TA7753-REG: Strengthening Coastal and Marine Resources Management in the Coral Triangle of the Pacific (Phase Two)

Length-based spawning potential stock assessment report for ten key species in Manus, Papua New Guinea

October 2016 – April 2018

Strengthening local capacity of vulnerable island communities in Papua New Guinea: an ecosystem-based approach to resource management

ASIAN DEVELOPMENT BANK

WILDLIFE CONSERVATION SOCIETY

ADB

WCS

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Sites: Andra, Baluan, Bipi, Lou, Mbuke, Pam, Pelipowai, Ponam, Tulu 1 and Tulu 2

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EXECUTIVE SUMMARY

The Asian Development Bank (ADB) allocated funds to strengthen coastal and marine resource management in the Coral Triangle of the Pacific, through subprojects in Papua New Guinea (PNG), Timor-Leste, Solomon Islands, Vanuatu and Fiji, which collectively form part of the Coral Triangle Initiative (CTI). The PNG Subproject and associated Technical Assistance (TA) was executed by the Wildlife Conservation Society at ten predetermined ADB community sites around the coastline of Manus province, PNG.

Background and methods

For thousands of years, coastal communities across Oceania have relied on marine resources for food and livelihoods. However, recent population growth, coupled with more efficient fishing methods, exposure to the cash economy, have led to declining fish stocks and the deterioration of many coral reefs. If such trends continue, coastal communities across the Pacific will soon move to urban areas – resulting in a loss of traditions and languages – or face increasing food scarcity. Accordingly, there is now a need to assess locally important fish stocks, the outcomes from which can be used to establish site-specific management methods for use at the community level. The coastal communities that live around Manus Island, in the northern region of Papua New Guinea, are reliant on seafood for dietary protein, and are therefore prone to food security issues – especially in light of projected climate change threats. Accordingly, during the first months of 2018, WCS conducted stock assessments of ten locally important reef fish species at ten sites around Manus Island in order to better understand the status of each fish population, the results from which can be used to devise site-relevant management approaches.

Length-based spawning potential (LB-SPR) assessment is a technique used to understand fishery stocks. The method requires two data components: (i) the spawning potential ability of a fish stock (in other words, the proportion of breeding adults within a population), and (ii) fish size dimensions. Using such data, an estimate of the size in which a fish species matures can be made, along with the proportion of spawning potential for the local fishery. It is generally accepted that when a fish population maintains a spawning potential of 20%, the stock has reached its replacement level (the number of offspring produced replaces the rate of fish mortality); above 40% spawning potential would suggest the fish stock is less heavily fished; below 20% spawning potential would indicate a fishery that is in decline. With low costs and a simple procedure, LB-SPR is considered an effective approach for assessing fish maturity, especially at the community level. The technique also encourages community participation through data collection, providing a sense of ownership and inclusion with the activity. The method allows for minimum size of maturity limits to be deduced, which can form a management tool to be implemented at the community level to help ensure local fisheries remain sustainable.

The WCS staff and community facilitators (CFs) were trained in the LB-SPR method during a week-long workshop facilitated by Dr Jeremy Prince from *Biospherics* and the Murdoch University of

Western Australia. Ten candidate reef fish species were selected according to how prevalent the species were within samples taken during a fisheries catch-and-effort data collection phase that occurred around Manus Island during the latter months of 2017. LB-SPR data collection occurred at ten sites around Manus. At each site, the CFs recorded the total the body length of each captured fish (either the total length or fork-length, deepening on the species), as well as the local, common and species names. A knife was used to open the abdominal cavity of each fish to reveal the gonads (reproductive organs), indicating fish gender and whether the individual was sexually mature. The results were subsequently analysed using the LB-SPR method.

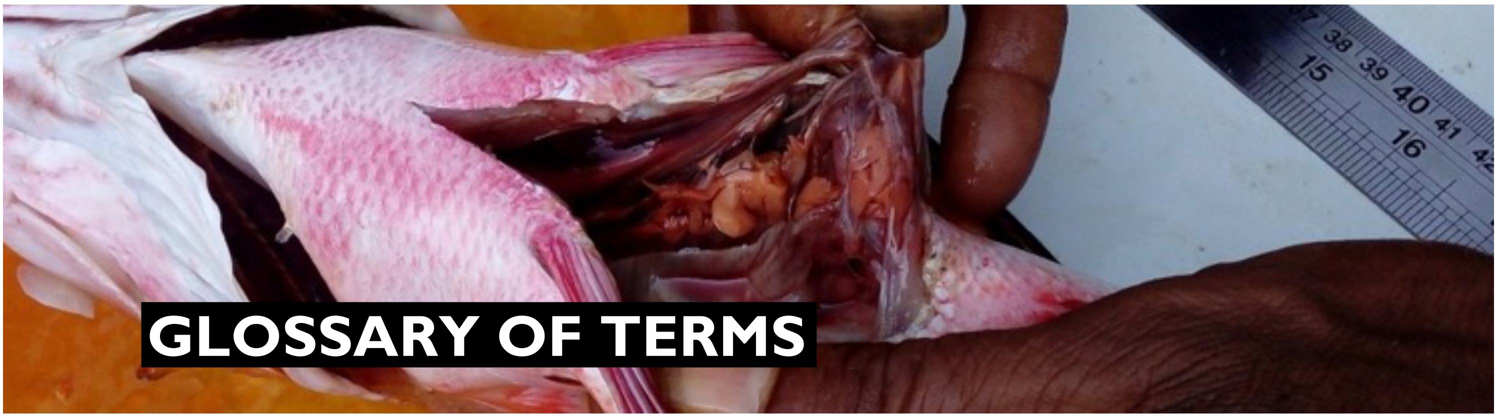
Outcomes and summary

Although ten fish were selected for study, sufficient data (150 individuals or more) were only obtained for five species: (i) the surgeonfish *Ctenochaetus striatus*, (ii) the rabbitfish *Siganus canaliculatus*, and three emperors, (iii) *Lethrinus harak*, (iv) *L. lentjan* and (v) *L. obsoletus*. It is anticipated that further data collection across all ten sites will continue to add data to each dataset, enabling more robust assessments. The outcomes from the LB-SPR models indicate that the two larger emperor species, *L. harak* and *L. lentjan*, are being heavily over fished, with spawning potential estimates for both species (*L. harak* spawning potential = 7%; *L. lentjan* spawning potential = 12%) below the 20% replacement level. The low spawning potential values for both species suggest population declines, which could lead to localised extinctions. In contrast, the spawning potential estimate for the smaller bodied *L. obsoletus* was 36%, which is above the replacement level.

The spawning potential estimates for *C. striatus* (45%) and *S. canaliculatus* (47%) were also greater than the 20% replacement level, indicating that these fisheries are less heavily fished. Reasons for the higher spawning potential estimates for *L. obsoletus*, *C. striatus* and *S. canaliculatus* could be due to the smaller body sizes of these fish species, and therefore, faster maturation rates. The low spawning potential estimates for *L. harak* and *L. lentjan* could be because these fish attain a larger body size, a process that requires a longer time period in order for the juvenile phase to reach maturation. Therefore, the larger-sized – and more valuable – juvenile fish are more likely to be targeted by fishers before they reach maturation, preventing the fish from having an opportunity to reproduce.

The outcomes from the LB-SPR assessment models suggest that the two larger emperors are experiencing population declines due to intensive fishing pressure. Once the larger and more valuable fish no longer provide sufficient food or income, the smaller bodied fish, such as surgeonfish and rabbitfish, are likely to be targeted. Both surgeonfish and rabbitfish are herbivores, feeding on algae that grows on the reef; removing the herbivores results in less algal growth management, and – during a short timeframe – a coral reef can be smothered in green algae, leading to further fish losses. Fishing down the food web has occurred in Indonesia and the Philippines, which resulted in people migrations to urban centres (and the loss of local traditions and languages) or food scarcity. To prevent such occurrences around Manus Island, site-based management approaches should be implemented at the community level to allow villagers to manage their own fish stocks.

Using the outcomes from the LB-SPR model, a simple and effective management method involves the implementation of minimum size limits for the species that were assessed. Once minimum size limits have been enforced, fishers soon witness the benefits, including higher catch rates and larger body sizes. However, efforts should be made to introduce only one minimum size limit for a species at a time, to not only prevent confusion or resentment among local fishers, but also to enable fishers to observe the direct benefits from the management method.



GLOSSARY OF TERMS

Algae: Simple life forms that have no major organs and use sunlight to photosynthesise. Algae live in aquatic environments or moist areas and can be microscopic, free living in the water column (for instance, phytoplankton), or large in size and attached to the seabed (including, seaweeds, such as kelp).

Anthropogenic: An event or process that occurs due to human activities, which is usually detrimental to the environment.

Asymptotic: A line that a curve approaches but only touches at infinity.

Biodegradable: A material that can be decomposed by bacteria, fungi or other life forms.

Biodiversity: The variety of plant and animal life in a particular habitat, a high level of which is considered important and desirable. Over 7% of global biodiversity is contained in Papua New Guinea.

Biomass: The total mass of all the organisms of a given type within a given area.

Benthos: Referring to the seafloor and organisms that live on or burrow into the seabed. Benthic organisms may be free-moving, such as worms, starfish and flatfish, or attached to the seabed, including seaweed, sponges and corals.

Carnivore: An animal that consumes other animals.

Carrying capacity: The maximum population size of a species that an environment can sustain indefinitely, given food, water, competition, and other habitat necessities within the environment.

Climate change: A long-term shift in climate over several decades or centuries, including changes in temperature, rainfall and air pressure, caused by natural events, such as volcanic eruptions, and anthropogenic sources, such as the release of carbon dioxide, methane and other gases from burning fossil fuels, vehicle exhausts, and agriculture.

Competition: The interaction between two or more organisms, populations or species that share ecological resources. Competition can occur between organisms of the same species (intraspecific competition) and between different species (interspecific competition).

Coral reef: A distinctive biologically-created seabed feature formed when hard corals grow and deposit limestone skeletons. Can be found in shallow and deep water areas, although the most familiar coral reefs are found in shallow tropical waters and support an abundance and diversity of other marine life.

Coral Triangle: A geographical term referring to the triangular-shaped area of tropical marine waters between the Philippines, Malaysia, Indonesia, Timor-Leste, Papua New Guinea and Solomon Islands. At least 500 reef-building coral species and a wealth of other marine life are found in each eco-region.

Dive fishing: To catch fish or collect invertebrates by any means while under water, when employing a mask, snorkel or other form of breathing equipment.

Ecosystem: A biological community (including microbes, plants, fungi and animals) and the associated physical environment.

Exclusive economic zone: An area prescribed by the United Nations Convention on the Law of the Sea in 1982, enabling coastal states to assume jurisdiction over the exploration and exploitation of marine resources within the adjacent continental shelf up to 200 nautical miles from the national shoreline.

Family: In biological classification, the taxonomic group above genus; families are used to group organisms that belong to similar or closely related genera.

Fecund: Fertile, and capable of producing many offspring.

Fertilisation: The union of male (sperm or pollen) and female (eggs or ovules) sex cells during sexual reproduction, resulting in the full complement of genetic material from both parents. For marine organisms, fertilisation can be external in the water column (such as for many seaweeds, sponges, corals, worms and many reef fish) or internally, within the females body (including sharks, turtles and dugongs).

Fishery: The industry of catching, processing and selling fish, and the location where this takes place.

Gamete: A reproductive cell that fuses with another reproductive cell during sexual fertilisation. Female and male animals produce different gametes, such as eggs and sperm. Plant gametes include female ovules and male pollen. Compared to other cells, gametes contain only half the genetic material, which becomes complete when two complementary gametes fuse during fertilisation to form a zygote.

Gastropod: Members of a large class of molluscs, which have a well-developed head with tentacles, a large flattened muscular foot for locomotion, and a conical or coiled shell that is twisted. Includes limpets, snails, whelks, conches, slugs, and sea slugs (slugs and sea slugs secondarily lost their shells).

Genus: A category used to classify organisms, consisting of similar or closely related species.

Gonad: The paired reproductive organs in many animals that produce gametes (sex cells), such as ovaries in females and testes in males. Gonads also produce sex hormones associated with development and reproduction, including oestrogen in females and testosterone in males.

Habitat: The place in which an animal or plant lives.

Herbivore: An animal that consumes algae, plants or other vegetation.

Invertebrate: An animal that lacks a vertebral column (backbone). Includes sponges, corals, jellyfish, worms, snails, oysters, squids, spiders, crabs, centipedes, butterflies, starfish and sea squirts.

Juvenile: An immature stage during the life cycle of many marine animals, following the larval phase and prior to the adult phase. Many juvenile organisms resemble adults but are not yet sexually mature.

K-strategist: Characteristics of *K*-strategist species include slow-growth rates and the production of few offspring that have a high probability of reaching adulthood, such as some sponges, corals, orchids, birds and humans.

Larvae: The initial stage during the life cycle of many marine animals, following the fertilisation of the sex cells and subsequent development of the embryo. Most larvae are vulnerable and found in open water, where they form part of the zooplankton. Larvae usually consume other plankton.

Life history: The series of biological events from birth through reproduction and death; includes the growth and maturation characteristics of a species.

Lorengau: The provincial capital of Manus province.

Mangrove: Tropical evergreen trees and shrubs with aerial roots that form dense thickets along coastlines. One of the few plants to adapt to living in the marine environment.

Maturity: The stage when an organism is fully developed – an adult – and capable of reproduction.

Melanesia: A region of western Oceania, characterised by the darker skin pigmentation of the inhabitants. Includes New Guinea, Solomon Islands, Vanuatu, New Caledonia and Fiji.

Metamorphosis: The transformation of a larval form into an adult form during the life cycle of many invertebrates and fish, involving enzymes and which is controlled by changes in hormone levels.

Mollusc: A large group of soft-bodied invertebrates that have a definite head, a non-segmented body, a muscular foot, and usually a protective shell. Includes snails, slugs, clams, oysters, squid and octopuses.

Mortality: The number of deaths in a given period.

Oceania: The smallest of the seven continents by land area. Oceania encompasses the South Pacific Ocean and comprises the continent of Australia, the large islands of New Guinea and New Zealand, and all the smaller islands and atolls of Melanesia, Polynesia and Micronesia. Unlike other continents, where most countries are connected by land borders, the nations of Oceania are connected by the waters of the Pacific Ocean.

Omnivore: An animal that consumes both plant and animal matter.

Organism: An individual living system, such as a microbe, plant, fungus or animal.

Ovary: The female reproductive organs, or gonads, of an animal that produce female gametes (eggs) and reproductive hormones; in flowering plants, ovaries produce egg-containing ovules.

Overfishing: A form of over-exploitation where fish stocks are reduced to below acceptable or sustainable levels. Occurs when more fish are caught than the population can replace through natural reproduction.

Pelagic: Referring to the open waters of the marine environment and organisms that swim through or drift in the water column, including plankton, jellyfish and oceanic fish species.

Plankton: Very small, open water organisms that drift passively with the current of an ocean, sea or lake. Plankton form an integral food source for other aquatic life forms and include phytoplankton (which photosynthesise and are the crux for most marine food webs) and zooplankton (small animals or larval animals that feed on phytoplankton).

Population: A group of individuals of a single species that live in a given geographical area.

r-strategist: Organisms that exhibit *r*-strategy life histories typically have high growth rates and produce many offspring, which have low survival rates. Examples including diatoms, marine worms, grasses and rodents.

Ratio: A quotient of two numbers or quantities and their relationship; expressed as a proportion.

Recruitment: The number of fish surviving to enter a fishery or to a particular life history stage, such as maturity.

Sea grass: The only flowering plants that are fully adapted for life within the marine environment. Usually live in shallow, sunlit waters and provide a habitat for many other organisms.

Spawn: To lay eggs. Many marine animals release their eggs and sperm into the water column in a process known as broadcast spawning, which enables fertilisation to take place. Usually, of the multitude of eggs released, only a small number will develop into adulthood.

Spawning aggregation: A mass assembly of fish in order to spawn, usually at designated areas within the marine environment and at a time determined by the lunar cycle and the influence of the moon on the tides.

Spawning potential: The proportion of unfished reproductive potential left at any given level of fishing pressure. In general, fish stocks tend to decline below 20% spawning potential. Above 40% spawning potential, a fishery is considered sustainable.

Spill over: The supply of marine ecological services to adjacent areas from a protected or managed zone.

Tenure: The ancestral rights to live in an area and to use the local land and coastal resources. Over 96% of Papua New Guinean land is held under customary ownership and through traditional tenure systems.

Testes: The male reproductive organs, or gonads, which produce male gametes (sperm) and male reproductive hormones (singular, testis).

Trolling: To fish by dragging a lure through the water.

Vein: A vessel that returns blood to the heart; usually contains deoxygenated blood.

Vertebral column: A series of bones, known as vertebrae, which protect the spinal cord and lie along the dorsal flank of a vertebrate animal (such as a fish, amphibian, reptile, bird or mammal). The vertebral column is connected to muscles and other bones to collectively form a flexible bony structure. During the fish dissections, the reproductive organs lie either side of the vertebral column. Also known as the spine or spinal column.

Yield: To produce or bear.

List of abbreviations

ADB	Asian Development Bank
CAE	Catch-and-effort
CF	Community facilitator
CPUE	Catch-per-unit-effort
CTI	Coral Triangle Initiative
EEZ	Exclusive economic zone
F	Fishing mortality
FAD	Fish aggregating device
L	Length
LB-SPR	Length-based spawning potential ratio
M	Mortality (natural)
MMC	Marine management committee
MSY	Maximum sustainable yield
NGI	New Guinea Islands
NGO	Non-governmental organisation
PNG	Papua New Guinea
SPC	Secretariat of the Pacific Community
SPR	Spawning potential ratio
TA	Technical assistance
US	United States
USD	United States dollar
WCS	Wildlife Conservation Society

In the following report, $ refers to US dollars (USD)

ACKNOWLEDGEMENTS

Gratitude must be given to Dr Jeremy Prince, from *Biospherics* and the Murdoch University of Western Australia, who conducted a week-long training workshop on length-based spawning potential analysis, and provided invaluable expertise, coupled with great patience, to ensure the WCS team were aware of the procedure and its importance. Jeremy also provided some of the photographs that are included in this report.

The Asian Development Bank (ADB) was the donor for the Subproject, entitled *Strengthening local capacity of vulnerable island communities in Papua New Guinea: an ecosystem- based approach to resource management*, which forms part of the Coral Triangle Initiative (CTI). The Wildlife Conservation Society (WCS), a global non-governmental organisation (NGO) based in Goroka, Kaviang and Manus, Papua New Guinea, was given approval to execute the Subproject; at the time of writing, Sven Frijlink, Sylvia Nobel and Ambroise Brenier were the WCS project managers. The current report is one of the key deliverables for the Subproject, which took place between October 2016 and April 2018. All the data and information used during the production of this report were obtained courtesy of the local residents that live in the ten ADB communities (Andra, Baluan, Bipi, Lou, Mbuke, Pam, Pelipowai, Ponam, Tulu 1 and Tulu 2), and extreme gratitude must be given to all community members that took part in the Subproject.

The Senior Marine Biologist for the Subproject was Anthony Nagul (WCS) who managed and co-ordinated all the Technical Assistance (TA) for the subproject, enabling the data collection and data analysis procedures to occur, as well as relevant stakeholder consultations. This report was written and compiled by Jonathan Booth and Yvonne Wong. Field-based data collection and subsequent data entry was completed by Yvonne Wong, and the WCS community facilitators (CFs): Misu Nick, Rubbie Aron, Blaze Dimura, Lawrence Effi, Michael Londron, Bernard Manus, Thomas Molok, Alani Pohei and Simon Smith. The WCS skippers, Bernard Manus, Pondrax and Joe Ludwig, supervised all boat transport to and from the ten ADB communities from mainland Manus.

FOREWORD

Only two degrees below the equator, the small Papua New Guinean island of Manus is surrounded by a wealth of marine habitats, including pristine coral reef systems that support an abundance and variety of species. For millennia, human communities living on Manus have relied on their local marine resources for sources of protein and income, a trend that continues to today. Even so, many coastal environments – including local reef fish stocks and the people that depend on them – are now threatened by rapid modernisation, population growth, and more efficient fishing methods, emphasising the need to better understand local fisheries and fishing processes.

Despite such threats, few regional fish stock assessments have been conducted around Manus, and little is known regarding the status level of many local marine resources. Indeed, it may come as a surprise to know that an area of such rich biodiversity and ecological importance remains poorly studied. However, considering the thousands of Manus residents that directly or indirectly depend on coastal resources, fishery assessments are necessary to enable the implementation of the best possible adaptive management approaches for certain areas.

This publication aims to assist regional stakeholders and policy makers in making sensible fisheries management decisions based on fisheries length-based spawning potential data, which were collected at ten sites around Manus from February to April 2018. The information and analysis presented in this report outlines species-specific spawning potential outcomes for ten reef fish species of local importance. The outcomes listed in this report could be used for future adaptive capacity building, integrated coastal zone management, and climate change resilience plans around Manus province.

It is hoped that future spawning potential assessments and similar studies will continue during subsequent years to enable temporal comparisons to be made between the assessed species. Such studies should demonstrate changes in fish population structure and fishing intensity around Manus province and, therefore, assist with the safeguarding of local marine reserves for future generations to utilise and enjoy.

1.0 INTRODUCTION

Across the maritime provinces of Papua New Guinea (PNG), inshore fisheries are of vital importance to coastal communities, providing sources of sustenance and income, symbols of cultural significance, and many other ecosystem goods and services (Worm *et al*., 2006). In 2013, PNG annual fishery exports were estimated at $125 million. In the same year, it was estimated that PNG's coral reefs could sustain 80,000 tonnes of fish per year, and that only 15,000 tonnes of fish were caught annually, less than 20% of the maximum sustainable yield (MSY). In view of the potential MSY, recent government policy has been to increase the number of local reef fisheries, providing food, employment and income for many inshore communities, despite the ecological and socio-economic ramifications of such actions (McClanahan & Cinner, 2008). Recent population growth, inshore pollution, more efficient fishing methods, market development, and exposure to the cash economy have placed increasing pressure on regional coral reefs and reef fisheries. The future extraction of fisheries resources in many coastal areas of PNG may not, therefore, be sustainable, especially in light of recent government policy and projected climate change threats (Bell *et al*., 2013), underscoring the need for better understanding the health of local fish stocks.

The island province of Manus is located in the northern waters of the PNG exclusive economic zone (EEZ) and supports a population of 61,000 people, many of which live in coastal areas and are reliant on seafood. The importance of seafood for coastal communities has been determined elsewhere in Melanesia, providing an indication of the significance of marine sustenance for the peoples of Manus. For instance, on the remote outer islands of Fiji, another small island region in the east of Melanesia, a two-decade study found that typical daily seafood consumption was between 365–380grams/day/person, 76% of which comprised local finfish (Rawlinson *et al*., 1994; Kuster *et al*., 2005).

Today, across the Pacific region, there are concerns regarding sustainable fisheries for both food and livelihood security, and the associated impacts on tropical shelf-sea biodiversity (Prince, 2017). Indeed, the Secretariat of the Pacific Community (SPC) has estimated that population growth in the Pacific will require an additional 115,000 tonnes of fish per year by 2030, and yet the supply of fish will not meet demands due to declining fish stocks (SPC, 2015). The SPC study concluded by stating that the main obstruction for the sustainable management of inshore fisheries was the absence of relevant site-specific fisheries data, to inform fisheries managers, policy makers, and other key stakeholders (Prince, 2017).

From February to April, 2018, the spawning potential status of ten reef fish species were assessed across ten coastal villages around Manus Island (the ten villages had a combined population of approximately 5,400 people, which was roughly 8.5% of the total population of Manus province). The process used a recently developed length-based spawning potential (LB-SPR) assessment technique. The technique compares fish sizes within a population to the size at which the fish start spawning, enabling an estimate of the fish stock's capacity to spawn, also known as *spawning potential*, to be made. The method assumes that in the absence of fishing, a fish population has the ability to complete 100% of its natural spawning potential. Yet when fishing occurs, the spawning potential of a fish population falls below the natural level of 100%, because fish are typically caught prior to completion of their natural life expectancies (Prince, 2017).

From previous studies, it is known that at roughly 30% spawning potential, a fish population can retain the ability to recover from local fishing pressure, and re-establish the population according to the carrying capacity of a reef (Prince, 2017). At approximately 20% spawning potential, a fish population can remain somewhat stable yet is unable to re-establish itself; this is because there are only enough spawning adults to replace the existing adults, and not enough to allow for population increase. 20% spawning potential is also known as the *replacement level* because sufficient spawning occurs to replace the existing adults. Less than 20% spawning potential can lead to long-term declines in a fish population because the fish are unable to achieve their reproductive potential prior to capture, and therefore, are unable to replace themselves (Prince, 2017). Figure 1 provides an overview of how fishing intensity can influence the spawning potential and population sizes of a fish stock.

Fishing pressure estimations depend on the ratio of fishing mortality (*F*) and natural mortality (*M*), represented as *F/M*. Former studies demonstrate that when fish are captured only as adults, the two mortality rates are almost equal (*F/M* = 0.8 - 1.0) and sustainable catches are achievable (Zhou *et al.*, 2012). Higher levels of *F/M* indicate overfishing, which can lead to stock declines and extinction if fishing levels continue to increase. If juvenile fish are captured together with adult fish, however, the *F/M* values are lower, also leading to overfishing and the inability for fish stocks to replenish themselves. Accordingly, if fishers only catch fish that are larger than their size of maturity, through regulated minimum size limits or restrictions of fishing gear types, more sustainable levels of *F/M* can be maintained (Prince 2017).

The straightforward techniques and rational basis of the LB-SPR data collection and assessment processes are designed in order for community members to assist with the data collection procedures and understand why the data are important and how they are used. Once villagers can perceive and understand what is occurring to their fish stocks within their customary marine areas, it is expected that new forms of fisheries management will be welcomed and implemented at the community level, enabling community capacity building and self-governance.

1.2 Objectives

The main objective of this report was to collect fisheries length-based spawning potential data for ten predetermined reef fish species of local importance from ten sites around Manus Island, PNG. Such an assessment should provide a better understanding of the state of the ten reef fish stocks in the region. Health assessments are based on the proportion of adult fish within a population, which are able to spawn and replenish or increase the fish population.

The sub-objectives of this study are to:

I – Determine the spawning potential for each of the ten selected fish species around Manus;

II – Gain an understanding of regional fishing intensity on the ten species;

III – Suggest methods for managing the species, especially those with low spawning potentials.

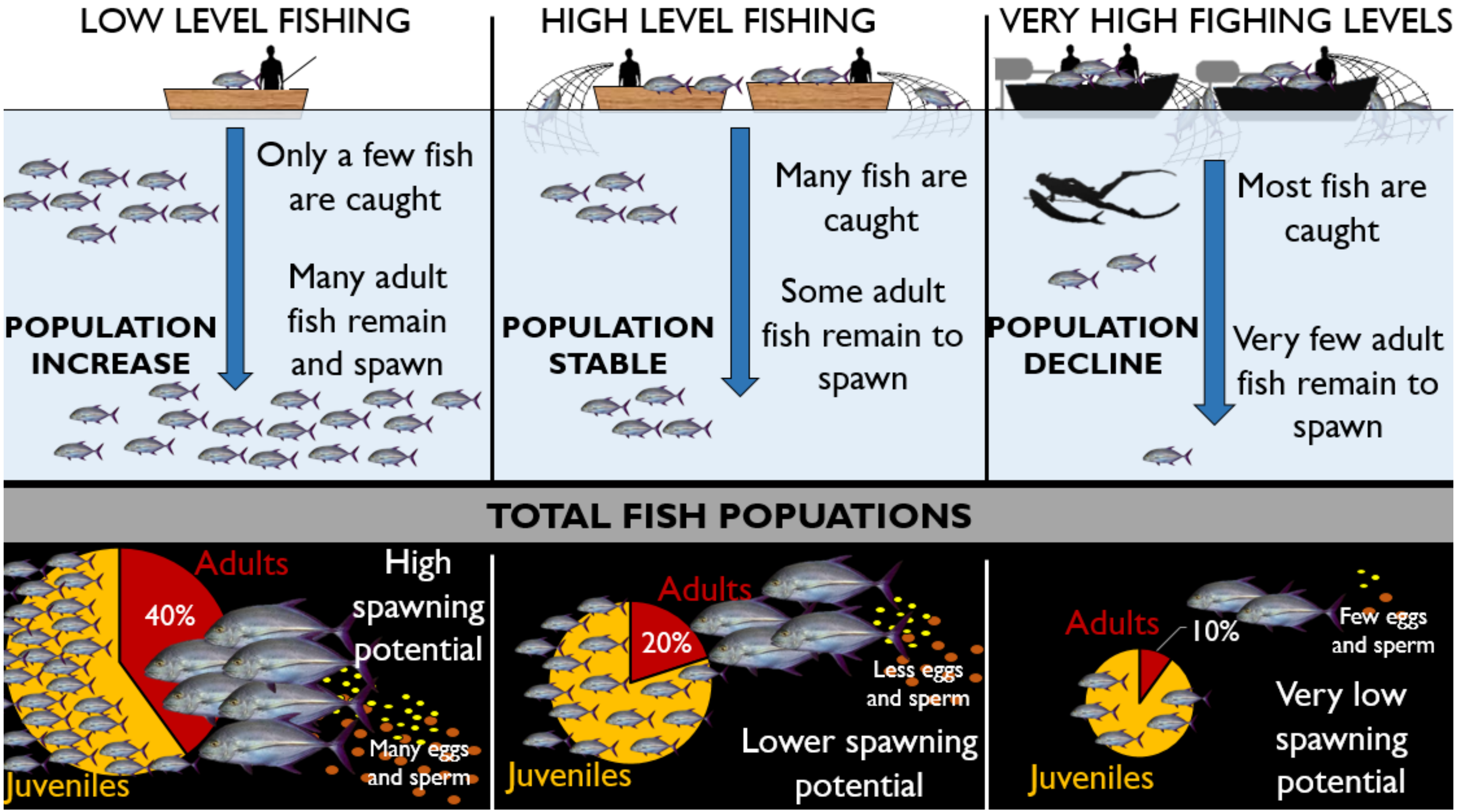


Figure 1: At low fishing levels, few juvenile fish are captured and enough adult fish survive to reproduce: at around 40% spawning potential, for example, a fish population may increase in numbers. With higher levels of fishing, juvenile and adult fish can be targeted, leading to fish stock declines. 20% spawning potential is the equivalent to when a human population has on average 2.1 children per couple, which is sufficient to replace the adult humans in a population, leading to a stabilised population that does not increase or decrease. Thus, 20% spawning potential in a fish population can be seen as the replacement level, resulting in a stable population size. Less than 20% spawning population results in few adult and juvenile fish remaining in the population, leading to population decline and ultimately local extinction.

2.0 MATERIALS AND METHODS

2.1 Study region

Located in the northern waters of Papua New Guinea (PNG), the island of Manus lies 280km west of New Ireland and 340km north of Madang (Figure 2), forming the western extent of the New Guinea Islands (NGI) region. To the south of Manus is the Bismarck Sea, while the Pacific Ocean lies to the north of the island. The rugged interior of Manus supports tropical rainforests and other forms of vegetation, with several rivers carving through the predominantly limestone bedrock. The Manus shoreline includes areas of sandy beach, rocky shores and mangroves, while the inshore waters are characterised by shallow lagoons sheltered from open water by prominent reef crests. The lagoons and upper reaches of the reef crests support abundant coral communities, many of which form extensive reef systems. Beyond the reef crest lie 160 provincial islands, each supporting coral reef and sea grass systems (Munday & Allen, 2000).

Even though the land area of Manus occupies only 2,100km^2, forming the smallest province in PNG, the surrounding waters of the exclusive economic zone (EEZ) cover 220,000km^2, the largest maritime area of any PNG province. The population of Manus is also small when compared to other PNG provinces. According to the 2011 National Population and Housing Census, Manus had a total population of 60,485 people inhabiting 10,360 households (Table 1). For most people in Manus province, and especially for communities living outside the provincial capital of Lorengau, fishing and gardening provide the primary sources of sustenance and income.

In 2016, seven coastal communities around Manus agreed to take part in the ADB Subproject. These communities were: (i) Tulu 1 and (ii) Tulu 2 on the northern mainland of Manus, and the island communities of (iii) Andra and (iv) Ponam that lie off the northern shores of Manus Island; (v) Bipi, an island that lies off the western coast of Manus; (vi) Pelipowai on the southern coast of Manus; and the archipelago of (vii) Mbuke that lies in the Bismarck Sea off the southern coast of the provincial mainland. In 2017, three more island sites were included, (viii) Lou, (ix) Pam and (x) Baluan, which are volcanic island located off the south-eastern coast of the Manus mainland (Figure 2b). Thus, in total, LB-SPR assessments were made at ten sites around the province (Table 3, on page 22, provides an overview of the ten sites, including the number of fish caught for LB-SPR study at each site).

Table 1: Total land and sea areas for Manus province, Papua New Guinea, as well as information concerning the regional demographics for the province, according to data presented in the 2011 National Population and Housing Census.

Total land area	Total sea area	Total population	Population density	Total males	Total females	Total households
2,100km^2	220,000km^2	60,485	29 people per km^2	31,161	29,324	10,360

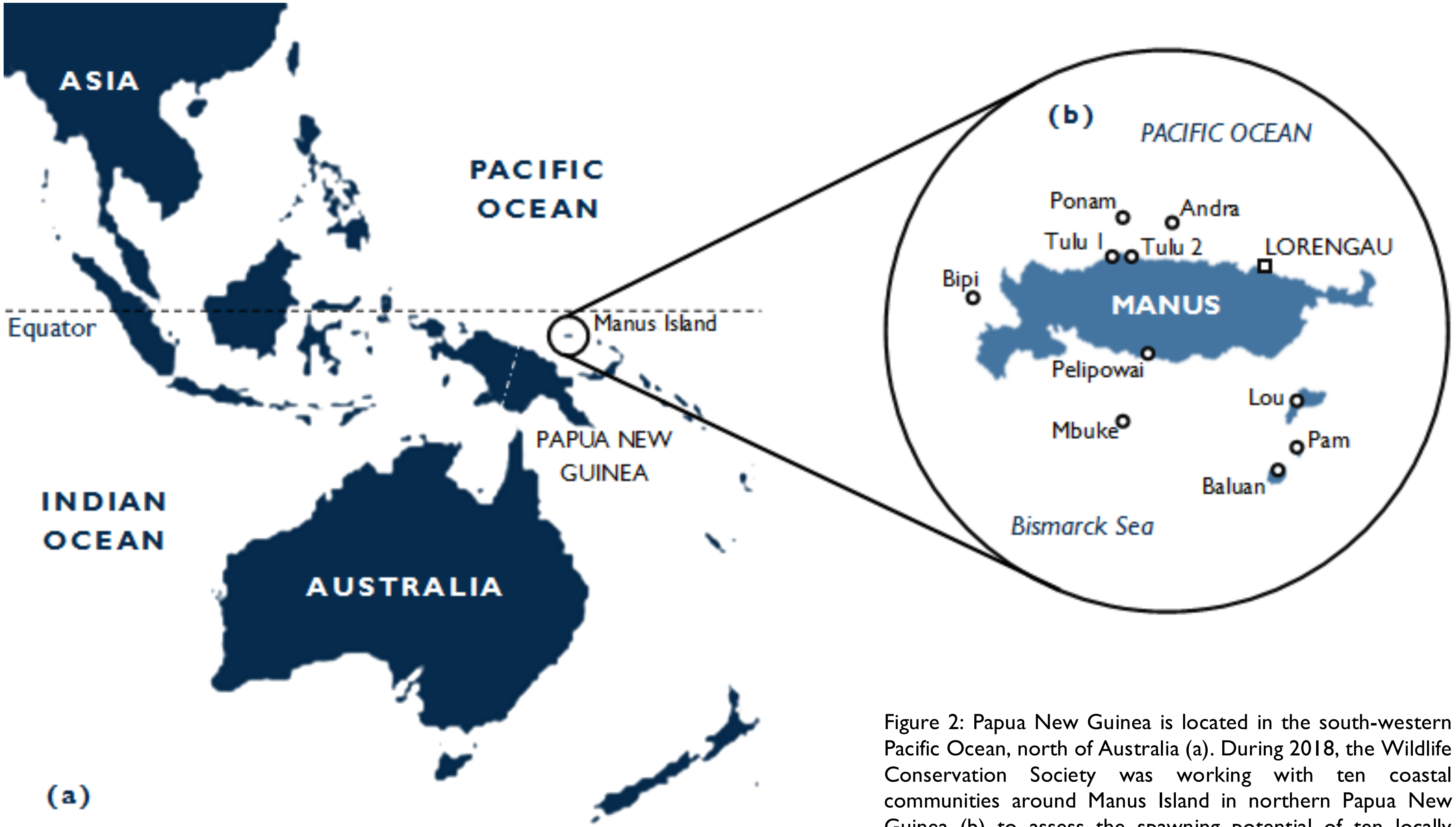


Figure 2: Papua New Guinea is located in the south-western Pacific Ocean, north of Australia (a). During 2018, the Wildlife Conservation Society was working with ten coastal communities around Manus Island in northern Papua New Guinea (b) to assess the spawning potential of ten locally important reef fish species.

2.2 Survey development and data collection

To estimate the spawning potential of a fish population, two sets of data were required. These were (i) the length of each fish, and (ii) whether the fish was an adult or juvenile and – if adult – its gender. The data collection procedure was relatively straightforward and self-explanatory, enabling community members to be trained as data collectors and thus promoting citizen science. Such a programme allowed villagers to (i) comprehend the assessment process, (ii) observe changes that are occurring to their own fish stocks, and (iii) recognise the importance of implementing new management methods. In order to train the villagers, eight community facilitators (CFs) from WCS were trained in the length-based spawning potential (LB-SPR) data collection and analysis techniques during a weeklong workshop in June 2017; the training was conducted by Dr Jeremy Prince from *Biospherics* and the Murdoch University of Western Australia.

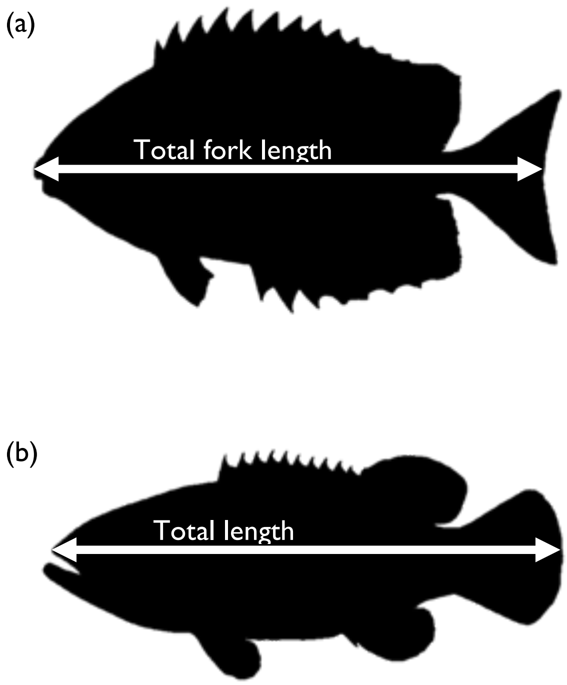


Figure 3: Fish length was attained by measuring from the tip of the snout to either (a) the centre of a forked tail (known as fork length) or (b) the central end of a rounded tail (known as total length). All measurements were made in millimetres (mm), and were obtained during February and April 2018 from ten coastal sites around Manus Island, Papua New Guinea.

At each ADB site, a trained CF spent fourteen days with each community to collect LB-SPR data for ten selected species (see Section 2.2.1 and Table 2 and 3 for details of species selection). The CFs recorded the total fish count of each species during a single fishing trip and the total body length (in millimetres) of each captured fish (either the total length or fork length, depending on the gross morphology of the finfish species (Figure 3)), as well as the local, common and species names. A knife was then used to open the abdominal cavity of each fish, starting from the anal vent and moving towards the pelvic fins, in order to reveal the paired reproductive organs (gonads) that lie either side of the vertebral column. The structure of the gonads indicated whether an individual was sexually mature – and if so – its gender (Figure 4). The CFs proceeded in disseminating the data collection procedures to community members at each of the ten sites from February to April 2018.

2.2.1 Species selection

Between August and November, 2017, WCS conducted the first wave of catch-and-effort (CAE) data collection at all ten sites around Manus Island. During this period, trained community facilitators (CFs) intercepted fishers at each site to obtain CAE data, which included the number of different fish and invertebrate species captured. From these data, which were pooled across all ten sites, the twenty-five most prevalent species were extracted as candidates for LB-SPR assessment. Of the twenty-five species, all gastropod molluscs were discounted due to difficulties in assessing gastropod maturity and gender. The pelagic fish representatives were also removed because the focus of the subproject was on reef

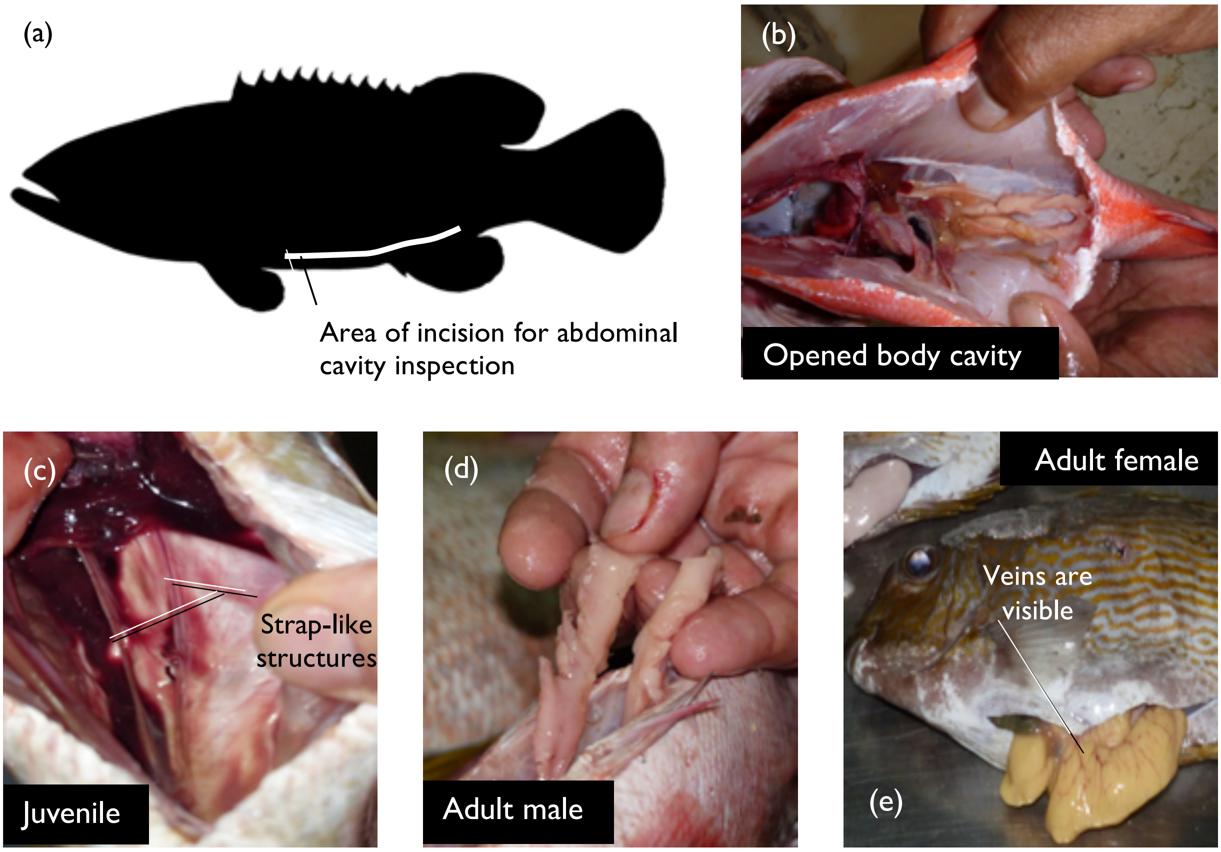


Figure 4: The procedure employed for determining fish maturity and gender. A knife was used to open the abdominal cavity of each fish (a), starting from the anal vent and moving towards the anterior region of the animal, enabling entry into the body cavity. The digestive system was removed (b) to expose the reproductive organs that lie either side of the vertebral column. Juvenile fish (c) have two slender strap-like structures that are not yet developed and, therefore, their gender cannot be determined. Adult males (d) have a pair of cream-coloured gonads (testes), which have no distinctive features. Yellow or orange-coloured gonads (ovaries), which often have distinguishing veins and other blood vessels, are diagnostic features of adult female fish (e). The photographs were provided by J. Prince (2017).

fisheries. Rather, attention was given to species that were considered important to all ten communities, according to previous key fish surveys, conducted by WCS between April and August 2017. In addition, at the time of writing, a similar assessment was taking place in New Ireland province, PNG, so attention was also given to species that were prominent in both the Manus and New Ireland studies. Furthermore, it was important that the species selected for LB-SPR assessment were found around the Manus coastline, ideally at all ten assessment sites. Thus, the prevalence of each of the top twenty-five species at each of the ten community sites was recognised. Table 2 provides an overview of the scoping technique used to select the ten fish species for the spawning potential assessment. Table 3 provides further information for each of the study sites.

In Manus, there are thought to be at least 36 distinct languages and perhaps as many as 80 linguistic dialects, with each vernacular having different local names for fish or fish groups. Therefore, to save confusion, this report will use scientific names when referring to each species chosen for assessment.

Table 2: The twenty-five most commonly caught fish species across all ten Manus sites from the first wave of catch-and-effort data collection (from August to November 2017). The number of fish caught and their preferred habitat as adults (pelagic, inshore or migratory (P), coral reef (R) or both (B)) is included. The most prevalent species from the catch-and-effort data obtained in New Ireland (N) are also included for potential cross reference. The blue column (T) indicates whether the species were among the pooled top five fish choices from all ten communities. The Manus sites are arranged geographically. Yellow denotes ten or less fish (1–10) of a particular species were caught at each site; orange indicates that more than ten (>10) fish of a certain species were caught at each site; white denotes no fish of that particular species were caught. The green and red column indicates the most relevant species for LB-SPR assessment (green = selected, red = rejected).

Species name	**Common name**	No.	**P**	**R**	**N**	**T**	TU I	TU 2	PON	AND	BIP	PEL	MBU	LOU	PAM	BAL	
Herklotsichthys quadrimaculatus	Bluestripe herring	1,134															
Katsuwonus pelamis	Skipjack tuna	894															
Mugil cephalus	Flathead grey mullet	262	B	B													
Melichthys vidua	Pinktail triggerfish	193															
Dussumieria elopsoides	Slender rainbow sardine	180															
Hemirhamphus far	Blackbarred garfish	178															
Lethrinus harak	Thumbprint emperor	177															
Caesio cuning	Redbelly yellowtail fusilier	164	B	B													
Lutjanus gibbus	Humpback red snapper	151															
Siganus canaliculatus	White-spotted spinefoot	133															
Lethrinus obsoletus	Orange-striped emperor	115															
Ctenochaetus striatus	Striated surgeonfish	110															
Grammatorcynus bilineatus	Double-lined mackerel	105															
Lethrinus lentjan	Pink ear emperor	87															
Lutjanus bohar	Two-spot red snapper	82															
Scarus oviceps	Dark capped parrotfish	81															
*Trochus niloticus**	Trochus snail*	81															
Lutjanus sebae	Red emperor snapper	76															
*Strombus luhanus**	Strawberry conch*	75															
Elegatis bipinnulata	Rainbow runner	72															
Thunnus albacares	Yellow-fin tuna	71															
Myripristis violacea	Violet soldierfish	64															
Acanthurus nigroris	Blue-lined surgeonfish	62															
Lutjanus kasmira	bluestripe snapper	61															
Monotaxis grandoculis	Humpnose big-eye bream	60															

*Gastropod molluscs

(TU 1, Tulu 1; TU 2, Tulu 2; PON, Ponam; AND, Andra; BIP, Bipi; PEL, Pelipowai; MBU, Mbuke; LOU, Lou; PAM, Pam; BAL, Baluan)

Table 3: Information on whether the sites are located on islands (I) or on the Manus mainland (M) is included, as well as whether each community relies primarily on fishing (F), gardening (G) or both (B) fishing and gardening for obtaining sustenance. In general, the Manus mainland communities and the fertile volcanic island of Lou (and to a lesser extent, Pam and Baluan) rely on gardening, while the smaller island and atoll communities rely on fishing.

Geographical region	Site name	Island or mainland site		Fishing or gardening community		
		I	M	F	G	B
Northern sites	Tulu 1		■		■	
	Tulu 2		■		■	
	Ponam	■		■		
	Andra	■		■		
Western site	Bipi	■		■		
Southern sites	Pelipowai		■		■	
	Mbuke	■		■		
South-eastern sites	Lou	■			■	
	Pam	■				■
	Baluan	■				■

2.3 Data analysis

Two key life history ratios can determine the size structure of a fish population. The first life history ratio, M/k, compares natural mortality (M) of a fish species with how quickly the fish grows to maximum size (k). The second life history ratio, L_m/L_∞, compares the size at which a fish becomes sexually mature (L_m) with the average maximum size that a fish could achieve if no fishing occurred (L_∞; also known as the asymptotic size). The size of sexual maturity is estimated by determining the size at which half (50%) of the fish population becomes mature, also known as L_{50} (Prince *et al*., 2014; Prince, 2017). The length-based spawning potential (LB-SPR) method analyses the size composition of a fish population to estimate spawning potential and relative fishing pressure (F/M). In simple terms, the technique mathematically compares the size compositions of catches to the local size of maturity (Hordyk *et al*., 2014). If few fish reach the size of maturity (L_m) then it is to be expected that low levels of spawning will occur; in contrast, if many fish achieve the average maximum size for that population (L_∞), closer to 100% of natural spawning potential can occur (Prince, 2017).

In general, it is accepted that similar life history traits and ratios can be exhibited by fish species classified within a certain taxonomic family. As a result, it has been possible to estimate life history ratios required for LB-SPR assessments for key reef fish species in the Indo-Pacific region (Prince, 2017). For this study, such estimations of life history ratios (M/k and L_∞) for the ten selected finfish species have been listed in Table 4, as well as estimations of L_{50} and L_{95}.

For the LB-SPR analysis to be robust, a large dataset is required. Therefore, only species that had a sample size of 150 individuals or more were selected for analysis. The LB-SPR analysis was conducted via the barefootecologist.com.au website.

Table 4: Estimates of major life-history ratios (*M*/*k* and L_∞) used as input parameters to assess the spawning potential of the ten selected reef fish species at all ten sites around Manus province, Papua New Guinea. The estimated lengths in which half (50%) of the fish population is mature (L_{50}), as well as an estimation of when 95% of the population is mature (L_{95}) are also included. The fish species are ranked according to how prevalent they were during the Phase I catch-and-effort data collection session at all ten sites. *M* represents natural mortality; *k* signifies the time taken for a species to attain maximum size; L_∞ denotes the average maximum size (in millimetres, mm) of each species when no fishing occurs (also known as the asymptotic size); L_{50} indicates the length (in mm) in which half (50%) of the population becomes mature; and L_{95} represents the length (in mm) in which 95% of the population reaches sexual maturity.

Family	Species	Common name	*M*/*k*	L_∞	L_{50}	L_{95}
Lethrinidae	*Lethrinus harak*	Thumbprint emperor	0.7	304	213	234
Lutjanidae	*Lutjanus gibbus*	Humpback red snapper	0.51	293	220	242
Siganidae	*Siganus canaliculatus*	White-spotted spine foot	2.5	309	170	187
Lethrinidae	*Lethrinus obsoletus*	Orange-striped emperor	0.7	273	191	210
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	0.35	199	159	175
Lethrinidae	*Lethrinus lentjan*	Pink ear emperor	0.7	343	240	264
Lutjanidae	*Lutjanus bohar*	Two-spot red snapper	0.5	581	436	479
Scaridae	*Scarus oviceps*	Dark capped parrotfish	0.65	220	160	175
Lutjanidae	*Lutjanus sebae**	Red emperor snapper	0.5	723	-	-
Lethrinidae	*Monotaxis grandoculis*	Humpnose big-eye bream	0.7	296	207	227

*No reliable L_{50} or L_{95} values for *Lutjanus sebae* could be obtained.

3.0 RESULTS

3.0 RESULTS

The outcomes from the length-based spawning potential (LB-SPR) assessments, which took place at ten sites around Manus province, Papua New Guinea, from February to April 2018, are presented below. Due to the short timeframe of the ADB Subproject, only a limited period could be allocated to LB-SPR data collection. Accordingly, there was insufficient data to assess all ten selected fish species (for the analysis to be robust, a large dataset is required; therefore, only species with 150 or more measured individuals were analysed). Indeed, assessments could only be made for the surgeonfish, *Ctenochaetus striatus*, the rabbitfish, *Siganus canaliculatus*, and three emperors, *Lethrinus harak*, *L. lentjan* and *L. obsoletus* (Table 5). Moreover, the datasets for the five assessed species were relatively small; additional data would be necessary to enable more robust assessments to be made.

It is hoped that further data collection procedures will be carried out to provide larger datasets, enabling more robust assessments to take place; additionally, further data will allow assessments to be made of the five species that were not assessed in this report. For convenience, the LB-SPR outcomes for the five reef fish species have been arranged in alphabetical order, according to scientific name.

Table 5: The number of individuals that were sampled from each of the ten selected species for length-based spawning potential (LB-SPR) assessment from all ten sites around Manus province; the data were collected from February to April 2018. Because large datasets are required to ensure a robust LB-SPR assessment, it was decided that only species with 150 or more sampled individuals would be analysed. Accordingly, only five of the ten species had sufficiently sized datasets for further analysis. The species have been ordered alphabetically according to scientific name.

Family	Species	Common name	Number sampled for LB-SPR	Selected or rejected for analysis
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	394	ACCEPTED
Lethrinidae	*Lethrinus harak*	Thumbprint emperor	299	ACCEPTED
Lethrinidae	*Lethrinus lentjan*	Pink ear emperor	151	ACCEPTED
Lethrinidae	*Lethrinus obsoletus*	Orange-striped emperor	262	ACCEPTED
Lutjanidae	*Lutjanus bohar*	Two-spot red snapper	101	REJECTED
Lutjanidae	*Lutjanus gibbus*	Humpback red snapper	142	REJECTED
Lutjanidae	*Lutjanus sebae*	Red emperor snapper	102	REJECTED
Lethrinidae	*Monotaxis grandoculis*	Humpnose big-eye bream	104	REJECTED
Scaridae	*Scarus oviceps*	Dark capped parrotfish	120	REJECTED
Siganidae	*Siganus canaliculatus*	White-spotted spinefoot	348	ACCEPTED

3.1 *Ctenochaetus striatus* (striated surgeonfish)

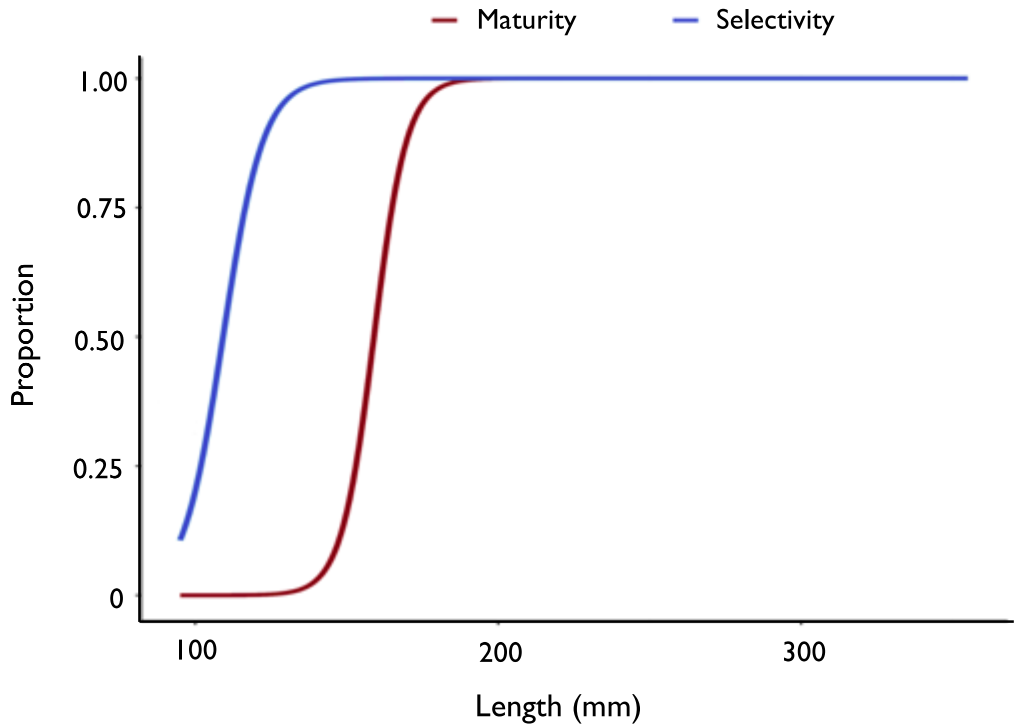
Ctenochaetus striatus, commonly known as striated surgeonfish, is grouped in the Family Acanthuridae. The species is most often associated with areas of reef flat, lagoon, and seaward reefs, reaching depths of 30m. *C. striatus* has a common distribution throughout the Indo-Pacific region and especially across the island nations of the South Pacific. *C. striatus* are herbivorous and feed on algae that grows on the reef. Along with other herbivorous fish, *C. striatus* form a key role within the reef ecosystem by controlling algal growth. Spawning occurs during the full moon, when large schools of fish gather. Spawning begins when fish leave the school to release their eggs and sperm. The species is an important food fish for coastal communities across Papua New Guinea and elsewhere in the Pacific.

In total, 354 *Ctenochaetus striatus* (Quoy & Gaimard, 1825) individuals were measured across the ten ADB sites around Manus province. From the data, it has been estimated that the size of 50% maturity is 15.9cm and the size of 95% maturity is 17.5cm (Figure 5 (a); Table 5). The assumed relative size of maturity for *C. striatus* (L_m/L_∞= 0.80) and the approximation of L_{50} (15.9cm) can be used to estimate the growth of *C. striatus* asymptotes (growth slowing to zero) occurring at an average maximum size of 19.9cm. Figure 5 (b) presents the length-frequency histogram, plotted from the collected *C. striatus* data, which has an approximate modal length of 15–17cm and a maximum length (excluding outliers) of 20cm. Using such input parameters and length-frequency outcomes, the LB-SPR model estimates that *C. striatus* becomes vulnerable to fishing at the size of maturity, and is being fished below what would be expected to maintain maximum sustainable yield (*F/M* = 7.3). Even so, *C. striatus* was fished at approximately 45% of the population's spawning potential, indicating that the species has been relatively lightly exploited thus far.

Table 6: Input parameters and assessment results for *Ctenochaetus striatus* (*n*=354), which were captured at ten sites around Manus province, Papua New Guinea, from February to April 2018. The input parameters include the size of maturity (L_{50} and L_{95}), as indicated by the red line in Figure 5 (a), and an approximation of the life history ratio *M/k*. Estimates from the LB-SPR model include spawning potential (SPR%), size of selectivity (SL_{50} and SL_{95}), indicated by the blue line in Figure 5 (a), relative fishing pressure (*F/M*) and asymptotic size (L_∞). The 95% confidence interval estimates are 45–56% for spawning potential (SPR%), 102.7–115.7mm for SL_{50}, 115.9–141.75mm for SL_{95} and 0.45–1.01 for relative fishing pressure (*F/M*).

SPR (%)	S_{50}	S_{95}	F/M	M/k	L_∞	L_{50}	L_{95}
45%	109mm	129mm	0.73	0.35	199mm	159mm	175mm

(a)



(b)

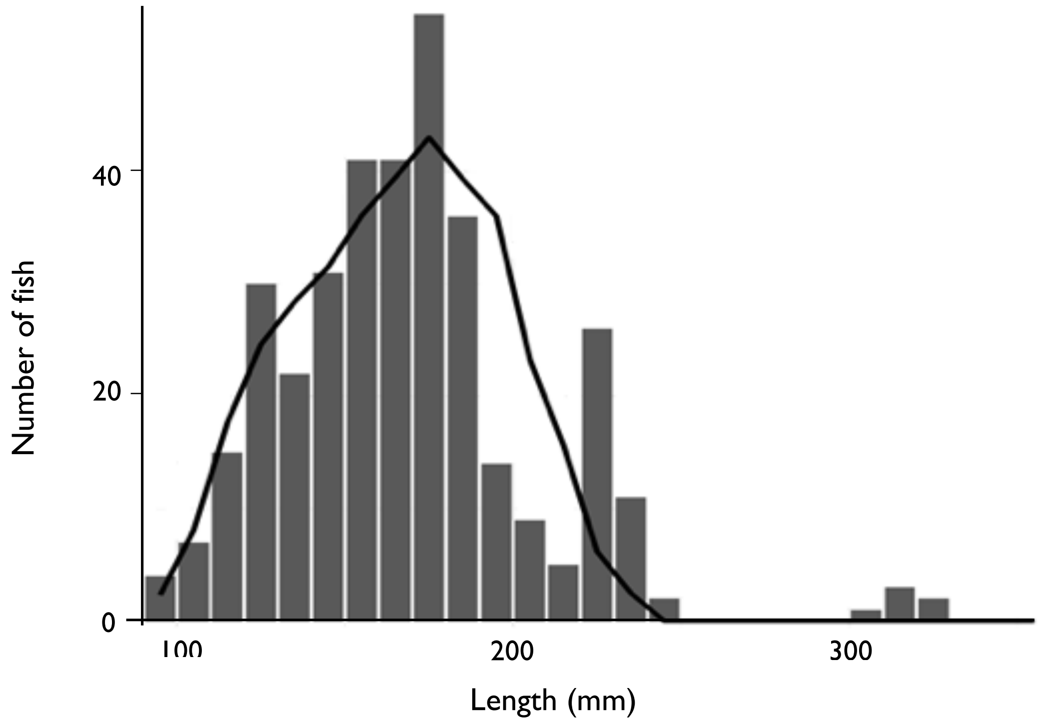


Figure 5: Outcomes from the length-based spawning potential (LB-SPR) assessments for the surgeonfish *Ctenochaetus striatus* (*n*=354), which were sampled at ten sites around Manus province from February to April 2018. **(a)** The red line denotes the proportion of *C. striatus* that were mature according to total length (mm) measurements. The blue line indicates the proportion of *C. striatus* that were vulnerable to fishing based on length measurements that were estimated by the LB-SPR model. **(b)** The histogram represents length (mm) frequencies of *C. striatus*, which were captured around Manus Island. The black line indicates the length-frequency histogram fitted to the data by the LB-SPR model.

3.2 *Lethrinus harak* (thumbprint emperor)

Lethrinus harak are widely distributed across the Indo-Pacific region. They inhibit inshore reefs as well as brackish environments with a depth range preference of 0 to 20m. *L. harak* are hermaphrodite and initially start as females before developing into males after a certain timeframe. Fertilisation occurs externally throughout the year following the first five days of the lunar month, which occurs as adult fish aggregate along reef crests. *L. harak* is carnivorous, with diets consisting of small fish, worms, crustaceans, molluscs and other small animals. Due to the abundance of invertebrates on coral reefs, *L. harak* is commonly associated with such areas. *L. harak* are important food fish for the people of the Pacific and because they exist in inshore areas, simple hook and line fishing method can be used to catch them. (The information was obtained from *Fish Base*.)

From all ten sites around Manus province, Papua New Guinea, a total of 301 *Lethrinus harak* (Forsskål, 1775) individuals were sampled. From the data, it has been estimated that the size of 50% maturity is 21.3cm and the size of 95% maturity is 23.4cm (Figure 6 (a); Table 6). The assumed relative size of maturity for *L. harak* (L_m/L_∞= 0.70) and the approximation of L_{50} (21.3cm) can be used to estimate the growth of *L. harak* asymptotes (growth rate that approaches zero) occurring at an average maximum size of 30.4cm. Figure 6 (b) presents the length-frequency histogram, plotted from the collected *L. harak* data, which has an approximate modal length of 16–18cm and a maximum length (excluding outliers) of 30cm. Using such input parameters and length-frequency outcomes, the LB-SPR model estimates that *L. harak* becomes vulnerable to fishing at the size of maturity, and with fishing rates exceeding the maintain maximum sustainable yield (F/M = 2.71) by almost three-fold. As a result, the spawning potential estimate for *L. harak* is only 7%, almost two thirds below the replacement level of 20% spawning potential, which is needed to maintain a stable fish population.

Table 7: Input parameters and assessment results for *Lethrinus harak* (*n*=301), which were captured at ten sites around Manus province, Papua New Guinea, from February to April 2018. The input parameters include the size of maturity (L_{50} and L_{95}), as indicated by the red line in Figure 6 (a), and an approximation of the life history ratio *M*/*k*. Estimates from the LB-SPR model include spawning potential (SPR%), size of selectivity (SL_{50} and SL_{95}), indicated by the blue line in Figure 6 (a), relative fishing pressure (*F*/*M*) and asymptotic size (L_∞). The 95% confidence interval estimates are 4–10% for spawning potential (SPR%), 121.2–145.8mm for SL_{50}, 161.1–206.98mm for SL_{95} and 2.01–3.41 for relative fishing pressure (*F*/*M*).

SPR (%)	S_{50}	S_{95}	F/M	M/k	L_∞	L_{50}	L_{95}
7%	134mm	184mm	2.71	0.7	304mm	213mm	234mm

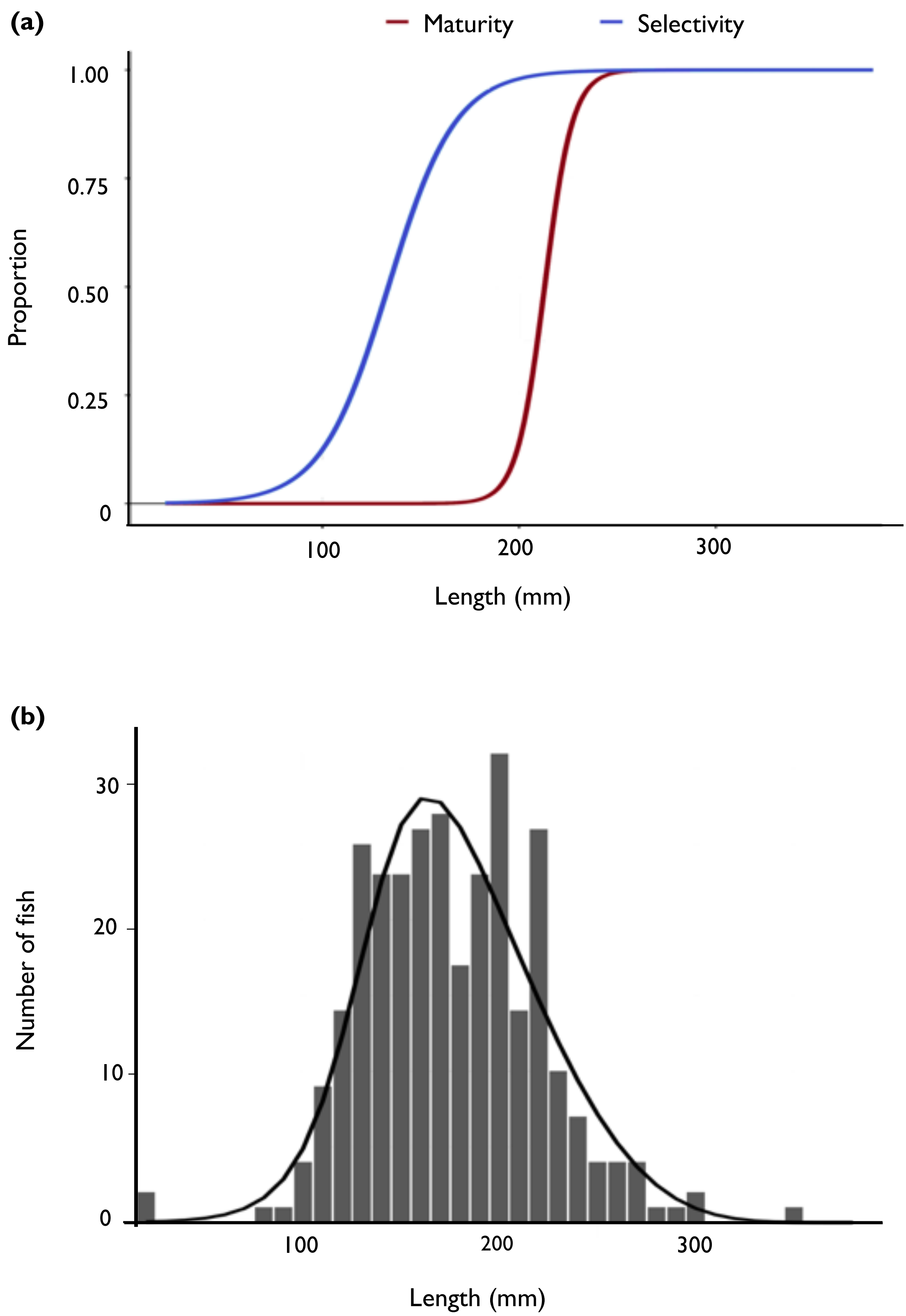


Figure 6: Outcomes from the length-based spawning potential (LB-SPR) assessments for the emperor *Lethrinus harak* (*n*=301), which were sampled at ten sites around Manus province from February to April 2018. **(a)** The red line denotes the proportion of *L. harak* that were mature according to total length (mm) measurements. The blue line indicates the proportion of *L. harak* that were vulnerable to fishing based on length measurements estimated by the LB-SPR model. **(b)** The histogram represents length (mm) frequencies of *L. harak*, which were captured around Manus Island. The black line indicates the length-frequency histogram fitted to the data by the LB-SPR model.

3.3 *Lethrinus lentjan* (pink ear emperor)

Lethrinus lentjan are widely distributed throughout the Indo-Pacific region, and occupy sandy areas, sea grass beds and coral reefs. *L. lentjan* are carnivorous with a diet consisting of crustaceans, worms, and other fishes. The species is hermaphrodite, and can grow to a maximum total length of 50cm; however, females usually change into males when reaching around 30m in total length. *L. lentjan* is often fished for subsistence benefits in many coastal and island communities across the Pacific and is an important food fish. (The information was obtained from *Fish Base*.)

In total, 150 individuals of the emperor *Lethrinus lentjan* (Lacepède, 1802) were measured from ten ADB sites around Manus province. From the data, it has been estimated that the size of 50% maturity is 24cm and the size of 95% maturity is 26.4cm (Figure 7 (a); Table 7). The assumed relative size of maturity of *L. lentjan* (L_m/L_∞= 0.70) and the approximation of L_{50} (24cm) can be used to estimate the growth of *L. lentjan* asymptotes (growth slowing to zero) occurring at an average maximum size of 34.3cm. Figure 7 (b) presents the length-frequency histogram, generated from the collected *L. lentjan* data, which has an approximate modal length of 20–22cm and a maximum length (exuding outliers) of roughly 32cm. Using such input parameters and length-frequency outcomes, the LB-SPR model estimates that *L. striatus* becomes vulnerable to fishing at the size of maturity, and is being fished more than two times beyond what would be considered acceptable for maintaining maximum sustainable yield for the species (*F/M* = 2.31). Moreover, the spawning potential estimate for *L. lentjan* is 12%, almost half the replacement level (spawning potential = 20%) that can allow a fish stock to remain stable.

Table 8: Input parameters and assessment results for *Lethrinus lentjan* (*n*=150), which were captured at ten sites around Manus province, Papua New Guinea, from February to April 2018. The input parameters include the size of maturity (L_{50} and L_{95}), as indicated by the red line in Figure 7 (a), and an approximation of the life history ratio *M/k*. Estimates from the LB-SPR model include spawning potential (SPR%), size of selectivity (SL_{50} and SL_{95}), indicated by the blue line in Figure 7 (a), relative fishing pressure (*F/M*) and asymptotic size (L_∞). The 95% confidence interval estimates are 2–23% for spawning potential (SPR%), 132.5–206.6mm for SL_{50}, 192–306.7mm for SL_{95} and 0.83–3.79 for relative fishing pressure (*F/M*).

SPR (%)	S_{50}	S_{95}	F/M	M/k	L_∞	L_{50}	L_{95}
12%	171mm	249mm	2.31	0.7	343mm	240mm	264mm

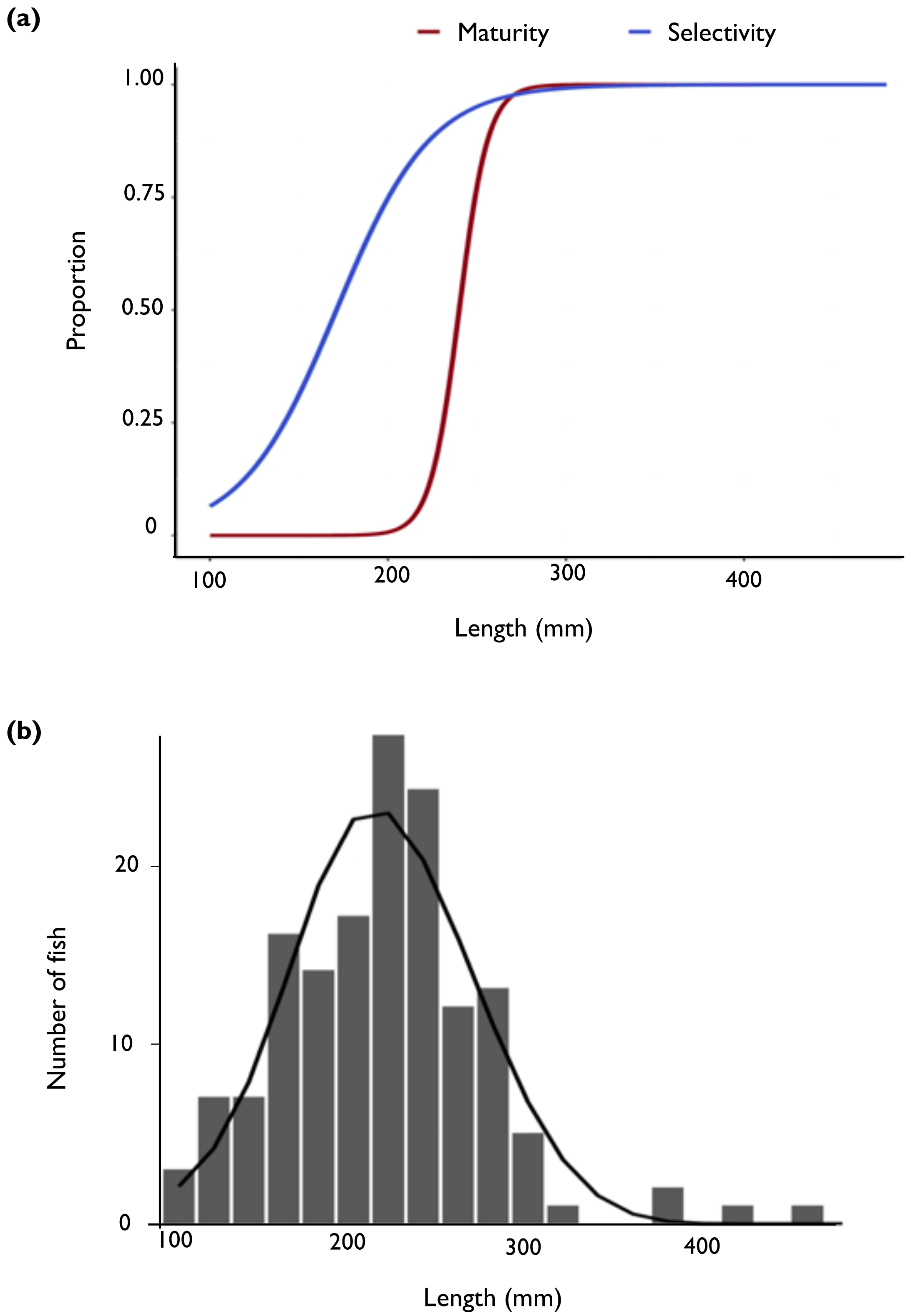


Figure 7: Outcomes from the length-based spawning potential (LB-SPR) assessment for the emperor *Lethrinus lentjan* (*n*=150), which were sampled at ten sites around Manus province from February to April 2018. **(a)** The red line denotes the proportion of *L. lentjan* that were mature according to total length (mm) measurements. The blue line indicates the proportion of *L. lentjan* that were vulnerable to fishing according to length measurements estimated by the LB-SPR model. **(b)** The histogram represents length (mm) frequencies of *L. lentjan*, which were captured around Manus Island. The black line indicates the length-frequency histogram fitted to the data by the LB-SPR model.

3.4 *Lethrinus obsoletus* (orange-striped emperor)

Lethrinus obsoletus can be found throughout the tropical regions of the Indo-Pacific. The species has a preference for coral reefs, sea grass beds and areas of rubble, reaching depths of 30m. Carnivorous, *L. obsoletus* feeds on, molluscs and crustaceans, and can reach a maximum fork length of 50cm.For many Pacific coastal communities, *L. obsoletus* is an important fish targeted by artisanal fishers. (The information was obtained from *Fish Base*).

From all ten sites around Manus province, Papua New Guinea, a total of 254 *Lethrinus obsoletus* (Forsskål, 1775) individuals were sampled. From the data, it has been estimated that the size of 50% maturity is 19.1cm and the size of 95% maturity is 21cm (Figure 8 (a); Table 8). The assumed relative size of maturity of *L. obsoletus* (L_m/L_∞= 0.70) and the approximation of L_{50} (19.1cm) can be used to estimate the growth of *L. obsoletus* asymptotes (growth rate that approaches zero) occurring at an average maximum size of 27.3cm. Figure 8 (b) presents the length-frequency histogram, plotted from the collected *L. obsoletus* data, which has an approximate modal length of 15–17cm and a maximum length (excluding outliers) of 33cm. Using such input parameters and length-frequency outcomes, the LB-SPR model estimates that *L. obsoletus* becomes vulnerable to fishing at the size of maturity, and with fishing rates below the recommended level for maintaining maximum sustainable yield (*F/M* = 0.76). Despite this, the spawning potential estimate *for L. obsoletus* is 36%, which is above the limit for maintaining a stable population (spawning potential = 20%).

Table 9: Input parameters and assessment results for *Lethrinus obsoletus* (*n*=254), which were captured at ten sites around Manus province, Papua New Guinea, from February to April 2018. The input parameters include the size of maturity (L_{50} and L_{95}), as indicated by the red line in Figure 8 (a), and an approximation of the life history ratio *M/k*. Estimates from the LB-SPR model include spawning potential (SPR%), size of selectivity (SL_{50} and SL_{95}), indicated by the blue line in Figure 8 (a), relative fishing pressure (*F/M*) and asymptotic size (L_∞). The 95% confidence interval estimates are 22–49% for spawning potential (SPR%), 88.6–125.5mm for SL_{50}, 119.4–197.9mm for SL_{95} and 0.41–1.11 for relative fishing pressure (*F/M*).

SPR (%)	S_{50}	S_{95}	F/M	M/k	L_∞	L_{50}	L_{95}
36%	107mm	158mm	0.76	0.7	273mm	191mm	210mm

(a)

(b)

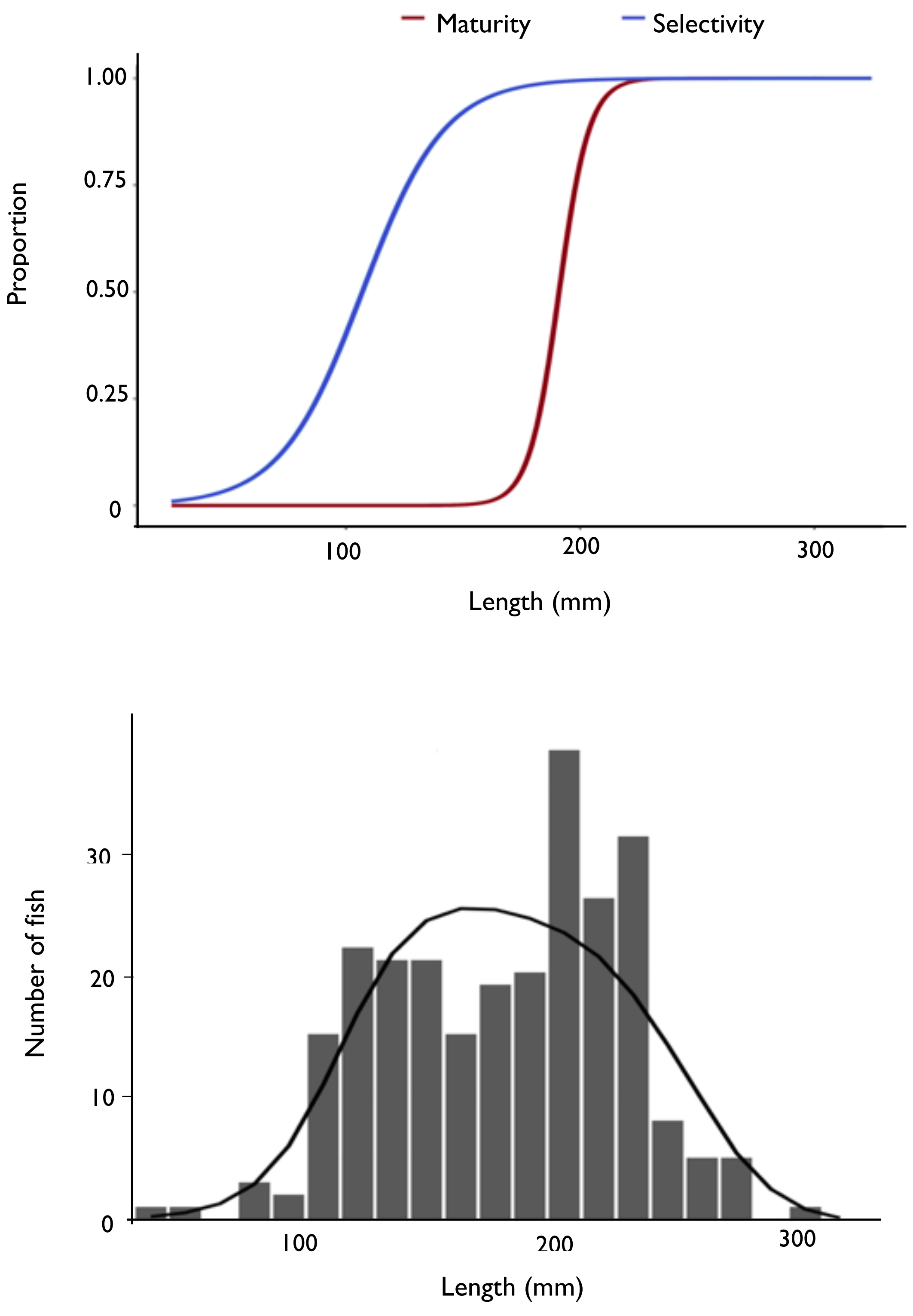


Figure 8: Outcomes from the length-based spawning potential (LB-SPR) assessment for the emperor *Lethrinus obsoletus* (*n*=254), which were sampled at ten sites around Manus province from February to April 2018. **(a)** The red line denotes the proportion of *L. obsoletus* that were mature according to total length (mm) measurements. The blue line indicates the proportion of *L. obsoletus* that were vulnerable to fishing based on length measurements estimated by the LB-SPR model. **(b)** The histogram represents length (mm) frequencies of *L. obsoletus*, which were captured. The black line indicates the length-frequency histogram fitted to the data by the LB-SPR model.

3.5 *Siganus canaliculatus* (white-spotted spinefoot)

Along with other rabbitfish species, *Siganus canaliculatus* live in algae rich habitats on reefs. *S. canaliculatus* are herbivorous, mostly feeding on algae, sea grass and weeds, and their presence on a reef contributes to maintaining the balance of algae cover. Widespread throughout the Indo-Pacific, this species inhibit estuaries, rocky lagoons and sea grass beds; adults may venture into deeper areas of water. Spawning takes place in groups with the larger fish contributing more effectively to fertilisation. Most often, juveniles form large schools in shallow bays and on coral reef flats whilst the adult have around twenty individuals per school. The species forms an important food fish in PNG and across the South Pacific. (Information was obtained from *Fish Base*).

In total, 375 individuals of the rabbitfish *Siganus canaliculatus* (Park, 1797) were measured from all ten ADB sites around Manus province from February to April 2018. From the data, it has been estimated that the size of 50% maturity is 17cm and the size of 95% maturity is 18.7cm (Figure 9 (a); Table 9). The assumed relative size of maturity of *S. canaliculatus* (L_m/L_∞= 0.55) and the approximation of L_{50} (17cm) can be used to estimate the growth of *S. canaliculatus* asymptotes (growth slowing to zero) occurring at an average maximum size of 30.9cm. Figure 9 (b) presents the length-frequency histogram, plotted from the collected *S. canaliculatus* data, which has an approximate modal length of 17–18cm and a maximum length of roughly 28cm. Using such input parameters and length-frequency outcomes, the LB-SPR model estimates that *S. canaliculatus* becomes vulnerable to fishing at the size of maturity, and is being fished below – by almost half – what is the recommended level to maintain maximum sustainable yield for the species (*F/M* = 0.58). Even so, *S. canaliculatus* had a spawning potential of 47%, which is above the replacement level for a fish population (spawning potential = 20%).

Table 10: Input parameters and assessment results for *Siganus canaliculatus* (*n*=375), which were captured at ten sites around Manus province, Papua New Guinea, from February to April 2018. The input parameters include the size of maturity (L_{50} and L_{95}), as indicated by the red line in Figure 9 (a), and an approximation of the life history ratio *M/k*. Estimates from the LB-SPR model include spawning potential (SPR%), size of selectivity (SL_{50} and SL_{95}), indicated by the blue line in Figure 9 (b), relative fishing pressure (*F/M*) and asymptotic size (L_∞). The 95% confidence interval estimates are 34–60% for spawning potential (SPR%), 139.7–159.3mm for SL_{50}, 175.8–206.4mm for SL_{95} and 0.29–0.87 for relative fishing pressure (*F/M*).

SPR (%)	S_{50}	S_{95}	F/M	M/k	L_∞	L_{50}	L_{95}
47%	149mm	191mm	0.58	2.5	309mm	170mm	187mm

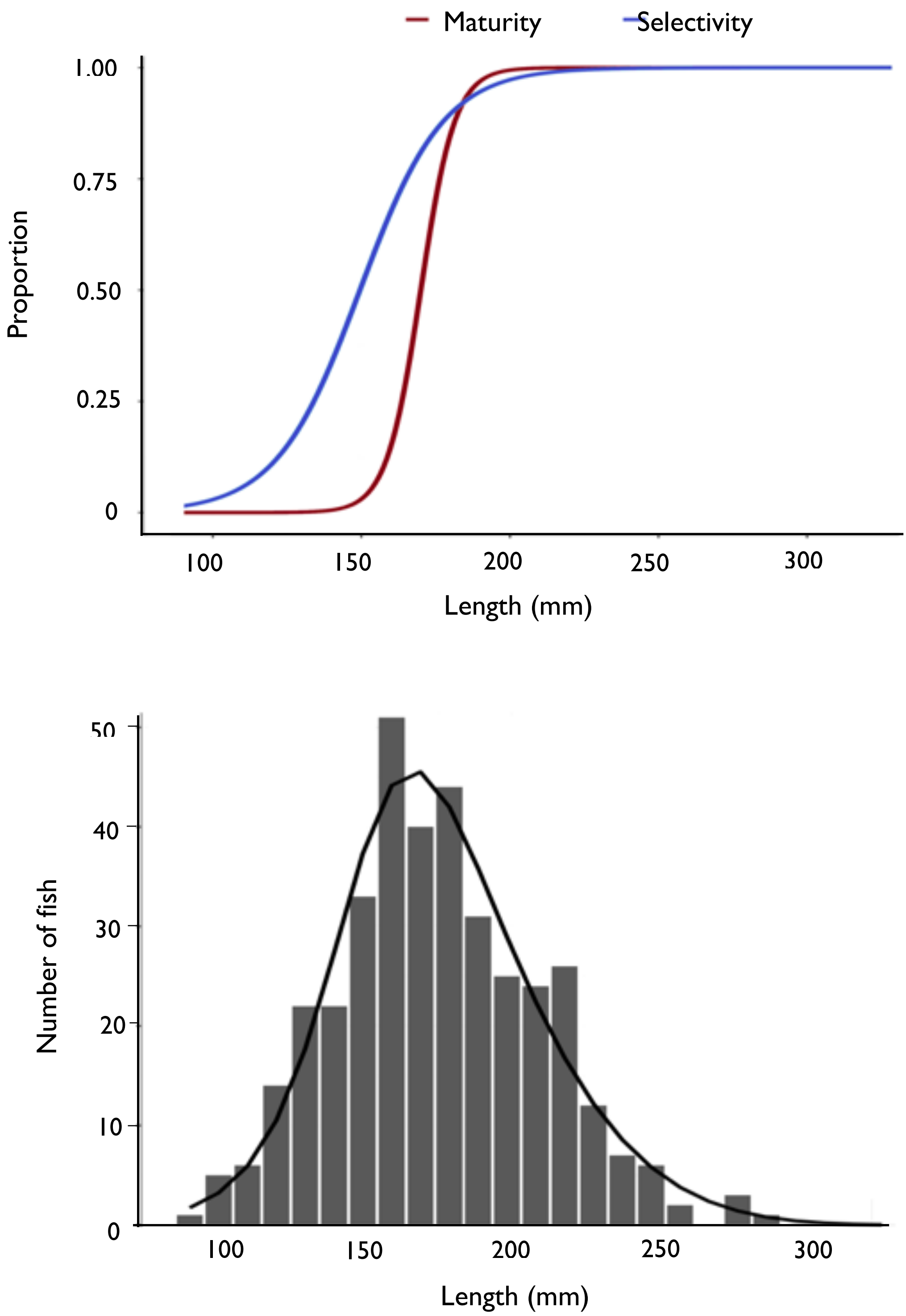


Figure 9: Outcomes from the length-based spawning potential (LB-SPR) assessment for the rabbitfish *Siganus canaliculatus* (*n*=375), which were sampled at ten sites around Manus province from February to April 2018. **(a)** The red line denotes the proportion of *S. canaliculatus* that were mature according to total length (mm) measurements. The blue line indicates the proportion of *S. canaliculatus* that were vulnerable to fishing based on length measurements estimated by the LB-SPR model. **(b)** The histogram represents length (mm) frequencies of *S. canaliculatus*, which were captured. The black line indicates the length-frequency histogram fitted to the data by the LB-SPR model.

3.6 Overview of spawning potential findings

Estimates of spawning potential were derived for five fish species that were sampled at ten sites around Manus Island, Papua New Guinea, from February to April 2018. In general, 20% spawning potential represents a stabilised fish population, while a spawning potential above 40% is thought to signify a fish stock that is not experiencing heavy recruitment overfishing. The spawning potential values indicate that *Lethrinus harak* and *Lethrinus lentjan* are experiencing unsustainable fishing pressure and therefore recruitment overfishing. The spawning potential outcomes for *Lethrinus obsoletus* indicate that the species is experiencing less recruitment overfishing fishing pressure than the other two emperors. The outcomes for *Ctenochaetus striatus* and *Siganus canaliculatus* suggest that each respective stock is not facing unsustainable recruitment overfishing fishing pressure (Figure 10).

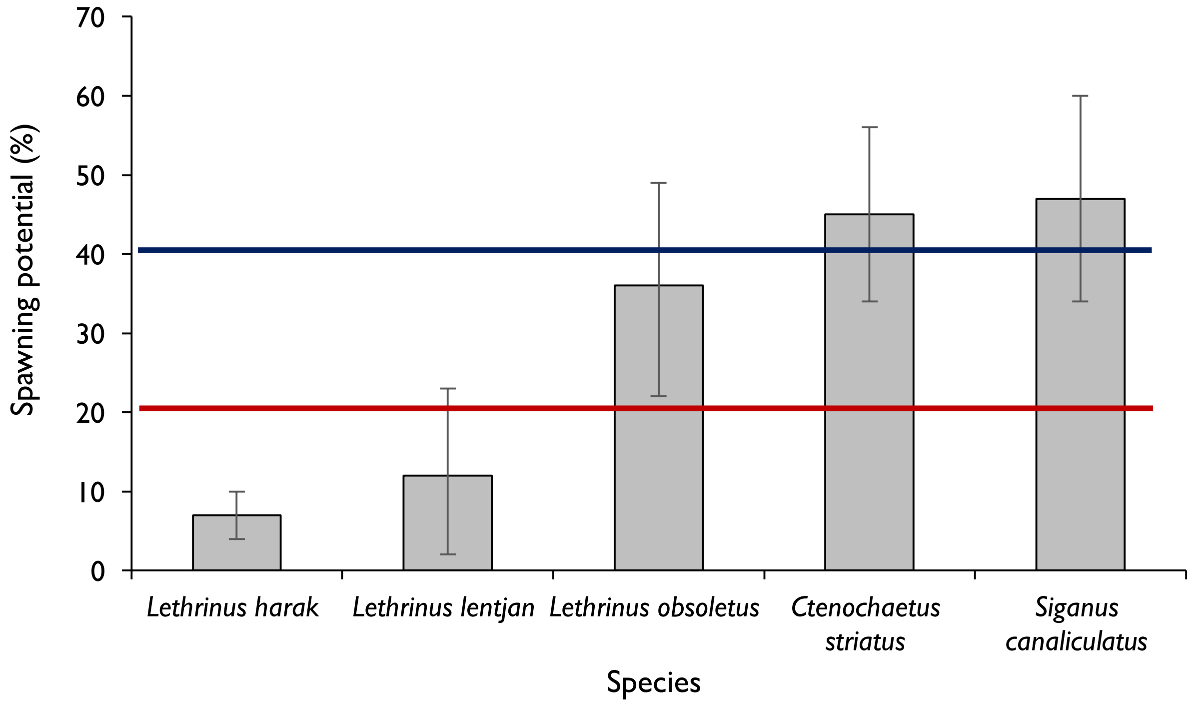


Figure 10: The estimated levels of spawning potential (%) for the five reef fish species that were assessed (±95% confidence intervals), according to the outcomes of the length-based spawning potential (LB-SPR) model. It is generally accepted that below 20% spawning potential, a fish species is at risk from population decline due to intensive fishing activity and a reduction in spawning stock biomass. Above 40% spawning potential indicates a fish population that is less heavily fished. The red bar denotes 20% spawning potential; the blue bar represents 40% spawning potential. *Lethrinus harak* and *Lethrinus lentjan* are both at risk from intensive recruitment overfishing; *Ctenochaetus striatus* and *Siganus canaliculatus* appear less vulnerable. Data were collected from ten sites around Manus Island, Papua New Guinea, between February and April 2018.

4.0 DISCUSSION

According to Prince (2017) and Hordyk *et al*. (2014), for the length-based spawning potential (LB-SPR) model outcomes to be robust, a sample size of 1,000 fish or more is necessary. In addition, the small number of larger individuals, which can be underrepresented in a sample, influences the spawning potential estimations, especially in areas that are heavily fished. Accordingly, spawning potential estimates that use small sample sizes are usually 5–10% lower than actual spawning potential levels; similarly, estimates of relative fishing pressure (*F/M*) can be higher than actual levels. All of the fish that were assessed in this study had sample sizes that were lower than 400 individuals, which therefore restricts the accuracy of the LB-SPR outcomes. Despite this, from the outcomes that were obtained from the LB-SPR assessments, a better understanding of each regional fish stock can be deduced. It is also anticipated that future data collection sessions at each of the ten sites will add further data, enabling more accurate LB-SPR assessments to be made for the five species, and also for the other five species that were not assessed within this report due to insufficient datasets.

4.1 Fish assessments

The LB-SPR outcomes indicate that two of the three emperor species, *Lethrinus harak* and *Lethrinus lentjan*, are currently experiencing intensive recruitment overfishing. Both species are being fished below the limits that have been recommended for maintaining maximum sustainable yields. In addition, both fish have spawning potentials that are below the accepted replacement level for maintaining a stabilised population. Such outcomes are also reflected in the sentiments provided by many senior fishers at the ten sites, who state that the fish are becoming less abundant and smaller in body size. Emperors were also considered key fisheries at most of the ten ADB sites, according to a previous study conducted by WCS. For these reasons, it is necessary to improve local fisheries management methods at each site in order to increase the local spawning potential of the two emperor species before they become too depleted in numbers. The other emperor species, *Lethrinus obsoletus*, appeared to be less vulnerable to recruitment overfishing, and had a spawning potential that was above the 20% threshold, which is considered necessary for maintaining a stabilised population. A possible reason for the greater fishing pressure placed on *L. harak* and *L. lentjan* could be due to the larger body sizes that these two species attain, which are both greater in size than the smaller *L. obsoletus*. In general, larger sized fish are more valuable to local fishers and are thus more likely to be targeted. In addition, the two larger emperors mature at a larger size than the smaller *L. obsoletus*, resulting in the capture of the larger sized juvenile fish prior to their sexual maturation.

The results for the two other species that were assessed – the surgeonfish *Ctenochaetus striatus* and the rabbitfish *Siganus canaliculatus* – suggest that both species have higher spawning potential estimates, which were above 40%. In comparison to the three emperor species, *C. striatus* matures at a smaller size, so is possible that less *C. striatus* juveniles are likely to be captured. The rabbitfish *S. canaliculatus* also matures at a smaller size than the three emperor species. Like *C. striatus*, the rabbitfish has a spawning potential above 40%. Yet *S. canaliculatus* experienced higher rates of fishing pressure than *C. stratus*. The larger maximum body size of *S. canaliculatus*, which would make the species more valuable among regional fishers, could be a reason for this outcome.

Unlike *C. stratus* and other surgeonfishes, the Family Siganidae, which includes all the rabbitfishes, have high *M/k* life history values: within this study, *S. canaliculatus* had an *M/k* value of 2.5. High *M/k* values are indicative of *r*-strategy species. In contrast, the Family Acanthuridae, which includes the surgeonfish and unicorn fish, have lower *M/k* values. Within the current study, the surgeonfish *C. striatus* had an *M/k* value of 0.35. Organisms with low *M/k* life history values tend to exhibit *K*-strategy characteristics. In general, *r*-selection species tend to maximise their reproductive success in uncrowded environments, in which population densities can fluctuate or in areas that experience low levels of ecological competition. Typically, *r*-selected species often have high growth rates and produce many offspring that have low survival rates; examples include grasses, marine worms and rodents. By contrast, *K*-selection species are sensitive to population density and tend to maximise population sizes. *K*-strategists include slow growth rates and the production of few offspring that have a high probability of reaching adulthood; examples include orchids, birds and humans (Nichols *et al*., 1976). The rabbitfish, *S. canaliculatus*, is an *r*-strategist species and therefore more likely to recover from a period of intensive fishing activity than *C. striatus*, which is a *K*-strategist species and thus likely to be more sensitive to fishing pressure.

4.2 Management approaches

Although the outcomes from the LB-SPR assessments are not robust, and only feature five species, it is apparent that two of the more valuable emperor species, *Lethrinus harak* and *L. lentjan*, are under threat from heavy recruitment overfishing. Moreover, even though the other three species – *L. obsoletus*, *Ctenochaetus striatus* and *Siganus canaliculatus* – appear less threatened, it is probable that during the coming decades, when many of the larger fish disappear, the smaller-bodied fish will be targeted: a trend that is occurring across the island nations of the Pacific Basin (Bell *et al*., 2013). Predictions by Prince (2017) stated that if Pacific coastal communities do not reform their management approaches, it is probable that the most valuable food and commercial fish species will be depleted to such an extent that such fish become insignificant for subsistence and livelihoods. For Manus, this could mean a future in which the residents rely less on marine resources for both protein and income. Prince (2017) continues by summarising the situation that now exists across many coastal communities in Indonesia and the Philippines, which also had vibrant fisheries prior to intensive fishing pressure. Today, many coastal communities within Indonesia and the Philippines rely on harvesting baitfish or have moved to urban centres and consume canned marine products. Surgeonfish and rabbitfish are also herbivores, feeding on algae that grows on a coral reef. When the herbivorous fish are removed, the growth of algae is not managed and soon an area of reef can be covered by green algae. A deteriorated reef will lead to further fish migrations, which will lead to less fish in the future: a situation that has already occurred in some areas of Indonesia and the Philippines.

Using the information provided from the LB-SPR models, a simple and effective approach to help stabilise the populations of the five species that were assessed, and ultimately replenish their stocks, is to set minimum size limits for each species. Establishing and implementing minimum size limits should safeguard a species until the completion of at least 20% spawning potential – the replacement level for a fish population – in order to maintain a stable fish stock. Size limits that maintain 20% spawning potential should allow for a sustainable fishery and also optimum catch rates, even if the level of fishing activity remains high. Tropical marine fish usually grow fast when they reach their size of maturity: even though a minimum size limit would initially lead to a reduced catch number, by the following year fishers should notice increased catch rates once fish stocks have recovered, and also larger sized animals, depending on the fish species (Prince, 2017). Such occurrences should be most apparent to the fishers themselves, who will notice the shift to increased catch numbers and larger sized animals. However, it is also important to introduce the size limits one at a time, to help prevent confusion or fear among community members, and to enable fishers to become accustomed to the changes while observing the benefits to the fishery under management (Klein *et al*., 2008). Minimum size limits should also be agreed upon by representatives from all local villagers and implemented at the community-level, which should ensure that such management approaches are put into practice and enforced.

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The World Bank: Data

http://data.worldbank.org/country/papua-new-guinea

http://www.wikimediacommons.com

http://www.fishbase.se

5.1 Photograph credits

Unless otherwise stated, all photographic images used within the current report were are the property of the Wildlife Conservation Society: Papua New Guinea.

Fish gender and maturity photographs were provided courtesy of Dr Jeremy Prince (2017).

Base maps that were included in the current report were obtained from Google Earth, 2018.

Other fish photographs used within the results section were obtained from Moore & Colas (2016).

APPENDIX

Date:	Fishing type:		
Measurer:	Day or night:		
Reef name:	Site:		
Name of fish:	Length (mm)	Maturity (A/J)	Sex (M/F)

Appendix I

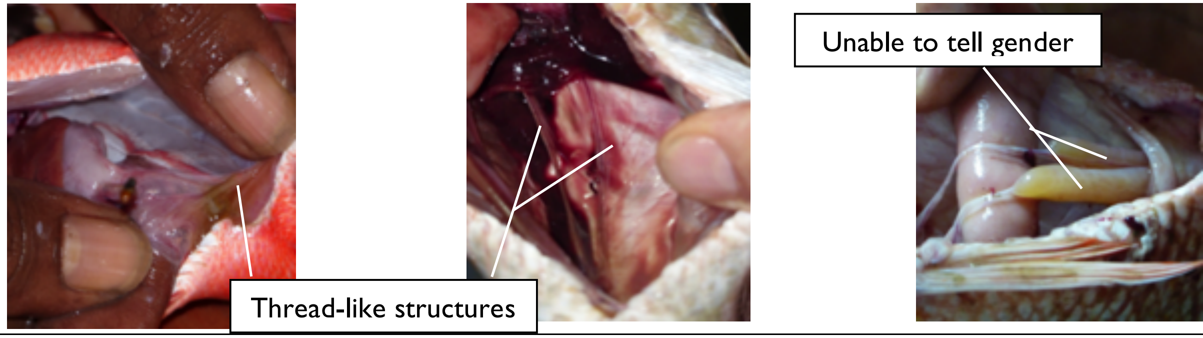
Datasheet used by the data collectors in the field to collect length-based spawning potential data at each of the ten sites

Appendix II

Identifying fish gender and maturity for length-based spawning potential assessments

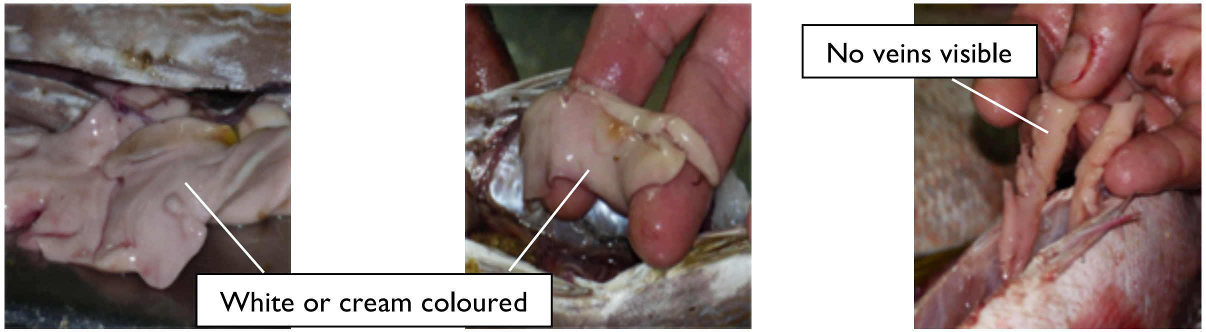
JUVENILE FISH

- Unable to tell fish gender
- Two thread or strap-like structures that run along the backbone



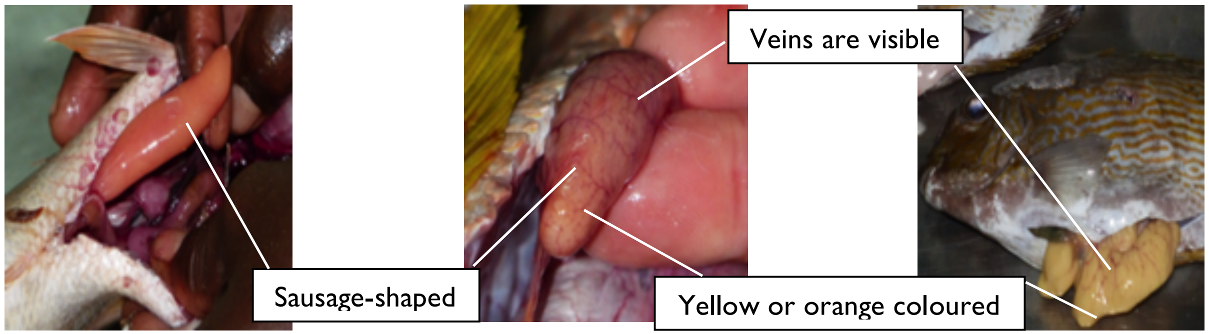
ADULT MALE FISH

- Two testis running along the backbone
- Milky-white or cream coloured
- No major veins visible
- Texture feels like live



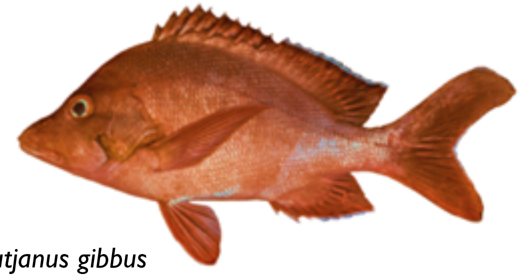
ADULT FEMALE FISH

- Two ovaries running along the backbone
- Yellow or orange coloured
- Veins are often visible
- Sausage-shaped organs
- Sand-like texture



Appendix III

Identification cards used to identify the ten selected species for length-based spawning potential analysis

FAMILY LETHRINIDAE  *Lethrinus harak* Thumbprint emperor Pale grey to greenish-grey. Has a dark-blotch on the middle of the side. Lives in sand-rubble bottoms, areas of sea grass and mangroves near coral reefs. Up to 40cm long.	FAMILY LUTJANIDAE  *Lutjanus gibbus* Humpback red snapper; paddletail Reddish-grey to red body. Older individuals with yellow gill covers and eyes. Arching forehead. Maroon tail with rounded tail fins. Lives on coral reefs. Up to 50cm long.	FAMILY SIGANIDAE  *Siganus canaliculatus* White-spotted spinefoot Silvery-grey to greenish-brown or yellowish-brown. Many blue or white spots on the head and body. Often with a dark patch behind the gills. Up to 30cm long.
FAMILY LETHRINIDAE  *Lethrinus obsoletus* Orange-striped emperor Pale grey-green; brown upper body. Lighter lower body. A yellow-orange stripe along the lower part of the body. Lives in coral reefs. Up to 50cm long.	FAMILY ACANTHURIDAE  *Ctenochaetus striatus* Striated surgeonfish Dark grey-brown to orange-brown body. Orange spots on the head. Blue lines on the body. Flexible teeth. Lives in coral reefs. Up to 26cm long.	FAMILY LETHRINIDAE  *Lethrinus lentjan* Pink ear emperor Silvery-grey with red area on the edge of the gills. When caught, the head usually turns purple. Lives in sandy areas next to reefs. Up to 50cm long.

FAMILY LUTJANIDAE

Lutjanus bohar

Two-spot red snapper; red bass

Large adults (shown) are red to red-grey. Juveniles have two white spots on the back. Fins are dark red to black at the edges. Up to 80cm long.

FAMILY SCARIDAE

Scarus oviceps

Dark capped parrotfish

Adults (shown): blue-green body; dark coloured head (forming a cap). Juveniles: light grey with yellow areas and dark grey cap. Up to 35cm long.

FAMILY LUTJANIDAE

Lutjanus sebae

Emperor red snapper; red emperor

Adults: pinkish-red coloured. Juveniles (shown) have white and pale red stripes crossing the head and body. Lives on coral reefs. Up to 110cm long.

FAMILY LETHRINIDAE

Monotaxis grandoculis

Humpnose big-eye bream

Adults (shown): grey to silver-brown in colour. Steep-sloping forehead. Large eyes. Juveniles: dark areas on back. Lives on reefs. Up to 55cm long.

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