?

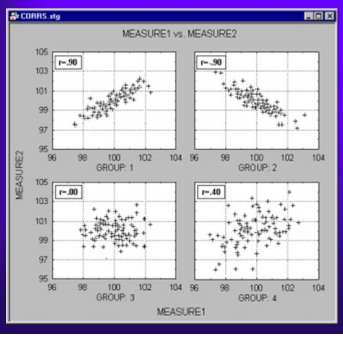


Results

ANOVA

Source Var	SS	df	MS	F	P-value	F crit
Between Groups	3010	2	1505.00	29.04	0.0000	3.89
Within Groups	622	12	51.83			
Total	3632	14				

$$r = \frac{n(\Sigma X^*Y) - (\Sigma X)^*(\Sigma Y)}{\sqrt{[n\Sigma X^2 - (\Sigma X)^2]^*[n\Sigma Y^2 - (\Sigma Y)^2]}}$$



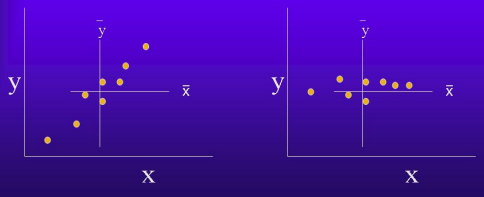
Correlation (Pearson's)

A	B
9	10
7	6
5	1
3	5
1	3

r = 0.7, NS (p=0.05)

The real formula (Pearson)

$$R = \frac{\Sigma (x - \bar{x}) * (y - \bar{y})}{\sqrt{[\Sigma (x - \bar{x})^2 * (y - \bar{y})^2]}}$$



LECTURE 7.12: INTRODUCTION TO ANALYSIS OF VARIANCE (ANOVA)

Introduction to Sampling & Statistics

COASTAL FISHERIES Management and Development Project

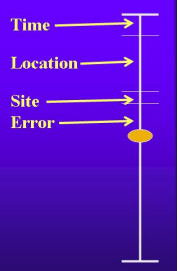
Lecture 6 : Data analysis – Part B ANOVA

Introduction to ANOVA

1. What is ANOVA?
2. Assumptions of ANOVA
3. Mechanics of a 1-Factor ANOVA
4. The results, F-distribution, interpretation and Type I and II errors

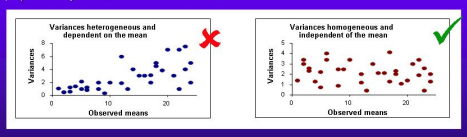
What is ANOVA ? Analysis of Variance

- Powerful tool
- Parametric test (assumes under-lying distributions)
- Assumes overall mean for study & that each datum deviates from it due to combination of factors
- PARTITIONS variance around a mean, attributing parts of it to factors we might be interested in (e.g. time, sites, treatments)
- It has other assumptions which must be met for the test to be valid (most through Green's Rules)



2. Assumptions of ANOVA

- The *main* ones are whether error variances are:
  (i) normally distributed 
  (ii) homogeneous (i.e. approximately the same size from treatment to treatment)
  (iii) independent of the means



- Test your data by plotting them or using simple tests (e.g Cochran's)

If not, you can.....

1. Transform your data ($\sqrt{x+1}$), ($\ln x+1$)
2. Use non-parametric statistics (i.e. distribution-free)
3. Test against simulated Ho data (Monte Carlo simulation)

Mechanics of a 1-Factor ANOVA

Observation
Motupore Lagoon is going downhill

Model
Human activities are damaging ecosystems

H_A

Hypothesis (H)
If we monitor seagrasses we will see % cover decrease with time

Null Hypothesis (H_O)
There is no change in % cover over time

Test
Use sampling to estimate % cover Time 1, Time 2, Time 3

Refine

Support

Fail to reject Ho

Reject Ho

So we set up a monitoring programme with Time as a factor of interest

The data matrix for this would be:

Time →	1	2	3
Replicate ↓	$x_{1,1}$	$x_{2,1}$	$x_{3,1}$
	$x_{1,2}$	$x_{2,2}$	$x_{3,2}$
	$x_{1,3}$	$x_{2,3}$	$x_{3,3}$
	$x_{1,4}$	$x_{2,4}$	$x_{3,4}$
	$x_{1,5}$	$x_{2,5}$	$x_{3,5}$

In general notation this would be:

Treatment (A) →
Replicate ↓

1	2	i	a
$x_{1,1}$	$x_{2,1}$	$x_{i,1}$	$x_{a,1}$
$x_{1,2}$	$x_{2,2}$	$x_{i,2}$	$x_{a,2}$
.	.	.	.
$x_{1,j}$	$x_{2,j}$	$x_{i,j}$	$x_{a,j}$
.	.	.	.
$x_{1,n}$	$x_{2,n}$	$x_{i,n}$	$x_{a,n}$

- Factor A ranges from 1 to a (general case i)
- Replicates range from 1 to n (general case j)

The model

The value of any datum in this system (i.e. the % cover by seagrasses for a replicate at the site at any single time) will be the result of the following model:

$$X_{ij} = \mu + A_i + \varepsilon_{ij}$$

This is Rep 2 at Time 3

Where:

μ	True mean
A_i	Effect of the ith level of Factor A
ε_{ij}	Individual error of replicate reading j in the ith level of Factor A

So... Now our statistical argument is...

Observation
Motupore lagoon is going downhill

H_A

Model
Human activities are damaging ecosystems

Refine
A1>A2>A3

Hypothesis (H)
A1≠A2≠A3 or T1≠T2≠T3

Support

Null Hypothesis (H_O)
A1=A2=A3 or T1=T2=T3

Test
Use sampling to estimate % cover Dec98, Jul99, Nov99

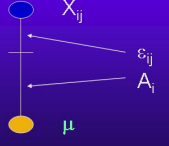
Fail to reject Ho

Reject Ho

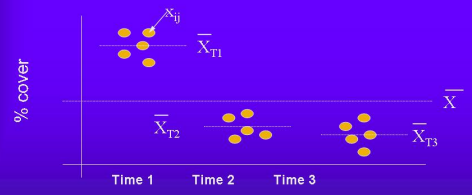
What is our aim?

- To try to separate the effect of sampling at different times (A_i) from the background variation (ε_{ij})

$$X_{ij} = \mu + A_i + \varepsilon_{ij}$$



So we go sampling and get this



- $\bar{x}$ is our best approximation of μ (based on the most observations)
- The overall variation in the survey is equal to the summed deviations^2 (so they are +) of each datum from the overall mean $\bar{X}$

Total sum of deviations = $\sum\sum^{a\ n} (x_{ij} - \bar{X})^2$

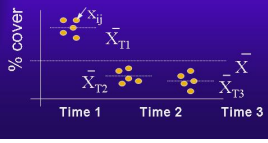
and, using this logic, it follows that ... Error variation (background)

Error sum = $\sum\sum^{a\ n} (x_{ij} - \bar{X})^2$

(The summed squared deviations, "sums of squares" of replicates from their treatment means, thus a measure of variation within treatments) *and ...*

TREATMENT sum = $\sum^{a} (\bar{x}_i - \bar{X})^2$

(measure of variation of the treatment means from the overall mean, i.e. among treatments)



Mean squares and DF

These "sums of squares" keep adding up, so must be divided by the number of observations made in each case to form a "mean square" to make them comparable.

In ANOVA we use "degrees of freedom" (DF) for a factor

DF for Factor A = (a-1)

DF for Error (Residual) = a(n-1)

DF for whole study (Total) = an-1

Note:

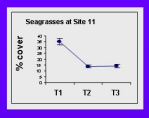
DF Factor A + Residual DF = Total DF

1-F ANOVA

Source of variation	Formula	What signal it estimates
Among treatments	$\frac{\sum^{a} (\bar{x}_i - \bar{X})^2}{a-1}$	$A_i + \varepsilon_{ij}$
Residual (error)	$\frac{\sum\sum^{a\ n} (x_{ij} - \bar{x}_i)^2}{a(n-1)}$	ε_{ij}
Total	$\frac{\sum\sum^{a\ n} (x_{ij} - \bar{X})^2}{an-1}$	

QUESTION: How would you isolate the signal from Factor A (the factor of interest)?

The results, F-distribution, interpretation and Type I and II errors



Output from a 1-F ANOVA

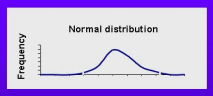
ANOVA						
Source	*SS*	*df*	*MS*	*F*	*P- value*	*F crit*
Factor A (Time)	1484.13	2	742.07	47.67	1.96×10^{-6}	3.89
Residual (error)	186.80	12	15.57			
Total	1670.93	14				

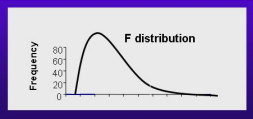
The data this ANOVA comes from are % covers of seagrasses from 1 site at 3 times

	Time 1	Time 2	Time 3
Rep 1	39	15	18
Rep 2	30	12	13
Rep 3	28	14	10
Rep 4	41	17	15
Rep 5	37	11	14

F-distributions

- Data and means of data are assumed to be distributed as NORMAL DISTRIBUTIONS (defined by mean, SD)
- Ratios of two variances are assumed to be distributed as F-DISTRIBUTIONS (a type of χ^2 or Chi^2-distribution) (defined by df_{num}, df_{denom})

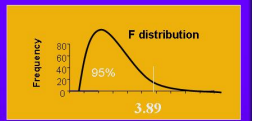




For our results....

Our data come from an H_o F-distribution defined by 2,12 df

H_o is $\frac{A_i + \varepsilon_{ij}}{\varepsilon_{ij}} \approx 1$



The 5% cut-off is at 3.89 (this is called α and is the Type I error rate)

ANOVA						
Source	*SS*	*df*	*MS*	*F*	*P- value*	*F crit*
Factor A (Time)	1484.13	2	742.07	47.67	1.96×10^{-6}	3.89
Residual (error)	186.80	12	15.57			
Total	1670.93	14				

LECTURE 7.13: STORING AND PRESENTING DATA

Introduction to Sampling & Statistics

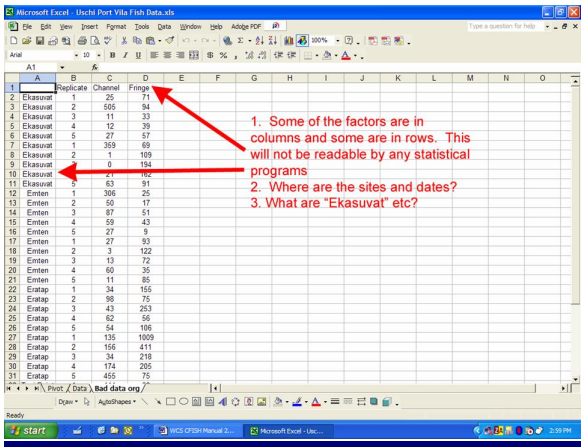
Lecture 7 : Storing & Presenting Data

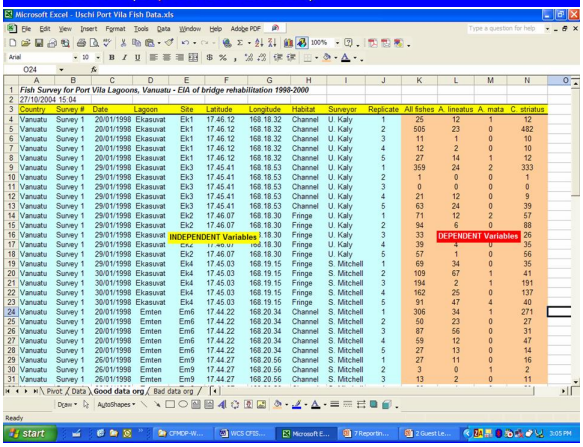
Introduction to Sampling & Statistics

- Introduction: Services you provide, skills you will need
- Green's Rules for sampling designs
- Optimising designs
- Data handling & storage
- Analysing results of surveys (Statistics)
- Presenting results

Data Storage

- Don't blow this one off ! This is important and one of the biggest causes of data loss (and wasted money, effort and time)
- Pay attention to:
  - Headings with dates
  - Labelling of all data – without exceptions
  - Recording all the details (lat/long, who did the work?)
  - Use one row per sample (quadrat, transect, water sample etc)
  - Include a column for all factors (times, sites, treatments) recording the level of each factor for each row (independent variables)
  - If more than one variable is recorded for each sampling unit, add columns on the RHS and continue the information all on one row (dependent variables)



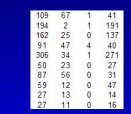


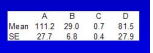
Dependent vs Independent

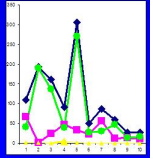
- Dependent variables – those you are measuring. We hypothesise they are DEPENDENT on the factors we are testing
- Independent variables – the factors we are interested in as influencers in our system
- Usually the relationship is one way: The growth rate of fish larvae is dependent on temperature; BUT it would be hard to say that the temperature of the sea is dependent on how fast fish are growing !
- Sometimes it can be two way ! e.g. Length : weight ratios

Presenting Data

- Data could be presented as:
  1. Lists of figures (raw)
  2. Tables & other summaries
  3. Graphs and other figures
- People often use combinations of 2 & 3, but the most common way is through GRAPHS which work well with the way the brain normally sees patterns
- We need to be able to pick up trends, and decide whether means are different

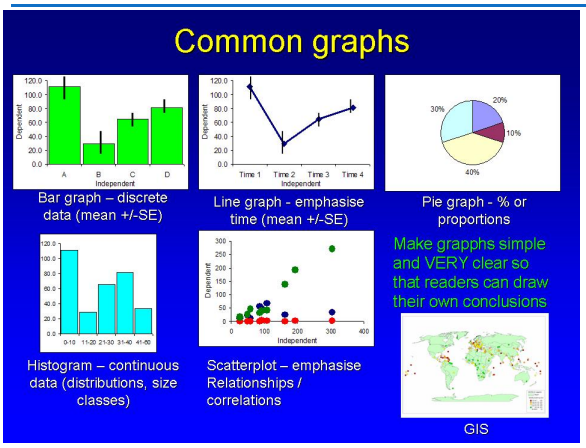


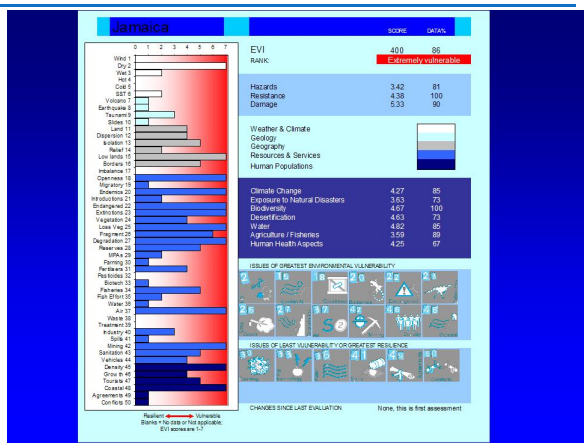


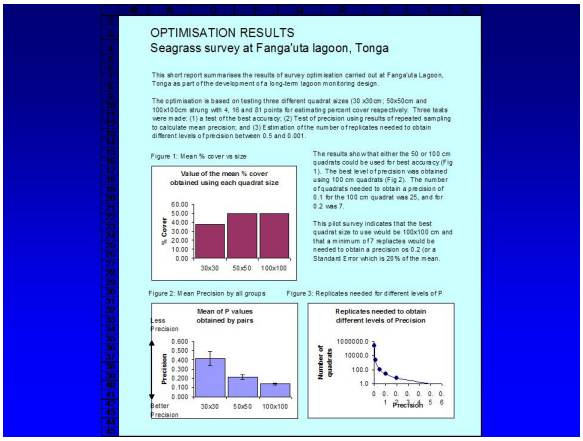


What graphs / tables do I need?

- Go back to your original questions (Green's Rule 1). What were they? Think about creating one graph / table for each
- Decide on table or graph for each
- Usually tables for results of statistical tests, or to describe details of your sampling design
- Use graphs for most results that summarise your data







OPTIMISATION RESULTS
Seagrass survey at Fanga'uta lagoon, Tonga

This short report summarises the results of survey optimisation carried out at Fanga'uta Lagoon, Tonga as part of the development of a long-term lagoon monitoring design.

The optimisation is based on testing three different quadrat sizes (30 x30 cm; 50x50cm and 100x100cm strung with 4, 16 and 81 points for estimating percent cover respectively. Three tests were made: (1) a test of the best accuracy; (2) Test of precision using results of repeated sampling to calculate mean precision; and (3) Estimation of the number of replicates needed to obtain different levels of precision between 0.5 and 0.001.

Figure 1: Mean % cover vs size

Value of the mean % cover obtained using each quadrat size

The results show that either the 50 or 100 cm quadrats could be used for best accuracy (Fig 1). The best level of precision was obtained using 100 cm quadrats (Fig 2). The number of quadrats needed to obtain a precision of 0.1 for the 100 cm quadrat was 25, and for 0.2 was 7.

This pilot survey indicates that the best quadrat size to use would be 100x100 cm and that a minimum of 17 replicates would be needed to obtain a precision os 0.2 (or a Standard Error which is 20% of the mean.

Figure 2: Mean Precision by all groups

Mean of P values obtained by pairs

Figure 3: Replicates needed for different levels of P

Replicates needed to obtain different levels of Precision

CHAPTER 8: STUDENT RESEARCH PROJECT AND WRITTEN REPORT

As part of the training course you will be carrying out a small research project. This project is designed to put into practice many of the skills you have learned over the two week course, as well as improving your abilities in report writing. Students will spend approximately one day working in groups to collect data on a number of variables at study sites around Motupore Island. Data analysis and discussion of the major results will be performed as a group in the laboratory on the following day. Each student then needs to INDIVIDUALLY write a brief scientific report (1000 – 1500 words) on the research and submit the report for assessment to staff by the due date. These reports are to be written in scientific format. Please refer to the section on writing a scientific report (Appendix 1.) for further information. A part of this assessment will also be related to your general participation and enthusiasm for the activities.

Project Title:

Investigating the impacts of zonation and wave exposure on the composition of coral reef communities around Motupore Island, PNG.

Aim:

To investigate differences or similarities in the composition of reef fish, coral and target invertebrates communities on the reef flat and reef crest in sheltered and exposed sites around Motupore Island.

Methods:

There are two main factors (treatments) that this project investigates:

1. Wave Exposure – sheltered versus exposed sites; and 2) Zonation – reef flat versus reef crest. Study sites will be chosen randomly from a range of potential sites located around Motupore Island. You will be sampling four replicate exposed sites and four replicate sheltered sites. Within each study site you will be sampling both the reef flat and the reef crest habitat. Surveys will be conducted in pairs via snorkel, and at each site each pair will record one of the following variables: 1) reef fish abundance and biomass using 2 x 50m transects;
2. Coral reef life-form and percentage cover using 2 x 50m transects;
3. Commercially targeted invertebrate abundances (beche de mer, trochus and giant clams) using 2 x 100m transects. In summary – there are 8 sites to survey, and two habitat types per site. So within each site and habitat you will conduct 2 x 50m fish transects, 2 x 50m coral life-form transects and 2 x 100m invertebrate transects. We will explain how to conduct the surveys during the course.

Results:

Following the surveys, the data will be pooled together and we will guide you through the analysis procedure. As a group we will statistically and graphically explore the data to determine how zonation and wave exposure impact the composition of coral reef communities.

Discussion

Following data analysis, you will be given time to access references and write a scientific report on the research discussing your findings.

PLEASE REFER TO APPENDIX 1. FOR INSTRUCTIONS ON HOW TO WRITE A SCIENTIFIC REPORT!!

APPENDICES

APPENDIX 1. COMPONENTS OF A SCIENTIFIC REPORT

Please use the following as a guideline for writing your report. Most scientific reports use the following format.

Title

Please remember to include a title for your report. Report titles should be concise and give a clear indication of the research. A suggested title for this report could be: Investigating the impacts of zonation and wave exposure on the composition of coral reef communities at Motupore Island, Papua New Guinea.

Abstract

Every report should have an abstract at the beginning. The abstract is summary of the entire study and should begin with an introductory statement, objective, methods, key results, key findings and brief conclusion. The abstract for this report should be no more than 150 words.

Introduction

The introduction in a report gives the necessary background information on the subject you are looking at and 'sets the scene' for the report. You should introduce the broad subject matter of the paper, i.e. why you studied the impact of zonation and wave exposure on coral reefs, why it is important. For example, the context could be in relation to management of commercially important species, or the maintenance of biodiversity, or the importance of maintaining ecological balance and a healthy reef environment. Once you've established why your work is important you should briefly discuss some of the work done previously that addresses the same or similar research questions. The final part of the introduction should specifically state your aim of the research, perhaps as a list of the questions or hypothesis that your research addresses. Your introduction for this report should be approximately 300 words.

Methods

The methods section should outline clearly exactly where you conducted your research and exactly what you did. You must provide enough information so that a fellow researcher can duplicate your study and get similar results. Provide a clear description of your study site starting with the location of Motupore Island and the time of year sampled. You will need to clearly state what your treatments are (wave exposure and zonation) and the number of replicate sites you surveyed. Make sure you also state what you actually surveyed (and to what taxonomic level). To improve clarity we recommend that you use subheadings. For example:

Study Site – the location of research, including latitude and longitude, and perhaps a diagram or map of the reefs around Motupore Island indicating the study sites. Also include in this section the dates that surveying took place.

Data Collection – a description of the methods you used to collect your data, including sampling techniques, transect widths, observation times, etc.

Data Analyses – a description of the types of statistical analyses you used to analyse the data.

Reports can be written in either the first or third person (eg. 'we measured fish abundance' or 'fish abundance was measured'). This requirement sometimes varies between journals. When writing a scientific report for publication, always check with the journal you are intending to target for the preferred format before you begin writing - this will save a lot of time later. This report can be written in either of a number of formats, so long as you are consistent throughout the report and don't change between one format and the next. The methods section for this report should be approximately 300 words.

Results

The results section is possibly the most important part of the paper, as it is in the results that the hard facts reside. The results should NOT be just a series of figures and tables with brief text associated with each. It is very important to have a written description of the results of the study, describing what you have found. The figures and tables merely support the written description of the results of the research. Write about the patterns that the results show, not just the bare facts. It is often very useful to begin each paragraph with a summarising sentence (eg. *Trochus had similar*

abundances at both exposed and sheltered reef sites, while Beche de mer were 50% more abundant at the sheltered reef sites). Above all, it is important that you *interpret* your results correctly. Each statement of fact should refer to the graph (Figure) or table (Table) supporting the result. Every graph or table should be labelled in order of appearance in the report (eg Figure 1, or Table 1), have a brief title and, if appropriate, a key. Try to summarise your results where possible in terms of mean +/- an estimate of variance or precision (e.g. standard error or 95% confidence interval), and plot these as line graphs, bar graphs or in tables. Your results section SHOULD NOT include any discussion of the findings. Only state WHAT was found, not WHY. Leave the WHY for the discussion.

You need to arrange your results in a logical flowing order. We recommend that you use sub-headings to help clarify your work. One suggestion is to split the results up based on the variables that you surveyed (eg. 'Reef fish abundance and number', 'Coral reef life-forms', and 'Abundance of commercially important invertebrates'). The results section for this report should be approximately 300 words.

Discussion

The discussion outlines the key results and describes the importance of your findings in terms of the significance of the study (which was outlined in the Introduction). This is where you get to write a story about your research. The results section should list *what* you found, while your discussion should suggest the reasons *why* you found it. Discuss the results that you have found, in particular, try to put your results in context with any other previous research of a similar type that has been done by other scientists. Talk about the impacts of wave exposure and zonation on your variables – discuss their importance in determining coral reef community assemblages. It may help to talk about each of the result subheading separately, but try to bring it all together at the end. Typically, a discussion will have a paragraph or two at the end of the discussion that summarises the major findings, indicates the implications of the research or how future research may proceed. For this report you can also mention how future studies of this type can be improved, but don't make this the focus of your discussion. A simple paragraph will do. The discussion will be the most substantial part of your report and should be approximately 600 words.

References

You MUST use references! In the text of your report, you should refer to sources you gained ideas from or that you used as a comparison to your study. Usually the introduction and, in particular the discussion, cite the majority of references. All references that you cite in the text should be listed in a reference section that goes at the end of your report. There are numerous formatting ways to cite references, and if publishing it is best to check with the journal or book for the appropriate format. Otherwise, you should always format your references consistently. A suggested format is listed below.

In the reference section list in alphabetical order the references you cite in the text. For example:

- For single authors in the text cite as (Shulman 1985). In the reference section cite as: Shulman, M.J. (1985) Recruitment of coral reef fishes: effects of distribution of predators and shelter. *Ecology*, 66: 1056-1066.
- If a paper has two authors cite in text as (eg. Munday & Wilson 1997). Then cite in the references as: Munday, P.L. and Wilson, S.K. (1997) Comparative efficacy of clove oil and other chemicals in anaesthetization of *Pomacentrus amboinensis*, a coral reef fish. *Journal of Fish Biology*, 51: 931-938.
- If there are more than two authors cite in the text as (Bertness *et al*. 1992). Then cite in the references as: Bertness, M.D., Gaines, S.D., Stephens, E.G. and Yund, P.O. 1992. Components of recruitment in the acorn barnacle *Semibalanus balanoides* (Linnaeus). *Journal of Experimental Marine Biology and Ecology,* 156: 199-215.
- Chapters in books should be referenced in the text as (Hixon 1991), and in the references as: Hixon, M.A. (1991) Predation as a process structuring coral reef fish communities. In: *The Ecology of Fishes on Coral Reefs*, ed. Sale, P.F. Academic Press, San Diego, California, pp. 475-508.
- Books should be referenced in the text as (Steene 1990), and in the reference section as: Steene, R. (1990) *Coral Reefs: Natures Richest Realm*, Crawford House Press Pty Ltd, Bathurst, Australia.

As a rule of thumb, make sure that you cite the authors and the year of publication in the text. Just use the last names of the authors. If there are two authors, cite both authors and year as shown

above, but if there are more than two authors then cite ONLY the first author followed by *et al*. and the year of publication. In the reference section be sure to list ALL the authors. Usually, the title of the journal or book is italicised NOT the paper title. In the reference section the following information is required:

Journal: Author/s (including initials of their first name/s), year of publication, title of paper, title of journal, volume of journal, page numbers of the article in the Journal.

Chapter in Book: Author/s (including initials of their first names/s), year of publication, title of chapter, title of book (use the prefix In: to show the book title), editor/s of book (including initials of their first name/s), company who published the book, place of publication, pages numbers of the chapter in the book.

Book: Author/s (including initials of their first name/s), year of publication, title of book, editor of book (if applicable), company who published the book, place of publication, page numbers within the book (if applicable).

APPENDIX 2. NOTE-TAKING AND RECORD-KEEPING

Data sheets

Data sheets are frequently used to record information for various survey and field research activities. As you have learned, you want to repeatedly sample standardized sample units. It is extremely helpful to have pre-prepared data sheets to help you when making repeated measurements. For example, an ornithologist usually measures the wing chord, leg length, bill length, and the weight of every bird captured. These measurements, along with additional information such as plumage condition, location of capture and band number, are recorded on data sheets. The evaluation forms used to analyse proposals in this manual are examples of data sheets. When used properly, data sheets remind a biologist of the measurements that are to be made, and they keep those measurements organized and thereby facilitate data storage, analysis and distribution. You should use data sheets whenever you will be repeating a similar set of measurements or observations.

All data sheets should be labelled with: 1) the name of the observer, 2) the time that observations started and finished 3) a description of the location, including coordinates and habitat, and most importantly: 4) the date of the observation. The data sheets should have a place to record the data for each measurement that you wish to make as well as an extra place in which observers can record information or comments that do not fit into any of the categories on the sheet. If you carefully plan your data sheets before you begin data collection you will find your fieldwork goes much more smoothly. When you are ready to compile and analyse your data you will be especially glad you used a data sheet. Data recorded in straight longhand in a book is extremely difficult to organize and analyse. Always keep your data as organized as possible.

It is vital you store your data in such a way that it cannot be lost. The data represents that much time of your life-- if you loose two day's worth of data you have thrown away two days of your life! Keep your data organized and neatly filed. Do not leave it lying around where someone might take the paper and use it for something else. Never leave your data unguarded, like in a bilum in an unlocked car, because someone might steal the bilum, not knowing it is only a notebook inside. Whenever possible make photocopies of your data and store these in a different place (like one copy at home, the originals in your office). Many people have not done this, then deeply regretted it when their office burned or their notebooks were stolen. Not only does this protect you from almost all crises (unless you should be so unlucky that your office and house both burn!), but it should also give you greater peace of mind. Your data represent a lot of time and effort; you will worry about it if you know it is not safe.

Daily journal

In the Field Techniques course we discuss field journals in greater detail. It is a very good idea to keep a journal with a daily entry of what you did that day and any notable observations that do not fit on your data sheets. In the journal also keep notes on the weather, who you were working with, where you worked, etc. This only takes a few minutes each evening but it makes your job much easier. You find you consult your daily journal often-- when you do your finances it will help you remember which day you hired a boat, or where you hired a guide. It will later help explain what a data sheet seems to be missing (it rained all day), or whose initials are on your data sheet because you wrote in your journal

who helped you each day. Record your impressions or any ideas for new research in your journal. Record observations that you or your colleagues might find interesting, for example if you see many tree kangaroos at a site where you are studying birds, you should record that, as you might someday help a scientist find tree kangaroos.

Good record keeping habits

A common mistake of young scientists and even very veteran ones is poor record-keeping and note-taking. When we record notes or observations we know what we are writing. However, very often we come back to these notes days, months or years later and the events are no longer clear in our minds. Often even if we understand our notes, they are being read by another person. I have had to throw out all the work of field assistants because of their failure to take good notes. I have had to throw out my own data at times because my notes were imprecise. If your experiment calls for ten replicates, but on two of those replicates your data is unclear, the whole experiment might need to be tossed out and you have wasted days or weeks of effort. You might as well take the few extra seconds to make good notes, or not bother doing the work at all. Below are a some common errors of note-taking. The instructors of this course have made all of these errors at some time and suffered because of it and we have had assistants who have made these mistakes who we made sure suffered too! Do not force us to make you suffer!

Dates-- Every page and every sheet of paper should have the date on it. If you have a piles of data sheets from a several days and they become mixed up, you need to be able to put them back together. Do not just date the first sheet of a series. Never, Never, NEVER write your dates as "6/7/99." Some people put the day first, some put the month first. Some people do both interchangeably. You simply cannot tell what the writer meant and you might not remember your own notes years later. Always, always, ALWAYS write the month out "7 June, 1999" (or at least give a three letter abbreviation "7 Jun., 1999"). This does not take much time and it can make difference between your notes being data and nothing more than scrap paper to light a fire with. Write the date on the front and the back of data sheets. Later you might photocopy your data and then the copy of the back is a separate page with no date on it anywhere.

Units-- Whenever you make any sort of measurement, make sure the units are stated. If you record a temperature is it Centigrade or Fahrenheit? Grams or kilograms? Centimetres or millimetres? Many times the lack of units has caused researchers to discard data. On a good data sheet the top of the columns states the units. This way you do not have to write the unit every time you fill in a row. If you give the time use military time, "1306 h" or label AM or PM, "1:06 PM." Whenever possible use metric units, they are the standard for scientists and ultimately much easier to use for you (e.g. it is easier to convert kilometres to meters than miles to feet).

Penmanship-- Take time to write legibly. You might be able to read your writing, but often we share our data and others might not. Anytime you are not sure "if that is a one or a seven?" you just have to throw out that data. It took time and money to get your data, if you throw it out because you can't read it, you have wasted your time and money. We recommend that you "cross your sevens" like Europeans and engineers.

Abbreviations-- When you are writing notes quickly it can save time to use abbreviations, especially when you are making behavioural or timed observations. BUT, make sure your abbreviations are standard and clear. When the observation period is over, note on the bottom of the page what the abbreviations mean. The bird "Mm" might mean the Honeyeater *Melilestes megarhynchus* when you write it, but later on will you know it wasn't the Honeyeater *Meliphaga mimikae*? Remember, others might need to consult your notes someday, so even abbreviations you think are obvious might confuse your collaborators.

Signatures-- Always put your name (or at least your initials) on datasheets and observations, especially when working in a team. Later on if someone in the team has a questions about some data, they know who to ask. Sometimes people on a team do things differently (like one measured in mm and another in cm) and having all data properly attributed helps clarify methodological differences. You work hard for your data, make sure anyone reading it knows who collected it!

Data transcription and entry-- It is good to get in the habit of transcribing your data as soon as possible and entering it in a computer file if possible. Usually if you work by day you have some time in the evening to transcribe your day's data in a summary

format; maybe on a new, summary datasheet. Doing this enables you to immediately spot potential problems and solve them while the day is fresh in your mind-- was that "Mm" a *Melilestes* or a *Meliphaga*? It helps you keep track of your data and arrange priorities for the next day(s). "Have I reached my sample size of 100 yet?" By having a transcribed set of data back at the camp or base you have an instant back-up in case you lose your field book one day. If you are going to enter your data in a computer you either want your original data sheet to copy the format you'll use in entry, or you should transcribe the data in the field into a format that is easily entered.

Financial record-keeping

If you are on a grant, contract, or employed by any sort of agency it will be necessary to keep good financial records while doing research. Donors, sponsors and employers usually want a full accounting of how all funds were spent. *It is in your best interest to always keep good financial records (even though it might seem tedious)!!* Keep a separate notebook where you record every expenditure. Try to get a receipt for every expenditure as well. Make sure the receipt is well labelled (e.g. a receipt might just have the amount on it, make sure it has a date and what it is for-- you can write this on yourself). Keep an envelope and store all receipts in it. At the end of the project you will be able to fully account for your budget if you do this as you go. If you do not keep good records daily, it is almost impossible to make a proper accounting. If you cannot do this and you do not have proper receipts, many employers and sponsors will suspect you have used money for unacceptable purposes. It is an unfortunate fact that there are corrupt people who will abuse research funds. The only way employers and sponsors can spot such people is to assume anyone without proper accounts is corrupt. Even if you are not corrupt, people will *assume* you are if you consistently fail to keep proper accounts.

Financial records also benefit you. Records from earlier research will help you know how much you need to continue a project or start a new project. When you write a budget for a grant proposal you use your past financial records to obtain a valid proposal budget. Good records help you keep you personal money separate from professional expenses. You do not want to end up using your personal funds to subsidize something your grant or employer is supposed to cover. As with your data, the sooner you can organize your financial records on a transcribed data sheet or computer file, the better-off you will be.

WILDLIFE CONSERVATION SOCIETY

PNG NATIONAL FISHERIES AUTHORITY
COASTAL FISHERIES
Management and Development Project
ASIAN DEVELOPMENT BANK

GPA

Tautai