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Editorial

Size limits seem to have regained popularity in the reef fisheries world. They are the main topic of two very interesting articles in this issue, among many others.

Imposing species-specific size limits is one of the management measures used to ensure that animals will have a chance to reach adult size and reproduce successfully before being caught. But for this to happen, the size of maturity of the species must be known, which is not the case for many tropical reef fish. In Fiji, scientists have partnered with communities to study and estimate the size of maturity of 46 of the main reef fish species consumed or sold there (see article by Prince et al. on page 51). They have also studied the pros and cons of placing these minimum size limits into categories that are rounded to the nearest 5 cm to facilitate monitoring and enforcement. They hope that their results will be broadly applicable across the Pacific Islands region with minor adjustments.

Imposing size limits also means imposing restrictions on fishers, which is a move that is rarely popular. The benefits of these restrictions, which should be increased stocks and better fishing, sometimes take a long time to come to fruition and are not always spectacular. It may, however, be different in sea cucumber fisheries. According to Lee and his colleagues (see article on page 29), who have studied the potential impact of a strict enforcement of sea cucumber size limits in four Melanesian countries, the benefits – particularly increased economic returns – should be spectacular. They estimate that 'if minimum legal size limits were enforced, the entire long-term harvest of some species could increase by up to 97% and generate up to 144% more revenue.'

If you look at it from the other side, slack enforcement of size regulations – often a consequence of a lack of political will or weak governance – may induce huge economic losses. If the economic benefits of carefully managing marine life are so obvious, what are we waiting for?

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Recording coral reef fish sizes at a Fiji market. Image: Sangeeta Mangubhai.

Prepared by the Pacific Community, Division of Fisheries, Aquaculture and Marine Ecosystems, Information Section

Community Marine Monitoring Toolkit: A locally-developed toolkit to inform community-based management of marine resources in Vanuatu

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Community engagement, participation and empowerment are key to effective and sustainable environmental management and climate change adaptation at the local level. Furthermore, if the widespread decline of coastal resources throughout the Pacific is to have any chance of recovery, then communities need to be part of the solution with the use of appropriate and effective tools. A novel marine monitoring toolkit ('the Toolkit') has been developed in Vanuatu under the Restoration of Ecosystem Services and Adaptation to Climate Change (RESCCUE) project, implemented by the Pacific Community (SPC), with the participation of community resource monitors in North Efate and the Vanuatu Fisheries Department (VFD), in order to inform local to national actions and management. The Toolkit has been successfully field tested to allow communities to take ownership of monitoring their marine resources. The Toolkit includes simplified versions of established monitoring methods for marine habitats and resources to achieve a balance between robust science and methods that are appropriate for communities to use. The key to its success in North Efate is that it was developed in response to communities' needs by using a participatory approach and a series of community training workshops with local environmental leaders. Uniquely, the Toolkit includes a standardised process for communities to use that monitors results instantly, and has also been delivered in Bislama language. Results from field surveys are translated directly on to data reporting posters that are used to inform community decisions on management actions in order to target key areas of concern. Furthermore, the Toolkit has been developed to link and align with government initiatives and policy, especially those of the Vanuatu Fisheries Department. By using these methods, communities are able to adapt their traditional management to address immediate and medium-term issues in their local marine environment. The observed benefits of the Toolkit include increased local awareness through community-led environmental outreach, increased ownership of and motivation for local monitoring and management, expansion of traditional tabu *(no take) areas, and new local ecotourism initiatives to generate revenue to support environmental management and climate change adaptation.*

Why is community-based monitoring important?

Marine resources are under pressure in the Pacific Islands region due to coastal development, over-exploitation, increasing human populations and demand for resources, land-based pollution and sand and coral mining (UNEP 2018). Climate change is expected to exacerbate these pressures and modify marine ecosystems throughout the Pacific Islands region, with implications for the communities that depend on them for food and livelihoods (Bell et al. 2011; Johnson et al. 2017). However, there is limited capacity within government departments in Pacific Island countries and territories (PICTs) to conduct regular or extensive monitoring, meaning that communities are a key group for identifying changes in local marine ecosystems. With simple and robust monitoring tools that link directly to management, communities become empowered to make effective and informed decisions in order to manage their marine resources and adapt to future climate change.

Developing local stakeholders' capacity to monitor marine resources has been trialled throughout PICTs with varying levels of success. Despite the immense amount of resources allocated by conservation practitioners to monitoring, often the right things are not being monitored in the right way to robustly assess the impact of conservation and management (Gurney and Darling 2017). Some of the main challenges of successful and sustainable local monitoring are poor engagement, complex methods and reliance on costly equipment and external data analysis.

In a pilot site in North Efate, Vanuatu, a marine monitoring toolkit was developed in response to community needs that aimed to address the above issues. The Toolkit provides a novel approach to community monitoring that was co-developed with community designated Marine Champions from Nguna-Pele Marine and Land Protected Area, Tasi-Vanua environmental networks representing 27 communities, and the Vanuatu Fisheries Department.

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The Toolkit supports local monitoring of marine environments to detect changes caused by human activities and natural events. Community monitoring is important as it provides regular information from many locations that is collected by people who are familiar with their environment, has the ability to support national initiatives and can:

- provide an early warning of changes or impacts (e.g. coral bleaching, crown-of-thorns starfish outbreaks, or decline in fish);
- raise awareness within communities about the condition of their marine environment;
- raise awareness about the impacts of fishing methods and gear;
- raise awareness about the range of management actions appropriate for local issues;
- empower communities to take control of local marine resource management through an inclusive and informed process; and
- determine if local management actions are effective and facilitate adaptive management.

How does the Toolkit work?

The Toolkit includes six modules that are independent of each other and communities select one or more module(s) depending on their local issues and resources: (1) fish catch surveys; (2) intertidal invertebrates; (3) reef health; (4) mangroves; (5) seagrass; and (6) crown-of-thorns starfish.

By using both qualitative and quantitative methods to monitor key local indicators of coastal habitats and resources, each module collects standardised data that is readily plotted on to a scale from nogat (none/unhealthy) to fulap (full/healthy). For each of the modules, relevant published scientific information was used as the basis for determining what is considered as a healthy or unhealthy state. Chiefs and community members of all ages are involved in the monitoring, management and review process (Figure 1). Importantly, this process also serves as an effective engagement and awareness-raising tool for communities.

The Toolkit provides information that can be used by government to inform national initiatives. For example, the catch surveys focus on subsistence catch, which fills a national (and regional) data gap, and complements national

Figure 1. Diagram of the monitoring, review and management process.

Figure 2. Some of the Vanuatu Marine Champions who are all trained in the six Toolkit modules and lead community training and monitoring sessions.

data monitoring of commercial catches. The catch surveys also focus on size data to inform community decision-making while also collecting catch per unit effort (CPUE) data that provide a long-term data set that is compatible with VFD requirements. Also, the mangrove and seagrass surveys adopt nationally used methods, and the crown-of-thorn starfish (COTS) module links directly with a current national initiative.

Importantly, the scientific basis of the data reporting outputs means that community-based monitoring can complement more technical scientific and regional monitoring that is conducted less frequently (e.g. once every three years). This multi-level involvement means that management actions are streamlined towards common goals. The key to the success of the Toolkit is the involvement of community Marine Champions in the training and delivery of monitoring methods and activities (Figure 2). Marine Champions were nominated by communities based on their demonstrated interest in environmental stewardship and prior experience in the networks as leaders or resource monitors. Keeping the Toolkit adaptive to community needs gives the Marine Champions and their communities the capacity to monitor and manage their resources without the need for external input.

What makes the Toolkit different from other monitoring?

The Toolkit is designed to be easy yet robust and to inform local to national actions, allowing communities to take ownership of all the stages of monitoring and managing their marine resources. The Toolkit has drawn on established survey methods and known species and ecosystem thresholds in order to apply standardised interpretation of monitoring results instantly, and to translate information from community surveys directly into management actions that target key local issues. This is achieved by plotting the survey results from the *nogat* to *fulap* scale on to the data reporting sheet, which is maintained as a poster in communities with pre-agreed management actions, so that results are readily available and the process is transparent (Figure 3). The data reporting sheets use the same colours as the cyclone warning colours; blue indicates no concern, yellow indicates there is a possible issue and red indicates there is an immediate issue. This means communities do not need to rely on outside experts to interpret the results, which empowers them to use the monitoring results to inform local management actions.

How does the Toolkit inform local management?

The Toolkit includes an important community meeting at the start, where everyone comes together to agree on what key local issues are to be monitored and what management actions are suitable and acceptable for their local environment if an issue is observed. If monitoring detects an issue, the community can meet again to confirm the management actions that will be implemented to address the issue. Communities can work together with provincial and national governments to ensure by-laws in the management plans are recognised and enforced. Some examples of this are shown in Figures 3 and 4. Using these methods, communities can adapt their traditional management to address growing pressures on their marine local environment, including the effects of climate change.

The Toolkit has been applied by many communities in North Efate, including as part of community conservation monitoring days and school awareness days (Figure 5). Additional benefits of this work include increased local awareness of climate change and marine issues, expansion of locally managed tabu (no take) areas, long-term recognition and importance of conservation areas and new local ecotourism initiatives for income generation to support climate change adaptation.

While the survey techniques are based on established protocols that have been used throughout the Pacific Islands region for years, the Toolkit provides easy to understand and robust methods with the ability to use monitoring results in order to directly and instantly inform local management decisions. The Toolkit methods can also complement other more technical approaches that are used in the Pacific Islands region, and are able to accommodate available existing data. The Toolkit therefore has the potential for broad application and provides relevant and appropriate methods for empowering communities in the Pacific Islands region to take affirmative and immediate action to ensure future food security and livelihoods from coastal resources.

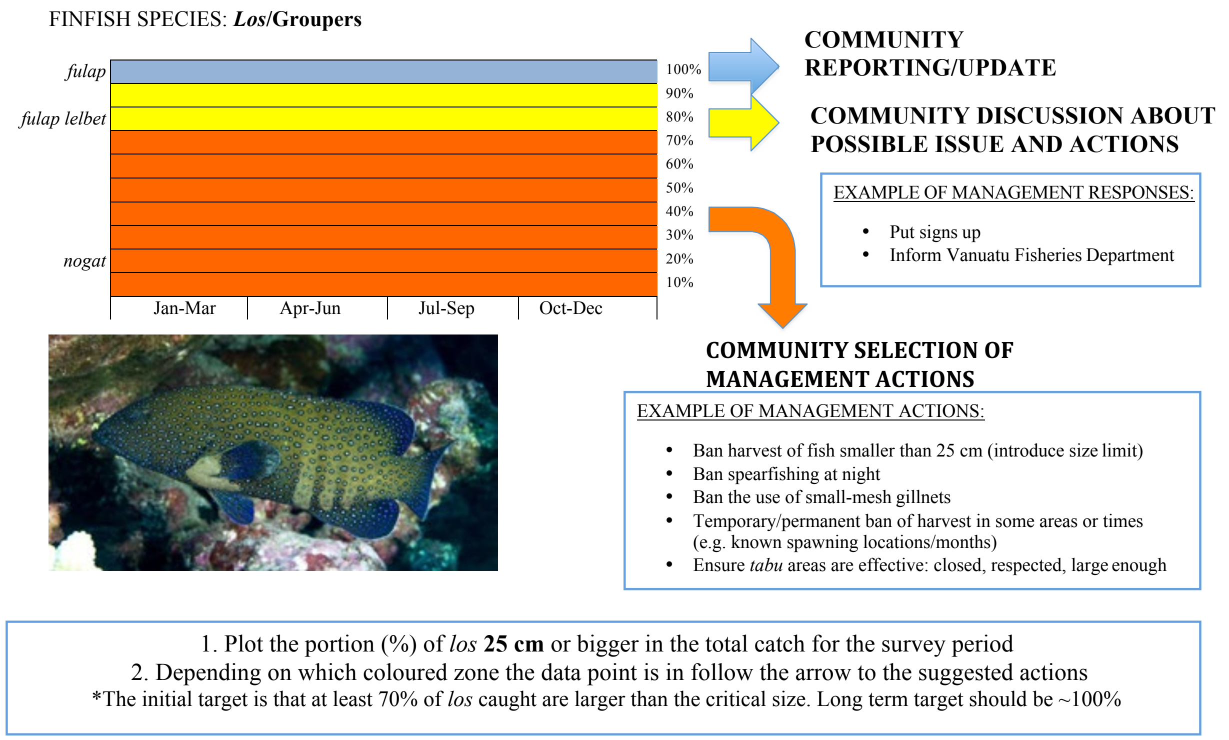

Figure 3. Data reporting posters showing the translation of *Fish Catch Survey* results (Module 1) on to a graph that includes appropriate management actions that are pre-agreed by the communities depending on the results.

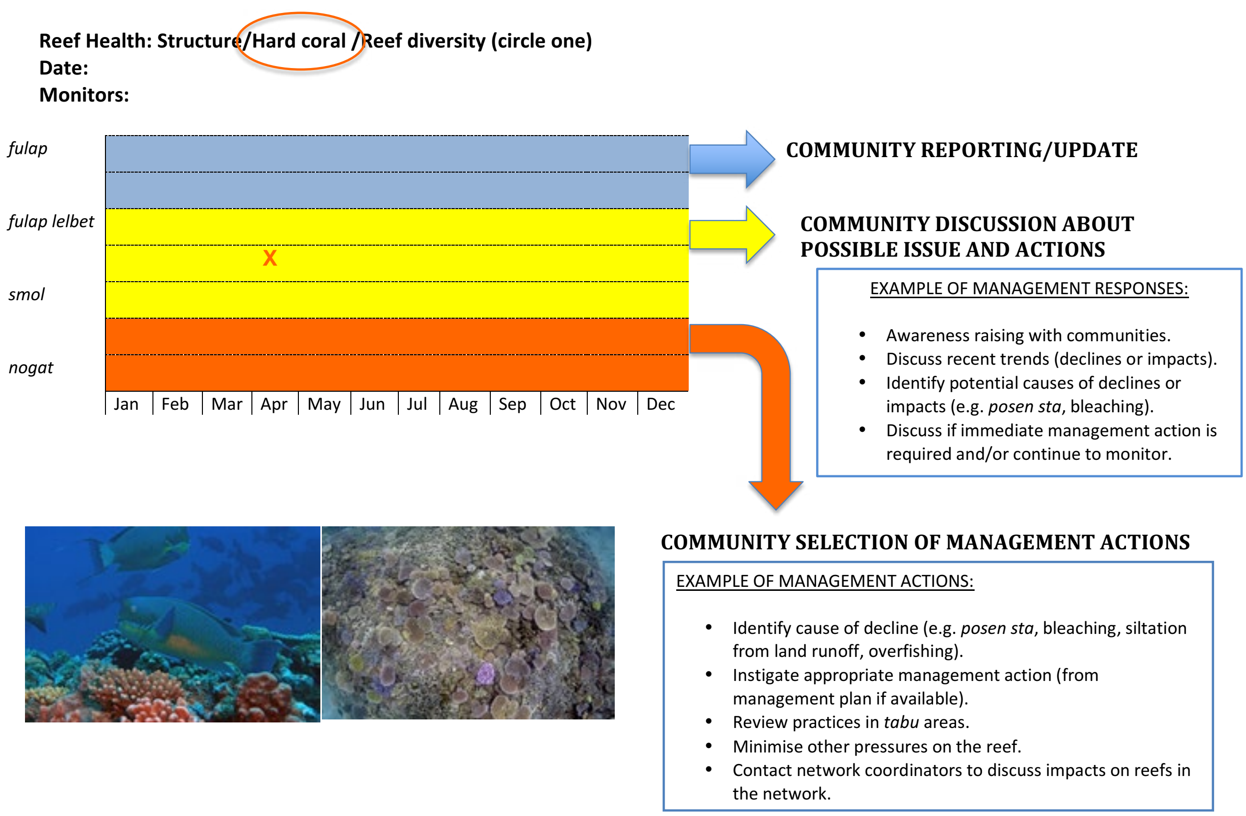

Figure 4. Data reporting posters showing the monitoring results of reef health indicators in the *Reef Health Survey* (Module 3) and how results are used instantly to identify appropriate and agreed management actions.

Figure 5. Community monitoring days demonstrating the utility of the Toolkit methods and the awareness raising benefits.

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Note

Videos about the Marine Monitoring Toolkit and testimonies from Marine Champions are available on the RESCCUE project Youtube playlist at the following link:

https://www.youtube.com/user/spcnc1

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Establishment of the Coastal Fisheries Working Group (CFWG)

Takwa market, Solomon Islands (image: Johan van der Ploeg, *WorldFish*).

In 2016, the Pacific Island Forum Leaders tasked the Pacific Community to 'coordinate with National Fisheries Agencies, CROP agencies and regional and national community groups, to strengthen support and resourcing for coastal fisheries management'. The leaders noted 'links to communities, food security, health issues and, in particular, non-communicable diseases'. Leaders also noted 'the need to ensure ecosystem integrity to address issues such as ciguatera outbreaks and to sustainably manage beche-de-mer'.

The setting up of a Coastal Fisheries Working Group (CFWG) was proposed by the SPC Fisheries, Aquaculture and Marine Ecosystems (FAME) Division in 2017 and the terms of reference were drafted and subsequently endorsed by the Forum Fisheries Committee. The intent of the CFWG is to bring together a small standalone stakeholder group of representatives of communities, national and regional agencies, donors and relevant institutions in order to look at the current and potential coastal fisheries initiatives, so as to ensure that an adequate level of support, resources and services are directed towards assisting national fisheries agencies and that local communities implement management of their coastal fisheries resources.

The CFWG's guidance on the way forward is contained in the *New Song for coastal fisheries – pathways to change: The Noumea strategy*[1] and the *Future of Fisheries: A Regional Roadmap for Sustainable Pacific Fisheries*[2], which were endorsed by Pacific Island Forum Leaders in 2015. Other national and sub-regional policies on coastal fisheries are also of relevance, including the *MSG roadmap for inshore fisheries management and sustainable development 2015–2024*[3].

The second meeting of the CFWG was held in Noumea on 18 April 2018. Participants approved the current terms of reference and commenced addressing matters of substance.

The participants of the meeting agreed to hear first from the community representatives from Solomon Islands and Nauru on the issues facing the local management of coastal fisheries in their countries. The participants then heard updates on the coastal fisheries report card[4], the Regional Technical Meeting on Coastal Fisheries that was held in December 2017[5], and other recent activities.

The work of the CFWG kicked off with an agreement on a draft work plan and activities, the approval of a task force on coastal fisheries law and policy (see p. 8 in this Newsletter), as well as collaboration on mapping activities that are linked to community-based ecosystem approaches to fisheries management in the region, developing training modules for coastal fisheries enforcement officers, and the development of key messages for the CFWG report to the Pacific Island Forum Leaders meeting to be held later in the year.

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1 http://purl.org/spc/digilib/doc/b8hvs
2 http://purl.org/spc/digilib/doc/xnc9f
3 http://purl.org/spc/digilib/doc/mgtfs
4 http://purl.org/spc/digilib/doc/i58vk
5 http://www.spc.int/fame/en/meetings/240

Coastal Fisheries Law and Policy Task Force

A Task Force on Coastal Fisheries Law and Policy was recently established under the Coastal Fisheries Working Group (CFWG)[1]*, which is coordinated by the Pacific Community (SPC). The aim of the Task Force is to advise the CFWG on options to improve the legal and policy frameworks for Pacific coastal fisheries and aquaculture management, in line with regional and global policy documents. The peculiarity of the Pacific context is the crucial role that is played by customary or traditional rights and practices related to coastal fisheries resources, as well as local tenure arrangements over inshore waters.*

Regional policy documents adopted in 2015, namely the *Future of Fisheries – A Regional Roadmap for Sustainable Pacific Fisheries*[2] and *A new song for coastal fisheries – pathways to change: The Noumea strategy*[3], highlight the need for Pacific Island countries and territories (PICTs) to have strong and up-to-date laws and policies to regulate coastal fisheries. Through these documents, PICTs have also committed to adopting policies and legislation that empower coastal communities to manage their fisheries resources by clearly defining their use rights.

These commitments are also reflected in global soft law instruments, such as the *Code of Conduct for Responsible Fisheries*[4] of 1995 and the *Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication*[5] of 2015, both endorsed by the member states of the Food and Agriculture Organization of the United Nations (FAO).

Against this backdrop, at the 47th Pacific Island Forum held in 2016, Pacific Island Leaders tasked SPC to coordinate with national fisheries agencies, regional agencies and community groups with a view to strengthening support and resourcing for coastal fisheries management. In response to this request, at its first meeting on 1 December 2017, the CFWG was established and the set-up of the Task Force on Coastal Fisheries Law and Policy was proposed. At its second meeting on 18 April 2018, the CFWG endorsed the creation of the Task Force.

Initially, the Task Force will be focusing on collecting relevant information and documentation from different sources in order to support the formulation of legal and policy advice as required by the CFWG. In particular, it will endeavour to identify constraints to the effective operation of law and policy and options to support community empowerment in coastal fisheries management in the Pacific context. It will also identify key indicators for the *Noumea strategy* outcomes, compile an inventory and repository of laws and policies, and map out the competence of different national and subnational authorities over coastal fisheries resources.

Comparing the enforceability of minimum fish size regulations to that of other types of regulations could be a piece of work to be undertaken by the Task Force (image: Ariella D'Andrea).

The Task Force is a small mix of legal and policy advisors, fisheries managers and field workers who are to be endorsed by the CFWG, and may include suitable national and international candidates. Members should be currently working in the Pacific Islands region or have significant experience in providing advice for law or policy formulation in coastal fisheries/resource management in the region. It is not intended to be a representative body but a tool for collaboration and information exchange. If you wish to help with any of the tasks and, most importantly have time to commit *pro bono*, please feel free to contact us.

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[1] See article on p. 7, this issue.
[2] http://purl.org/spc/digilib/doc/xnc9f
[3] http://purl.org/spc/digilib/doc/b8hvs
[4] http://www.fao.org/docrep/005/v9878e/v9878e00.htm
[5] http://www.fao.org/3/i4356en/I4356EN.pdf

Observer safety and new technologies discussed at the 18th Regional Observer Coordinators Workshop

Tropical Pacific region tuna fisheries observers, just like the fishers they work alongside, work hard at a job that they believe in. They live and work on-board commercial fishing boats and collect data on what is being caught and how it is being caught. Their work helps to safeguard the globally significant resources of Pacific region tuna fisheries by ensuring that they are fished sustainably.

The Western and Central Pacific Ocean (WCPO) is home to the world's largest tuna fishery and produces around 60% of the global tuna catch. There are now more than 820 active observers working across 15 observer programmes in Pacific Island countries and territories (PICTs). They act as the eyes and ears of the regulatory bodies that protect the globally significant tuna stocks of the Pacific Ocean.

In February 2018, the Forum Fisheries Agency (FFA) and the Pacific Community (SPC) held the 18th Regional Observer Coordinators Workshop (ROCW18) in Pohnphei, Federated States of Micronesia. The forum provided an opportunity for Pacific Island Regional Fisheries Observer (PIRFO) managers and coordinators to meet and discuss technical improvements, improved cooperation and to provide technical recommendations to improve regional harmonisation. Recommendations developed at the workshop will help to direct policy development throughout the Pacific Islands region.

The ROCW18 theme was *Observer Programme best practices with enhancement of observer safety and electronic monitoring and reporting*.

Observer's dual data collection and monitoring role can isolate them from the captain and crew, their only company, sometimes for months at a time, when they are on the high seas. The Western and Central Pacific Fisheries Commission (WCPFC) has identified instances of observers being assaulted, prevented from doing their job, asked not to report an incident, or denied food, water and safety gear. There have been six observers lost in the Pacific Islands region over recent years due to accidents, undisclosed medical issues that were exacerbated by working at sea and even suicide. One observer was allegedly killed by crew members, and one death remains a mystery. These incidents have all occurred since observers were given the role of monitoring the closure of fish aggregating devices, catch retention and other compliance issues.

Since the beginning of 2017, observers are all meant to be equipped with an emergency beacon and two-way communication device in order to stay in touch with their agency. This is an important first step; however, the accidental loss of an observer in 2017 resulted in the implementation of a regional regulation on observer safety with obligations in relation to search and rescue and the treatment of observers who are placed on the fishing vessels. ROCW18 recommended further requirements on this regulation to include the need for better coordination between fisheries observer programmes and search and rescue agencies.

Along with observer safety, there is currently a regional investigation into the recommendations that deal with allegations that are made by the captain and crew of a vessel of observers' behaviour. To contribute to this investigation, ROCW18 recommended a set of minimum requirements for an observer programme's code of conduct as well as formalising any allegations made by a vessel's crew members through a compulsory report on observer. This is in order to improve transparency in processes that are available for reporting observer conduct, whether it is good or bad, including processes resulting from alleged observer misconduct (i.e. investigations and subsequent outcomes).

Science-based management of tuna fisheries requires a steady flow of good data. Managers need to understand how tuna populations are changing and responding to environmental pressures and industrial fishing. The data collected by observers help scientists create a picture that is

Observer's dual data collection and monitoring role can isolate them from the crew; a situation that can become problematic when fishing trips on the high seas last for months (image: Thomas Auger).

as complete as possible on which to base management decisions. The ROCW18 recommended improvements in data flow and communication of reported critical incidents. Also of significant is that debriefing evaluations are included in the database to verify the accuracy of all data – for the users – that is collected by an observer on their trip.

Observers record everything that's brought on to a fishing boat, as well as the fate of everything that leaves it. As well as tallying target catches of tuna, they also monitor bycatch and discards. Discards are everything else that is caught and released or tossed overboard because it is the wrong kind of fish, or too small – or not even a fish at all. As well as fish, discards can include seabirds, turtles and other marine mammals.

However, observers do not simply identify, count and measure the tuna, bycatch and discards that are caught. They also record the location of the catch, weather conditions and the activity of the vessel at any time; describe the fishing gear and new technology that is being used; and collect biological data of the fish. This information helps scientists to monitor the abundance of tuna and bycatch species and helps fisheries managers to judge the way fish populations are responding to their regulations, changing environmental conditions and intense industrial scale fishing.

Over the past several years, the role, information being collected and workload of an observer has increased. Their value in collecting independent, unbiased and accurate information on fishing operations has been recognised and rewarded with an increasing list of monitoring duties. The increased workload has caused a role shift towards collecting data to support the monitoring of fishers' compliance with regional regulations, which has been to the detriment of some of the observers' more 'traditional' roles of collecting biological information. The ROCW18 noted this and recommended a shift back towards collecting biological data, which is important for assessing the status of fish stocks.

New technologies for electronic-reporting (e-reporting) and electronic-monitoring (e-monitoring) are being implemented to help with validating and strengthening the work that is already being done by observers.

E-reporting allows for the electronic entry and transmission of observer reports, ensuring real-time reporting of critical information through satellite transmissions or mobile networks. Tablets and mobile devices are gradually replacing paper workbooks, which makes the flow of data more efficient.

E-monitoring uses on-board cameras and sensors on equipment to collect data in order to verify and strengthen the data collected by observers. These systems include several still and/or video cameras and sensors that are installed on a fishing vessel to record activities and data on board, including catch, location, course, images, and speed of the vessel. There are huge opportunities to make the most of e-monitoring as a complement and to expand the coverage of human observers. E-monitoring can be placed on smaller vessels that have limited capacity to accommodate a human observer. E-monitoring can simultaneously monitor different areas of a vessel, and can operate consistently at all hours of the day.

The ROCW18 discussed the impact of new technologies on observers. They recognised that integrating e-reporting and e-monitoring into the observer programme will help to improve data collection and flow to fisheries scientists and managers. Furthermore, the ROCW18 also recommended that clear definitions, standardised collection protocols and defined verification processes of e-monitoring be made in order to avoid conflicts in the perception of the roles of e-monitoring and observers. They also recommended a comprehensive analysis to identify the potential impacts on observers, data management and the PIRFO once an e-monitoring framework has been defined. To do this, the ROCW18 recommended that paired trips using both methods should be made on longliners and the data be analysed to determine the statistically sound coverage levels required by scientists and managers.

The regional Monitoring, Control and Surveillance Working Group at FFA in the Solomon Islands subsequently endorsed the outcomes of ROCW18 in March. In May, these recommendations will be discussed by the 17 PICTs of the 106th Forum Fisheries Committee and may support the initiatives of these nations in managing fish stocks of the region.

From little things, big things grow.

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French Polynesia is 'OnBoard': implementation of an electronic logsheet application for longline fishing vessels

Captain Taura Tehahe is using the OnBoard app. on his fishing vessel *Vini Vini 9* (image: Malo Hosken).

In 2016, the Oceanic Fisheries Programme (OFP) of the Pacific Community (SPC) developed the Android application 'OnBoard'. This application allows captains of tuna longline-fishing vessels to electronically fill in and send a report of their effort and catch data, which is commonly known as the logsheet, to their fisheries authorities. The application works offline while the vessel is at sea. The data is easily transmitted once in the reach of connectivity when back in port. OnBoard data integrates with the tuna data management system TUFMAN2 that is used by all the fisheries authorities in the Pacific Island countries and territories (PICTs).

Initial field tests were successfully carried out in collaboration with a vessel captain in New Caledonia who was equipped with a ruggedised tablet and OnBoard. Regular feedback from the captain allowed SPC to improve the application.

In French Polynesia, the fisheries authorities (*Direction des Resources Marines et Minières* – DRMM) manage the activities of 61 domestic longline vessels, including the collection of vessels' logsheets.

In July 2017, in collaboration with SPC, DRMM launched a four-vessel trial. Starting the trial with only four vessels allowed DRMM staff to familiarise themselves with this new tool in order to be able to provide technical support to captains when returning from their fishing trips. The trials were carried out with success and with all four vessels submitting all their logsheets electronically during the remainder of 2017. The success of the trials is also attributed to DRMM taking sufficient time to meet and collaborate with vessels' owners and captains.

In January 2018, after the success of the first trials, DRMM decided to roll out OnBoard to the entire fleet of longline vessels; again, through a collaborative approach with the fishing industry. In March 2018, two SPC agents assisted DRMM staff in beginning the full-scale implementation.

DRMM purchased 21 tablets to this effect and signed letters of agreements with the vessel operators, which explained the conditions under which a tablet is lent to a fishing vessel for the purpose of using OnBoard. The roll out to the 21 vessels is incremental in order to ensure DRMM staff can provide timely and quality support to the new users. A third roll out will be introduced later in 2018 to finish the implementation.

So why did French Polynesia decide to implement OnBoard to its entire fleet of 61 tuna longline vessels? It comes down to major efficiency gains:

- *Efficiency of the new logsheet collection process.* With paper logsheets, it used to require significant efforts by DRMM staff members to track down the captains or vessel owners to collect the data. With OnBoard, the electronic logsheets are sent to the database system on the same day that the vessels return to port.

- *Efficiency in data quality.* OnBoard features data entry checks that ensure that captains enter data more accurately. Captains can still make mistakes, but the DRMM staff members have more time at hand to check for those mistakes, since they no longer need to transcribe the logsheet data into the database.

How did French Polynesia successfully implement OnBoard? It was essential to have a well-planned trial phase, which included good collaboration between all parties. The investment of DRMM staff time into providing quality training and support to vessel captains was likely the key ingredient of this successful implementation recipe.

Moeana Jo-Ann Pere, from DRMM, provides insight into the training and support aspect of the implementation:

> Given our experience from the trials, we held the training sessions in a comfortable location, where it was possible for the captains to concentrate and still be relatively close to their vessels. Holding the trainings on their vessels was not ideal because their owners were regularly disturbed. On average, a training session lasted one and a half or even up to two hours. During the training, it was important to pay attention to the degree of ease with which the captains used the tablet and OnBoard so that the speed and details of the training could be adjusted. It was also important to listen to the captains' questions and stories. The training also included a species identification booklet and a colour printed OnBoard's user manual. We have close relations with our captains, based on mutual respect. We don't hesitate to take time to meet with them in person as soon as they return to port. Those approaches have helped create a real feeling of ownership of the OnBoard project by the captains.

Current regulations require the submission of a hard-copy logsheet that is signed by the captain. This was a challenge in this electronic transition. To overcome this, SPC developed 'Export OnBoard' – a feature that allows one to export the electronic logsheet into a printable format. When the captains upload their electronic logsheets, they validate them through signing by using the tablet's stylus. The signature can then be transposed to the printable version.

Captain Tauraa Tehahe is widely recognised as the best offshore fisher in French Polynesia. Accustomed to electronic tools, he was eager to try this new tool that he had been hearing about. He has already submitted two logsheets since his training in March of this year and he is 'OnBoard' with this progress! He is so keen that he uses OnBoard on a tablet but has also installed it on his own smartphone. It is always good to have a backup when using electronic equipment.

In conclusion, Vaiana Joufouques who is in charge of this project at DRMM says:

> The implementation of OnBoard in French Polynesia is a major project for the country and we hope it will also have echoing effects in the region. OnBoard saves us data collection time and also allows us to integrate logsheet data with other fisheries data for making timely and informed management decisions. We are very happy to have benefited from the assistance of SPC staff during OnBoard's roll-out and we encourage our fellow member countries to consider this new tool and to create a collaborative environment to allow for its successful implementation.

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OnBoard training – Left to right: Bruno Deprez (SPC), Moeana Jo-Ann Pere (DRMM), Captain Mataiva Arai and Teremoana Taioho-Aumeran (DRMM) (image: Malo Hosken).

The aquatic biosecurity component of the 'Sustainable Pacific aquaculture development for food security and economic growth' project meets success

The New Zealand funded project 'Sustainable Pacific aquaculture development for food security and economic growth', which was implemented by the Pacific Community (SPC), was launched in June 2016. It has a specific component of aquatic biosecurity and aquatic animal health management that includes the development and update of import and export standards and requirements for live aquatic organisms and their products. The first results within the framework of the implementation of this component are becoming visible, as shown by two successful examples from Papua New Guinea (PNG) and Vanuatu, which are presented here.

Improvement of the National Quarantine Authority's capacities on aquatic biosecurity to facilitate access to the Australian market for fishery and aquaculture products from Papua New Guinea

In January 2017, the National Agriculture Inspection and Quarantine Authority (NAQIA) of Papua New Guinea requested the technical support of SPC in order to assist with the development of their capabilities in aquatic biosecurity, aquatic animal health management, and import and export standards and requirements for live aquatic animals and their products.

Thanks to the actions carried out in these matters, and through collaboration with PNG National Fisheries Authority and the Pacific Horticultural and Agricultural Market Access Program (PHAMA), the doors have been opened to possible exports of crustaceans of various species (from capture fisheries in first instances) to Australia.

In 2017, NAQIA carried out an evaluation of the sanitary status of the stocks of wild and domesticated crustaceans, based on the evaluation of pathogens of mandatory declaration for the World Organisation for Animal Health (OIE). The results of this evaluation have been extremely positive and led to the development of an epidemiological surveillance programme and strict national aquatic biosecurity measures.

Thanks to these measures, the Department of Agriculture and Water Resources of Australia has taken the decision to evaluate the possibility of importing fresh and frozen crustaceans from several fisheries export companies of PNG.


The development and implementation of an epidemiological surveillance programme in Papua New Guinea will assure a high health status of farmed and wild aquatic stocks (image: Ruth Garcia-Gomez).

If possible, it would bring great benefits for fishers, producers and exporting companies in the future. And, it already confirms the importance of NAQIA's role and responsibilities in the field of aquatic biosecurity.

This action is being completed nowadays with the development and implementation of an epidemiological surveillance programme that is based on Australian requirements.

Development of a new regulation on crustacean imports in Vanuatu

In January 2017, SPC was approached by the Vanuatu Biosecurity Agency for technical assistance in the domain of marine biosecurity.

There is only one prawn farm located in Vanuatu nowadays, which produces around 120 tonnes per year that are destined for export markets such as Europe and Japan (60–70% of production) and to the local market (30–40% of production). The Government Agency 'Biosecurity Vanuatu', under the Ministry of Agriculture, estimated important to evaluate the biosecurity hazards that may affect this activity.

During 2017 and early 2018, SPC carried out a first screening of the prawn farm, followed by an epidemiological surveillance programme for diseases of mandatory declaration for prawns. The list of diseases that were tested was based on the list that has been established by OIE.

The epidemiological surveillance programme demonstrated that Vanuatu is free of all diseases of compulsory declaration for crustaceans (OIE notifiable diseases), which gives it a great comparative advantage over other producing countries.

To protect this advantage, and, therefore, to avoid possible risks of entry of exotic crustacean diseases into the country, the National Biosecurity Agency of Vanuatu has decided to develop a new, stricter legislation on the importation of live and processed crustaceans.

While reducing possible risks of entry of exotic pathogens that are not present in the country, this legislation will probably reduce competition from imported crustaceans and, therefore, in a way, will promote and encourage the development of the local aquaculture sector.

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Prawns produced in this Vanuatu farm are free of all diseases of compulsory declaration for crustaceans (image: Ruth Garcia-Gomez).

Fiji clams on the rise again

A group of private sector and government participants gathered at the Galoa Brackish Water Research Station in Fiji from 12–24 February 2018 for training in giant clam hatchery techniques. This was the first such training to be organised by the Pacific Community (SPC) in the region since 2014 and it was delivered by the Aquaculture Section Mariculture Specialist, Michel Bermudes with the assistance of Antoine Teitelbaum, who brought his extensive technical expertise in giant clam hatchery operations. Training activities were carried out seamlessly with the assistance and collaboration of the Fiji Ministry of Fisheries staff members Saras Sharma and Babitu Rarawa.

Fiji has a long history in giant clam hatchery production with the Makogai hatchery being established in the mid-1980s and giant clam production starting in 1989, with the first mass production batch being that of *Tridacna derasa*. From 1984 to 1993, Fiji's Ministry of Fisheries took part in three Australian Centre for Agricultural research (ACIAR) projects with goals ranging from stock assessment, conservation, development of hatchery, nursery and grow-out techniques, and assessing the economic feasibility of giant clam farming in Pacific Island countries and territories (PICTs).

In Fiji, the projects resulted in a 10-year ban on the export of giant clam meat, the reintroduction of *Tridacna gigas* and *Hippopus hippopus* (which had become extinct), and in the development of hatchery and nursery techniques for mass production of clams destined for restocking in marine protected areas (MPAs). The Makogai hatchery has been in continuous operation ever since, with the main activity being to supply MPAs with juvenile clams and the export of clams to the US for the aquarium trade.

The Makogai hatchery and fisheries officers living quarters were badly damaged during Cyclone Winston in 2016. Despite the extensive damage to the facilities, Research Division staff of the Minister of Fisheries produced a batch of *T. gigas* in 2017. Some of these clams were sent to Tavarua Island later that year, which was an event that was highly publicised in Fiji and which has contributed to reenergising giant clam conservation efforts.[1]

Production at Makogai has, however, been highly disrupted since Cyclone Winston and this has caused a significant loss of momentum. The training comes at a time when the Ministry of Fisheries is in the process of rebuilding the Makogai hatchery and refreshing staff capacity to meet a growing demand for giant clam juveniles for restocking in MPAs.

Workshop activities were hands-on with daily work with clam broodstock and larvae. Participants were placed in conditions of routine hatchery production with livestock (broodstock and larvae), which was their number one priority and required all of their attention. The day generally started with observations of broodstock and larvae in order to decide on the day's planning of activities.

Participants were faced with common hatchery problems and issues for which they had to find practical and effective solutions. Examples of problems that were faced included the following:

- Sourcing of ripe broodstock. The first lot of broodstock was sourced from Serua Island and consisted of seven *Tridacna squamosa* and two *T. derasa,* all of which failed to spawn a significant amount of eggs following natural induction techniques and serotonin injections. A second batch of broodstock was obtained from Makogai including four *Tridacna noae*, five *T. squamosa* and two *T. derasa*. *T. noae* responded immediately to serotonin injections and 92 million eggs were obtained from four brooders. *T squamosa* broodstock also started spontaneously spawning following transport from Makogai. This exercise demonstrated the need to monitor and record spawning seasonality and cycles for each species, and to be prepared and able to source broodstock from different locations to obtain eggs of targeted species.
- Ciliate infestation during larval culture. The solutions discussed and implemented included daily tank draining to keep the ciliate population under control, the redesign of tank setup to keep larvae and larvae equipment furthest away from the floor as possible, and changes to protocols with larvae buckets where they are kept off the floor to prevent further contamination.

The take home messages at the end of the two-week training period were as follows:

- Understand, plan and be prepared: in particular for broodstock so that there is sufficient contingency to spawn the intended species at the right time. This is in order to be able to respond to demand by stakeholders to target certain species like *T. gigas* for clam gardens in resorts or *T. maxima* for the aquarium trade.
- Use best practice in the hatchery and nursery: adhere to simple rules (daily observations to guide decision-making, quality before quantity, keep records, etc.) and stay abreast of recent developments in the field so that hatchery and nursery operations can be optimised. Hatchery output is critical to any restocking or commercial aquarium and food production operation.

[1] See : https://www.tavarua.com/news/2017/07/10/tavaruas-giant-clam-restoration-project

- Always review current practices to implement change and incorporate new techniques. Work as a team in the process of change and consider one's own context before trying something new. Always maintain a record in order to keep track of change and how it can benefit (or sometimes not) one's own operations.

The workshop concluded on some very positive notes for the future of giant clam aquaculture for restoration. The giant clam is still an emblematic animal with so much potential for its capacity to contribute to food security and livelihoods via meat and shell products, and for the aquarium trade. While there has been extensive research that was done in the 1980s and 1990s, and the premises for the production of giant clams have not changed since (i.e. conservation, aquarium trade and food security), one can only wonder whether the significant socio-economic changes that have taken place in Fiji over the last two decades would make giant clam aquaculture for conservation and/or production for the aquarium trade or food security a more profitable proposition at community or commercial levels. The presence at the workshop of private sector operators from the aquarium trade and tourist resorts certainly indicates that giant clam seed production is still relevant and that the sector will benefit from the national planning process proposed by the Fiji Ministry of Fisheries, which is to be supported by continued development activities.

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A: Antoine Teitelbaum, from Aquarium Fish NC, manipulating broodstock sourced from Serua Island.

B: Incubation tanks being stocked with plenty of fertilised eggs after a day of successful spawning (from left to right: Babitu Rarawa: Fiji Ministry of Fisheries, Sivo Naivua: Aquarium Fish Fiji and Kuva Vatunilagi: Mago Island).

C: Vivina Baukari (Fiji Ministry of Fisheries) carrying out routine daily inspection of larvae tank.

All images by Michel Bermudes.

Solomon Islands and Timor Leste exchange knowledge in tilapia aquaculture

*A delegation made up of five officers from the Solomon Islands Ministry of Fisheries and Marine Resources (MFMR), the Mekem Strong Solomon Islands Fisheries (MSSIF) Programme and the Pacific Community (SPC) visited Timor Leste in April 2018 to examine the development of the country's Nile tilapia (*Oreochromis niloticus*) hatchery and farming systems.*

The group, which was led by Deputy Director MFMR and head of Aquaculture Division Mr James Teri, spent one week of studying the operations of a recently rehabilitated tilapia hatchery that is now producing Nile tilapia fingerlings for small scale farmers in rural Timor Leste.

The delegation was warmly welcomed by the Minister of Agriculture and Fisheries, Mr Estanislao da Silva in Dili during a courtesy visit on 9 April 2018. The Minister noted that this is not the first time that Solomon Islands and Timor Leste have found commonalities in the fisheries sector. The relationship has been cemented during Coral Triangle Initiative activities, which kicked off in 2009.

MFMR Deputy Director, Mr Teri, expressed his thanks on behalf of the Solomon Islands delegation for the invitation to visit Timor Leste and the opportunity to learn from their experience gained over the last three years since re-establishing a small-pond tilapia aquaculture industry using the improved (GIFT)[1] strain of Nile tilapia supplied by WorldFish.

Billy Meu (centre) of Solomon Islands MFMR gains some tips about fish-egg washing steps from his Timor Leste counterparts Oscar Martins (left) and Marcos Martins (right) at Gleno Tilapia Hatchery in the highlands of Timor Leste (image: Tim Pickering).

[1] Genetic improvement through selective breeding has been used for millennia on crops and livestock, but up until the 1980s, little had been done to utilise this process for farmed fish. In response to the inadequate supply of tilapia seed and the deteriorating performance of the fish in many aquaculture systems in Asia, WorldFish and partners began the Genetic Improvement of Farmed Tilapia (GIFT) project to develop a faster-growing strain of Nile tilapia (*Oreochromis niloticus*) that was suitable for both small-scale and commercial aquaculture. Source : https://www.worldfishcenter.org/content/genetically-improved-farmed-tilapia-gift

Collection of eggs by Timor Leste hatchery staff members Bendito Alve (left) and Domingos Martins (right) from the mouth brooding tilapia fish, for egg incubation and hatching in the hatchery (image: Tim Pickering).

The Timor Leste Government has re-established its Nile tilapia industry with technical support from WorldFish through a New Zealand Aid funded project (2015–2019). WorldFish officers based in the Ministry of Agriculture and Fisheries in Dili kindly hosted the Solomon Islands delegation for the duration of their visit.

After visiting the Nile Tilapia hatchery in Gleno, which is southwest of Dili, Senior Aquaculture Officer Mr Billy Meu noted that 'the challenges that Solomon Islands and Timor Leste face in terms of establishing a Tilapia farming industry are similar. The scale of production, the type of technology, the extent of aquaculture knowledge in the farming communities and even the community setting are similar to Solomon Islands'. The similarities mean that the delegation could gain a realistic view of how a planned quarantine and hatchery development will operate in Solomon Islands.

In late 2016, the Solomon Islands government cabinet approval was given for the importation of Nile tilapia by MFMR and the development of a fry production system to support rural farmers.

The New Zealand funded programme MSSIF as well as New Zealand funded programmes that are run by the Pacific Community's Fisheries Aquaculture and Marine Ecosystems (FAME) Division are currently supporting the initial stages of rollout in Solomon Islands. One of the lessons learnt from the Timor Leste visit is about how a donor model can be successfully applied in partnership with the responsible government ministry. While in Timor Leste, the Solomon Islands delegation was also able to refine and fine-tune their proposed design for the construction of a Honiara-based Nile tilapia hatchery.

The MFMR delegation returned to Solomon Islands expecting that the next stages of planning will proceed rapidly because of the new information that they can draw upon from Timor Leste. In coming years, as the Solomon Islands government hatchery begins operation, it is anticipated that further exchanges will take place between the two countries for training and capacity building purposes.

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Nadi tilapia cluster aquaculture equipment handover

Efforts are currently underway to boost tilapia production in the Western Division of Fiji Islands. The Fiji Ministry of Fisheries (MoF) and the Pacific Community (SPC) joined forces to assist a cluster of tilapia fish farmers in the Nadi district. Seven farmers from Nadi and two from Lautoka have come together to work as a group to take their fish farming activity up to a commercial level.

Four main constraints that were identified by the farmers have been slowing down their progress. The first is shortage of availability of tilapia fingerlings for pond stocking. The second is that fingerlings, when available, are often delivered as a mixture of different shapes and sizes. The third is that there is no local supplier of specialised aquaculture equipment for operation of hapa-net based breeding systems at the farm level, or for monthly pond sampling and final harvest of fish. The Fourth and final is a shortage of water to fill and maintain ponds, which is a constraint in some cases.

In the framework of the New Zealand government funded Sustainable Pacific Aquaculture project that is being implemented through SPC, the SPC Aquaculture Section worked with MoF and the farmers to prioritise actions and develop collaborative plans for the farmers in the Nadi cluster. The project has sourced specialised aquaculture equipment to assist with hapa-based tilapia fry production systems to be operated by selected farmers for distribution of fingerlings to the whole group of farmers. This includes breeding and nursing hapa that will enable production and supply of tilapia fingerlings at uniform sizes to farmers at a consistent cost. Equipment that is to be shared by the farmers in the cluster include weighing scales, cast nets and harvest nets for assisting in the sampling and harvesting of their fish stock.

Based on the production survey that was conducted last year to benchmark the current performance of the nine farmers, only 1 tonne of fish was produced between them. With the assistance provided through the NZ funded project, it is projected that this will increase to 5 tonnes of table size tilapia worth FJD 50,000 by the end of 2018.

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Tim Pickering, SPC Inland Aquaculture Adviser, hands over tilapia farming equipment to the farmers on behalf of SPC and Fiji Ministry of Fisheries in a ceremony conducted on 28 April 2018, during the Nadi Tilapia Cluster meeting hosted by the Azad Ali Farm in the hills behind Nadi, Fiji (image: SPC).

A checklist and status overview of the sharks and rays of Solomon Islands

Andrew Chin[1], Rosalie Masu[2] and Agnetha Vave-Karamui[3]

The Pacific holds a rich diversity of sharks and rays and these animals have important social, cultural and economic values. In large-scale commercial tuna fisheries, shark catch and by-catch are important issues in managing bycatch and as by-product. For some coastal small-scale fishing communities, sharks may be taken for meat and fins, and this income may be crucial to livelihoods (e.g. Vieira et al. 2017). However, sharks are also important as living tourist attractions in many Pacific countries, and shark tourism can have real and significant economic and community benefits (Brunnschweiler 2010; Vianna et al. 2012). For other communities, sharks and rays have important cultural and spiritual values that go beyond income.

In spite of these different values, scientific understanding of the Pacific's sharks and rays is still very limited. Most research has been done on the species taken in larger quantities in commercial fisheries, but there are many other important and significant species and discoveries. Some of the most commonly encountered species have recently been found to be species complexes – a group of species that may look alike but have completely different biology (Last et al. 2016). In other cases, species are being 'rediscovered' by scientists who have taken the time to engage local people who know their waters the best and know where these 'hidden' species occur (White et al. 2015). These examples highlight the need to better understand the diversity of sharks and rays in the Pacific, especially as these diversity catalogues are essential to reporting on the Convention on Biological Diversity (CBD), or for developing an FAO National Plan of Action for sharks and rays.

Shark Search Indo-Pacific (SSIP) is a new programme focused on filling this need. Launched in 2017, SSIP is slowly assembling a checklist of sharks and rays for every country in the Pacific. Each checklist is paired with a *Status Overview* which is a synthesis of the diversity, values, threats, and management aspects relating to sharks and rays in that country. SSIP is aiming to complete lists and overviews for all the PICTS by 2022 (see SPC Fisheries Newsletter Issue 151). SSIP has now published its first checklist, the Sharks and rays of the Solomon Islands.

SHARK SEARCH INDO-PACIFIC

The Shark Search Indo-Pacific programme aims to build a checklist and status overview for every country and territory in the Pacific by 2022.

Building a checklists and synthesis for the Solomon Islands

Each SSIP checklist is a desktop study that synthesizes the available information on sharks and rays for each country. To build the data for the Solomon Islands checklist, Sarah Hylton and the SSIP team dug into reference guides, scientific databases such as museum databases, fisheries databases and knowledge repositories (such as SPC and SPREP online data), as well as scientific journal articles. Given that much knowledge in the Pacific is contained in grey literature (reports and documents that aren't published as scientific papers), Sarah also used Google Scholar and Google to find information. Perhaps most importantly, each checklist and *Status Overview* is built with the help of *In-Country Partners*, people in or with experience within each country that help provide useful data, but also check the checklists and *Status Overview* to ensure they are accurate. For the Solomon Islands checklist, this included eleven different in-country partners including government officers, scientists, and also tourism operators who provided photographs and resort checklists to add to the data. SSIP also includes citizen science where fishers and SCUBA divers are invited to send photos of the sharks and rays and these photos provide important visual verification of different species, especially those species that aren't captured in fisheries. Data also came from some usual sources, like footage from National Geographic of the Kavachi underwater volcano that showed several species such as the sixgill stingray (*Hexatrygon bickelii*) and the southern

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[3] Solomon Islands Ministry of Environment, Climate Change, Disaster Management and Meteorology

Kuhl's devil ray *Mobula kuhlii* photographed by Andrew Short from Maravagi Bay, Mangalonga Island. Andrew was diving aboard the live-aboard vessel Bilikiki in September 2017 and kindly sent SSIP several photos of these species.

sleeper shark (*Somniosus antarcticus*). Furthermore a historical photo provided by local contacts provided for the presences at one time of the dwarf sawfish (*Pristis clavata*), representing a global range extension for the species.

The Solomon Islands checklist now includes 50 species of sharks and rays of which 36 are confirmed species, seven are provisionally confirmed (species that may need taxonomic revision); and seven are 'likely' but need to be confirmed (Hylton et al. 2017). Fishing appears to be the main threat to Solomon Islands sharks and rays but there could also be impacts from habitat loss. Sharks and rays also have social and cultural values, but these vary widely across the Solomon Islands archipelago.

This checklist and *Status Overview* provide an important reference account for the Solomon Islands because they provide a systematic review and reference point.

This information is important for Solomon Islands, especially in national functions of both the Ministry of Fisheries and Marine Resources (MFMR) and the Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM).

This information can assist programs for shark identification, research, conservation and management programs of both Agencies. These programs and efforts include:

- National Observer Program which records shark interactions and shark bycatches from purse seine and longline fishing vessels. Observers' onboard tuna fishing vessels complete these records during fishing, port samplings and transshipment in port. This is a reporting requirement under the Western and Central Pacific Fisheries Commission as part of on-going shark conservation measures.
- Convention of International Trade of Endangered Flora and Fauna Species (CITES) – Appendix II shark species require export/import trading permits and must be verified and checked by both Agencies.
- Improved Shark research – future shark research can build on these data and information to inform protection and management measures such as the elimination of finning of pelagic sharks.
- Biodiversity Conservation programs – These records are an update of sharks' biodiversity in country and can guide efforts in establishing of national marine protected areas for protection of sharks from targeted fishing (local).

- Illegal, Unregulated and Unreported (IUU) – The Solomon Islands' Monitoring Compliance and Surveillance (MCS) program will also benefit from this information, as this will become a hand-on-guide for accurately recording sharks and curb any illegal, unregulated and unreported (IUU) activities. There is currently strong enforcement underway nationally in implementing the Fisheries Management Act 2015, Fisheries Management Regulations 2017 and National Plan of Action for Sharks that is currently near finalization. These national efforts contribute to both regional and international effort to protect and conserve sharks and IUU efforts.

Other sectors such as Tourism will also benefit from this information. Sharks are amongst many other national attractions for both local and international divers. Artisanal and recreational fishers will also find this information useful.

This information is useful for public awareness and schools. This can be integrated into the different school curricula, primary, secondary, tertiary schools, in and around Solomon Islands. An appreciation of the wealth and biodiversity of the country's ocean is a national goal.

To make sure that this information is always available, all SSIP publications will be made available as *Open Access* articles that can be downloaded by anyone for free from the SSIP Website, and the Solomon Islands synthesis paper and status overview are already available (see https://www.sharksearch-indopacific.org/solomon-islands). However, the checklist and webpages are not static – they will be updated as new information is provided. This is essential. For example, within months of the paper and checklist being published, the SSIP team received a photo of *Mobula Kuhlii* from Andrew Short who was on a dive trip in the Solomon Islands. This photo provides hard evidence that this species exists in the Solomon Islands, and thus the checklist has had one more species added, bringing the Solomon Island's total to 51 sharks and rays. As more checklists are built and more photos are accumulated, we envisage that the number of sharks known in each country will slowly grow.

While the Solomon Islands checklist and status overview are valuable reference points, it is important to remember that they are largely desktop studies. Several species are still only considered as 'Likely' or 'Provisionally confirmed', and without more extensive field studies in the Solomon Islands, this list and overview should be considered only as a starting point. Given that the checklist has already had species added within months of its publication, it is clear that more work needs to be done to properly describe and account for the sharks and rays of the Solomon Islands.

As for the rest of the Pacific, SSIP has draft checklists and overviews prepared for Fiji, French Polynesia, Tuvalu, and Niue, with working continuing on checklists. In 2018, the programme is planning checklists and overviews for Palau, Kiribati, Singapore and Tonga. SSIP is actively interested in locating more in-country partners for these countries, so if you are working in, or have data or expertise for these countries, please contact us at:

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Boat fuel consumption by sea cucumber fishers: new study raises concern

Sea cucumber fishers can earn substantial incomes from harvesting these animals, but what is the environmental cost of their fuel consumption to access fishing grounds? A new study conducted in Fiji before the sea cucumber fishery closure shows that fishers were earning, on average, about USD 4000 per year from sea cucumbers. But their annual fuel consumption averaged more than 400 litres each, equating to around 8000 tonnes of greenhouse gases for all fishers across the fishery. Longer trips to access sea cucumbers on distant reefs and the use of scuba gears worsen the ecological footprint. The study's findings offer insights to managing sea cucumber fisheries at a critical time when Pacific Islands are campaigning for action on climate change.

Sea cucumber fisheries throughout the tropics are dominated by artisanal fishers using small boats and simple fishing gears. But does this mean that fishing is not lucrative, or that their collective use of fuel for outboard motors is insignificant?

A study from eight locations in Fiji was recently published in the *ICES Journal of Marine Science* and sheds new light on artisanal fishers (Purcell et al. 2018). Through funding from the Australian Centre for International Agricultural Research (ACIAR), the study interviewed 235 sea cucumber fishers in Fiji during 2014, before the cessation of exemptions on the use of scuba gears and before the eventual closure of the fishery.

Sea cucumbers are known to be a valuable resource for Pacific Island fishers, but few studies have actually presented data on their incomes. The recent study showed that fishing and selling sea cucumbers provided fishers with an average net income of FJD 8171 per year. Net income of women fishers was less than half of that of men, which is attributed to a range of factors. Apart from gendered variation in the net income of sea cucumber fishers, the study also showed that fishing income tended to decline with age of the fishers. Also, fishers with multiple income sources depended on sea cucumbers for a much lower proportion of their total income – so livelihood diversification should help fishers to reduce their dependency on the resource.

We gained data on fuel use by asking each fisher how much fuel they consumed on their last sea cucumber fishing trip, how many fishers shared that fuel cost and how often they went fishing. Fuel consumption differed greatly among sea cucumber fishers and locations. Nonetheless, the average fuel consumption to travel to and from fishing grounds was 428 L per fisher, per year. On average, sea cucumber fishers each spent FJD 3774 per year on boat fuel, which constitutes 28% of their average gross income.

We converted the fuel consumption to carbon emission equivalents using universal conversion rates for petrol. Estimates from experienced exporters indicated that there were around 8000 sea cucumber fishers in Fiji during the 2014–2016 period. Extrapolating the average carbon dioxide (CO_2) emissions per fishers yielded an annual estimate of 8050 metric tonnes of CO_2 from boat fuel for the entire sea cucumber fishery. This estimate does not even take into account the carbon emissions from compressors to fill scuba tanks, wood and fuel used to cook sea cucumbers, and the land transport that is used to trade the products. The most striking finding was that this level of carbon emissions was

Village fishers in Fiji in a boat loaded with scuba tanks before heading off to distant fishing grounds in search of sea cucumbers (image: S.W. Purcell).

greater than many industrial fisheries throughout the world. The large 'ecological footprint' of Fiji's sea cucumber fishery is attributed to the fact that the thousands of fishers were making daily trips back and forth to fishing grounds in relatively fuel-inefficient boats.

We also found that men fishers had a greater fuel use compared with women fishers. Women fishers used 33% less fuel than men when colleting sea cucumbers via breath-hold diving because they tend to collect the animals at nearby sites. Women also tended to use gleaning (collection by walking on reef flats) more often than men and they were rarely engage in scuba diving. Therefore, female fishers were more economical than men, in terms of fuel usage.

Insights for fishery managers

The study's findings indicate that resource managers should promote and provide enabling environments for fishers in order for them to depend on a wide variety of livelihood sources. In doing so, fishers will be less dependent on the sea cucumber fishing and less likely to have to keep exploiting wild stocks when the populations are diminished.

The study also shows that some small-scale fisheries can be significant contributors of carbon emissions into the atmosphere. This means that even artisanal fisheries can have a large ecological footprint. The result is germane in current times, when Pacific Island governments are campaigning on the international stage for action on carbon emissions in order to reduce climate change impacts on rising sea levels and coral bleaching on reefs. So what can be done?

We suggested three potential responses by fishery managers:

1. Prohibit fishing methods that contribute greatly to carbon emissions. In sea cucumber fisheries, bans on the use of scuba gear and limits on using large boat motors would be strategies to consider.

2. Design fishery regulations and development initiatives in such a way to promote women in fisheries, since their fishing strategies tend to have a much lower ecological footprint than those of men.

3. Intervene with much more conservative fishing regulations much earlier, before wild stocks become too scarce. This will help to make fisheries more economical and avoid the scenario of fishers needing to travel far from villages in order to find reefs with decent stocks of sea cucumbers.

Women fishers on Taveuni, Fiji, with a bag full of sea cucumbers collected by way of snorkelling on a shallow reef flat near the village (image: S.W. Purcell).

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Not all tuna are equals in terms of mercury: location matters

Francisco Blaha[1]

*One of the questions I get asked quite often refers to the 'dangers' of mercury (Hg) when eating pelagic fish – particularly tuna. A lot about this issue has been mentioned in social media and the news, and it seems to be a topic that never ends. So I was interested to read an recent article that states in the title Mercury levels of yellowfin tuna (*Thunnus albacares*) are associated with capture location*[2].

Before writing about the impact of mercury in human health, it is important to clear up the basics: methylmercury (MeHg – which is the form of mercury mostly found in organisms) is naturally produced in the ocean from mercury sources that can be natural (e.g., volcanism) or anthropogenic activity (e.g., industry, gold mining, coal burning, etc.).

The key issue with mercury is that it bio-accumulates when in the form of MeHg, which means that the older and the higher-up in the trophic chain (who eats who) that an organism is, the higher the potential levels of MeHg will be. Furthermore, different groups of 'fish' have different capacities to metabolise MeHg (i.e. get rid of it naturally). Sharks, for example, have a very low capacity to metabolise MeHg. Therefore, as they are also apex (at the top) predators, their Hg levels are found in higher concentrations than, for example, in tunas that have better ways of dealing with it. Finally, depth is an important parameter to take into account, as MeHg in the ocean is at its maximum at depths of about 400 m. The deeper an organism feeds, the higher the chance it will be exposed to prey that exhibits a high levels of MeHg, which impacts its own levels.

To make things more complicated, human exposure plays a big role (i.e., the quantity of fish you eat per day or week). In simple words, if a person ate a 100 kg shark, which has MeHg levels way above the recommended maximum, by themselves in one sitting, not much would happen (beyond indigestion!); yet if an individual ate 200 g of shark meat with the same very high levels of MeHg, every day for 20 years, chances are they will be in trouble.

The first confirmation and quantification of the neurological impacts of mercury were demonstrated by the Minamata case – an environmental disaster that occurred in Japan in the 1950s. Mercury in the effluent from an industrial plant was dumped into the Minamata Bay area and contaminated the aquatic environment and local people, whose diet was mostly based on seafood from these waters, which led to severe health effects.

Yet this was an extreme case and most of the tuna that we consume today is at a safe level (because many of the big – ergo older – ones have been fished already, but that is another fisheries issue) and furthermore, our diet is not just based on tuna.

Offloading a large yellowfin tuna for processing, Fiji (image: Francisco Blaha).

The demonstrated benefits of including seafood in the diet outweigh the potential risks that are associated with it. This was researched in a huge study and consultation by FAO (Food and Agriculture Organization of the United Nations)

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[2] See https://www.sciencedirect.com/science/article/pii/S0269749117308850

and WHO (World Health Organization) in 2010[3], thereby, is not a conspiracy of the seafood industry!

One of my mentors at FAO, David James, wrote a seminal book on the risks and benefits of seafood consumption[4] (it is not too big and is a 'must read'). In his conclusions section, he wrote:

> … an analysis leaves in no doubt the conclusion that the benefits of seafood consumption vastly exceed the risks, except under extreme circumstances involving excessive consumption of a few species.

And, he added:

> When comparing the benefits of LC ω -3 PUFAs with the risks of methylmercury among women of childbearing age, maternal fish consumption lowers the risk of suboptimal neurodevelopment in their offspring compared with the offspring of women not eating fish in most circumstances evaluated.

Now, back to the paper that I was referring to at the beginning of this article, there is another reason to insist (and pay) for provenance and traceability. It looks like tuna caught in

The French Research Institute for Development (IRD) and the Pacific Community (SPC) are investigating mercury levels in tuna in deeper details in the Pacific Ocean

Working in collaboration, these two research institutions are investigating the mercury contamination in several species of tuna in the western and central Pacific Ocean (Project VACOPA funded by France through The Pacific Fund). Based on samples collected by observer programmes of the Pacific Ocean, and stored in the Tuna Tissue Bank managed by the Pacific Community (SPC), IRD has processed more than 1000 mercury analyses of yellowfin, bigeye and albacore tuna in the past few years (see Figure 1). Results of the study demonstrated that contamination varied with the species and the size of the specimens, and presented high differences according to the sampling area (e.g., central versus southwest Pacific). This work is under revision for scientific publication and detailed results cannot yet be provided; but an article in a future issue of the SPC Fisheries Newsletter will detail the findings of the study, as soon as possible.

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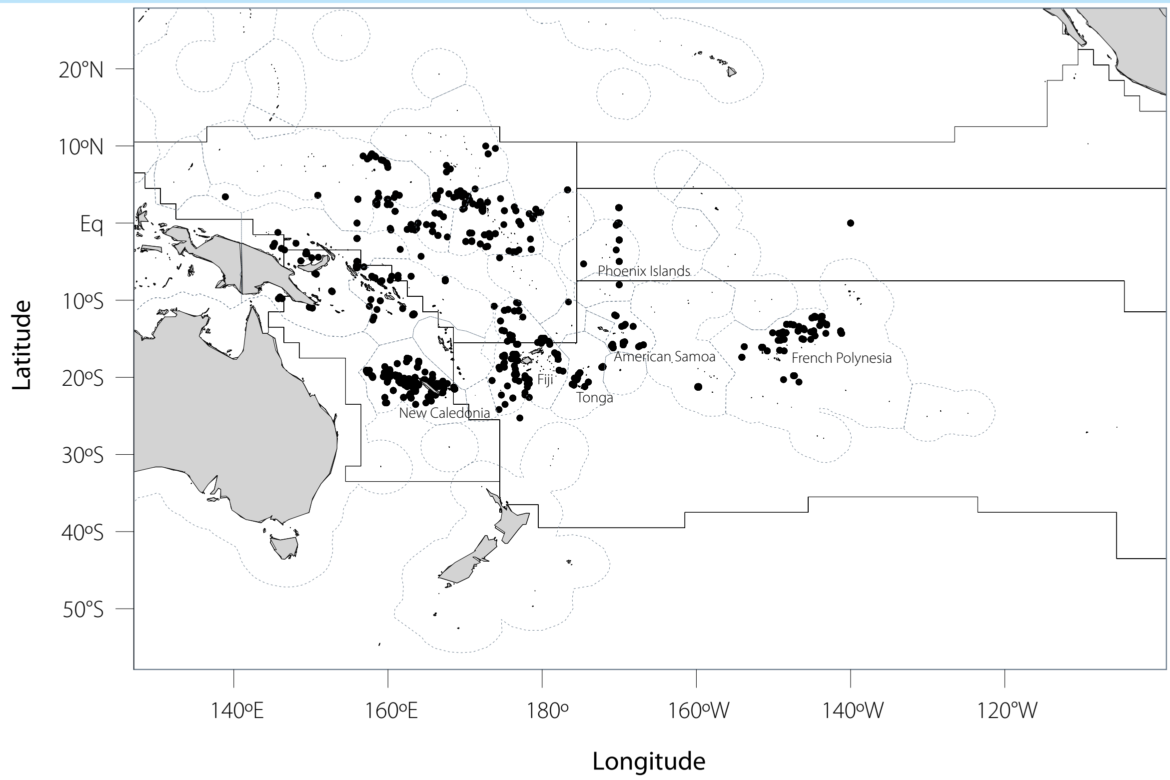


Figure 1. Map showing the 1000 tuna muscle samples analysed by the VACOPA project.

[3] See http://www.fao.org/docrep/014/ba0136e/ba0136e00.pdf
[4] See http://www.fao.org/3/a-bb211e.pdf

different parts of the world have different levels of MeHg, which in principle should not be a surprise since the main source of inorganic mercury to the ocean is through atmospheric deposition, and anthropogenic emissions are considered to be higher in the northern hemisphere.

Furthermore, as testing for mercury is expensive, regulated and needs an independently certifiable structure of determinations, it represents a huge expense for Pacific Island countries and territories since samples need to be sent to one of the following: Australia, New Zealand, Europe, Thailand or Singapore (hence think about the logistics of sending frozen samples!). The lab capacity was available at the University of the South Pacific in Fiji, but certification costs were outrageous for the level of samples required.

This paper is good news, as it gives us, in the Pacific region, the chance to confirm something we knew: our yellowfin tuna has low levels of mercury. And, more importantly, this could argue for a possible reduction in the frequency of sampling and therefore the costs for the battled seafood safety Competent Authorities in the region.

The paper highlights are as follows:

- Mercury levels of 117 wild yellowfin tuna, a commercially important species caught worldwide, were measured.
- Fish were captured from 12 known locations around the globe, representing four major yellowfin stocks.
- Geographic origin is an important factor that determines mercury levels in yellowfin of similar size.
- Low mercury fish clusters were found and argue for traceability as a tool to reduce human mercury exposure.

And the abstract says the following:

> Current fish consumption advisories focus on minimizing the risk posed by the species that are most likely to have high levels of mercury. Less accounted for is the variation within species and the potential role of the geographic origin of a fish in determining its mercury level. Here we surveyed the mercury levels in 117 yellowfin tuna caught from 12 different locations worldwide. Our results indicated significant variation in yellowfin tuna methylmercury load, with levels that ranged from 0.03 to 0.82 μg/g wet weight across individual fish. Mean mercury levels were only weakly associated with fish size ($R^2 < 0.1461$) or lipid content ($R^2 < 0.00007$) but varied significantly, by a factor of 8, between sites. The results indicate that the geographic origin of fish can govern mercury load, and argue for better traceability of fish to improve the accuracy of exposure risk predictions.

Fisheries of the Pacific Islands: Regional and national information

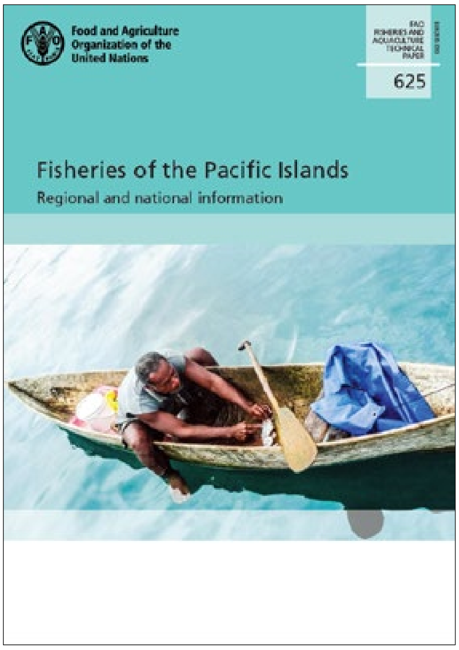
Mele Ikatonga Tauati[1] and Robert Gillett[2]

The Food and Agriculture Organization of the United Nations (FAO) Subregional Office for the Pacific Islands, has published a new book entitled the Fisheries of the Pacific Islands: Regional and national information.

The publication consolidates a variety of sources of information into a single coherent review in order to provide a quick and general understanding of the status of fisheries and aquaculture in the Pacific Islands region. It is an update of the 2011 FAO publication '*Fisheries of the Pacific Islands: Regional and national information*' by Robert Gillett and the 2010 FAO online fishery and aquaculture country profiles for the 14 independent Pacific Island countries.

The 400-page book consists of two main parts: a regional overview, and the updated fisheries and aquaculture country profiles for the 14 independent Pacific Island countries:

- The regional chapter describes the region's two main categories of fishery resources: oceanic and coastal or inshore, the status of the resources, and the fisheries management that occurs.
- Each country profile reports on data that are mainly from 2014 and provide an overview of the following:
  - General geographic and main fisheries economic indicators, including a summary of fisheries statistics reported to FAO.
  - Production sectors.
  - Post-harvest sectors.
  - Socio-economic contribution of the fishery sector.
  - Trends, issues and developments.
  - Institutional framework.
  - Legal framework.



The updated country profiles will be available online from: http://www.fao.org/fishery/countryprofiles/search/en

The updated publication has been published under the following reference and is available online as a PDF file[3]:

Gillett R. and Tauati M.I. 2018. Fisheries in the Pacific. Regional and national information, FAO Fisheries and Aquaculture Technical Paper No. 625. Apia, FAO.

1 FAO Subregional Office for the Pacific Islands, Apia, Samoa.
2 Gillett, Preston and Associates, PO Box 3344, Lami, Fiji.
3 http://www.fao.org/3/i9297en/I9297EN.pdf

Economic and other benefits of enforcing size limits in Melanesian sea cucumber fisheries

Steven Lee[1], Hugh Govan[2], Matthias Wolff[3], Steven Purcell[4]

Abstract

Melanesian countries have made recent progress in developing sea cucumber fishery management systems including tools such as species-specific minimum legal size limits. Despite a consensus among the scientific community that size limits are a vital management tool, decision-makers, fishers and traders might not fully appreciate the benefits of minimum size limits. Consequently, compliance and enforcement is often weak. It is relatively clear that any increase in the length of time sea cucumbers are allowed to grow increases the chances of reproductive success and prolongs their beneficial impacts on the ecosystem; however, the economic benefits of doing so are not so straightforward. This study modelled the economic benefits of imposing and strictly enforcing science-based minimum size limits in sea cucumber fisheries. Four high-value species *Thelenota ananas, Holothuria scabra, H. fuscogilva, H. whitmaei* were investigated, using size limits that have been recently agreed upon by the Melanesian Spearhead Group (MSG), and size distribution samples from recent export data from Fiji and Vanuatu. Our analysis found that if minimum legal size limits were enforced, the entire long-term harvest of some species could increase by up to 97% and generate up to 144% more revenue. In other words, fishers and governments lose significant revenue by not strictly enforcing size limits. This economic loss reinforces the importance of enforcing strict science-based size limits in sea cucumber fisheries.

Introduction

Many coastal and island communities of Pacific Island countries and territories (PICTs) have generated considerable income from sea cucumber fisheries over the last two centuries (Turbet 1942; Russell 1970; Ward 1972). The sea cucumber fisheries of Melanesian Spearhead Group (MSG) countries (Papua New Guinea, Solomon Islands, Vanuatu, New Caledonia and Fiji) have traditionally supplied the majority of exports from the Pacific Islands region (Govan 2018). Furthermore, Melanesia's sea cucumber fishery is reputedly the second-most valuable export fishery in that region, after tuna (Pakoa et al. 2013; Léopold 2016; Govan et al. 2018). The animals are almost exclusively exported in the processed form known as beche-de-mer (BdM).

Growing demand from Asian markets, particularly China, has fuelled a rapid expansion of sea cucumber fisheries throughout the region in recent decades (Purcell et al. 2013; Eriksson et al. 2015). However, development and adaptation of management systems of these fisheries have been outpaced by the rate of exploitation. Consequently, most, if not all, sea cucumber stocks of PICTs have been overexploited (Carleton et al. 2013; Purcell et al. 2014). In response to population collapses caused by overfishing, many PICTs have imposed moratoria to allow stocks to recover that are alternated with short fishing seasons. Although some form of periodic exploitation cycle has characterised the fishery since it began in the early 1800s (Kinch et al. 2008), recently, the loss of production caused by over-exploitation has been equated with substantial economic loss to fishers and national export tariffs (Carleton et al. 2013).

Over the last five years, Melanesian countries have made progress on developing sea cucumber fishery management systems (Govan 2018). Their management plans – along with the improvements in staffing and/or technical capacity, which are evident in fisheries agencies – provide the basis for improving the sustainability of the fisheries and increasing revenue for fishers and national coffers.

As part of these management systems, three Melanesian countries (Papua New Guinea, Solomon Islands and Vanuatu) recently introduced national sea cucumber fishery management plans (Govan 2018). However, the enforcement of the two main management tools, i.e. catch quotas and minimum legal size limits, has been extremely poor (Govan 2018). When exports have been sampled, a considerable proportion of the animals were found to be under the minimum legal size. For example, in Vanuatu, Léopold (2016) found that 83% of BdM exports in 2015–2016 were under the national legal size limit. In Fiji, 31% of exports were found to be below the current minimum legal dry size limit (Tabunakawai-Vakalalabure et al. 2017). If the best

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available size-at-maturity data from countries in the region (Papua New Guinea, Solomon Islands, New Caledonia and Australia) calculated by Tabunakawai-Vakalalabure et al. (2017) are used then 67% of Fiji's exports would be immature specimens.

Minimum size limits (MSLs) provide a powerful and relatively easy tool for managing sea cucumber fisheries (Friedman et al. 2008; Purcell 2010). MSLs set that are well above the estimated size-at-maturity can ensure that animals are able to reproduce before entering the fishery – improving the fishery's sustainability, and possibly increasing revenue as well (Pakoa et al. 2013; Léopold 2016; Purcell et al. 2018). Furthermore, sea cucumbers fulfil important ecosystem functions (Purcell et al. 2016a; Lee et al. 2017). Allowing these animals to reach MSL means they perform their ecosystem roles for a longer period of time. MSG countries recently agreed that common MSLs should be implemented in future management plans (Govan et al. 2018) based on those proposed by Tabunakawai-Vakalalabure et al. (2017).

Although MSG countries have made some progress towards managing their sea cucumber fisheries, gaining political and public support for fishery management interventions remains a challenge. If enforcing science-based MSLs could increase revenue from the fishery it should provide a strong impetus for the political will to enforce these measures and improve the likelihood of public compliance. It could also provide the opportunity to recover enforcement costs. The purpose of this study was to estimate the potential changes in stock biomass and revenue for four species of harvested sea cucumber (*Thelenota ananas; Holothuria scabra; Holothuria fuscogilva; Holothuria whitmaei*) if MSLs were enforced, and compare the resulting revenue and biomass to actual exports.

Modelling methods

Full details of the modelling methods are provided in Annex 1. Biological parameters to estimate growth of the animals to a given size were based on the best conservative estimates from published studies.

Essentially the model did three things:

1. Calculated the time it takes for a sea cucumber to grow to MSL
2. Calculated the number of animals that would survive during the time taken to grow to MSL
3. Calculated the biomass and value (yield) of the surviving animals (survivors) that have reached MSL

The yield of survivors, and the yield of the animals already >MSL were added together to determine the yield of the entire harvest if MSLs were enforced. This was then compared with the estimated yield of the current situation in which MSLs are inadequately enforced – i.e. the length-frequency of BdM reported in Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016).

The authors note that the modelling method used in this paper has been simplified and restricted to only four species, which is due to the scarcity of available data. As new and reliable data become available, this work should be built upon and refined. Similar research is encouraged, since investigating economic returns brought about by fisheries management tools/schemes can provide tangible results that are useful for policy makers.

Results

Table 1 summarises the undersized portion of samples reported by Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016) for Fiji and Vanuatu, respectively, using the MSG-agreed MSLs. Figure 1 illustrates the differences in biomass and revenue of the entire harvest between the current situation in which MSLs are inadequately enforced and if MSLs were adequately enforced.

If MSLs were enforced, the biomass from the entire harvest of the four species would have been between 8–69% greater for Fiji, and 1–97% greater for Vanuatu. Likewise, revenue from the entire harvest of the four species would have been between 12–111% greater for Fiji, and 2–144% greater for Vanuatu.

Table 1. Portion of the sample reported by Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016) – Fiji and Vanuatu, respectively – that were undersized compared to agreed MSG minimum size limits (Govan et al. 2018).

Species	Dry size limit	Percentage of sample undersized	
		Fiji	Vanuatu
Thelenota ananas (prickly redfish)	15 cm	39 %	72 %
Holothuria scabra (sandfish)	10 cm	93 %	25 %
H. fuscogilva (white teatfish)	15 cm	45 %	30 %
H. whitmaei (black teatfish)	15 cm	n.a.	94 %
		Mean: 57 %	

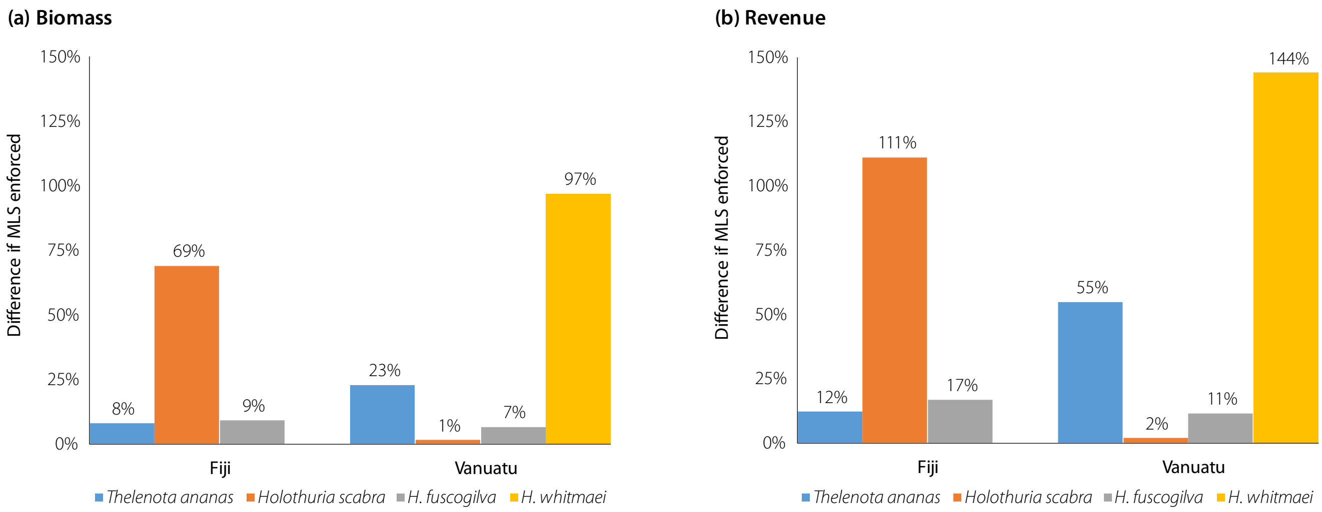

Figure 1. Difference in biomass (a) and revenue (b) of the entire BdM harvest if MSG MSLs were applied and enforced compared to the current practice. Expressed as a percentage of the biomass and revenue from the entire sample reported in Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016).

Discussion

If all four species had been harvested at their respective MSLs, immediate landings of small sea cucumbers would have stopped, which represents approximately 57% of the entire harvest (Table 1). However, if these undersized animals had been left in the sea longer to grow to MSL before being harvested, some would have been lost to natural mortality, but the surviving cohort would have gained up to 91% more biomass and consequently become worth up to 144% more (Figure 1). For all species tested, the results represent a greater yield in terms of biomass and value from the entire harvest than the returns of the current practice.

The improved yield is the product of two factors: 1) increased biomass due to growth outweighing the biomass loss through natural mortality had the animals been left longer in the sea, and 2) the general trend of larger sea cucumbers commanding higher prices (Purcell 2014; Purcell et al. 2018).

While this study looked at size limits as one management measure, decision-makers should also be aware that fisheries will need other regulations and better enforcement in order to become sustainable. Several fishery researchers have concluded that sea cucumber fisheries should also be regulated by short fishing seasons and/or limiting the number of fisher licences, shortlists of permissible species (rather than bans on certain species), and bans on the use of underwater breathing apparatus (UBA). In the case of size limits, better enforcement should entail more frequent inspections of sea cucumbers at processing and export stations, and strict penalties.

For the four species investigated, countries could expect more sustained export volumes of higher-value specimens, and higher economic returns from their respective

The price per kilo of these undersized beches-de-mer would have more than doubled if they had been left long enough in the sea to reach their size-at-maturity (image: Ian Bertram).

sea cucumber fisheries if science-based MLSs are adopted and enforced. Currently, all of the MSG sea cucumber fisheries have followed a process of opening the fishery then closing by moratorium. For fisheries currently under a moratorium, there are unlikely to be any shortfalls in landings from imposing the recommended minimum size limits if the fisheries re-open with the new size limits in place. This will require a public awareness campaign to ensure that fishers are aware of new size limits and the incentives of leaving undersized sea cucumbers to grow to a legal market size, as well as restricting legal market outlets for undersized sea cucumber products.

These findings support the MSG's recent adoption of more stringent MSLs, and suggest that the enforcement of these MSLs are not only beneficial but costs could be recovered if a proportion of the increased value can be captured (e.g. through taxes). Furthermore, these economic benefits do not take into account the increased reproductive capacity afforded by only harvesting adults of the population that have had an opportunity to spawn or the ecological benefits of leaving animals to perform their ecosystem function for an increased period of time (Purcell et al. 2016a; Lee et al. 2017).

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Annex 1. The model

Four species were studied: *Thelenota ananas*, *Holothuria scabra*, *Holothuria fuscogilva*, and *Holothuria whitmaei*. These were selected as they are commercially harvested for the beche-de-mer (BdM) trade and have sufficient life-history data available for modelling.

Total sea cucumber biomass change is dependent on growth (*K*) and natural mortality (*M*). The model presented does not consider migration as studies have shown that sea cucumbers are mobile within a limited range (e.g. Purcell et al. 2016). Under the enforced MSL situation, fishing mortality (*F*) for animals below minimum legal size (MSL) is zero ($F = 0$) as is their exploitation rate ($E = 0$)[1] and for animals >MSL all mortality is due to fishing and $E = 1$; i.e. all animals <MSL are not fished or exploited and all animals >MSL are captured as it is probable that fishers would hardly ever leave any accessible specimens >MSL unharvested.

Two sets of values for *K* and *M* are used:

- *Deep water*: $K = 0.09$ and $M = 0.125$
- *Shallow water*: $K = 0.18$ and $M = 0.25$

Deep water values were based on recent studies (e.g. Uthicke et al. 2002, 2004; and Purcell et al. 2016) and discussions (S. Uthicke and S. Purcell *pers. comm.*). *Shallow water* values were calculated by doubling the *deep water* values. *Deep water* values result in slow growth and low natural mortality; *shallow water* values result in a faster growth rate but higher natural mortality.

Recent research suggests that many species of sea cucumbers are slower growing, longer lived, and have lower rates of natural mortality than previous research has indicated (Purcell et al. 2015). As such this study assumed a slower growth and lower natural mortality for all species compared with previous work (e.g. Plagányi et al. 2015). This is particularly true for species that inhabit deeper sections of reefs such as slopes and channels. *Deep water* values are applied to *T. ananas*, *H. fuscogilva*, and *H. whitmaei* as they inhabit such environments. *Shallow water* values are applied to *H. scabra* as this species predominantly inhabits shallow waters and is known to be relatively fast growing (Hamel et al. 2001).

While the parameter values used in this study are based on the best available information they are likely to vary spatially, temporally, and for different species. This issue could be addressed by using a range of values for each species as a sensitivity analysis. As preliminary results of this sensitivity analysis showed no large changes, we have omitted it in this version for simplicity.

The instantaneous rate of change (*b*) is calculated for every species. This was done by inserting length-at-maturity and age-at-maturity data into the equation and changing the value of *b* until the equation agreed with length-at maturity and age-at-maturity data. Length-at-maturity and age-at-maturity data were chosen as the MSLs used were based on length-at-maturity (Tabunakawai-Vakalalabure et al. 2017, Govan et al. 2018). The values of *K*, *M*, and *b*, and other information used in the model are provided in Table A1.

Spreadsheet procedure (see Table A2)

1. Dry length is taken as the mid-point of the respective size class

2. Dry length is converted into live length by dividing [1] by the length retention rate (Table A1)

3. Live length is converted to live weight using the respective length-weight relationship (Table A1)

4. Number of animals of each dry length/live length inserted here.

5. Growth required to reach MSL is calculated by subtracting the live length [2] from MSL

6. As growth rate is often rapid in the early life stages of an animal and gradually reduces as that animal ages a negative exponential relationship was used to determine the time (years) taken for an animal to grow to MSL. The equation below reduces *K* at a rate of *b* for the duration it takes to reach a length of [5]. Once the specimen reaches MSL it is presumably taken by fishers therefore growth is no longer a consideration – i.e. fishing mortality (*F*) of a specimen >MSL = 100%. Time (years) taken to reach MSL is given as:

   $$[5]/(K^{-b})$$

   Similarly, natural mortality (*M*) is reduced as an animal grows, and the equation below reduces *M* for a duration of [6]. This mortality rate is subtracted from one (1) to determine the survival rate. The overall effect is an increase in the survival rate as an animal ages. As it is assumed that *F* of specimens >MSL is 100%, *M* is only applied for the duration that the animal is <MSL. Survival rate is calculated as:

   $$1 - M^{\frac{1}{[6]}}$$

[1] Exploitation rate (E) = Fishing mortality (F) / Total mortality (Z)

7. Survival rate is applied to size-frequency data from sampling:

$$[7]\times[4]$$

8. Weight of all animals at each size is determined:

$$[8]\times[3]$$

9. The weight of survivors at MSL is calculated by multiplying the number of survivors by the weight of an animal at MSL (Table A1):

$$[8]\times \textit{Weight at MLS}$$

10. Value[8] of the sample is calculated by applying the length-value relationship (Table A1) to the respective length [2] then multiplying this value by the weight of the sample [9], providing the total value of animals of that particular length. If the animal's length is below the data range provided by Purcell (2014), the minimum price point is used; if the animal's length was greater than the data range, the maximum price point is used (Table A1).

11. The value of survivors at MSL is calculated by multiplying the weight of the undersized portion of the surviving sample [10] by the value of an animal at MSL (Table A1). This is added to the value of animals from sampling that were >MSL [11]. Such that:

$$([10]\times \textit{Value at MLS})+[11]_{>MLS}$$

Table A1. Summary of parameters and additional inputs used in the model. MSLs are the minimum size limits agreed upon by MSG countries (Govan et al. 2018). Minimum and maximum price points are based on the minimum and maximum range of length data used by Purcell (2014) to produce the respective length-weight relationships.

Parameters	*T. ananas*	*H. scabra*	*H. fuscogilva*	*H. whitmaei*
K (growth constant) (y^{-1})	0.09	0.18	0.09	0.09
M (natural mortality)(y^{-1})	0.125	0.25	0.125	0.125
b (instantaneous rate of change)	0.837	1.175	0.837	0.777
Size-at-maturity (cm)[2]	30	15	32	26
Age-at-maturity (y)[2]	4	2	4	4
Length retention rate[7]	0.375	0.400	0.429	0.500
Length-weight relationship	[4]Log *W* = -6.67+2.36*Log(L*10)	[5]*W* = 0.1878 L ^ 2.5807	[4]*W* = 0.0011*L^2.407	[6]*W* = 0.9345*L^1.927
Length-value relationship[7]	*V* = 143.0175 + (-10685648.95*exp(-L))	*V* = 63.0807 / (1 + (-0.0771*L))	*V* = *L*/(0.48375 + (-0.052125*L) - (-0.0017185*L^2))	*V* = -195.06 + 95.6813*L^.5
MSL (live, cm)	40	25	35	30
MSL (dry, cm)	15	10	15	15
Value at MSL (dry, USD kg^{-1})	140.65	275.46	169.42	175.51
Weight at MSL (live, kg)	1.932	0.491	3.768	0.992
Min. price point (USD kg^{-1})	35.67	102.65	45.27	39.00
Max. price point (USD kg^{-1})	143.92	556.51	107.81	227.18

2 Taken from Table S1. Plagányi et al. (2015)
3 Calculated by dividing the MSG agreed dry MSL by the live MSL
4 Conand (1989)
5 Lee et al. (in press)
6 Prescott et al. (2015)
7 Purcell (2014)
8 It is acknowledged that the length-value relationships used in this study (Table A1) apply to BdM therefore steps [11] and [12] should first convert weight into dry weight; however, as we are only interested in percentage changes and not the actual monetary value, converting back into dry (BdM) weight is unnecessary.

Table A2. *H. fuscogilva*, Fiji export sample. MSL = 15 cm (dry)/35 cm (live). Life-history parameters used: $K = 0.09$, $M = 0.125$, $b = 0.837$

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Dry length (cm)	Live length (cm)	Live weight (kg)	Number observed	Growth needed to reach MSL (cm)	Time taken to reach MSL (y)	% of sample that will reach MSL	Number of animals that will reach MSL (survivors)	Total weight of sample (live, kg)	Total weight of survivors at MSL (live, kg)	Value of sample exported (USD)
4.5	8.8	0.315	0	24.5	3.26	47%	0	0.00	0.00	0.00
5.5	10.8	0.511	0	22.1	2.95	51%	0	0.00	0.00	0.00
6.5	12.7	0.763	14	19.8	2.64	55%	8	10.69	43.60	483.83
7.5	14.7	1.077	32	17.5	2.33	59%	19	34.47	107.95	1560.63
8.5	16.7	1.456	32	15.2	2.02	64%	21	46.59	117.56	2402.49
9.5	18.6	1.903	30	12.8	1.71	70%	21	57.09	120.66	3775.43
10.5	20.6	2.421	17	10.5	1.40	77%	13	41.16	75.19	3433.02
11.5	22.5	3.014	0	8.2	1.09	85%	0	0.00	0.00	0.00
12.5	24.5	3.684	15	5.8	0.78	93%	14	55.26	79.82	6859.44
13.5	26.5	4.434	36	3.5	0.47	99%	36	159.62	203.32	23106.08
14.5	28.4	5.266	49	1.2	0.16	100%	49	258.03	279.97	41920.48
15.5	30.4	6.183	43	-1.2	0.00	100%	43	265.87	245.69	46468.69
16.5	32.4	7.187	22	-3.5	0.00	100%	22	158.12	125.70	28497.34
17.5	34.3	8.281	20	-5.8	0.00	100%	20	165.61	114.27	29617.88
18.5	36.3	9.466	27	-8.2	0.00	100%	27	255.57	154.27	43943.77
19.5	38.2	10.744	26	-10.5	0.00	100%	26	279.35	148.56	45104.78
20.5	40.2	12.119	30	-12.8	0.00	100%	30	363.56	171.41	54248.61
21.5	42.2	13.591	9	-15.2	0.00	100%	9	122.32	51.42	16703.81
22.5	44.1	15.163	22	-17.5	0.00	100%	22	333.58	125.70	41483.03
23.5	46.1	16.836	24	-19.8	0.00	100%	24	404.05	137.13	45682.39
24.5	48.0	18.612	32	-22.1	0.00	100%	32	595.58	182.84	64209.57
25.5	50.0	20.493	20	-24.5	0.00	100%	20	409.86	114.27	44187.48
26.5	52.0	22.481	0	-20.5	0.00	100%	0	0.00	0.00	0.00

[12]	Total weight of sample in current situation[9] (kg)	4016	
	Total weight if MSL enforced (kg)	4382	9% increase
	Total value of sample in current situation (USD)	543689	
	Total value if MSL enforced (USD)	634322	17% increase

[9] MSLs are inadequately enforced i.e. the length-frequency of BdM reported in Tabunakawai-Vakalalabure et al. (2017) and Léopold (2016)

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Once processed and dried, these juvenile sea cucumbers will weigh a few grams, and be worth almost nothing on Asian markets that favour large specimens (image: Antoine Teitelbaum).

Cost–benefit analysis of the emergency 'grab bag' programme

Carah Figueroa[1], Philip James[2] and Michel Blanc[3]

Another successful rescue of three fishers at sea occurred on 4 March 2018 in Tuvalu after they activated the personal locator beacon (PLB) from their emergency 'grab bag', which has been promoted by the Pacific Community (SPC)[4] and supplied by the Tuvalu government. There have now been at least four known successful rescues of vessel crews since the grab bags were distributed in Tuvalu in 2015. This article presents the findings of a cost–benefit analysis of the grab bag programme. It demonstrates that the grab bag programme has excellent value for money and leads to significant cost savings and social benefits. The results call for an expansion of the programme throughout the country and Pacific Islands region more broadly to ensure fisher safety in a cost-effective manner.

Introduction

Coastal resources are an important source of the Pacific region's nutrition, food security, culture, employment, and recreational activities (SPC 2017a). In Tuvalu, 74% of households engage in reef fishing and the estimated annual coastal fisheries production is over 1400 tonnes, which is worth AUD 2.3 million (Gillett 2016). Small vessels[5] are not only used extensively by people of the Pacific Islands countries and territories (PICTs) for commercial and subsistence fishing, but also commonly used for inter-island transportation and recreational diving (Gillett 2016). Given the intensity of their activity in the region, most maritime incidents[6] are associated with small-scale fishers (SSFs) and small vessels (Danielsson et al. 2010; Gillett 2003). For example, a collation of records obtained from the civil registry, health departments, news reports and police reports of incidents at sea within the last 10 years in Fiji and Kiribati showed that at least 58 incidents occurred in Fiji and 28 incidents in Kiribati[7]. The collated data showed at least 58 deaths, 54 missing and 129 people rescued at sea in Fiji, and at least 80 deaths, 97 missing and 41 people rescued at sea in Kiribati during this period. In Tuvalu, five incidents were reported to the Fisheries Department and seven deaths at sea were captured in the civil registry and health records within the last five years. However, incidents remain poorly recorded in PICTs and many more incidents are probably unreported, particularly those associated with SSFs and small vessels.

Local fishers are typically exposed to numerous risk factors for incidents at sea including bad weather, engine failure, fires, improper vessel construction, overloading, prolonged trips, and limited safety equipment or training.[8] In Tuvalu, the high dependence on single outboard skiffs and widely dispersed islands compound these challenges. In addition, overfishing alongside a range of environmental and ecological stressors has forced SSFs to switch their effort from harvesting reef and coastal species to the more abundant oceanic resources, especially where they can be found relatively close to shore (Adams 2012). This increases the safety risks as the fishers are not visible from land and are often out of mobile signal range. The low-lying topography in Tuvalu is particularly important in this regard.

Measures that improve sea safety[9] are crucial as most PICTs have limited resources to conduct extensive search and rescue (SAR) operations and rely on foreign assistance (SPC 2013). Gillet (2003) estimates the actual cost for SAR activities by PICTs may be between USD 0.75 million to USD 1 million (2003 prices). The New Zealand Government expenditure for SAR for the 2016–2017 year included NZD 2.639 million by the New Zealand Defence Force and NZD 6.624 million by the Rescue Coordination Centre New Zealand, which both conduct SARs in PICTs (New Zealand Search and Rescue Council 2017).

To improve sea safety, the emergency grab bag programme has been implemented throughout the region. The use of grab bags has been spearheaded by SPC since the mid-1990s to ensure SSFs have essential equipment in a compact bag to signal for help and ensure survival in the case of an

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2 Fisheries Economist, SPC
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4 See http://www.spc.int/DigitalLibrary/Doc/FAME/Brochures/Anon_17_safety_grab_bag.pdf
5 In this article, small vessels refer to locally based boats of up to eight metres in length. Small-scale vessels are defined as <7 metres in Tuvalu.
6 'Incident' refers to any occurrence on board a vessel, involving a vessel, or associated with the activities of a vessel at sea, which 1) causes death or injury to any person, or, 2) whereby the vessel is lost or presumed to be lost at sea (adapted from Danielsson, Kuyateh, Ravikumar, Westerberg and Yadava, 2010; International Maritime Organisation, 2008). 'Incident' is preferred over 'accident'.
7 Research findings of Carah Figueroa's internship project.
8 See SPC Sea Safety Information Bulletins: http://coastfish.spc.int/en/publications/bulletins/sea-safety
9 'Sea safety' refers to the preparations and activities associated with safely returning a vessel to its home village, island or port at the conclusion of a trip without outside assistance (FAO 2004).

emergency. Table 1 and Figure 1 lists the contents of the SPC emergency grab bag[10]. Safety gear provision is an integral part of a holistic approach to sea safety that encompasses standards for vessels, trained personnel, incident reporting systems, and safety objectives in fisheries management.

The grab bag programme was introduced in Tuvalu in 2015 by SPC, which prompted the Tuvalu Fisheries Department (TFD), along with other funding partners, to procure and distribute more bags to fishers. Besides the provision of bags, the programme also provides training to fishers on

Table 1. Contents of an SPC emergency grab bag for motorised small vessels (numbering also relates to Figure 1).

Safety item	Description
1 Floating emergency grab bag	Water-proof bag used to store all of the above items; it should of a size large enough to store additional items such as tinned food, water bottles, a knife, some light fishing tackle and a few basic tools
2 Manual inflatable lifejackets	Very light-weight and compact personal flotation device that may be inflated by either activating a self-contained CO_2 cartridge or by exhaling through a blow tube
3 Sea rescue streamer	Signalling-device used at night or in foggy conditions to attract the attention of nearby boats as well as aeroplanes
4 Whistle	Signalling-device used at night or in foggy conditions to attract the attention of nearby boats
5 Mirror	Signalling-device used during day-time to attract the attention of nearby boats, as well as aeroplanes and people on the coast
6 Rescue laser flare	Long-range, AAA battery-operated laser device used at night to attract the attention of nearby boats as well as aeroplanes; the rescue laser flare favourably replaces flares or parachute rockets, although the later may still be required under national sea safety regulations
7 Personal locator beacon (PLB) with built-in global positioning system (GPS) [7]	When activated the PLB transmits a signal with the beacon's ID and vessel position to the nearest rescue coordination centre (RCC)
8 Strobe light	AAA battery-operated, waterproof, flashing light that is visible for a long distance at night and lasts longer than flares and parachute rockets
9 Batteries	AAA-size dry cell batteries used in portable electronic devices such as the hand-held GPS, VHF radio, the strobe light and rescue laser flare
10 Hand-held VHF radio (waterproof)	Multi-channel, two-way radio (can transmit and receive) that enables boat-to-boat and boat-to-land communication; the operating range is 5–10 nautical miles in open water and distress signals should be sent on channel 16 (international calling frequency for distress messages)
11 Map compass	A device used to determine geographical direction and consisting of an horizontally mounted magnetic needle that is free to pivot until aligned with the Earth's magnetic field
12 Emergency blankets	Very low-weight, low bulk first-aid blanket made of heat-reflective plastic sheeting; it reduces the heat loss in a person's body and because of its large metallic surface, it can be used as an improvised signalling device by drifters if the sun is shining or as a locator-beacon by searchers
13 Mobile phone	Useful communication tool in areas with adequate mobile phone coverage; does not allow boat-to-boat communication with unidentified/unknown boats and, from a legal point of view, does not replace the VHF radio
14 Hand-held GPS	Navigation device that uses the GPS and relies on a network of satellites to give the user's a geographical position; it increases the safety of boat operators who are navigating at night or with poor visibility and, in a distress situation, the exact geographical position of the vessel is known and can be given to the rescue team using the VHF radio or mobile phone
15 Medical kit	Box or bag containing medical supplies and tools to give emergency medical treatment to a sick or injured person on board
16 Sea anchor or drogue	Device, usually made of canvas, deployed upwind of the vessel to keep the vessel heading into the wind and to slow its drift; unlike a conventional bottom anchor, the sea anchor can be deployed whatever the depth of water

[10] See more about the grab bag in the recent leaflet here: http://www.spc.int/DigitalLibrary/Doc/FAME/Brochures/Anon_17_safety_grab_bag.pdf

Figure 1. The safety grab bag and its contents (images: Jipé Le-Bars, SPC).

how to use and maintain the grab bag contents. Since its introduction, grab bags have played a role in at least four known successful rescues of small vessels. Given the notable success of the grab bag programme in Tuvalu, this article outlines a cost–benefit analysis (CBA) of the grab bag programme, which was undertaken for this country, in order to highlight the benefits arising from the positive commitment that Tuvalu has shown, and to provide a case for greater investment by the governments of other PICTs. By doing so, the CBA also provides supporting evidence for greater awareness and prioritisation of the safety of SSFs and small vessel operators across the Pacific Islands region.

Methods

A CBA framework was used to assess whether investment in the grab bag programme was justified based on the expected changes in direct financial and social costs and benefits resulting from increased sea safety. This CBA evaluated scenarios where an incident occurred and: 1) no grab bag was on-board resulting in death; 2) no grab bag was used and the fishers sustained injuries requiring treatment; and, 3) a grab bag was used resulting in an efficient rescue and minimal injury. These scenarios were established based on the following assumptions:

- 168 grab bags were distributed by the end of 2017, covering 44% of the fishing vessels in Tuvalu. Each vessel carries two to three fishers, all of whom are trained in the correct use and maintenance of the bag and its contents (James et al. 2018).
- The grab bag is expected to last five years (the length of the PLB warranty)[11].
- There were two rescues within a one-year period that involved four people in total in which a grab bag was used; therefore, it is expected that 10 rescues will to be linked to the use of a grab bag within five years (Poulasi 2017).

[11] The battery in the personal locator beacon is expected to last a minimum of six years

Figure 2. Tuvalu Pacific Patrol boat, *Te Mataili* (image: Tuvalu Fisheries Department).

Figure 3. New Zealand Air Force P-3K2 Orion Aircraft (image: NZDF and Maritime New Zealand).

- Both Tuvalu's patrol boat (*Te Mataili*) (Figure 2) and New Zealand Air Force patrol aircraft (Orion) (Figure 3) are mobilised when an incident occurs at sea where the distressed occupants of the vessel have no grab bag and thus no PLB is available. SAR activities are also performed by local community members, local police, and other foreign countries (e.g. by Australia or the United States of America); due to uncertainty these costs are not included in the CBA.

- Should a PLB from a grab bag be used, it is assumed the Orion does not need to be mobilised and only the local patrol teams are recruited and diverted from their current patrol duties.

- The search time for locating a vessel without a grab bag is estimated to be up to 20 hours longer than the search time for a vessel that has a grab bag (PLB activated), based on available media releases from relevant agencies (New Zealand Defence Public Affairs 2013, 2015; Poulasi 2017).

A CBA lists, quantifies, and monetises all potential costs, as far as possible, that will be incurred and all expected benefits in order to determine whether the benefits outweigh the costs invested for the programme. In this CBA, the costs and benefits were evaluated from a regional perspective. The grab bag programme costs cover the contents of bags, training, and radio awareness programme. The direct costs of the programme have borne by donor funding sources.[12] Costs data were obtained from TFD and SPC personnel or estimated from secondary sources (Asian Development Bank 2016; Kelleher 2002; Sharpe 1996; Tuvalu Fisheries Department 2017).

The benefits of the programme comprise the saved costs resulting from reduced SAR operations costs and reduced loss of life, as well as fewer serious injuries, including financial costs for treatment and health impact costs. SAR operation costs – including fuel, medical/hospital costs for treating injuries including drowning/near-drowning injury, burns or striking/crushing injuries – were estimated using

[12] The SPC and FFA's Development of Tuna Fisheries in the Pacific Project (DevFish2), the United Nations Development Programme's National Adaptation Programme of Action II project (NAPA II), and the New Zealand Aid Programme.

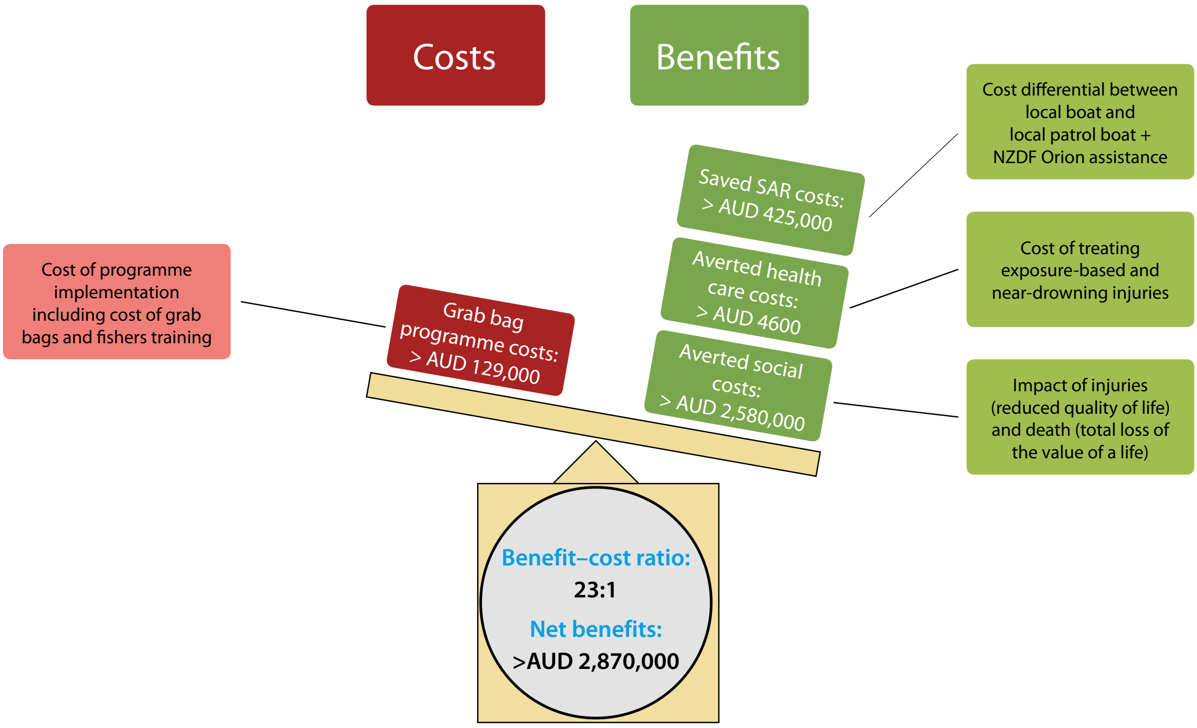

Figure 4. Cost–benefit analysis of one-year implementation of the grab bag programme in Tuvalu.

the available information from relevant agencies[13]. Other potential costs incurred such as vessel damage and costs of incident investigation, were not directly included in the model due to limited data availability. To measure the social costs, the value of a statistical life (VSL) measure was used. In the absence of Tuvalu-based studies, the VSL was calculated using an Australian meta-study and by transferring the values to the Tuvaluan context using GDP per capita purchasing power parity comparison as recommended by the World Bank (Access Economics 2008). Using this technique, the total VSL is calculated at over AUD 15,000 per year (assuming optimal health). Injuries have a disability weighting, which reduces this value for each year or part year that the injury is suffered. Future health impact costs were discounted at standard rates in order to estimate their present value. Other anticipated benefits such as the earnings and harvest of the fishers and vessel users, which are assumed to reflect the economic value of their productivity to society, were not directly included in the model.

The total programme benefits, net present value, and the benefit–cost ratio (BCR) were calculated. The total programme benefits equate to the sum of all the saved costs from injuries, loss of life and SAR costs. The net present value is the difference between the total programme benefits and direct programme costs. The BCR equates to the total programme benefits divided by the direct programme costs and represents the return per AUD 1 that is invested in the programme. A BCR of >1 means that the benefits outweigh the costs. The impacts of the programme were assessed over a one-year period of programme implementation.

Results

Figure 4 details the estimates of the total costs, total benefits and social costs and social benefits of the grab bag programme. The total costs of the programme amount to over AUD 129,300 per year. The costs of SAR operations were estimated to be over AUD 9000 during the rescue where a grab bag is used (assuming only the local patrol boat is mobilised), versus over AUD 430,000 during the SAR of a fisher missing at sea without a grab bag (assuming New Zealand air force assistance is also recruited). Without a grab bag, the direct financial costs of treating injury incurred during the incident amount to over AUD 4600. The social costs of injury are over AUD 19,000. The social impact of total loss of VSL is valued at over AUD 2.14 million.

[13] German Agency for International Cooperation 2016; Toafa 2016; http://www.airforce.mil.nz/about-us/what-we-do/aircraft/orion.htm

The results of the CBA show that the grab bag programme is significantly cost-beneficial. A BCR of 23.20 means every AUD 1 society pays yields AUD 23.20 of benefits. The present value of the total monetised benefits of over AUD 2.87 million demonstrates the amount saved by society due to the grab bag programme in one year. Within a five-year timeframe, this equates to an undiscounted average amount of over AUD 14.36 million. If earnings and harvest of the fishers and vessel users were included in the model, the BCR would be expected to be higher than 23.20.

The model only included the estimated costs of treating a few injury types that are commonly sustained during incidents at sea. These costs are valuated only for the directly affected individual; the impact of the incidents on family members of the affected individual including loss of household income have not been valued. If the costs of other injuries and the costs to victims' families were included, this would increase the value of the programme benefits. The key assumptions have been sensitivity tested and the results are robust to this testing.

Discussion

The CBA demonstrates that the grab bag programme has a positive social impact. This study benefited from having actual cost data on the programme as well as incident data. The CBA highlights a capital investment of the programme with potential benefits accruing in the following years, as longs as the battery in the PLB is replaced every five to six years. The current programme only covers 44% of the vessels in Tuvalu; hence, much greater benefits are foreseeable for distributing the bags to all small vessels in Tuvalu in terms of reducing the costs per bag.

The Tuvalu Fisheries Department is seeking a grab bag memorandum of understanding between fisheries, local government and fishers associations on every island. They hope to establish a land-based VHF station on each island to receive and rapidly respond to distress signals from fishers who are at risk at sea (Tuvalu Fisheries Department 2017).

Although the estimated programme costs and benefits were specific to Tuvalu, the findings are highly relevant to all other PICTs, where the number of active SSFs is high and for which sea incidents are a well-known concern. Scaling the programme to a regional level by providing grab bags to every local fisher or fishing community may be a worthwhile investment for donors, particularly from countries involved in SARs across the region, and governments for improved sea safety in PICTs.

Investment in the grab bag programme would promote the interests and vision of key search and rescue organisations in the Pacific Islands region. For example, the Pacific Search and Rescue (PACSAR) Steering Committee's[13] mission is, by 2021, for:

> the SAR capability of each PICT in the Pacific region, and of the region as a collective, has measurably improved in line with international standards and our success measures [for responsible SAR governance, efficient SAR coordination, effective SAR operational response, and SAR prevention] in order to respond to distress. (Pacific Search and Rescue Steering Committee 2016)

Similarly, the New Zealand Search and Rescue Council seeks:

> an informed, responsible, adequately equipped and appropriately skilled public who are able to either avoid distress situations or survive them should they occur... We will collaborate with, inform, and contribute to partner organisations and when required, enable, coordinate or lead public focussed SAR preventative strategies and actions in order to reduce the number and/or the severity of SAR incidents within the NZSAR region. (New Zealand Search and Rescue Council 2017).

Conclusion and recommendations

The grab bag programme in Tuvalu, which comprises both distribution of the bags and training on the proper use and maintenance of the grab bag equipment, is highly cost-beneficial to society. The CBA found that AUD 1 invested in the programme can be reasonably expected to yield over AUD 20 of benefits, reflecting current net benefits for society of over AUD 2.87 million, and an undiscounted annual average amount of over AUD 14.36 million, in addition to saved household costs and improved productivity.

With an assessment of the resources available and the cost distribution, scaling up the grab bag programme in Tuvalu and in the Pacific Islands region should be considered by all other relevant stakeholders. The value of programme benefits, nationally and regionally, is crucial for the strengthening of small vessel safety together with complementary initiatives, which include the following: standard incident reporting procedures; small vessel safety regulations; vessel crew training; boat building standards; education for school children; awareness-raising for fishers, their families, and local community members; and, above all, the raising of political will to address small vessel safety in a holistic manner.

[13] The Pacific Search and Rescue (PACSAR) Steering Committee is a group of search and rescue agencies from Australia, Fiji, France, New Zealand, and the United States of America that manage major search and rescue regions (SARs) of the central and south Pacific regions.

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Spatiotemporal variability in bigeye tuna vertical distribution in the Pacific Ocean

Tom Peatman[1] and Francisco J. Abascal[2]

Introduction

Bigeye tuna (*Thunnus obesus*) is a target species of the tropical longline fishery in the Pacific Ocean, with annual catches of large, mainly adult fish of approximately 100,000 tonnes (t). Longline caught bigeye tuna are high-quality and destined for fresh and frozen tuna markets in Asia, North America and elsewhere. Bigeye tuna are also caught in the purse seine fishery in the Pacific Ocean, ranging from <5% of the total catch in the western Pacific region to >10% in the eastern Pacific region. Catches have generally exceeded 120,000 t annually since the mid-1990s, which coincides with a large increase in the use of drifting fish aggregation devices (FADs) in Pacific region purse seine fisheries (Harley et al. 2015; IATTC 2015). Purse seine caught bigeye tuna are mostly smaller, juvenile fish, and are sold for canning along with much larger quantities of skipjack tuna and yellowfin tuna, which are the primary target species of this fishery.

In the Pacific Ocean, highly migratory species are managed separately by the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). While most Pacific Ocean tuna stocks are not estimated to be overfished or subject to overfishing, the most recent estimate of current spawning biomass for 2015 in the eastern Pacific Ocean (EPO) was 20% of the unexploited level (Aires-da Silva et al. 2016). The 2015 assessment of bigeye tuna in the western and central Pacific Ocean (WCPO) indicated it was overfished, and subject to overfishing. While the results of the latest bigeye tuna stock assessment in the WCPO (McKechnie et al. 2017) are more optimistic, they vary significantly depending on the growth curve and regional structure used, and there is still some probability the stock is overfished or subject to overfishing (Anon. 2017). We refer interested readers to SPC Fisheries Newsletter No. 153 for more information on the recent developments in the WCPO bigeye tuna assessment (Hampton 2017) .

These assessments rely primarily on data from the purse seine and longline fisheries. An understanding of the vulnerability of bigeye tuna to these fishing methods, including the environmental drivers of variability, is necessary for interpreting catch rates, size composition and other features of the data. In particular, a key question is the extent to which spatial and temporal variations in catch per unit effort (CPUE) in longline and purse seine fisheries reflect changes in abundance or vulnerability (catchability) to the fishing gear being used. Vulnerability of bigeye tuna to both purse seine and longline gear is likely influenced by their vertical distribution in the water column (Evans et al. 2008; Fuller et al. 2015). Purse seine fish aggregating device (FAD) sets are usually deployed in pre-dawn hours (Harley et al. 2009) with nets hanging from the surface to depths of 100–200 m (Lennert-Cody et al. 2008; Delgado de Molina et al. 2010). Bigeye tuna will therefore tend to be more vulnerable to capture by purse seine at times and in locations where they are associated to the FADs, close to the surface at night. Longline sets that target bigeye tuna are typically deployed during the day at depths of 100–400 m, with most hook fishing in the upper part of this range (Evans et al. 2008; Bigelow et al. 2002). Bigeye tuna will therefore be more vulnerable to capture by longline gear when their daytime swimming depth is <300 m. We summarise here the results of a recent study (Abascal et al. 2018), which explored spatiotemporal variability in vertical distribution of bigeye tuna in the Pacific Ocean using data from internally-implanted archival tags.

Data available from archival tags

A total of 851 bigeye tuna were tagged (Figure 1) and released with archival tags (Figure 2) from 1999 to 2014, with tagging efforts being concentrated in the equatorial central Pacific region (5°N–5°S, 140°W–180°), and in the north-western Coral Sea (10–25°S, 146–150°E). 137 archival tags were recovered (16%), of which 65 (7.6% of the 851 archival tags) had useful information for a period of more than 30 days. The archival tags provide observations of swimming depths, internal and external temperatures, and light intensity readings that can be used to estimate geographical positions.

Bigeye tuna exhibit a variety of vertical movement profiles that were previously classified into three broad behavioural types: characteristic, associative, and 'other' (see Fuller et

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[3] http://coastfish.spc.int/en/component/content/article/479-spc-fisheries-newsletter-153.html

Figure 1. An archival tag has been inserted in a bigeye tuna; the incision is closed with a few stitches (image: Bruno Leroy).

Figure 2. A bigeye tuna fitted with an electronic tag ready to be released (image: Bruno Leroy).

al. 2015). Bigeye tuna generally stay close to the surface at night. At dawn, bigeye tuna that are displaying characteristic behaviour descend well below the thermocline where they generally remain throughout the day and feed on prey. They briefly return to warmer waters above the thermocline during this period to increase their internal temperature, before returning to deeper and colder waters. Bigeye tuna displaying associative behaviour generally remain within the mixed layers throughout the day. The 'other' behaviour type covers all depth profiles that do not fall under characteristic behaviour or associated behaviour. For each day of tag data, we assigned 'associative', 'characteristic' or 'other' behaviour, using the classification method of Fuller et al. (2015). The median depths for each day and night were calculated from the tags' depth measurements, removing data recorded within one hour of dawn and dusk. Depths of the 18°C and 20°C isotherms were calculated for each 24 h period using the depth and temperature information recorded by the tags.

Vertical distributions of bigeye tuna

Median recorded depths displayed strong spatial trends for all combinations of behaviour type and daytime/night-time, with the shallowest average depths generally at the most easterly range of observations, and increasing average depths moving westwards (Figures 3 and 4). The spatial trends in average depths displayed a positive relationship with the thermal structure of the water column. Average depths were generally deeper in areas with deeper thermoclines (i.e. the western equatorial Pacific region and in the Coral Sea, and vice versa for the eastern Pacific region). Additionally, the strength of thermal stratification displayed an association with average depths. For example, average night-time depths were shallower in the Coral Sea than in the western equatorial Pacific region; both regions have similar thermocline depths but thermal stratification is generally stronger in the Coral Sea with lower sea surface temperatures.

Models of median vertical depths

Exploratory analyses of swimming depths recorded by the archival tags demonstrated strong spatial and temporal variation in swimming depths (see above). Statistical models are simplified representation of reality, and provide a way to disentangle the effects of different variables on swimming depths (e.g. what is the effect of fish size on swimming depths, if all else is equal?). We used additive mixed models to estimate the effects on average depths of the thermal structure of the water column, of fish size, and for models of night-time depths, of lunar illumination. The depth of the 20°C isotherm was included as a proxy for thermocline depth, with the difference in depth between the 18°C and 20°C isotherms being included as a metric of thermal stratification. Tag identification was

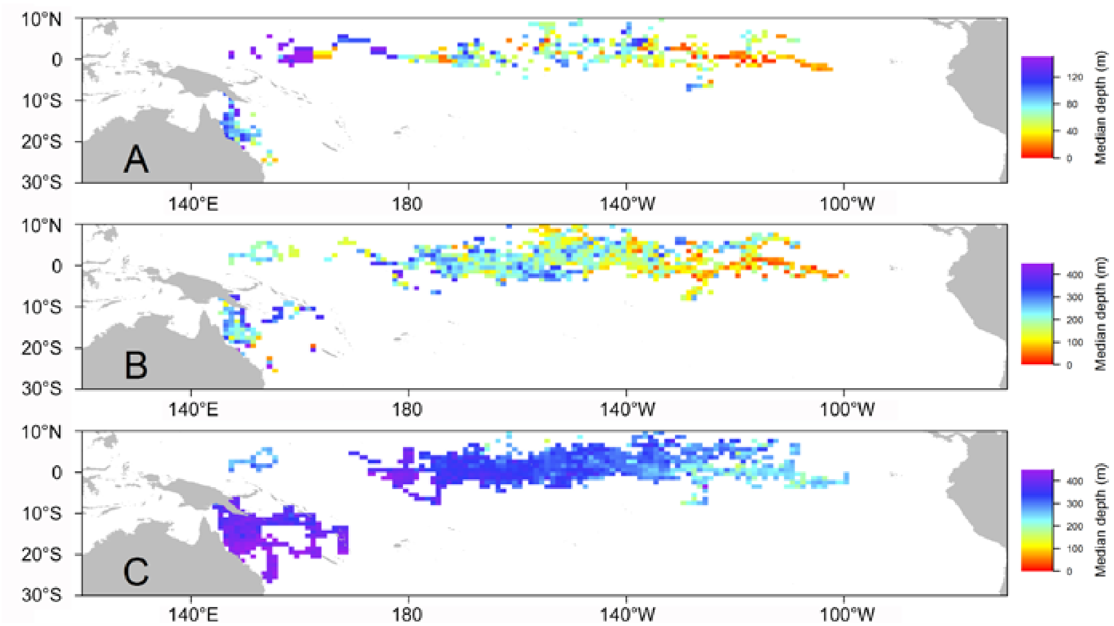

Figure 3. Daytime median depths averaged for spatial cells of one degree of longitude and latitude for fish showing associative (A), other (B) and characteristic (C) behaviours.

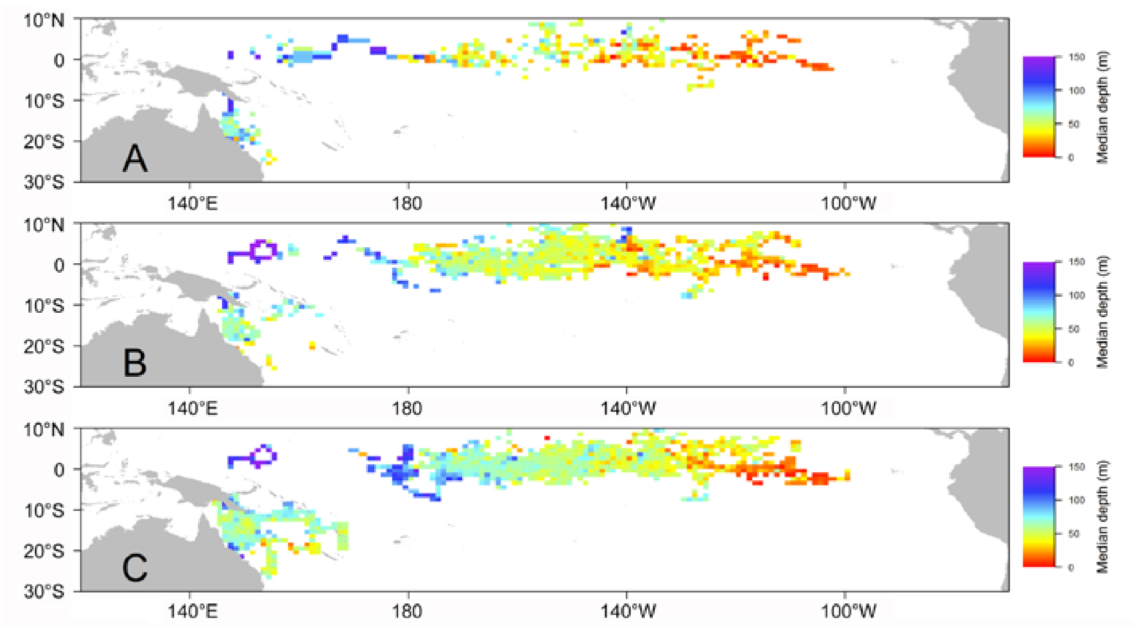

Figure 4. Night-time median depths averaged for spatial cells of one degree of longitude and latitude for fish showing associative (A), other (B) and characteristic (C) behaviours.

included as a random intercept to account for variations in depths between individuals. Separate models were used for each day/night-behavioural type combination.

For all models, thermocline depth had the strongest effect on median depths, with median depths increasing with thermocline depth (Figures 5 and 6). Median depths decreased with stronger thermal stratification for daytime-characteristic behaviour, and average depths increased with fish length for fish smaller than 80 cm. Median fish length and thermal stratification had no detectable effect on median depths for daytime-associated behaviour. It was not possible to fit robust models to median depths for the daytime-other category.

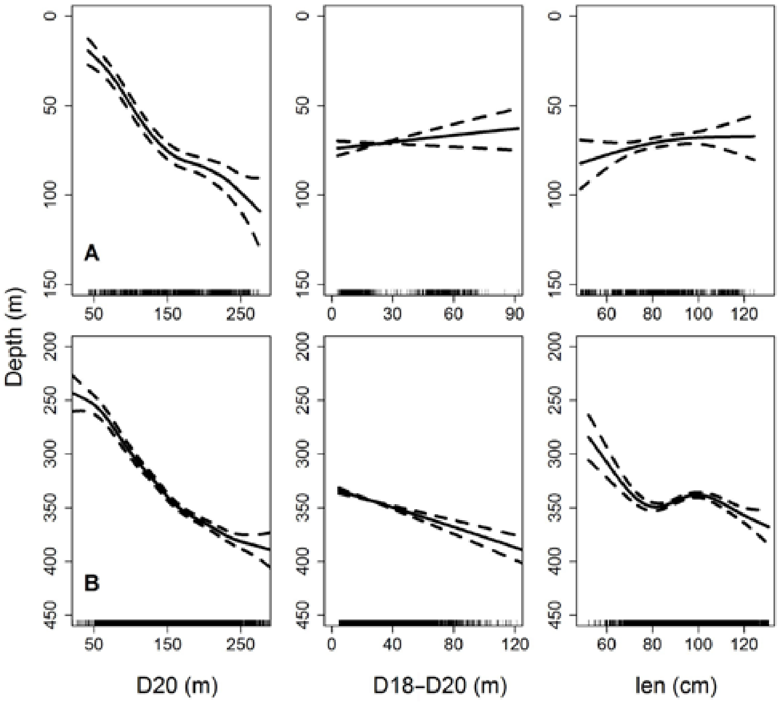

Figure 5. Modelled effects of depth of the 20°C isocline (D20), water column stratification (D18–D20) and fish size (len) on median depth during daytime.
A- Associated; B- Characteristic.

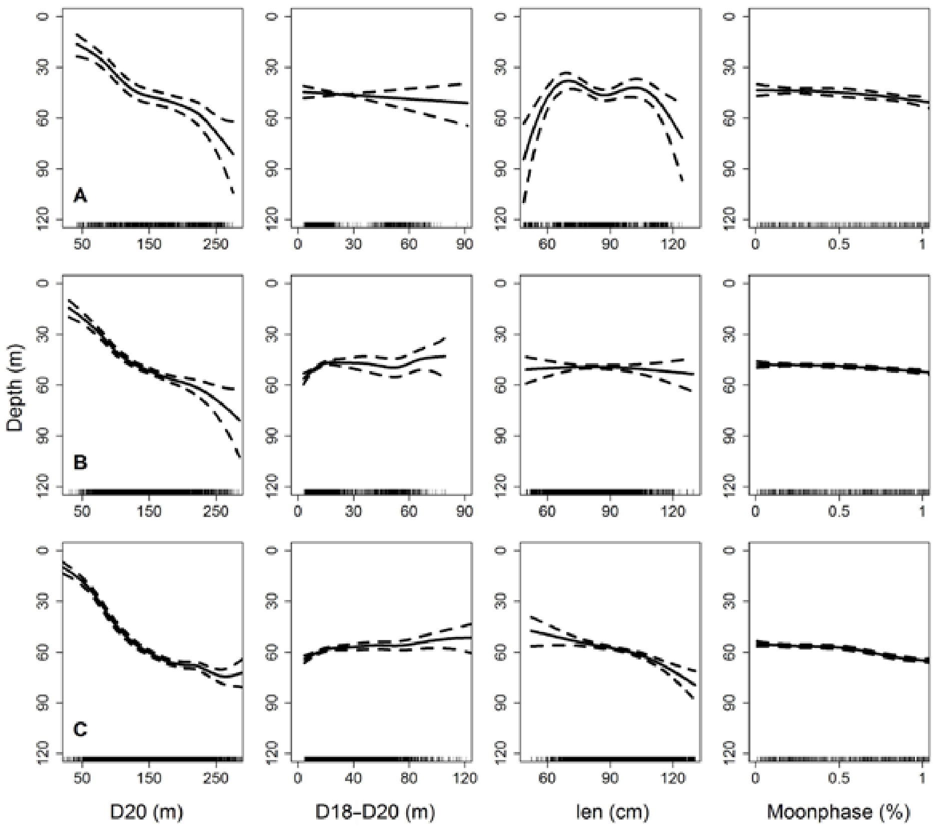

Figure 6. Modelled effects of depth of the 20°C isocline (D20), water column stratification (D18–D20), fish size and phase of the moon on median depth during night-time. A- Associated;
B- Other; C- Characteristic.

For night-time-associated behaviour, there was no detectable effect of thermal stratification on median depths. Median depths for night-time-other and night-time-characteristic behaviours were generally insensitive to thermal stratification, with the exception of a slight decrease in median depths as thermal stratification weakened from the highest observed levels (i.e. when the 18°C and 20°C isotherms were less than 15 m apart). Median depths increased with fish length for night-time-characteristic behaviours, with a non-linear relationship between median depths and fish length for night-time-associated and no detectable effect of fish length on median depths for night-time-other. Night-time median depths increased weakly with moon-illumination for all three behaviour types, particularly for bigeye tuna displaying characteristic behaviour.

Predicted median depths and potential effects on standardised CPUEs

Thermocline depth had the strongest effect of the modelled explanatory variables on median depths for bigeye tuna during both daytime and night-time, regardless of behaviour type. Thermal stratification of the water column was also influential on daytime median depths for bigeye tuna displaying characteristic behaviours. Thermocline depth and thermal stratification display substantial spatial and temporal variation in the Pacific Ocean, which is reflected in strong spatial and temporal variation in predicted median depths throughout the Pacific Ocean (Figure 7). For example, longitudinal trends in predicted depths of daytime-characteristic and night-time-associated behaviours strengthen in La Niña conditions and weaken El Niño conditions.

We tested for a potential relationship between estimated median depths and fish catchability by modelling standardised catch per unit effort (CPUE) from region 4 of the 2017 bigeye tuna assessment (i.e. 170°E to 150°W, 10°S to 20°N; McKechnie et al. 2017) as a function of estimated daytime median depths for bigeye tuna displaying characteristic behaviour. A clear negative relationship between standardised catch rates and median fish depth was identified (Figure 8). This suggests that standardised catch rates – used as indices of relative abundance in stock assessments – also reflect changes in vulnerability of bigeye tuna to longline gear due to varying swimming depths.

Discussion

The analysis summarised here represents the first basin-wide analysis of archival tagging data within a statistical framework to identify the main drivers of swimming depths in bigeye tuna.

Observations of swimming depths from the archival tags clearly demonstrated strong spatial variation in swimming depths, with deeper swimming depths in the western Pacific region compared to the eastern Pacific region. The statistical modelling of median depths indicated that the local oceanographic environment had the strongest effect on swimming depths – in particular the depth of the thermocline,

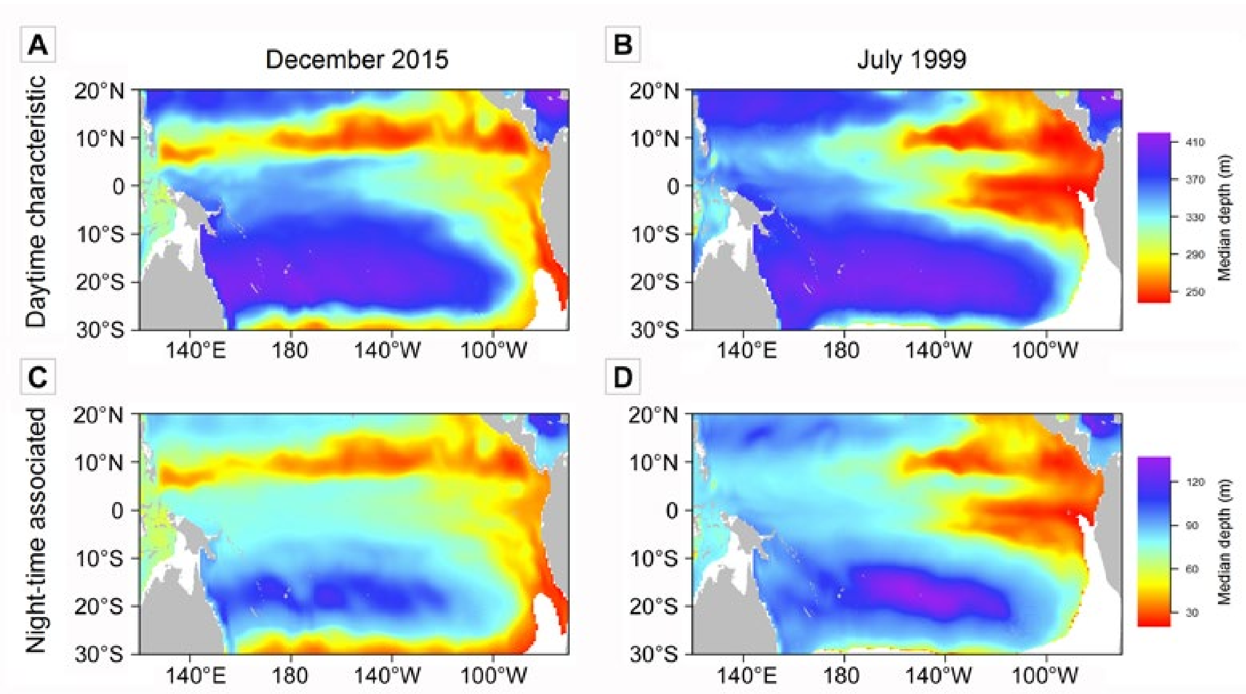

Figure 7. Predicted daytime depth distribution for a 115 cm fish showing characteristic behaviour (A, B) and night-time depth for a 50 cm fish displaying associated behaviour (C, D), under strong El Niño (A, C) and La Niña (B, D) conditions.

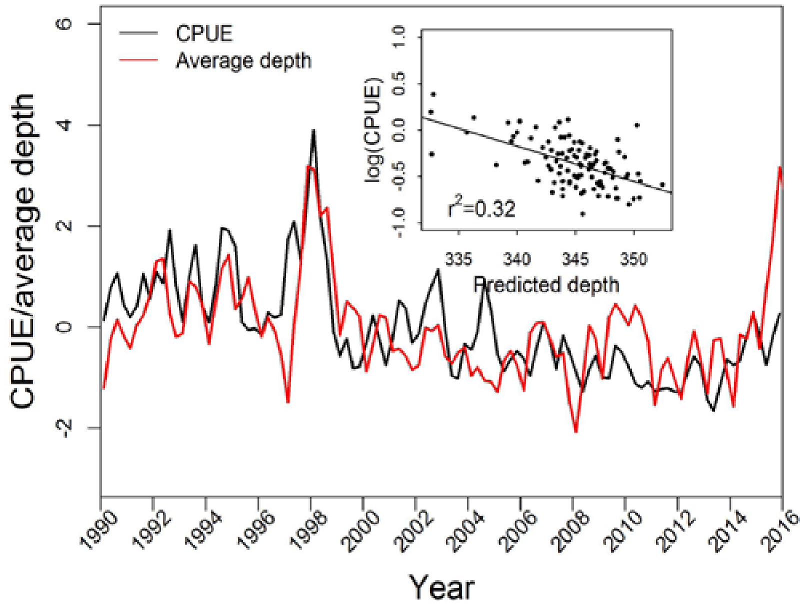

Figure 8. Time series of standardised longline CPUE in region 4 and predicted average depth in the region. Values are provided as z-scores, and the axis for predicted average depth has been reversed for illustrative purposes.

regardless of the time of day (day/night) or behaviour type. We used thermocline depth and thermal stratification as explanatory variables in the statistical models because they gave superior fits to observed swimming depths, and because these variables were based directly on data from temperature and depth sensors on the archival tags. However, it seems likely that bigeye tuna depth distributions are strongly linked to diurnal vertical migration of prey, but are constrained by the thermal layer and the oxygen concentration tolerance of bigeye tuna (e.g. Evans et al. 2008; Schaefer and Fuller 2010). We also fitted statistical models with oxygen concentration, and deep scattering layer depths, which rely on linking to external datasets using estimates of tag geolocations. The inclusion of these alternative environmental variables, at the expense of thermocline depth and thermal stratification, worsened fits to observed swimming depths. Light-based estimates of geolocations can be uncertain (e.g. see Basson et al. 2016) and as such we might expect tag-sensor derived environmental variables to better explain observed variation in swimming depths.

Predicted swimming depths of bigeye tuna throughout the Pacific Ocean demonstrated strong temporal and spatial variability, in part driven by the El Niño Southern Oscillation (ENSO) cycle. Furthermore, the detected relationship between predicted swimming depths and standardised CPUE suggests that indices of relative abundance used in the assessment models also reflect varying vulnerability of bigeye tuna to longline gear due to varying swimming depths.

This is problematic as the indices of relative abundance are assumed to reflect only changes in abundance, not vulnerability. Work is ongoing on including the effects of environmental variables on catchability within models used to standardise catch rates of tropical tuna (Tremblay-Boyer et al. 2017). This should improve the assessment models, through the use of more appropriate CPUE series as indices of abundance, and better estimates when scaling the biomass between regions.

There were limited data available from instrumented bigeye tuna in the western equatorial region – in fact all observations in the equatorial region west of 160°E came from just two tags. There was some suggestion that the swimming depths of these two tagged fish were inconsistent with expected depths based on the local oceanography and estimated fish length; this difference can be attributed to variation in swimming depths between individuals. Data from additional archival tagged bigeye tuna in the area would allow this to be explored in more detail. We note that few bigeye tuna were released with archival tags on the skipjack-focussed 2017 WP4 tagging cruise in the western equatorial region, due to the low numbers of large bigeye fish caught. Additional tag releases in the western equatorial region would improve the spatial coverage of the archival tagging dataset, which would crucially increase the amount of information available from an area with extensive purse seine and longline fishing efforts.

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Developing a system of sustainable minimum size limits for Fiji

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Introduction

The depletion of reef fish stocks across the South Pacific poses a major threat to both food security and preservation of biodiversity (Newton et al. 2007; Sale and Hixon 2015). Highly prized large-bodied grouper, snapper, parrotfish and wrasse have become harder to catch and more expensive in markets everywhere. Once common, some species are now rare or locally extinct in many places. Researchers are predicting that many species face global extinction if effective management is not implemented (Sadovy et al. 2003, 2013; Dulvy and Polunin 2004). Most Pacific Island countries and territories (PICTs) have yet to develop the administrative capacity that is needed to tightly manage fishing pressure or the amount of fish being caught; thereby, the simplest and most effective way to sustain reef fish stocks will be to protect species with minimum size limits (MSLs) until they reproduce sufficiently in order to replace themselves.

In a parallel study, we demonstrate with simulation modelling that even under very heavy fishing pressure, fish stocks can be sustained by setting MSLs that protect fish until they have completed at least 20% of the breeding that they would naturally carry out, if there were no fishing activities (Prince and Hordyk in prep.). This level of reproduction, which is referred to as 20% of the spawning potential ratio (SPR), is internationally recognised as a limit reference point that stocks should be maintained above to prevent the recruitment of young fish from declining (Mace and Sissenwine 1993). In addition to sustaining stocks, setting MSLs to the size at which 20% SPR is achieved, also prevents fish being caught before fulfilling their potential for growth, and so ensures that optimal yields are attained. In that analysis, Price and Hordyk also demonstrate that for most of the main reef fish, the size at which 20% SPR can be approximated in a simple manner is by using a factor of 1.2 to multiply a species size of maturity (SoM), which is defined here as the size at which 50% of fish become adults ($L_{50\%}$). This rule of thumb can simplify this process and thereby circumvent the need for complex yield-per-recruit analyses to set MSLs – especially for data-poor fisheries. However, even with this simplification, setting MSLs in many of the PICTs that are scattered across the expanse of the Pacific Ocean is a challenging prospect. This attempt has been made difficult due to the large numbers of species from catches that have not been studied in depth, along with the impracticality of implementing large numbers of species-specific MSLs for an assemblage of species that appear to be similar.

This article describes a study undertaken in Fiji in order to address this challenge. The study, which was supported primarily by the David and Lucile Packard Foundation and NZAID, involved a unique collaboration of international scientists from Biospherics Pty Ltd, Australia, University of British Columbia (UBC) and local scientists from the Fiji Ministry of Fisheries, Wildlife Conservation Society (WCS), and World Wide Fund for Nature (WWF), in order to co-ordinate a programme of data collection and analysis to determine the size of maturity (SoM) of the most common fish species consumed or sold in Fiji. We expect this result to be broadly applicable across the tropical Pacific and Indian Oceans, although the size limits applied to each group of species may need to be adjusted between PICTs, depending on local water temperatures at different latitudes.

Methodology

Determining size of maturity

Good estimates of the size of maturity for the main species in a catch are the most critical input for any analysis of MSLs. Maturity in fish is studied most precisely with microscopic techniques that require access to expensive histological techniques and laboratories. In countries without these resources, SoM estimates made in other countries have commonly been borrowed and are assumed to apply. It is, however, becoming increasingly evident that SoM and body size in fish vary considerably between countries, mainly in relation to water temperature and latitude. In the absence of fishing, the further from the equator fish mature at, the more they will grow to larger sizes (Pauly 2010).

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When this project was initiated, the size of maturity had been determined for only three Fijian species, by Lasi (2003) using microscopic techniques. To address this gap in information on the SoM for most coral reef fish in Fiji, the collaborating partners initiated a programme to collect macroscopic size of maturity data on as many fish species as possible. The macroscopic techniques we have applied are less precise than microscopic techniques, but cheaper and less technical, they simply require trained observers to cut fish open in the field and gauge maturity from the appearance of sex organs (gonads). Partners trained representatives of communities from Bua, Macuata, Ba, Serua, Tavua and Kadavu on how to examine their own catch, and used their own staff members to sample fish in the main fish markets of Suva (Viti Levu) and Labasa (Vanua Levu). Over three years, this collaboration sampled 13,901 fish of 129 species.

An analytical workshop that involved all the partners was held recently in Suva (27–29 March 2018). Attendees developed initial estimates of SoM for 31 species using their separate datasets, including comparative estimates from multiple regions for five species. The workshop concluded that with the data available, some difference in SoM between areas could not be entirely excluded; however, for the species studied, geographical differences appeared to be small enough to allow the data from all areas to be combined to estimate a single SoM for species, and to implement a single system of MSLs across Fiji.

Subsequent to the workshop, the datasets were amalgamated, which made it possible to estimate SoMs for 46 species (Table 1). Many of these estimates are based on relatively small samples (31 have samples sizes <100, 21 of which have samples sizes <50), which together with our reliance on macroscopic examination might reduce their precision. However, as a part of this project a meta-analysis of the literature for Indo-Pacific reef fish has been conducted by compiling a database that contains 469 SoM estimates. Checking our SoM estimates against this database reveals a consistent pattern of our Fijian estimates,

Table 1. Estimates of the size (in mm) at which 50% (L_{50}) and 95% (L_{95}) mature and samples sizes (n) for 46 species of Fijian reef fish that have been developed through the collaborative fish sampling project undertaken by project partners.

Species	L_{50}	L_{95}	n
Acanthurus nigrofuscus	298	380	51
Acanthurus xanthopterus	306	385	105
Caranx papuensis	330		30
Chlorurus microrhinos	375	450	92
Crenimugil crenilabis	322	380	164
Epinephelus caeruleopunctatus	396	480	131
Epinephelus coiodes	585	700	28
Epinephelus cyanopodus	405	440	12
Epinephelus fuscoguttatus	592	690	72
Epinephelus maculatus	397	480	78
Epinephelus ongus	326	400	43
Epinephelus polyphekadion	412	470	57
Hipposcarus longiceps	365	440	515
Lethrinus atkinsoni	253	330	428
Lethrinus erythracanthus	356	420	26
Lethrinus harak	232	290	899
Lethrinus lentjan	206	240	95
Lethrinus nebulosus	412	500	75
Lethrinus obsoletus	260	310	386
Lethrinus olivaceus	498	640	377
Lethrinus xanthochilus	390	480	254
Lutjanus agentimaculatus	442	570	24
Lutjanus bohar	468	550	46
Lutjanus gibbus	298	380	666
Lutjanus quinquelineatus	184	210	21
Lutjanus semicinctus	223	260	25
Monotaxis grandoculis	346	420	182
Naso unicornis	371	450	110
Parupeneus barberinus	325	400	44
Parupeneus cyclostomus	260	280	12
Parupeneus indicus	257	340	32
Plectorhinchus albovittatus	550	675	19
Plectorhinchus chaetodoinoides	437	520	137
Plectorhinchus gibbosus	417	480	15
Plectropomus areolatus	430	520	216
Plectropomus laevis	498	675	23
Plectropomus leopardus	435	525	72
Scarus ghobban	329	360	39
Scarus globiceps	270	390	45
Scarus niger	249	280	13
Scarus rivulatus	292	340	353
Scarus rubroviolaceus	369	400	85
Siganus doliatus	204	220	13
Siganus punctatus	241	260	21
Siganus vermiculatus	236	270	79
Variola louti	350	420	16

fitting into the upper end of published estimates in keeping with Fiji's higher latitudes (~18°S), suggesting internal consistency among our estimates. Three of our estimates can also be compared with those that Lasi (2003) derived by using microscopic techniques and in each case are similar: *Lethrinus atkinsoni* (232 mm, cf. 236 mm); *L. harak* (253 mm, cf. 254 mm); and *L. obsoletus* (260 mm, cf. 240 mm). Despite our reliance on macroscopic techniques and small sample sizes, these comparisons give us some confidence in our estimates.

Size limit clustering analysis

In collaboration with this project, Dr Adrian Hordyk (UBC) developed a novel multi-species yield-per-recruit model to evaluate the trade-offs involved in grouping a species assemblage into differing numbers of MSLs – estimating aggregate yields and the number of species prone to extinction for any number of MSL groupings. As with standard yield-per-recruit modelling, this analysis is equilibrium based, and estimates states that are predicted to exist in the long-term after all transitional dynamics have passed through the modelled populations. In other words, the model estimates the final state that populations will eventually come to rest in, if the modelled conditions were applied constantly into the long-term future.

The model proceeds as follows:

1. First, the MSL is estimated for each species in the assemblage that is being analysed (in this case 74 species) to optimize the long-term sustainable yield and reproductive potential (SPR) for each species, which is approximated for most species by 1.2 x SoM.

2. The species-specific MSLs are then grouped into all the possible number of groupings (in this case from 1 to 74). Groupings are initially formed using the similarity of the species-specific MSLs, with the overall MSL for each group being initially set to the average of the species-specific MSLs in each group. For example, if there are five species in a group with individual species-specific MSLs of 30, 35, 40, 40, 45 cm, the MSL for that group will be 38 cm.

3. In the next step, the model adjusts the average MSL for each group so as to optimize the expected yield from each group by giving weight to the most productive and abundant species in each group.

4. Finally, the MSLs for each group are optimized for ease of implementation by being rounded to the nearest 5 cm and any resulting change in yield that is caused by the final rounding is estimated (but is usually very small).

Model output

The trade-offs associated with each number of MSL groupings (in this case from 1 to 74) are calculated assuming both moderate (i.e. managed) fishing pressure ($F = 0.3$), which even without MSLs is expected to produce pretty good yields and minimise species extinctions, and heavy (i.e. unmanaged) fishing pressure ($F = 0.9$), which is expected to depress yields and maximise species extinctions. Reference levels of fishing pressure (F) can be adjusted within the model, but these default levels were used throughout this analysis. An important constraint is that fishing pressure is applied equally across all species (i.e. assuming no targeting occurs within the assemblage).

The final outputs of the modelling are:

1. the relative yield expected at equilibrium from each species in the assemblage;

2. the aggregated relative yield expected at equilibrium from the entire species assemblage;

3. the number of species expected to have gone extinct at equilibrium; and

4. lists of species in any number of 5 cm rounded MSL groupings.

Input parameters

Species list

The most fundamental input for the model is the list of species that comprises the assemblage that is being modelled. For this study, a list of 74 main species was developed through the sampling programme that was organised by the project partners, which together, comprise ~95% of the sampled catch.

Size of maturity

At the conclusion of our sampling programme, we had Fiji-derived SoM estimates for 44 of the 74 species that we modelled; while our database contained estimates for 21 of the 30 species for which we had no Fijian estimate.

Fiji lies at relatively high latitudes (~18°S) and the size of fish are apparently larger than most of the estimates in our database; thereby we preferentially used estimates from similarly high latitudes (i.e. 13°–25°), and if there was more than one estimate for a species, we used the average. Where there were only estimates from low latitude countries (<13°) we used the largest of those estimates, otherwise we used the only estimate available. This left nine species for which we had no SoM estimate. For these species, we developed two correlations between the 469 estimates in our database and estimates of maximum size that are published in the fish identification guides of Allen et al. (2003) and Moore and Colas (2016). With those correlations, we could make two estimates of SoM for unstudied species, and we used the average of those estimates in our model.

Biomass distribution

Estimates of relative unfished species composition (i.e., virgin biomass) of the assemblage being analysed provide weightings for species within each MSL group. We based our estimates on a synthesis of published studies as follows:

- Biomass surveys of relatively remote and/or pristine locations: Friedlander et al. (2010) for surveys of Kingman Reef in the Line Islands of the central Pacific region; Friedlander et al. (2012) for surveys of Coco Park off Costa Rica, and Williamson et al. (2006) for surveys of closed areas in the Great Barrier Reef Marine Park in Australia.

- Earlier studies of catch compositions in Palau (Kitalong and Dalzell 1994) and Fiji (Jennings and Polunin 1995; Kuster et al. 2005) when the fish assemblage might have been expected to be less impacted by fishing.

- And estimates of the sustainable catch composition in New Caledonia (Labrosse et al. 2000).

These studies show that in unexploited or lightly exploited states the reef fish biomass of the tropical Pacific region tends to be dominated by larger bodied predatory species, and tends to be distributed relatively uniformly across the main family groups (emperors, snappers, groupers, parrotfish and surgeonfish); thereby, we weighted our modelled biomass composition accordingly.

These assumptions are not as critical to the analysis as the SoM estimates. They mainly affect how species are grouped when a sub-optimally low number of MSL categories (2–4) are being modelled. In this context, the model prioritises the creation of MSL categories in order to optimize the yield of species with a large biomass, at the expense of species with a small biomass. As our interest focuses on solutions with a larger number of MSL categories (5–10) that are estimated to achieve ~100% of potential yields and zero species extinctions, our results are relatively insensitive to our assumptions of initial estimates of relative virgin biomass.

Other biological parameters

Biological parameters that describe the growth and longevity of each species are required in the form of life history ratios, along with the size at which fish are selected for catching.

The life history ratios we derived through a meta-analysis of >500 published studies of the age and growth of Indo-Pacific reef fish, which will be published separately. We estimated species-specific sizes of selectivity from the size composition of fish catches in Fiji that were determined by our sampling programme.

Results

Based on our assumptions the model estimates that with optimal management the 30 most important species comprise >70% of the catch, with the 10 most important being: blue spine unicorn fish (*Naso unicornis*), thumbprint emperor (*Lethrinus harak*), paddle tail snapper (*Lutjanus gibbus*), pink ear emperor (*Lethrinus lentjan*), vermiculate rabbitfish (*Siganus vermiculatus*), spangled emperor (*Lethrinus nebulosus*), long nose emperor (*Lethrinus olivaceus*), bumphead parrotfish (*Bolbometopon muricatum*), yellowlip emperor (*Lethrinus xanthochilus*), and two-spot red snapper (*Lutjanus bohar*). Together the 17 grouper species that were modelled comprise ~16% of the catch.

Without size limits, the model estimates that 82% of the potential yield can be obtained with moderate fishing pressure ($F = 0.3$) but that in the long-term, nine species go extinct (Table 2; Figure 1). With heavy fishing pressure ($F = 0.9$) only ~42% of the potential yield is achieved and 38 of the 74 species go extinct. The species predicted to go extinct under heavy fishing pressure, and from 0–5 MSLs, are listed in Table 3, which makes it clear that the large and medium bodied species will be the most likely to become extinction.

If only one MSL were to be implemented, then the model suggests this should be set at 25 cm. With moderate fishing pressure, this actually results in a slightly lower relative yield than no MSL (79% cf. 82%) but also reduces the species that are vulnerable to extinction from nine to six. With heavy fishing pressure, a single 25 cm MSL improves a potential yield from ~42% to ~52% and reduces the species at risk of extinction from 38 to 35.

The model optimizes two MSLs by giving protection to both small species with a 25 cm MSL, and larger species with a 55 cm MSL. Under this scenario, with moderate fishing pressure, no species are prone to extinction and potential yield increases ~89%. With heavy fishing pressure 21 species remain prone to extinction but potential yield increases to ~63%.

The model sets three MSLs to protect small species with a 25 cm MSL, mid-sized species with a 50 cm MSL and large species with an 85 cm MSL. Yields under heavy fishing pressure increase to ~74% and >90% with moderate fishing pressure. This scenario predicts that five, mainly mid-sized species, remain prone to extinction at high fishing pressure (*Acanthurus xanthopterus, Cephalopholis argus, Gymnocranius grandoculis, Lutjanus gibbus, Naso hexacanthus*).

Four MSLs are optimized with one (25 cm) protecting small fish and three protecting mid and large species (40, 55, 85 cm). Under heavy fishing pressure potential yields increase to ~83% and ~96% with moderate fishing pressure. Three mid-sized species are still predicted to go extinct with high fishing pressure (*Naso annulatus, N. unicornis, Plectorhinchus albovittatus*).

Table 2. Tabulated modelling results showing for each number of minimum size limits (0–14 first column) the expected percentage of potential yield relative to the maximum possible yield, and numbers of species extinction at moderate (*F* = 0.3) fishing pressure (columns 2 and 3) and high (*F* = 0.9) fishing pressure (columns 4 and 5), and the number of species grouped into each MSL category from 25–90 cm (columns 6 to 20).

Number of size limits	Potential yield with moderate fishing pressure (% of max. possible)	Number of species extinct with moderate fishing pressure	Potential yield with high fishing pressure (% of max. possible)	Number of species extinct with high fishing pressure	Number of species (n) in each size limit category (cm)														
					20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
0	81.7	9	42.5	38															
1	79.0	6	51.6	35		74													
2	88.8	0	63.3	21		49						25							
3	90.2	0	73.8	5		38					25							11	
4	94.6	0	82.9	3		27			22			18						7	
5	95.6	0	84.7	1		27			22			14			7				4
6	96.2	0	92.6	0		20		16		13		14			7				4
7	97.3	0	95.3	0	13	14		11		11		14			7				4
8	97.6	0	95.8	0	13	14		11		11		14		4		3			4
9	98.4	0	96.2	0	13	14		11		11		14		4		3			4
14	99.0	0	98.7	0	7	14	6	11	3	8	4	5	5	4	2	1		3	1

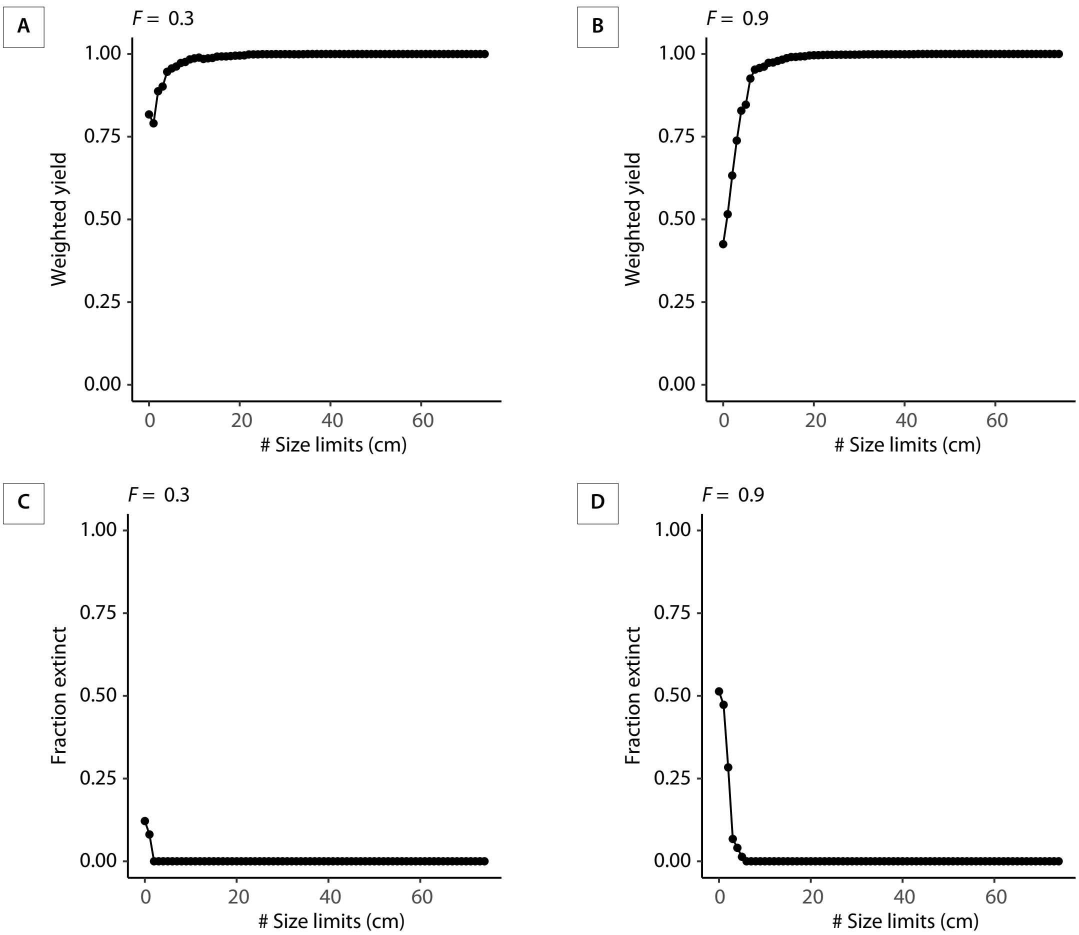

Figure 1. Plots of estimated relative yield (plots A and B) and proportion of the 74 species prone to extinction (plots C and D) by number of minimum size limits (x-axis) under scenarios of moderate fishing pressure (*F* = 0.3) in plots A and C, and heavy fishing pressure (*F* = 0.9) in plots B and D.

Table 3. The species predicted to be left vulnerable to extinction with heavy fishing pressure ($F = 0.9$) under each number of minimum size limits (0–5). Species extinctions are predicted to be prevented with six minimum size limits.

Number of size limits

0	1	2	3	4	5
Acanthurus xanthopterus	*Acanthurus xanthopterus*	*Acanthurus xanthopterus*	*Acanthurus xanthopterus*	*Naso annulatus*	*Naso unicornis*
Bolbometopon muricatum	*Bolbometopon muricatum*	*Bolbometopon muricatum*	*Cephalopholis argus*	*Naso unicornis*	
Caranx ignobilis	*Caranx ignobilis*	*Caranx sexfasciatus*	*Gymnocranius grandoculis*	*Plectorhinchus albovittatus*	
Caranx sexfasciatus	*Caranx sexfasciatus*	*Cephalopholis argus*	*Lutjanus gibbus*		
Cephalopholis argus	*Cephalopholis argus*	*Cetoscarus oscellatus*	*Naso hexacanthus*		
Cetoscarus oscellatus	*Cetoscarus oscellatus*	*Cheilinus undulatus*			
Cheilinus undulatus	*Cheilinus undulatus*	*Chlorurus microrhinos*			
Chlorurus microrhinos	*Chlorurus microrhinos*	*Epinephelus coioides*			
Epinephelus caeruleopunctatus	*Epinephelus caeruleopunctatus*	*Epinephelus fuscoguttatus*			
Epinephelus coioides	*Epinephelus coioides*	*Epinephelus tauvina*			
Epinephelus cyanopodus	*Epinephelus cyanopodus*	*Gymnocranius grandoculis*			
Epinephelus fuscoguttatus	*Epinephelus fuscoguttatus*	*Lethrinus erythracanthus*			
Epinephelus maculatus	*Epinephelus maculatus*	*Lethrinus xanthochilus*			
Epinephelus ongus	*Epinephelus polyphekadion*	*Lutjanus gibbus*			
Epinephelus polyphekadion	*Epinephelus tauvina*	*Monotaxis grandoculis*			
Epinephelus tauvina	*Gymnocranius grandoculis*	*Naso annulatus*			
Gymnocranius grandoculis	*Lethrinus erythracanthus*	*Naso unicornis*			
Lethrinus atkinsoni	*Lethrinus nebulosus*	*Naso vlaminghi*			
Lethrinus erythracanthus	*Lethrinus xanthochilus*	*Plectorhinchus albovittatus*			
Lethrinus nebulosus	*Lutjanus bohar*	*Scomberomorus commerson*			
Lethrinus xanthochilus	*Lutjanus gibbus*	*Sphyraena barracuda*			
Lutjanus bohar	*Monotaxis grandoculis*				
Lutjanus gibbus	*Naso annulatus*				
Monotaxis grandoculis	*Naso hexacanthus*				
Naso annulatus	*Naso unicornis*				
Naso brevirostris	*Naso vlamingii*				
Naso hexacanthus	*Plectorhinchus albovittatus*				
Naso unicornis	*Plectorhinchus chaetodonoides*				
Naso vlaminghi	*Plectorhinchus gibbosus*				
Plectorhinchus albovittatus	*Plectropomus laevis*				
Plectorhinchus chaetodonoides	*Plectropomus leopardus*				
Plectorhinchus gibbosus	*Scomberomorus commerson*				
Plectropomus laevis	*Sphyraena barracuda*				
Plectropomus leopardus	*Sphyraena jello*				
Scomberomorus commerson	*Symphorus nematophorus*				
Sphyraena barracuda					
Sphyraena jello					
Symphorus nematophorus					

The model spaces five MSLs relatively evenly across the size range (25, 40, 55, 70, 90 cm). Yields increase to ~85% with heavy fishing pressure, and ~96% with moderate fishing pressure. Only one species, *N. unicornis*, remains vulnerable to extinction with high fishing pressure.

Six MSLs are apparently optimal with no species being left prone to extinction under moderate or high fishing pressure. Relative yields remain ~96% of the maximum potential under moderate fishing pressure but increase to ~93% under heavy fishing pressure. The application of additional MSLs is predicted to result in only marginal yield increases (Table 2). In these cases, the model redistributes the small and mid-sized MSL categories, placing them at 25 cm and 35 cm to protect a wide range of the small-bodied emperors, goatfish, groupers, snappers, surgeonfish, parrotfish and rabbitfish (e.g. *Acanthurus lineatus, A. xanthopterus, Cephalopholis miniatus, Epinephelus fasciatus, Lethrinus harak, L. obsoletus, Lutjanus gibbus, Parupeneus barberinus, Scarus ghobban, S. rivulatus, Siganus vermiculatus*), and 45 cm and 55 cm to protect mid-sized groupers, jacks and parrotfish, along with the larger emperors, snappers, surgeonfish and sweetlips (e.g. *Caranx melampygus, Chlorurus microrhinos, Epinephelus caeruleopunctatus, Hipposcarus longiceps, Lethrinus olivaceus, L. xanthochilus, Lutjanus bohar, Naso unicornis, Plectropomus aerolatus, Plectorhinchus chaetodoinoides*) and using MSLs at 70 cm and 90 cm to protect 12 of the largest bodied species (including *Bolbometopon muricatum, Caranx ignobilis, Cheilinus undulatus, Plectropomus laevis* and *Scomberomorus commerson*).

Discussion

Interpreting model results

Our results suggest that without management >57% of the potential reef fish yield and 38 of the 74 species in the modelled assemblage will be lost in Fiji, but that a system of six MSLs set at 25, 35, 45, 55, 70 and 90 cm can protect ~93% of the yield and prevent extinctions.

We should not, however, rush blindly into applying these 'research results' too literally. All models are limited by the simplifying assumptions used within them to approximate the real world. The effects of these assumptions need to be considered when interpreting results. The most important assumptions to be mindful of here are: 1) that the size at which fish are selected for catching is fixed at the sizes we determined from our samples; and 2) that fishing pressure is applied equally across all the species. The effect of this first assumption will be to underestimate the long-term loss of species and yield under the heavy fishing pressure scenarios. The second will cause our results to over-emphasise the need to protect small-bodied species with MSLs.

Observing reef fish fisheries across PICTs reveals that the size of the fish being selected for catching depends on the depletion of a fishery; where large species are available to be caught, fishers target them in preference to catching smaller fish, but as large fish become scarce, fishers respond by targeting progressively smaller fish. This is seen by comparing catch compositions between countries, and between regions close to population centres with those from remote lightly fished areas. Fisheries ecologists call this process fishing down the food web (Pauly et al. 1998). Our model cannot take this into account; instead we assume that the size of fish being selected will remain as measured by our sampling. If this were true some species, and a level of yield, would be protected in the long-term, which is what our model predicts; but in reality, as fishers respond to depleting stocks by targeting smaller and smaller fish the loss of yield and species will be greater than our results suggest. This then sets the sobering context of why effective management of reef fish is needed in Fiji and other PICTs; more than 57% of the potential yield and more than 38 of the 74 species modelled will eventually be lost without it – a reality that has already been observed in many places, including close to the main urban centres of Fiji.

The positive side of our model's inability to describe the flexible way in which fishers target catch (by size and species) is that our results over-emphasise the need to manage small-bodied species if the more highly preferred large-bodied species are successfully managed. Smaller species only begin to be depleted once the larger species become scarce, which leave fishers with no other choice. If the abundance of larger species can be restored or maintained with effective MSLs, there will be less need for the smallest MSL categories. Thus while our results suggest placing MSLs first on the small species, where there is higher biomass, a higher priority should, in fact, be placed on protecting the larger bodied species with MSLs, as this will also give some level of protection to smaller bodied species.

Moving towards implementation

In turning these model results into policies that can be implemented, the human side of this equation will also have to be considered. The job of fisheries managers is after all more about managing humans than fish. Successful implementation requires fisheries science to be blended carefully with an understanding of human nature, and an acceptance of what is humanly possible.

Effective monitoring and enforcement is clearly essential to support successful implementation, especially at the outset to ensure a new system becomes quickly embedded as normal behaviour. The building of community support – so that compliance comes voluntarily, rather than by compulsion through enforcement – reduces the workload of enforcement officers. Two critical factors will largely determine the ease of implementation: how compatible our system is with local fish names, and the degree of hardship caused by implementation.

Species identification and local names

Our modelling implicitly assumes all species can be distinguished from each other and separated into the MSL categories. In reality, many species are so difficult to distinguish from each other that trained fish biologists using Fish-ID books commonly struggle. In Fiji, and throughout the Pacific Islands region, local names are commonly not species-specific, and are more a case of similarly sized species from the same genus or family being lumped together. Without targeted training, community members perceive the specific differences that taxonomists focus on as just being a normal variation within a type of fish – much as people have differing body shapes and facial appearances. To facilitate successful implementation, the system of MSLs that is being developed must work with, rather than against, local naming systems.

In all countries the complex of similarly appearing small-bodied emperors are difficult to distinguish, and Fiji is no exception. At least seven species are found in Fiji, *Lethrinus atkinsoni, L. harak, L. lentjan*, *L. obsoletus, L. ornatus, L. rubrioperculatus, L. semicinctus*, but the average Fijian only distinguishes between those with a longer body shape and more slanting snout, which they call *kabatia*, and those with a deeper body and more vertical snout, which they call *sabutu*. Complicating the situation further, there is apparently some variability in species composition between regions and despite the Ministry of Fisheries' best efforts to standardise and expand these root names with species specific qualifiers (e.g. *kabatia dina, kabatia gusudamu,* or *sabutu dina, sabutu levu, sabutu-ni-cakau*), there are some variation in each area as to which species the root names refer to (A. Batibasaga *pers. comm.*). Given the difficulty that many people have distinguishing these species, it would be easiest to apply the same MSL to this entire group of species. Fortunately, many of the species have SoMs in the 20–24 cm range and the model places them together in the 25 cm MSL, including the most common (overall) species in our samples (*Lethrinus harak*) and the fifth (*L. obsoletus*) and sixteenth (*L. lentjan*) most common; however, the fourth most abundant species *L. atkinsoni* (*sabutu*) has a larger SoM (25 cm) and is placed in the 35 cm MSL. Placing the smaller species into the 35 cm MSL will severely limit catches, as even without fishing few can grow as large as 35 cm, but placing *L. atkinsoni* into the 25 cm MSL will leave it relatively unprotected where fishing is heavy. Given the issue with how these species are most commonly recognised, a trade-off will be required here between grouping these species together in the 25 cm MSL for ease of identification, and fully protecting *L. atkinsoni* with the larger 35 cm MSL.

Smaller parrotfish are grouped similarly into two groups, which vary and overlap between regions: *rawarawa* being generally applied to *Chlorurus bleekeri*, *Scarus rubroviolaceus, S. globiceps, S. ghobban, S. niger, S. rivulatus*; and *ulavi* mainly to *Hipposcarus longiceps*, but also in some cases to *S. rubroviolaceus* and *S. ghobban*. For ease of implementation it would be best to cover all these species with the same MSL and the model suggests most of the *rawarawa* can be protected with the 35 cm MSL; however, *S. rubroviolaceus* and *H. longiceps* have larger SoMs (36–37 cm) and belong in the 45cm MSL. Being the third most common species in our samples, *H. longiceps* is an important species, and at the risk of causing some confusion with names, may well require the protection of the 45 cm MSL.

Local naming conventions will also necessitate trade-offs between surgeon fish in the *Naso* genus, which Fijians lump together as *ta*. By far the most important species in the catch is *Naso unicornis* (SoM = 37 cm), which the model protects with the 45 cm MSL; however, the minor *ta* species vary in size, *N. brevirostris* (SoM = 25 cm), *N. vlamingii* (SoM = 32 cm), *N. hexacanthus* (SoM = 48 cm), and are placed in the 35, 45 and 55cm MSLs, respectively. For the sake of maintaining yield and protecting the main species *N. unicornis*, the minor species would have to be placed in the same 45 cm MSL, meaning *N. vlamingii* would be over protected and under fished, while *N. hexacanthus* would be left vulnerable to depletion if fishing pressure becomes too heavy.

Trade-offs will also be required among the small-bodied lutjanids if they are to be included in the system of MSLs. Fijians lump many of these species under the name *kake*, which includes the smaller bodied *Lutjanus fulvus* (SoM = 20 cm) and *L. semicinctus* (SoM = 22 cm), which are placed in the 25 cm MSL, and the larger *L. monostigma* (SoM = 33 cm) for which the 45 cm MSL is suggested. However, unlike the species groups discussed above, none of these small snappers are highly targeted or very important in the catch at this time, so the impact of a smaller MSL for *L. monostigma* may be minimal, and leaving these species out of the system entirely might also be considered.

Food security in the short- to medium-term

In developing an implementation strategy, the most important factor to plan around is the short- to medium-term impact on food security.

Implementing a system of MSLs where none has existed before will inevitably cause an initial reduction in the amount of fish that can be legally caught, as small fish that could previously be landed must be left to grow through to the new MSL before they can be legally retained. The extent to which catches will be depressed and the time taken to recover depends on the growth rates of the fish and how depleted the stocks are when the MSLs are implemented.

The small and mid-sized reef fish grow relatively rapidly and most will grow from current sizes through to the MSLs being recommended in just 6–12 months. During that process, although only increasing about 10–20% in average length, they will almost double in weight. This means that if communities comply with the new MSLs, they will have reduced catches for 6–12 months before their catches recover and they are rewarded with a greater weight of fish to catch and higher catch rates than before the MSLs were implemented. After that, their catches and catch rates should continue to gradually improve for anything up to 5–10 years, just depending on how depleted their stocks were in the first place. However, if badly depleted to start with, the catch of larger bodied slower growing species could take 2–3 years to recover to pre-implementation levels before they start increasing above that level.

The issue for successful implementation is that no matter how strongly motivated communities start out being, and how rigorous the monitoring and compliance, or how effective the community education programme is, the reality is that people will not starve themselves, or send children to school hungry, just for the promise of a better future. Instead, they will find some way of being non-compliant to avoid starvation. The bottom line for a successful implementation is the extent to which it threatens food security in the short- to medium-term. If the initial period of 'belt tightening' is too extreme, compliance will be poor, and implementation will fail, because the expected long-term benefits will not materialise, leaving the fledgling system of MSLs dead in the water.

Conclusions

Unmanaged fishing of reef fish poses a major threat to food security and biodiversity for PICTs. The results of our modelling suggest that without effective management >57% of potential yields and more than half the main species will eventually be lost. Our modelling studies suggest that in Fiji a relatively simple form of management with six MSLs set at 25, 35, 45, 55, 70 and 90 cm could preserve ~93% of potential yields and prevent extinctions. The challenge confronting fisheries managers is how to adapt and apply these research results to the reality of managing artisanal fishers in the real world.

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Working with sellers at the Labasa municipal market, Fiji, to sample coral reef fish (image: Sangeeta Mangubhai).

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