

# Fisheries

## Newsletter

# 162 | May–August 2020



Pacific  
Community  
Communauté  
du Pacifique



ISSN 0280-0735

SPC  
activities



Regional  
news



Feature  
articles



FAME

Fisheries,  
Aquaculture  
and Marine  
Ecosystems  
Division



# In this issue



## SPC activities

- 3 How the Pacific Community contributes to the annual WCPFC Scientific Committee meeting  
*by Graham Pilling*
- 6 Back to the ocean  
*by Bruno Leroy and Valérie Allain*
- 10 Let them go: Release undersized, untargeted or unwanted fish!  
*by Céline Muron and William Sokimi*
- 13 From luxury lotions to tasty local dishes  
*by Avinash Singh*
- 14 Tilapia feed trials conducted at the Navuso Agricultural Technical Institute in Fiji  
*by Avinash Singh*



## News from in and around the region

- 16 The return of the true giant clam to Kosrae  
*by Martin Selch*
- 17 A roadmap for electronic monitoring in regional fishery management organisations  
*by Mark Michelin et al.*
- 23 A survey of the number of coastal fishing vessels in Fiji  
*by Robert Gillett*
- 27 Using local knowledge to guide coconut crab science in Fiji  
*by Epeli Loganimoce et al.*
- 32 Developing participatory monitoring of community fisheries in Kiribati and Vanuatu  
*by Neil Andrew et al.*
- 39 A novel participatory catch monitoring approach: The Vanuatu experience  
*by Abel Sami et al.*



## Feature articles

- 46 Population genetics: Basics and future applications to fisheries science in the Pacific  
*by Giuliana Anderson et al.*
- 58 Spawning potential surveys in Solomon Islands' Western Province  
*by Jeremy Prince et al.*

page 8

page 30

page 42



# How the Pacific Community contributes to the annual WCPFC Scientific Committee meeting

*An interview with Dr Graham Pilling, Deputy-Director of the Pacific Community's Fisheries, Aquaculture and Marine Ecosystems Division (Oceanic Fisheries Programme).*

## What is the Scientific Committee meeting?

This is a key meeting supporting the work of the Western and Central Pacific Fisheries Commission (WCPFC), whose goal is to conserve and manage tuna and other highly migratory fish stocks across the western and central Pacific Ocean (WCPO). The Scientific Committee (SC) meeting is held in August each year, prior to the annual Commission meeting in December. The SC is composed of the 33 WCPFC member countries and territories, and it scrutinises a range of scientific issues, including data and statistics, stock assessments, management issues, and ecosystem and bycatch mitigation.

The Pacific Community's Oceanic Fisheries Programme (SPC OFP) has been the Commission's Science Services Provider and Data Manager for almost 15 years, which means that the SC meeting is a key opportunity to present SPC OFP's analyses and inform scientific advice from SC on which the Commission will base its fishery management decisions.

## What process did SPC follow to submit the scientific papers?

Each SC meeting defines the stock assessments to be developed by OFP for the following year. This year, the two key SPC assessments were WCPO bigeye and yellowfin tuna.

There are many key inputs to these assessments, and I'll give an example of two. First, we need to understand the biology of each tuna stock, to gauge how they may have reacted to fishing pressure. A key part of this is understanding how tuna grow. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia led work developing new information on bigeye and yellowfin growth this year. They used tuna otoliths (ear bones) collected within the WCPO by scientists and fishery observers to provide information on the age of tuna at different sizes. This work refined our understanding of growth for bigeye tuna, which has previously had a significant impact on the results of our assessments.<sup>1</sup> For WCPO yellowfin tuna, CSIRO's work since 2019 provided our first otolith-based understanding of growth, which was used in a yellowfin stock assessment. Another key input is the information available from fishing

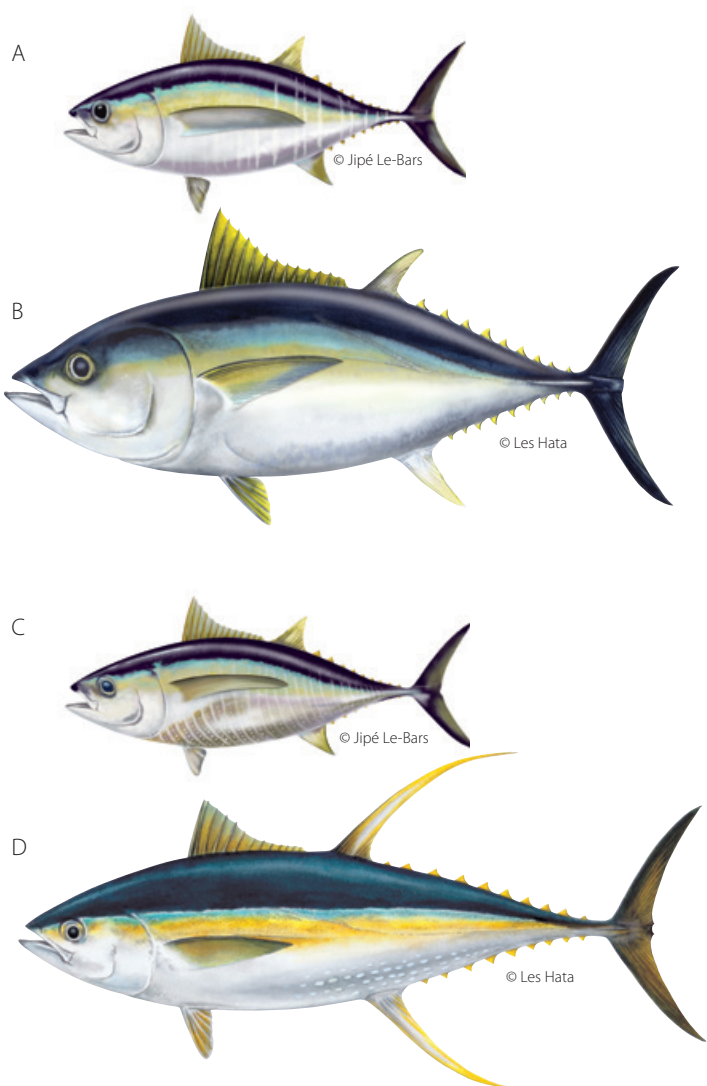


Dr Graham Pilling (image: Toky Rasoloarimanana, ©SPC)

vessels and fishery observers on the levels of catch taken by different fishing gear within the Pacific Ocean. SPC manages the data for the WCPFC and for SPC members, and the annual statistics are submitted to us by members by the end of April in the following year. Once all inputs are available, our assessment scientists need to work incredibly long hours to develop and refine each stock assessment to ensure they represent the best scientific information prior to the deadline for papers to be submitted to the SC – often less than three months after the data are received.

During the development and production of SC papers, OFP holds regular internal meetings to refine analyses. Then, before papers are submitted to SC, we also perform internal peer reviews to “sign off” each paper to ensure that scientific quality is maintained.

<sup>1</sup> See: Hampton J. 2017. What is going on with bigeye tuna? SPC Fisheries Newsletter 153:24–29. Available at: <http://purl.org/spc/digilib/doc/76mjb>



The two key stock assessments presented by SPC to the WCPFC Scientific Committee in 2020 were WCP bigeye (A, B) and yellowfin (C,D) tuna.

Papers for the SC must be submitted to WCPFC over two weeks before the meeting starts, so well before the end of July. This ensures that all members have time to read and consider them. Then, when the SC meets, members will have had time to prepare their questions and statements on the work.

SPC is not the only organisation submitting papers to SC, but OFP's staff significantly contributed to 70 papers this year – over 75% of the papers submitted. OFP's output at SC16 represents a group effort that could not have been achieved without the hard work undertaken by all 60+ staff in OFP, and in particular the 22 OFP staff that were lead authors. Our papers represented key inputs to support the stock assessments themselves,

informed SC of the status of data collection and fishery knowledge, provided scientific information to support advice on fishery management approaches, or provided information on the wider WCPO ecosystem, climate change and fishery impacts. All papers are freely available on the WCPFC website at: <https://www.wcpfc.int/meetings/16th-regular-session-scientific-committee>

## Once the papers are completed, is OFP's work for the SC meeting finished?

OFP's work for SC does not end once the papers are submitted. Prior to the SC meeting, we provide scientific support to members of the Pacific Islands Forum Fisheries Agency and the Parties to the Nauru Agreement in SPC's role supporting Pacific Island countries and territories, to ensure they can take full account of the scientific information being provided within their decision-making.

During the SC meeting itself, we present our papers and respond to scientific questions that SC members have on the work and our recommendations, which represents a further peer review of our work. The meeting generally runs for more than a week, during which we continue to deliver scientific advice on all subjects, in what are usually very intense sessions.

## Why is this annual tuna scientific assessment process important?

Given the value of the tuna fishery to all members, as well as the global importance of the fishery – this region supplies over half of the world's tuna – the sustainability of our tuna stocks and fisheries is of paramount importance. The stock assessments provide the clearest indication of stock status and underpin further analyses to identify whether current fishery management regimes are likely to maintain the stocks at healthy levels. In turn, they form key building blocks of the "harvest strategy" management approach that WCPFC is undertaking to help ensure long-term stock health. By the end of the meeting, all members agree on scientific advice and recommendations to the Commission meeting, including in particular the status of assessed stocks and any scientific recommendations on actions needed to ensure fishing remains sustainable.

## What was different about the 2020 SC?

Our approach to delivering the stock assessments and range of papers to the 16<sup>th</sup> SC meeting this year were no different from any other year. However, the COVID-19 pandemic has had a massive impact on regional fishery management processes in the Pacific,<sup>2</sup> and the SC meeting itself did not

<sup>2</sup> See: Smith N. 2020. How the COVID-19 crisis is affecting Pacific Island fisheries and aquaculture. SPC Fisheries Newsletter 161:2–3. Available at: <http://purl.org/spc/digilib/doc/cz32c>



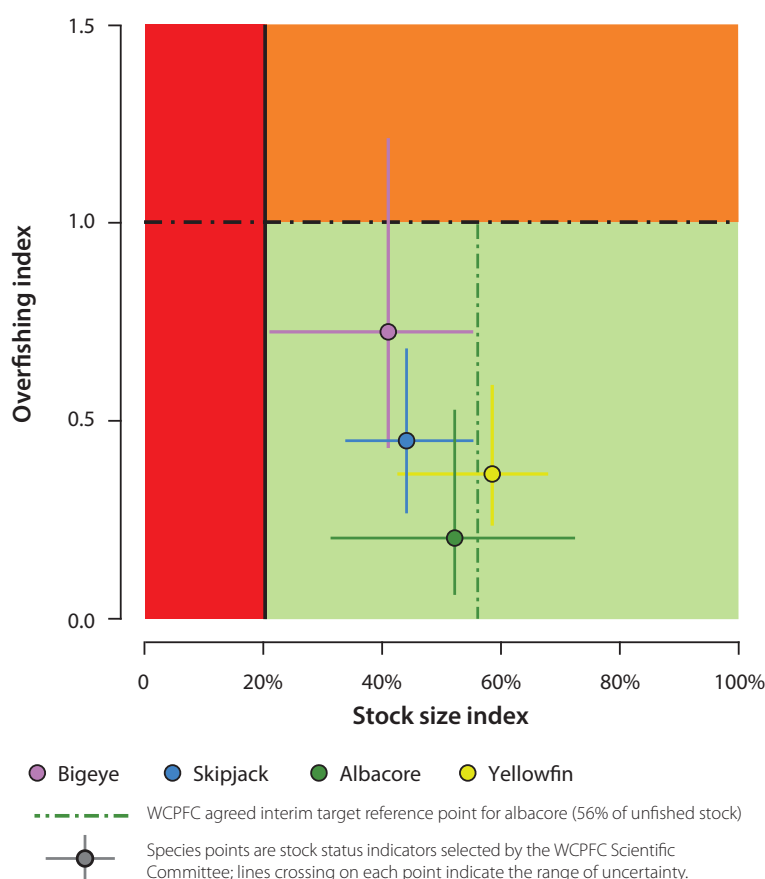


Figure 1. Stock status of the four main tuna species in the western and central Pacific Ocean.

escape the effects. This year's SC meeting was held online, with a shortened agenda that covered only essential issues that required SC advice to the Commission. To help deal with other important issues, an "online forum" was set up by the WCPFC Secretariat prior to the meeting to get written responses from members. In general, while the level of discussion was less than it would have been during a physical meeting, and we could not discuss all the papers submitted, this year's SC process worked pretty well, and the bigeye and yellowfin tuna assessments were agreed as being the best scientific information available, and indicate that these stocks are in the green (safe) zone of the Majuro plot (Fig. 1). But I hope we can meet face-to-face next year.

## Speaking of next year, what's next?

For the remainder of this year, we will be providing scientific support to members of WCPFC's Technical and Compliance Committee, which meets in September, and the Commission meeting itself in December. We already have tasks from SC16 for further scientific analyses to be performed and presented to the meetings this year to help inform discussions.

Our work for next year's SC started as soon as SC16 had agreed on its recommendations. Next year, we are scheduled

to assess South Pacific albacore tuna and Southwest Pacific swordfish stocks, with an assessment of South Pacific blue shark awaiting funding decisions. We are also directed to investigate and develop further this year's yellowfin tuna assessment, with an external peer review scheduled for 2022.

So, we have already started reviewing recommendations that arose during the previous assessments of albacore and swordfish, and started specific projects to analyse biological information to address some of these recommendations and help inform the assessments and continue to ensure that the best scientific information is available for managers to make decisions.

Another busy year ahead!

### For more information:

Graham Pilling  
Deputy-Director, FAME Oceanic Fisheries  
Programme  
grahamp@spc.int

## Back to the ocean

*Going to sea to collect new scientific information is part of the core business of the Pacific Community (SPC), and despite the challenging COVID-19 situation, SPC is soon embarking on two expeditions to learn more about tunas.*

### Tuna tagging

The Pacific Tuna Tagging Programme (PTTP) was launched in 2006 and, since then, at least one cruise per year has been implemented in the western and central Pacific Ocean (WCPO) by SPC. The relevance of tagging large quantities of tagged tunas on an annual basis to better monitor their stocks was standardised in 2016<sup>1</sup> by the Western and Central Pacific Fisheries Commission (WCPFC).

After the 2019 Western Pacific pole-and-line cruise, which successfully released over 16,600 tagged tunas in waters of Papua New Guinea, Palau and the Federated States of Micronesia,<sup>2</sup> the PTTP had planned to organise in 2020 a central Pacific (CP) cruise<sup>3</sup> to depart from Funafuti in Tuvalu. Tuvalu's waters are traversed by a very high density of drifting fishing aggregating devices (dFADs), deployed by the tuna purse-seine fishery (Fig. 1). As the present principal goal of the CP cruise research is to focus on tuna aggregating around those dFADs, the choice of Funafuti as an embarking/disembarking point for scientists would save many

steaming days compared to previous central Pacific (#12 and #13) cruises<sup>4</sup> that started from Majuro in the Marshall Islands (Fig. 1).

Alas, this plan was ruined by the COVID-19 pandemic and the unprecedented travel restrictions that were imposed by Pacific Island nations to protect their populations from the virus. As with the vast majority of Pacific Islands, Tuvalu closed its borders to both non-essential air and boat access. To maintain the continuity of the long-recorded series of tuna monitoring, SPC has modified the cruise design (Fig. 2) to minimise the potential for homeport infection rates and onboard incidence, as well as ensuring avoidance of port calls to any Pacific Island country or territory. The vessel will depart from Honolulu and head south to the equator, undertaking research in the high seas and exclusive economic zone of Kiribati (Line and Phoenix Islands). All persons (five scientists and five crew) will isolate for 14 days prior to departure and must present a negative COVID-19 test before departure. The vessel will return to Honolulu after 50 days at sea with no port calls to other locations.

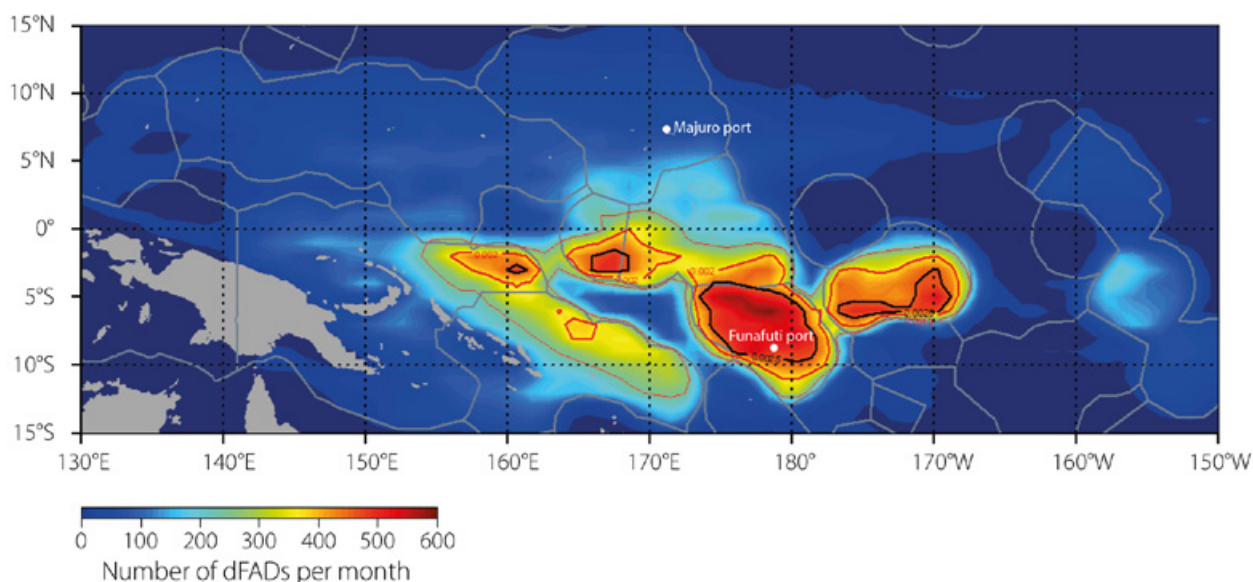


Figure 1. 2018 FAD density per month per 1 x 1 degree. From: Escalle L., Muller B., Hare S., Hamer P., Pilling G. and PNAO. 2020. Report on analyses of the 2016/2020 PNA FAD tracking programme. WCPFC Scientific Committee. WCPFC-SC16-2020/MI-IP-14.

<sup>1</sup> See: <http://purl.org/spc/digilib/doc/kgmrk>

<sup>2</sup> See: <http://purl.org/spc/digilib/doc/ek462>

<sup>3</sup> See: <http://purl.org/spc/digilib/doc/waw9f>

<sup>4</sup> CP12 and CP13 cruise reports are available from: <https://tagging.spc.int/en/publications/tagging-publications/viewcategory/12-phase-2-central-pacific>



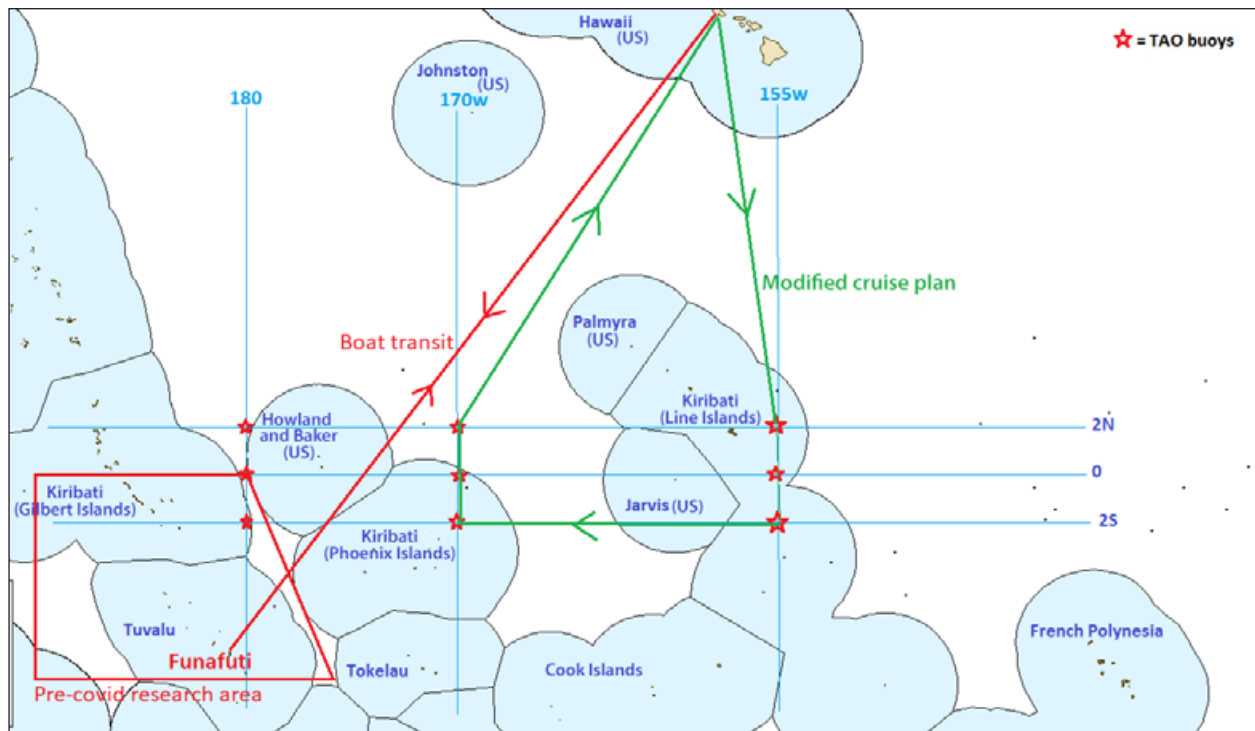


Figure 2. CP14 cruise plan; red indicates the previous scheduled research area, green indicates the modified cruise plan.

The current main goals of the CP cruises are to augment data collection for studies on tuna movements, exploitation rates and FAD association dynamics. The CP14 research cruise, in addition to continuing routine tuna tagging activities, will test innovative sampling methods for enhanced molecular analyses that can be used to quantify the structure and behaviour of tuna populations. The research cruise will also visit the Phoenix Islands Protected Area (PIPA) to

collect information on tuna residence time and movements in relation to this large marine reserve.

Thirteen CP cruises have already been conducted, resulting in over 44,000 tags placed on tunas that were caught and released, including 1162 archival tags mostly placed on big-eye tuna (Fig. 3), which were caught on schools associated with dFADs and the Tropical Atmosphere Ocean (TAO)

Figure 3. Target species for the central Pacific tagging experiments: the bigeye tuna. Here, a nice specimen is ready to be released after being inserted with an archival tag. The blue circle indicates the antenna of the archival tag implanted in the fish's abdomen. (image: ©SPC)







Figure 4. Docked at Kewalo Basin in Honolulu, the FV *Gutsy Lady 4* is in full preparation for CP14 adventures. Note the full fuel totes on the deck, their content will be transferred to the boat tanks during the transit time to the fishing grounds. (image: ©SPC)

buoys anchored along the meridians 140°W, 155°W, 170°W, 180° and 165°E, mainly between 5°N and 5°S.

From cruise CP1 to CP9, tagging results only relied on the presence of bigeye aggregations around the TAO buoys.

Since CP10 (2014), agreements with purse seine (PS) fishing companies provided, during FAD fishing closure period, full access to their FADs in areas where the tagging vessel operated during the cruise. It should be noted that the success of the last four cruises was dependent on these dFADs, as no major tuna school was observed around the visited TAO buoys.

Multiple purse-seine companies agreed this year to share their dFADs to facilitate the research in the targeted area. Fishing on these dFAD, which are dispersed among multiple exclusive economic zones and international high-seas pockets in the western Pacific, requires tagging platforms with a very large autonomy.

The FV *Gutsy Lady 4* (Fig. 4) can carry over 100 tonnes of fuel, which allows the vessel to safely cover the huge distances this voyage will require (estimated to be 5000 nautical miles).

As usual, the SPC will soon alert the tag recovery network of the WCPO (and beyond...) to draw its attention to the search for tagged tuna in the catches of the commercial tuna fishery. During CP14, the scientific team will send us weekly reports to be posted on SPC's website: stay tuned!

## Tuna ecosystem

Another important part of the work conducted by SPC at sea is the monitoring of the pelagic ecosystem, and since 2011, SPC has conducted or participated in a dozen scientific cruises. During those cruises onboard research vessels, samples and data on temperature, currents, nutrients, phytoplankton, zooplankton and micronekton are collected. The samples allow SPC to characterise the physical and biological ecosystem in which tuna evolve to better relate variations in tuna abundance to physical and biological parameters, and to ultimately be able to forecast changes in tuna abundance or movement. The research campaign named WARMALIS2020, the first regional cruise of a series of three was planned for this year. It was supposed to start in September and travel from Noumea, New Caledonia to Pohnpei, Federated States of Micronesia within three weeks (Fig. 5).

As with the CP14 tagging cruise, the COVID-19 pandemic had made impossible to travel across the region in 2020; WARMALIS2020 cruise had to be postponed to 2021. If the research vessel *Alis*, based in New Caledonia, cannot touch port outside of New Caledonia's EEZ, it is still possible to work inside it. The scientific team decided to conduct a short four-day technical trial cruise off the coast of New Caledonia. The objective of this short cruise is to develop a new standardised sampling method to collect micronekton from 600-m depth up to the surface, in preparation for the WARMALIS cruises (Fig. 6). This short cruise will be co-organised by SPC and the French Institute for Development Research. Six scientists will participate, including five from SPC, all women.



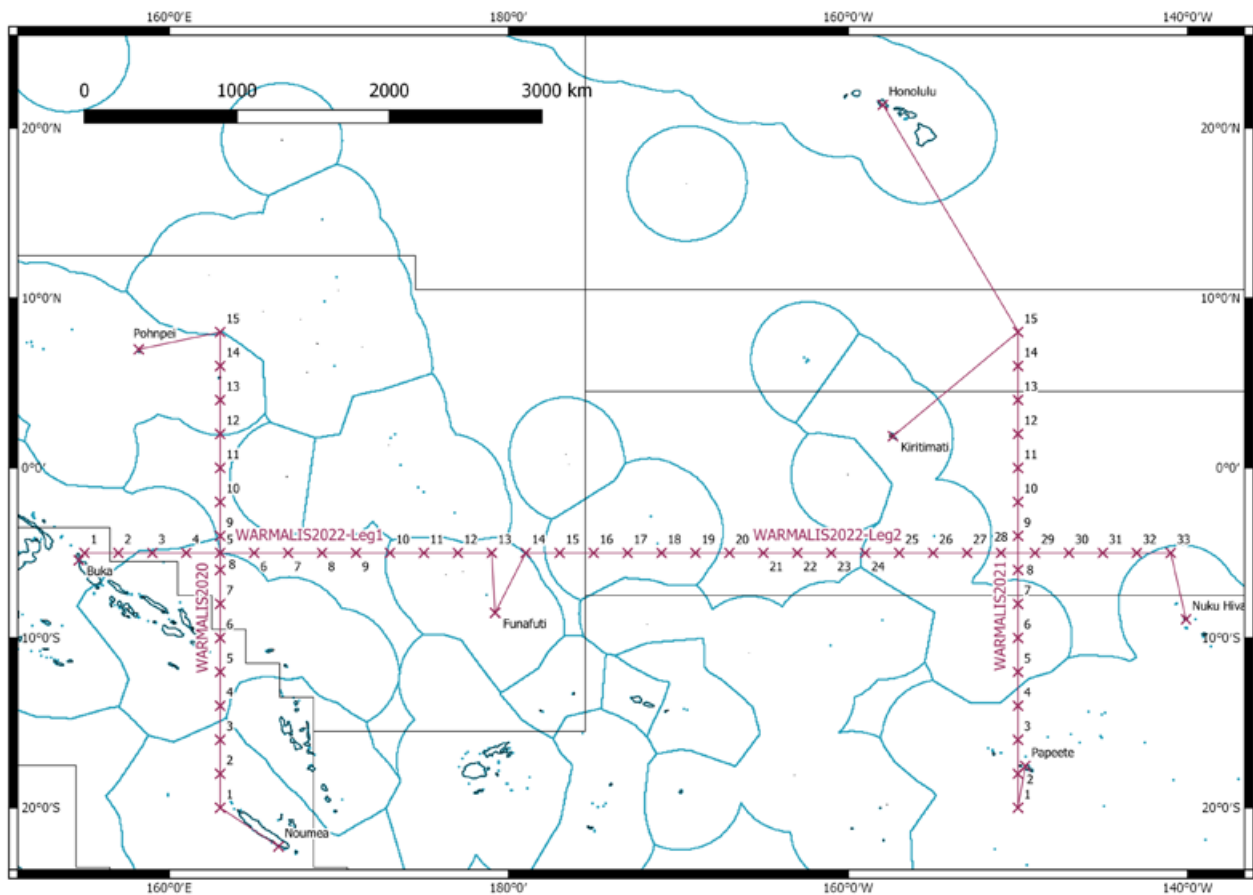


Figure 5. The WARMALIS cruises originally planned for 2020, 2021 and 2022.



Figure 6. Onboard the R/V *Alis*, the crew hauls in the large micronekton net, and specimens collected are then sorted in the small onboard laboratory. (images: ©Valérie Allain, SPC)



#### For more information:

**Bruno Leroy**  
Fisheries Scientist (Ecosystem  
Monitoring), SPC  
[brunol@spc.int](mailto:brunol@spc.int)

**Valérie Allain**  
Senior Fisheries Scientist (Fisheries  
and Ecosystems Monitoring and  
Analysis), SPC  
[ValerieA@spc.int](mailto:ValerieA@spc.int)

## Let them go: Release undersized, untargeted or unwanted fish!

*Is it weird for fishers to release fish? Not at all. It is actually smart to let some fish go back to the ocean, such as fish that are under the minimum size limit or are protected during their spawning season. Fishers who catch them and release them alive give them a chance to reproduce. Also, fish that are poisonous or not edible should go back to the ocean because they help keep the reefs alive and healthy.*

### Fish remain on the surface, sometimes belly up

Have you ever noticed that some released fish remain on the surface, sometimes belly up? That is the result of what is called barotrauma: when you quickly bring a fish from the bottom to the surface, the rapid change in pressure causes the gases in the fish's body to expand. Sometimes it causes the stomach to get pushed out through the mouth and leaves it with swollen eyes.

Why release a fish if it will just float helpless at the surface, ready to be eaten by large predators such as sharks or barracuda? Because, thanks to a specific gear (called descending gear), you can quickly send fish back down to the deep, where the pressure of the gases will go back to normal naturally, allowing it to recover and swim away.

### Field trip

In November 2019, Fiji's Ministry of Fisheries requested the Pacific Community (SPC) to provide advice on simple and practical ways for Fijian fishers to immediately release groupers that they catch incidentally during the four-month grouper ban.

Following this request, SPC worked to produce and test various types of descending gear. A small "SPC grouper release team" (Ian Bertram, Alexandre Brecher, Celine Muron, Watisoni Lalavanua and William Sokimi) was formed in May 2020 to collect information on methods used in other parts of the world, contact a few well-known Pacific Island fishers, and produce several models of descending gear using materials commonly available in the Pacific Islands region. In the middle of the worldwide lockdown due to COVID-19, the team could not travel to Fiji and decided to tap into local networks to finalise the method and produce a training video with images taken locally. The team travelled to New Caledonia south lagoon with local fishers to test the descending gear and refine the method with the help of New Caledonia's Province Sud fisheries authorities. And it worked!

### How to produce and use descending gear

You can make a simple descending gear using a hook, a longline clip or a clothes hanger, and a weight. The idea is to make a special "hook" linked to a weight that will allow the fish to free itself when it reaches the right depth or the bottom. The illustrations displayed on the two following pages detail how to make descending gear, and how to use it.

### A video and brochure to promote the use of descending gear

Using images taken during the field trip as well as illustrations and animated images specifically created for the project, a brochure and a training video have been produced and made available at:

Brochure: <http://purl.org/spc/digilib/doc/zjtmz>

Video: <https://youtu.be/3R2f7pWMisg>

This regional information tool was produced by the Pacific Community thanks to the New Zealand-funded Effective Coastal Fisheries Management project<sup>1</sup> and the Pacific-European Union Marine Partnership Programme.<sup>2</sup>

---

#### For more information:

**Céline Muron**

Coastal and Community Fisheries  
Information and Outreach Officer, SPC  
[CelineM@spc.int](mailto:CelineM@spc.int)

**William Sokimi**

Fisheries development Officer  
(Fishing Technology), SPC  
[WilliamS@spc.int](mailto:WilliamS@spc.int)

<sup>1</sup> The Coastal Fisheries Governance project, officially titled "Improving fisheries food security and sustainable livelihoods for Pacific Island communities", is funded by the New Zealand Ministry of Foreign Affairs and Trade. More information is available at: <https://fame1.spc.int/en/projects/mfat>

<sup>2</sup> Funded by the European Union and the Government of Sweden, the EUR 45 million PEUMP programme promotes sustainable management and sound ocean governance for food security and economic growth, while addressing climate change resilience and the conservation of marine biodiversity. It follows a comprehensive approach, by integrating issues related to oceanic fisheries, coastal fisheries, community development, marine conservation and capacity building under one single regional action.

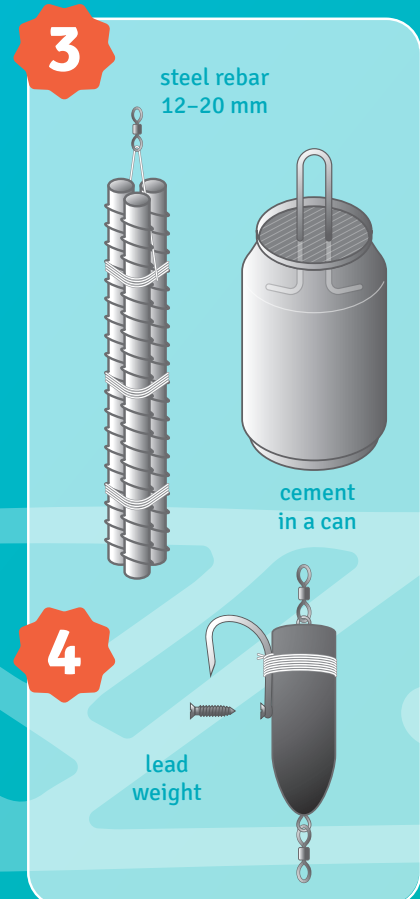
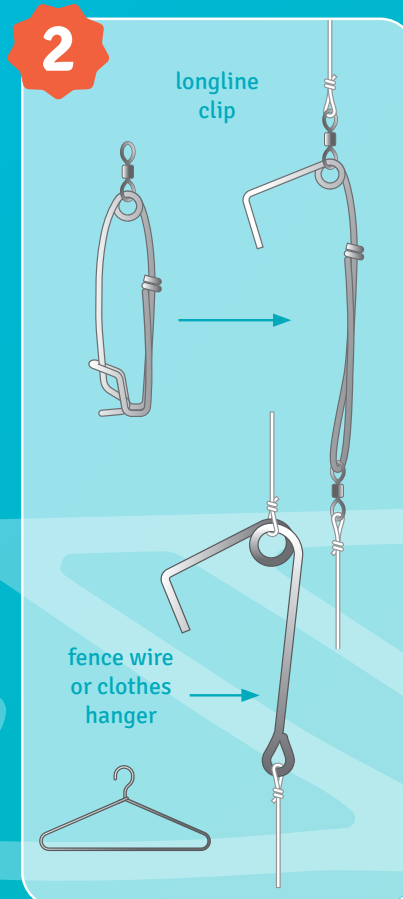
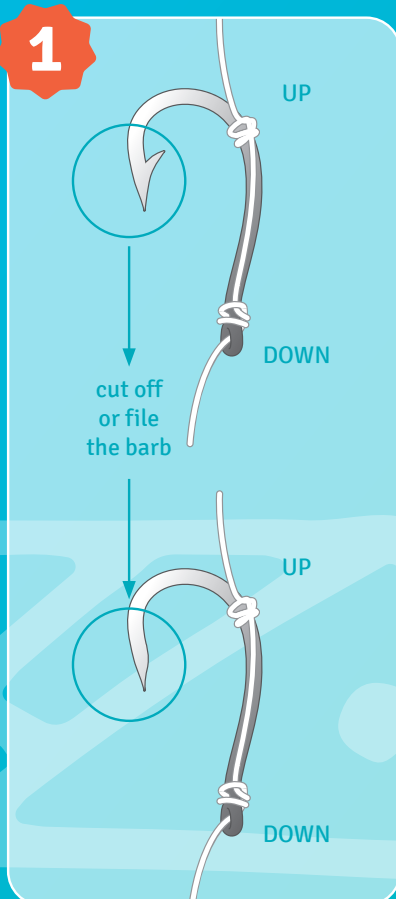


# How to make descending gear?

A descending gear is a device that allows you to take a live fish back down to the bottom.

You can make a simple descending gear using a **hook**, a **longline clip** or a **clothes hanger**, and a **weight**. The idea is to make a special “hook” linked to a weight that will allow the fish to free itself when it reaches the right depth or the bottom.

- 1 If using a large “J” **hook**, you need to cut off or file the barb.
- 2 If using a **longline clip** or a **clothes hanger**, you will have to cut the ends and give it the shape of a big barbless hook. Small gauge (but strong) wire can be easily shaped as release hooks.
- 3 As for the **weight**, it can be made of lead, steel rebar, cans or PVC pipes filled with cement, or any other heavy material.
  - The size of the weight should match the size of the fish released, so it doesn’t go too fast to the bottom.
  - For small fish, 500 grams should be enough. For bigger fish, more than 750 grams may be needed.
- 4 You can also fix the **barbless hook** to the weight.



# How to use descending gear?

You've just caught an undersized, untargeted or unwanted fish. How to deal with it?

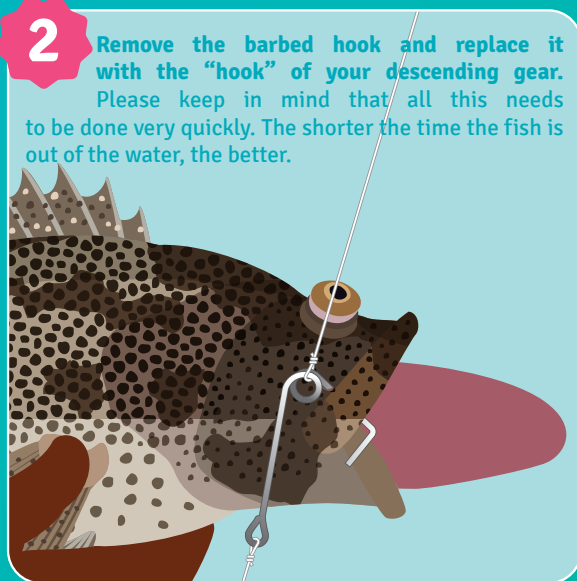
1

Take it out of the water carefully.



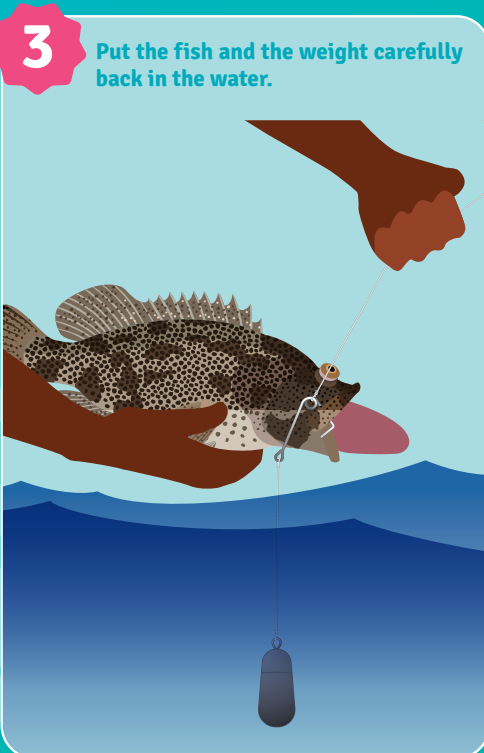
2

Remove the barbed hook and replace it with the "hook" of your descending gear. Please keep in mind that all this needs to be done very quickly. The shorter the time the fish is out of the water, the better.



3

Put the fish and the weight carefully back in the water.

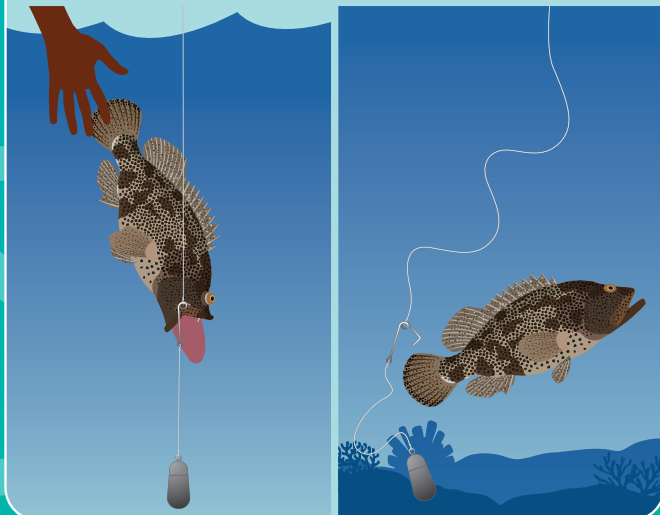


4

Let them sink to the bottom.

The weight will drag the fish down until it reaches the bottom. Then, just give some slack to the line and a little tug, and you will allow the fish to free itself from the hook and swim away for protection.

And that's it!





## From luxury lotions to tasty local dishes

Tonga's *mozuku* seaweed producer reinvents itself to face the challenges of the COVID-19 pandemic.

Three thousand miles from Australia, in the Kingdom of Tonga where there are zero COVID-19 cases, borders are closed due to the global pandemic and local businesses are being severely affected. The South Pacific Mozuku (SPM) company, with support from the Pacific Community's Sustainable Pacific Aquaculture Development Project (PacAqua), has been developing a line of luxury cosmetics and lotions whose key ingredient is the seaweed *mozuku* (*Cladosiphon* sp.) that grows in Tongan waters. Tonga is regularly visited by luxury cruise liners such as *Queen Elizabeth II* that can deliver up to 5000 visitors to Tonga in a single day, but now the number of visitors has dropped to zero. SPM faces a new reality where their intended luxury market for seaweed lotions has evaporated.

"COVID-19 has pretty much decimated the tourist market," said Mr Masa Kawaguchi, Director of SPM who is of Tongan and Japanese descent. "In Japan, I know that *mozuku* is valuable as an edible seaweed. It's very nutritious and reputed to have immune boosting properties. Our best hope now is to pivot away from lotions and find out whether we can launch *mozuku* locally as Tonga's own edible super seaweed".

SPM first developed fresh seaweed packs and started to sell them in two large supermarkets and through a local distributor. However, entering the domestic market has its own challenges, and SPM found that sales were slow in the retail market due to consumers' lack of familiarity with *mozuku* seaweed products, which were not traditionally eaten by Tongans. SPM needed to do more to convince Tongans about the tasty and healthy properties of *mozuku* seaweed, which is known to Tongans as *limu tanga'u*.

By linking with the Tonga Youth Employment Entrepreneurship (TYEE), which provides training in cooking, food packs were developed to increase the visibility of *mozuku* products and make them appealing to Tongan diners. Ms Lusie Latu-Jones of TYEE said, "It is a privilege to use these quality seaweed products from SPM in our meals. We made an attempt to mix the *limu tanga'u* with cherry tomatoes, onions and coconut cream for our meals. I also added a twist of fresh lemon juice to the soy sauce flavour. We served it as mini entrée packs to go with the main meals. Oh, tasty!"

These food packs were then featured by TYEE in a major fund-raising event for their organisation. They organised a *mozuku* tasting and cocktail event, facilitated with The TOP Restaurant and Lounge, a premier eatery in Nuku'alofa, whose chef created dishes using the *limu tanga'u* product as the main feature. TYEE has also set up a successful local competition to create recipes using *mozuku* seaweed.



*Mozuku dishes on display. (image: ©South Pacific Mozuku)*

Mindful of *mozuku*'s reputation in Japan for its strong nutritional and health properties, SPM next linked with Vaiola Hospital to incorporate the seaweed into their Friday lunch menus. Mr Kawaguchi said that, "The feedback we got from the hospital is that people love the seaweed, but they just didn't know it existed! This is what we heard from patients, and even from some doctors and nurses."

Vaiola Hospital's Chief Nutritionist, Esiteli Pasikala, says that "I have served the *mozuku* in Tongan style as *miti limutanga'u* to 45 doctors and nurses during our Friday doctor's lunch hour and to some other workers we invited to test the new dish, and they all liked it. They said it was delicious. They asked me how to find it and I directed them to stores where I knew it was being sold."

SPM is a family-run business that originated in 1998 to export *mozuku* seaweed, trading under the name Tangle Nano Co., Ltd. Mr Kawaguchi states that "My dad ran the business until 2007 when the business died due to the global recession. In 2015, I came back to Tonga to start the business back up, and slowly we have been growing our customer base, not only in Japan but in other markets such as the USA, and we are currently prospecting the Chinese market."

Mr Kawaguchi's dream is to make Tongan *mozuku* a global brand, and his short-time goal is to increase awareness of *mozuku* seaweed in Tonga itself. SPM employs three permanent local staff and 20–30 seasonal staff, depending on the amount of work.

### For more information:

Avinash Singh,  
PacAqua Aquaculture Officer, SPC  
avinashs@spc.int

## Tilapia feed trials conducted at the Navuso Agricultural Technical Institute in Fiji

*The Pacific Community (SPC) and Navuso Agricultural Technical Institute (NATI) in Fiji have been conducting trials of a new Pacific Maleya formulated diet on tilapia. This new diet was formulated by Dr Albert Tacon, world-renowned tilapia feed expert, during a feed training consultancy in 2019.<sup>1</sup> At the conclusion of the seven-month trials at NATI, tilapia were partially harvested using seine nets and sold in fresh bundles on ice to customers after they had been weighed and counted. Similar on-farm trials were also conducted simultaneously at Eden's Garden farm in Nausori. Replicated trials were undertaken at Naduruloulou Freshwater Research Station with the Ministry of Fisheries.*

According to NATI Farm Manager, Mr Basilio Rokorauwa, the feed trials have resulted in large fish being produced in a shorter production cycle. "We are currently harvesting and selling the fish. Once we have completed the process in the coming weeks, we shall evaluate the economic viability of this new feed as it is slightly more expensive than our current feed, which is purchased from the same manufacturer". Any improvement in growth rate must be assessed against the increase in cost of ingredients to ensure value for money for fish farmers. SPC's Aquaculture Section will assist NATI with calculating the cost of production in order to select the best-value feed.

Mr Rokorauwa added that tilapia has been an important source of nutrition and protein for local people around Suva, Nausori and Sawani, where the fish are sold. Especially during these tough COVID-19 times, having access to good fresh fish helps people feed their families. He said that, "Our staff and church members also love this fish and are placing regular orders. We have kept prices as affordable as we can to help our customers".

Mr Rokorauwa also highlighted that NATI was now placing regular orders for male-only tilapia fingerlings from Kaybee Enterprise, a private hatchery based in Nakasi. "These fingerlings are being delivered at larger-than-normal initial size, and this is yielding better growth and survival in our production ponds". More work is still required for large-scale marketing of tilapia, because live or fresh fish are currently being partially harvested and sold in batches that the current market can utilise.

Preliminary results from the on-farm trials showed that when comparing different farms, it was farm management practices that had the bigger impact on the growth performance of fish, rather than the type of feed being used. Good pond preparation, water management and feeding practices by skilled farmers leads to better growth,

survival and production. Large variation in these practices among different farmers was the main explanation for big differences in growth and production, despite all farms in the trial being stocked from the same batch of fingerlings of the same size that were fed the same feed. Implementation of improved farm management practices is, therefore, of great benefit to farmers, potentially leading to lowered production costs and higher output. This is good news because it means that tilapia farming businesses can be significantly improved by making changes that are within the farmers' control. This result further highlights the need for access to knowledge and information by farmers that the Sustainable Pacific Aquaculture Development Project,<sup>1</sup> which is operated by SPC along member-country national institutions – is helping to address.

Research for the tilapia feed trials was conducted through the Sustainable Pacific Aquaculture Development Project and funded by the New Zealand Ministry of Foreign Affairs and Trade.

---

### For more information:

Avinash Singh  
PacAqua Aquaculture Officer, SPC  
avinashs@spc.int

Photo on next page: Pulling the net requires a lot of work.  
(image: ©Avinash Singh, SPC)

<sup>1</sup> See: Jimmy R. 2019. Tilapia farmers in Fiji learn to make floating feed. SPC Fisheries Newsletter 159:13. Available at: <http://purl.org/spc/digilib/doc/ww97c>

<sup>2</sup> The Sustainable Pacific Aquaculture Development (PacAqua) project aims to increase adoption and application of aquatic biosecurity standards, enhance business acumen among aquaculture operations, and increase uptake and adoption of improved aquaculture practices.







## The return of the true giant clam to Kosrae

*For many years, aquaculture activities in the Federated States of Micronesia (FSM) have focused on the production of giant clams for both natural stock enhancement activities and the aquarium trade. Martin Selch, manager of the National Aquaculture Center (NAC) in Kosrae, one of the most successful giant clam farming spots in the Pacific, has been involved in this activity for more than 20 years. A few years ago, he began to assess the possibility of bringing *Tridacna gigas* (the true giant clam) broodstock to Kosrae from neighbouring Palau where it is still present, as FSM's population was completely depleted. The objective of this introduction was to try to spawn *T. gigas* artificially in order to produce spat for restocking and, depending on the results, to produce juveniles for the aquarium trade.*

The project has been privileged to benefit from the commitment and collaboration of many stakeholders within the Micronesia subregion, including Minister F. Umiih Sengebau of the Palau Ministry of Natural Resources, Development and Tourism, who delivered the research permit for the project; Hon Marion Henry, Secretary for FSM Department of Resources and Development who established the contact to Minister Sengebau; Dr Victor Yano and his team from Belau Aquaculture who made all arrangements in Palau and organised the packing of the animals; and Mr Sone Shigeaki and his team at the Micronesian Mariculture Demonstration Center for general assistance. Thanks to this great support, Martin got the authorisation and all permits, including CITES permits, to transfer five medium-size *T. gigas* clams from Palau to FSM, for research purposes. Each animal was about 60-cm wide and weighed close to 65 kg.

The animals were imported in May 2019, following strict quarantine measures. They were kept under observation for four weeks at the College of Micronesia Land Grant hatchery in Pohnpei, as authorised by Dr Singeru Singeo, Executive Director and Dr Manoj R. Nair, Aquaculture Programs Director and Chief Scientist. The owner of the private company LP Gas, William Hawley, arranged all logistics on Pohnpei, while the FSM Resources and Development Department issued the import permit, and United Airlines Cargo Guam offered a very low freight rate to support the return of the true giant, the world's largest bivalve, to FSM.

Quarantine protocols included external (shell) cleaning and disinfection of animals before and after shipment, complete isolation of the animals, treatment and filtration of effluent waters, daily monitoring during quarantine, observation of behaviour and abnormal clinical signs, and the removal and biosecure disposal of one clam that died during quarantine. The other four were packed and shipped to the NAC hatchery in Kosrae, where they were quarantined for an additional six months.

After several months of acclimation, the animals were strong enough for spawning to be induced. Spawning was successful in early 2020, and the first batch of juveniles were visible in NAC raceways shortly thereafter.

Martin Selch is very pleased with the outcome of the experiment and has announced that “we plan to grow them at the hatchery for about two years before transferring them to sea cages to let them grow further and, if possible, to send some to neighbouring islands or other FSM states.”

---

### For more information:

**Martin Selch**

Manager, National Aquaculture Center, Kosrae,  
Federated States of Micronesia  
[info@imtrona.de](mailto:info@imtrona.de)

Left: *Tridacna gigas* prepared in Palau for shipping to FSM. ©National Aquaculture Centre

Right: Juvenile *Tridacna gigas* growing steadily in National Aquaculture Center tanks in Kosrae. July 2020. ©National Aquaculture Center





# A roadmap for electronic monitoring in regional fishery management organisations

Mark Michelin,<sup>1</sup> Nicole Sarto<sup>2</sup> and Robert Gillett<sup>3</sup>

## Introduction

Regional fisheries management organisations (RFMOs) play a key role in managing highly migratory fish stocks, such as tunas, that span the jurisdictions of multiple countries as well as the high seas. In order to sustainably manage this valuable resource, RFMOs and their member countries require sufficiently accurate information on target catch, by-catch, fishing effort, and compliance with regulations.

Human observers, who are deployed on fishing vessels to collect data on fishing activities, have played a critical role in collecting this information. Observers collect and record information on a large portion of fishing activity for most of the world's tuna purse-seine fleets, and RFMOs require human observers on all purse-seine trips. However, other fishing fleets, such as the longline fleet, have very low observer coverage targets that they often struggle to meet. The Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC) have, for example, a five per cent observer coverage target for longline vessels, but these fisheries often struggle to meet this low level of coverage. A combination of harsh working environments, costs, and the challenging logistics of deploying observers on many longline fleets make it unlikely that observers will ever be able to achieve much higher coverage levels for these fleets. With such low monitoring coverage, there is uncertainty about what longline vessels are catching, which makes it difficult to set and enforce management measures that protect the health of fish stocks and the economic productivity of the fishery.

Even in fisheries with high rates of observer coverage, there are opportunities to enhance the reliability of reported data. Although onboard observers currently represent the gold standard in fishery data collection, observers must take breaks to sleep and eat, and cannot keep track of all activities happening at once. In the worst cases, they may also be subject to intimidation, interference, bribery, and even violence in the name of falsifying reports. These serious issues are one of the reasons observers are sometimes used solely for scientific data collection and not for compliance functions. The recent suspension of observer requirements on purse-seine

vessels in the western and central Pacific Ocean (WCPO) in response to COVID-19 has demonstrated that there is still room to improve the reliability of monitoring, even in fisheries with 100 per cent observer coverage.

While observers may be limited in their ability to monitor large portions of tuna fishing for some fleets, the emergence of electronic monitoring (EM) offers a solution to the challenge of increasing the robustness and coverage levels of at-sea monitoring. There are now more than two decades of experience with electronic monitoring in fisheries, with at least 100 trials, and 12 fully implemented programmes.

## What is electronic monitoring?

The on-vessel components of EM consist of an integrated system of cameras, gear sensors, video storage, and global positioning system (GPS) units, which capture videos of fishing activity with associated sensor and positional information (Fig. 1). The videos are typically stored on a hard drive that is collected at the end of fishing trips and can then be reviewed by an onshore analyst. Some EM vendors are moving to systems that use Wi-Fi, satellite, or cellular networks to transmit data, some in near real time, instead of physically moving hard drives. An EM system also includes shore-based software and hardware that support the acquisition, analysis and reporting of EM records.

EM requires much more than placing cameras and sensors on vessels, and computers on shore. The hardware needs to be complemented by an EM programme that includes the standards and methods to collect, analyse and store videos of fishing activities, and to share the results with authorised entities (e.g. fishery managers, scientists, vessel owners).

## A roadmap for EM in RFMOs

The Pew Charitable Trusts teamed up with CEA Consulting to produce an overview of some of the key steps and design choices that fishery managers need to consider when designing and implementing an EM programme in the

<sup>1</sup> Director, CEA Consulting. Author for correspondence: mark@ceaconsulting.com

<sup>2</sup> CEA Consulting

<sup>3</sup> Director of Gillett, Preston and Associates

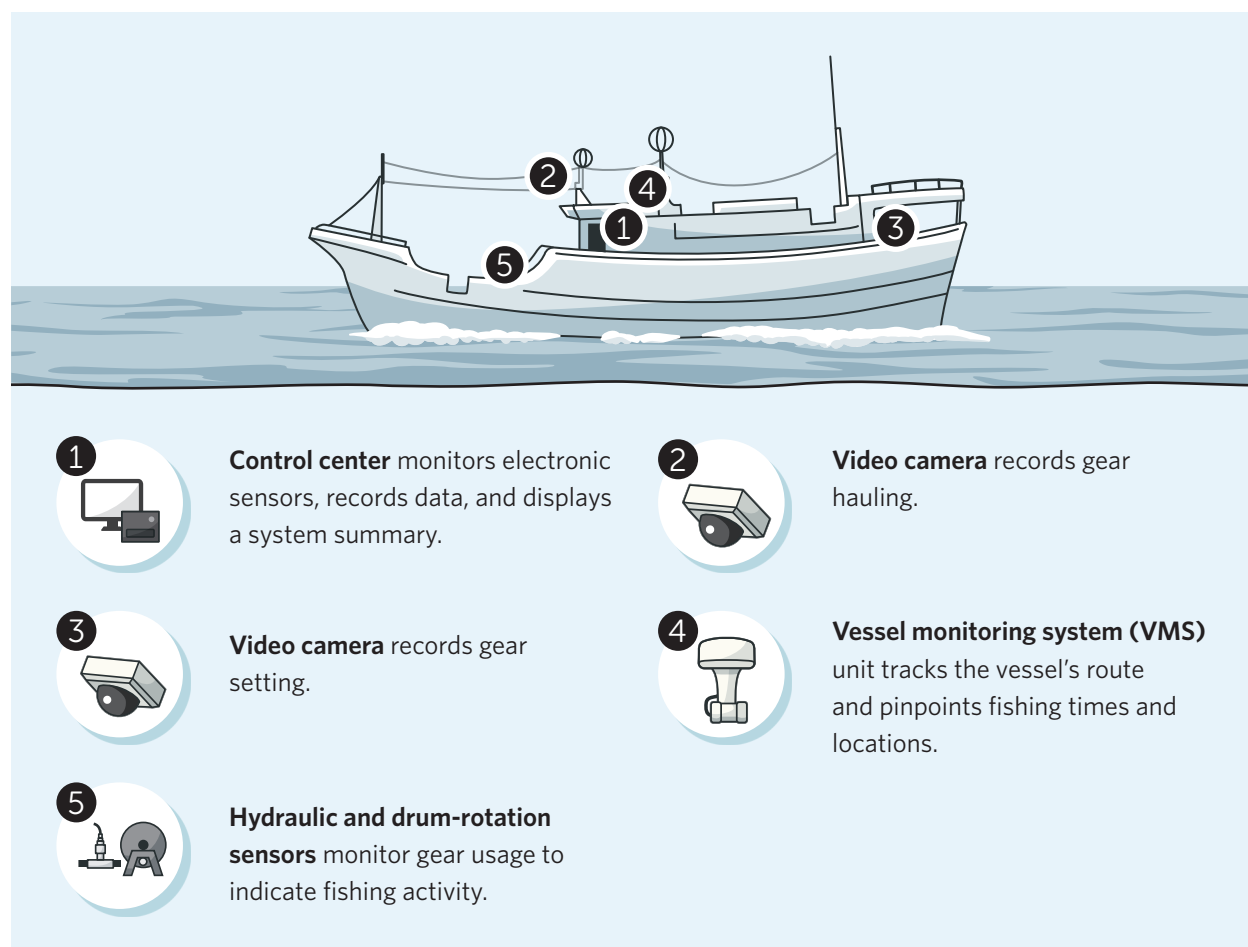


Figure 1. Overview of the on-vessel components of an electronic monitoring system on a longline vessel.

RFMO context. In the past, there have been a handful of reports that summarise the current status of EM in fisheries, and toolkits that outline a process for developing an EM programme. None of them, however, have specifically focused on the unique challenges of designing and implementing an EM programme in an RFMO context, which covers numerous countries, a wide range of vessel sizes, gear types, fishing locations, and catch compositions. The Pew Roadmap explores the necessary elements of a well-designed and effective EM programme and examines the unique considerations for fisheries that are managed by an RFMO.

## Strengths, challenges, and opportunities for EM in tuna fisheries

There have been numerous trials and fully implemented EM programmes for tuna fisheries, and these trials have covered both longline and purse-seine fisheries. From these trials, some general conclusions can be reached about the efficacy of EM as a monitoring and compliance tool:

### Strengths of EM

1. Provides accurate data on the location and time of fishing activity.
2. Accurately assesses the set type in purse seine fisheries.
3. Accurately estimates total catch per set in purse seine fisheries.
4. Provides good estimates of the catch of main target species in longline and purse seine fisheries.
5. Identifies most endangered, threatened, or protected (ETP) species interactions.
6. Incentivises more accurate reporting of data in logbooks.
7. Covers multiple views of the vessel at the same time, does not require breaks, and video can be reviewed multiple times.
8. Is less prone to intimidation, bribery, or interference in order to falsify reported data.
9. Review of much of the fishing activity can happen at high speed (e.g. >8 x speed).



10. A space-efficient solution for longline vessels with limited room for a human observer.
11. Can sometimes provide cost savings relative to human observers.
12. Helps document conformity with management measures and international obligations.
13. Scalable option to implement on various vessels with different gear types.

### Challenges for EM

1. Accurate estimates of non-target species in purse-seine and longline fisheries can be challenging with EM depending on catch-handling techniques and camera placement.
2. Identification of ETP species may only be accurate at higher taxonomic levels (e.g. shark or turtle), but not at the species level. However, additional or higher resolution cameras may be a solution.
3. Accurate identification of juvenile tunas (e.g. small yellowfin and bigeye) is difficult, although this is similarly difficult for human observers.
4. EM systems are not linked to FAD buoy identification systems.
5. EM is not currently suitable for biological data collection (e.g. sex identification, otolith measurement), which could be addressed by complementing EM with dockside sample collection.
6. EM cannot be used to accurately assess the condition or life status of fish.

In general, it is easier to extract detailed information about catch in longline fisheries, where the catch is brought on board one fish at a time, but EM has proven successful in purse-seine fisheries as well.

The growing body of experience with EM has demonstrated that it can complement human observer programmes. For longline fisheries, where low levels of human observer coverage mean that there are little data about what is happening at sea, EM can be a valuable tool to help fill this information gap.

### Designing an EM programme

The Pew Roadmap details the 15 elements of an EM programme that should be considered during development and implementation. These elements are:

- Engaging stakeholders
- Establishing programme objectives
- Mitigating challenges to advancing EM
- Defining EM programme standards
- Structuring the EM programme

- Calculating and allocating costs
- Defining programme coverage levels
- Capturing EM records
- Retrieving EM records
- Reviewing EM videos
- Accessing EM videos and data
- Storing EM records
- Maintaining privacy and confidentiality
- Servicing EM hardware systems
- Contracting vendors

In the Roadmap, an overview of each element is presented as well as some of the design choices or options that could be considered. Building an EM programme is an iterative process. Mechanisms should be included for continuous review, refinement and improvements as experience is gained and technology evolves.

### Aspects of EM programmes

An interesting point is that almost all stakeholders see positive and negative aspects of EM, but these views vary widely across groups. Table 1. Stakeholders and the potential benefits of and concerns with EM. shows some common stakeholders and their perceptions of EM.

Although conditions vary considerably among RFMOs, there are two commonly cited concerns about EM. One is the cost of an EM programme and who will pay for it, and the second is that vessel operators and flag states can be resistant to additional monitoring requirements. Under these two broad headings, there are some related challenges, which are briefly described below:

- For coastal states that license DWFN fleets, there is concern that an EM requirement will drive fleets away from their exclusive economic zone, and they will lose license revenue. This challenge could be addressed with a synchronised implementation of EM across the entire fishery. There is growing recognition that RFMO fisheries need to be better monitored, and fleets that attempt to subvert this trend by moving into high seas areas will be increasingly considered as renegades, which could have repercussions for fleet vessel owners and flag states. International pressure on RFMOs and on the market will also help to mitigate this challenge. Over time, this concern is likely to fade.
- It may be difficult to reconcile coastal states' contention that industry should be responsible for all costs associated with the management of a fishery (including EM), with the industry thinking that the cost of EM is the major constraint of implementation, especially for

Table 1. Stakeholders and the potential benefits of and concerns with EM.

Stakeholder	Potential benefits of EM	Potential concerns with EM to address/mitigate
RFMO secretariat staff	<ul style="list-style-type: none"> <li>✎ Efficient mechanism for encouraging compliance</li> <li>✎ Monitoring bycatch and catch levels, especially in fisheries with catch quotas</li> </ul>	<ul style="list-style-type: none"> <li>✎ Increase in workload for formulating standards and implementation</li> <li>✎ Cost of the system and associated costs of increased workload</li> <li>✎ Alienation of member countries that are reluctant to adopt EM</li> </ul>
Coastal states	<ul style="list-style-type: none"> <li>✎ Monitoring catch levels, especially in fisheries with catch quotas</li> <li>✎ A mechanism to deter illegal activity that cannot be corrupted</li> <li>✎ Ability to monitor observers</li> <li>✎ Deflecting criticism that tuna fisheries are unsustainable</li> <li>✎ Showing the public that tuna fleets are being effectively monitored</li> </ul>	<ul style="list-style-type: none"> <li>✎ Loss of revenue if vessels move to the high seas to avoid EM requirements</li> <li>✎ Hesitancy of some coastal states to be an “early adopter”</li> <li>✎ Increase in workload for programme implementation</li> <li>✎ Cost of the system (e.g. added costs such as dedicated equipment) that industry does not want to pay for</li> <li>✎ Pressure by flag states that are reluctant to adopt EM</li> <li>✎ Concessions that might be made to get distant water fishing nations (DWFNs) to agree to EM</li> </ul>
Flag states	<ul style="list-style-type: none"> <li>✎ Deflecting criticism that tuna fisheries are unsustainable</li> <li>✎ Showing the public that tuna fleets are being effectively monitored</li> </ul>	<ul style="list-style-type: none"> <li>✎ Pressure from domestic vessel operators that are opposed to EM</li> <li>✎ Additional enforcement responsibilities and expenses</li> <li>✎ Cost of the system (e.g. added costs such as dedicated equipment) that industry does not want to pay for</li> </ul>
Vessel owners	<ul style="list-style-type: none"> <li>✎ Avoiding criticism for low human observer coverage in longline fleets</li> <li>✎ Ability to demonstrate that fishing operations are legitimate</li> <li>✎ Monitoring quality control</li> <li>✎ Protection against frivolous claims by observers or crew</li> <li>✎ Greater management flexibility afforded when vessel is fully monitored</li> </ul>	<ul style="list-style-type: none"> <li>✎ Cost of the system, especially a) if industry is expected to pay all EM expenses, and (b) considering the current low profitability of the fishery.</li> <li>✎ Fear of minor or unavoidable infractions being taken out of context</li> <li>✎ Extra work and difficulty of compliance with a whole new set of rules for the fishery</li> <li>✎ Having to return to port if vessel monitoring system becomes inoperable (i.e. not convinced of reliability of system)</li> </ul>
Science agency staff	<ul style="list-style-type: none"> <li>✎ Ability to efficiently collect many types of data</li> <li>✎ Greater confidence in collected data</li> <li>✎ Ability to verify data collected by human observers</li> </ul>	<ul style="list-style-type: none"> <li>✎ Inability to collect some kinds of data (e.g., possibility of loss of human observer coverage and associated opportunities for collection of biological samples)</li> </ul>
Major tuna companies	<ul style="list-style-type: none"> <li>✎ Ability to demonstrate that fishing operations are legitimate</li> <li>✎ Meeting market demand for sustainably fished product</li> </ul>	<ul style="list-style-type: none"> <li>✎ Fear of minor or unavoidable infractions being taken out of context</li> </ul>
Vessel crew	<ul style="list-style-type: none"> <li>✎ Does not take up as much room as human observer</li> <li>✎ Elimination of logistical problems and loss of fishing time for observer logistics</li> <li>✎ Captain has the ability to monitor crew at all times</li> <li>✎ Protection against frivolous claims by observers</li> <li>✎ Ability to monitor labour and safety practices</li> </ul>	<ul style="list-style-type: none"> <li>✎ Concerned about always being recorded in their workplace and invasion of privacy (e.g.9 showering, defecating)</li> <li>✎ Elimination of some income-earning opportunities</li> <li>✎ Extra work during port calls of dispatching the hard drives</li> <li>✎ Fear of minor or unavoidable infractions being taken out of context</li> </ul>
Observers	<ul style="list-style-type: none"> <li>✎ Reduction of harassment by vessel crew</li> <li>✎ Increased observer safety</li> <li>✎ Possibility of onshore employment as EM reviewer</li> </ul>	<ul style="list-style-type: none"> <li>✎ Unwanted auditing of work</li> <li>✎ Loss of on-vessel employment</li> </ul>



fisheries that are not very profitable. Addressing this challenge may require some flexibility on the part of coastal states in allocating EM costs, especially during the start of a programme. It may be possible to provide additional incentives to industry or obtain external support for the initial implementation of a new EM programme (e.g. foreign aid, foundation grants).

- Numerous stakeholders may face a “fear of the unknown” or an aversion to change due to uncertainty about system costs, reliability, impact of additional monitoring, and the extra work EM may require. Pilot projects, and effective dissemination of the results, could dispel much of this fear. Inter-RFMO cooperation and exchange of experiences could also help demystify EM.

As experience with EM increases, more mitigating mechanisms for addressing these challenges are emerging. Several stakeholders are likely to be strong supporters of EM for RFMO fisheries, and their support can help positively influence others. These may include:

- early adopting countries, especially those with individuals who are fishery champions;
- coastal states, especially if they anticipate that costs to them will not be great; and
- branded tuna companies, especially those that wish to promote the image that the concerned fishery is transparent and sustainable.

Although it may take some time, there is a growing recognition that better information is required for effective management of RFMO fisheries. This sentiment is growing among even the most reluctant stakeholders. This concept, combined with the push from supportive stakeholders, suggests that other actors are likely to come around.

Once stakeholders agree on objectives for an EM programme, defining standards for an EM programme is a logical step for formalising an RFMO requirement for EM. A few of the RFMOs have developed or are engaged in discussions to create EM programme standards:

- Member countries of the Pacific Islands Forum Fisheries Agency have produced, for future consideration by their governing body, a draft regional longline fisheries EM policy that includes standards on EM systems, data management, data ownership and access, and data security and confidentiality.
- The WCPFC has established a working group for developing EM standards, which were presented to the annual meeting of WCPFC in December 2019.
- In 2019, ICCAT adopted a measure to propose longline EM standards by 2021.

- The Indian Ocean Tuna Commission (IOTC) is conducting EM trials that will eventually inform draft standards.
- The IATTC is developing standards for both longline and purse seine and will be presenting them for discussion to its Scientific Advisory Committee (SAC) in 2020.

EM programmes for international fisheries could have several types of structures, including an RFMO-wide programme, individual national programmes, subregional programmes, or aspects of national programmes being pooled between countries. Each type has its advantages and disadvantages, with the most appropriate type for a region being influenced by the fishery management history, geography and politics of the area. If a region has previously enjoyed an effective network of national observer programmes, countries may feel comfortable staying with that model for an EM programme.

## EM costs

Because the costs associated with an EM programme are a concern for many stakeholders, additional attention to expenses is required. To date, most of the costs for EM programmes in tuna fisheries have been paid by non-governmental and international organisations, but this model will not continue forever. Currently, much of the enthusiasm by coastal states for EM is related to the idea that in the future, industry will be responsible for paying for most, or all, of the costs. The draft Regional Longline Fisheries Electronic Monitoring Policy, formulated by FFA member countries, states as a guiding principle: “User pays – full cost recovery as a default.” Many segments of the fishing industry feel that costs could be high and are also uncertain about how an EM programme will affect their business. As the group that will be most impacted, they may believe that it is unfair for them to be entirely responsible for funding an EM programme. This difference of opinion on who should pay for EM is seen by many as the most significant impasse for EM implementation.

## Data review

The process for reviewing and extracting data from video footage is a critical element of EM programme design. Video review is typically the costliest component of an EM programme – often about 50 per cent of overall programme costs – and decisions about how much video to review and what data to extract need to be guided by and aligned with the overall EM programme’s objectives. The more video that is reviewed and the more detailed the data extracted, the more costly it will be. There are different models for assigning responsibility of the video review process, each with their own pros and cons.

## Privacy and access

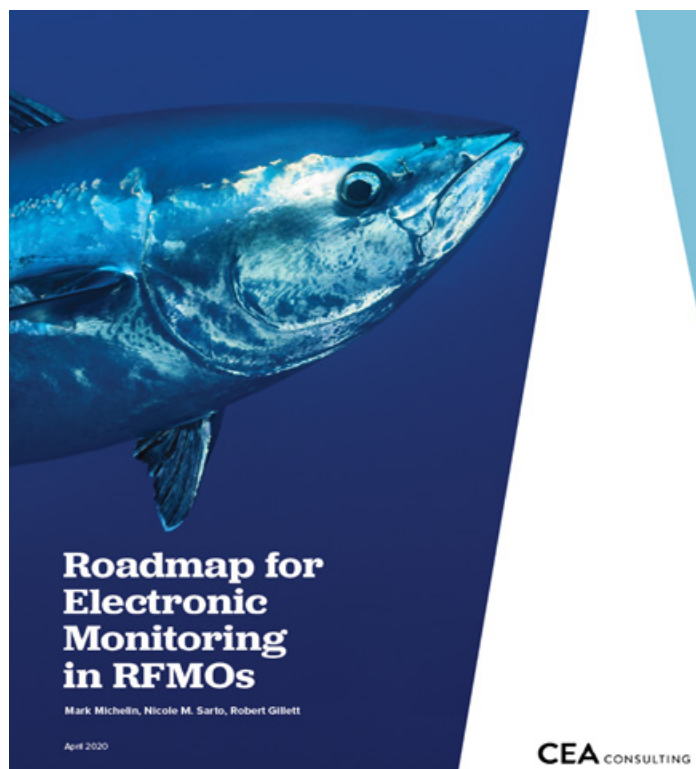
There are many entities that would like to be able to access raw video footage or processed data from EM programmes, and therefore a data management plan will need to be developed that covers many issues, such as data movement, confidentiality and access. All RFMOs have very detailed data policies in place that cover confidentiality and sharing. Examples of this are the IATTC's "Data Confidentiality Policy and Procedures", ICCAT's "Rules and Procedures for the Protection, Access to, and Dissemination of Data", and the IOTC's "Data Confidentiality Policy and Procedures." Although none of these policies cover EM data, there are procedures in these policy documents for covering new types of data. It is likely that in many RFMOs, the EM data policy and procedures will follow those of the observer programmes.

## In conclusion

A clear movement appears to be underway in which demand for better data and accountability in fisheries is increasing. Seafood and fishing companies are taking more action to improve the sustainability of their products driven by market pressure and as a way to mitigate risk of illegal or unsavoury practices in their supply chains. Import regulations, such as the European Union's illegal, unreported

and unregulated fishing carding system and the US Marine Mammal Protection Act, are also compelling countries to improve the monitoring and accountability in their fisheries. Many fisheries managers and scientists would also like to have better data so that they can have a clearer picture of the status of fishery resources and how much fish is being caught. These forces appear to be driving a slow but steady increase in monitoring requirements in fisheries, and modern fisheries management is turning towards EM as a tool to help meet these objectives. With thousands of vessels and low rates of observer coverage in some fleets, EM appears to be especially relevant for RFMO fisheries.

There is a growing recognition that better information is required for the effective management of RFMO fisheries, and this sentiment is growing among even the most reluctant stakeholders. Human observers will continue to play an important role in collecting this information, but it is unrealistic that they will be able to cover the required percentage of fishing. The emergence of EM offers a solution to scale up monitoring coverage and to help meet this need for better information. There are real challenges to developing an EM programme, and the characteristics of RFMO fisheries can make this a bit more complex, but these are solvable challenges. Time appears to be on the side of EM and the question is no longer whether EM will become a widely used tool in RFMO fisheries, but when.



Michelin M., Sarto N. and Gillett R. 2020.  
Roadmap for Electronic Monitoring in RFMOs.  
CEA Consulting for Pew Charitable Trusts.

The full 41-page report is available at:  
[www.ceaconsulting.com/casestudies/the-pew-charitable-trusts/](http://www.ceaconsulting.com/casestudies/the-pew-charitable-trusts/)

# A survey of the number of coastal fishing vessels in Fiji<sup>1</sup>

Robert Gillett<sup>2</sup>



A variety of small coastal fishing vessels in Lautoka Port, Fiji. (Image: R.E. Gillett)

## The importance of knowing fishing vessel numbers

Estimating the number of vessels that are involved in coastal fishing in a country such as Fiji is important for several reasons. For fisheries management purposes, it is generally agreed that an intimate knowledge of a fishery is an important prerequisite for management to be effective – and the number of vessels is an important aspect of that knowledge. In addition, fishing effort is often key to determining when and where management measures should be applied. In many Pacific Island, however, where it is difficult to quantify fishing effort (e.g. person-days), the number of vessels involved in a fishery could serve as a crude proxy for effort. The reality is that it is much easier counting boats than counting fishing days or even fishers. At various times in the past, Fiji's Ministry of Fisheries has subsidised small fishing vessels or given vessels away for free. In the future, before increasing the number of fishing vessels further, it would be sensible to know the current number of vessels and their geographic distribution. Other reasons for knowing vessel numbers include:

- The distribution of vessels is also quite useful for targeting non-vessel initiatives of the Ministry of Fisheries, such as the establishment of fisheries centres, promotion of fisher associations, and provision of fish warden training.

- In assessing the impacts of natural disasters and the subsequent rehabilitation efforts, much attention is given to fishing vessels, but there is considerable uncertainty in determining how many were actually lost due to the inability to establish pre-disaster numbers.
- In some respects, fisheries surveillance and enforcement efforts could be made more effective by focusing operations where there is a high density of vessels.

There is considerable uncertainty as to the number of coastal fishing vessels in Fiji. Although there is a requirement that fishing vessels be registered with the Ministry of Fisheries, that requirement is only for commercial vessels (i.e. does not include vessels used for subsistence fishing). Further complicating the situation is that an unknown but probably large proportion of coastal commercial fishing vessels in Fiji are not registered.

## This study

This short study was sponsored by the Packard Foundation and was carried out as a desk exercise in late May and early June 2020. The purpose of the study was to obtain a crude estimate of the number of small fishing vessels in the country. Secondly, it was to explore mechanisms for obtaining better estimates in the future.

<sup>1</sup> The full report of the study is available from the author at [gillett@connect.com.fj](mailto:gillett@connect.com.fj)

<sup>2</sup> Director of Gillett, Preston and Associates.



Some definitions were established for this study:

- “Coastal fisheries” are equivalent to “inshore fisheries”, and are the fishing activities that occur on reefs, in lagoons, and up to 10 km offshore.
- “Small fishing vessels” are generally those craft that are smaller than 10 metres in length. In practice, it includes almost all vessels used for marine fishing in Fiji except those involved in longlining and the larger boats involved in deep slope bottom fishing.

## Previous documentation on the number of vessels

The Ministry of Fisheries registers commercial vessels, and information on the number of registered fishing vessels has appeared in some of its annual reports. The last time information for all four of Fiji’s geographic divisions was published was in 2008, when the annual report indicated 1276 registered fishing vessels. According to several sources, the actual number of small fishing vessels (including non-registered commercial boats and boats used for subsistence fishing) is probably much greater.

Other estimates of small fishing vessels in Fiji (and some comments in italics) are:

- A Food and Agriculture Organization sea safety survey in 1991 (McCoy 1991) estimated that there were about 1600 motorised fishing vessels under 10 m in length, including 450 inboard-powered vessels, plus 400 non-motorised vessels. *Because this survey operated in Fiji for only a few days and was primarily concerned with sea safety legislation, the numbers of vessels are likely to have been based on estimates by staff of the Fisheries Division, but not on the Division’s vessel registration system due to the large number of unmotorised vessels included in McCoy’s estimate.*
- The Asian Development Bank Fisheries Sector Review (Hand et al. 2005) stated: “There is currently an estimated 895 boats operating in the country’s small-scale fisheries, most of which are small 15 foot skiffs, although there are also a small number of small-scale tuna boats and deepwater snapper boats in operation (around 6–10). *Although I participated in this review, I have no idea where Tony Hand got this number of vessels. Tony had only limited experience in Fiji and certainly did not survey vessels himself. The Fisheries Department annual report for 2005 showed many more vessels than the 895 mentioned by the review.*”
- A Pacific Community project to establish a small-scale vessel registration system (Welch 2016) estimated “more than 1,500 vessels less than 15 m”. *Welch did not enumerate vessels on his short stay in Fiji, so the number is likely to have come from the Ministry of Fisheries. The report mentions canoes as a small-scale vessel type, but canoes are not a common fishing craft in Fiji.*

- In a World Wildlife Fund study of fish markets in the Western Division, Takali (2018) states there are about 666 registered fishing boats in Ba Province. *Data from the Ministry of Fisheries Western Division office show 490 registered fishing vessels in 2018 in the entire Western Division (which includes Ba Province and two other provinces). This suggests that the difference between the number of registered fishing vessels and the actual number is quite large.*

The above information does not appear especially useful in estimating the current number of small fishing vessels in Fiji, but it does reinforce the idea that estimating vessel numbers in the country is difficult.

## Alternative ways to estimate vessel numbers

During the study, several ways for obtaining an idea of vessel numbers were explored, and included: 1) the use of Google Earth images, 2) satellite-based long-wave radar, 3) aircraft-based light detection and ranging (LIDAR), 4) estimates of the number of non-registered vessels by the staff of the Ministry of Fisheries, 5) knowledge of boatbuilders, 6) my personal experience with Fijian coastal villages, and 7) the use of cyclone assessment data.

Google Earth maps the Earth by superimposing satellite images, aerial photography, and geographic information system data onto a 3-D globe, allowing users to see cities, landscapes and various objects (Fig. 1). At the beginning of this study, Google Earth appeared to have considerable potential for counting fishing vessels, and so exercises were carried out to test this potential by ground truthing. After this work, it was concluded that there are several difficulties with using Google Earth for a census of small fishing boats, with the most serious being the inability to count vessels that are being stored under trees.

Other forms of aerial technology that could conceivably be used to count coastal vessels were examined in this study: spaceborne systems (i.e. longwave radar) and airborne systems such as LIDAR. It was concluded that various forms of aerial technology hold considerable promise for censusing coastal fishing vessels, but none appear to be ready for use at the present time by the staff of the Ministry of Fisheries.

The other approaches used by this study for estimating vessel numbers showed more promise (Table 1). There appears to be some convergence in vessel numbers in the above four approaches. Selectively using the information Table 1, the number of small fishing vessels in Fiji can be crudely estimated to be about 3800.

This estimate could be very inaccurate due to weaknesses in the approaches used. Especially troublesome are combining data (and guesses) from different years, the issue of inactive vessels, and non-fishery vessels (transport, tourism).

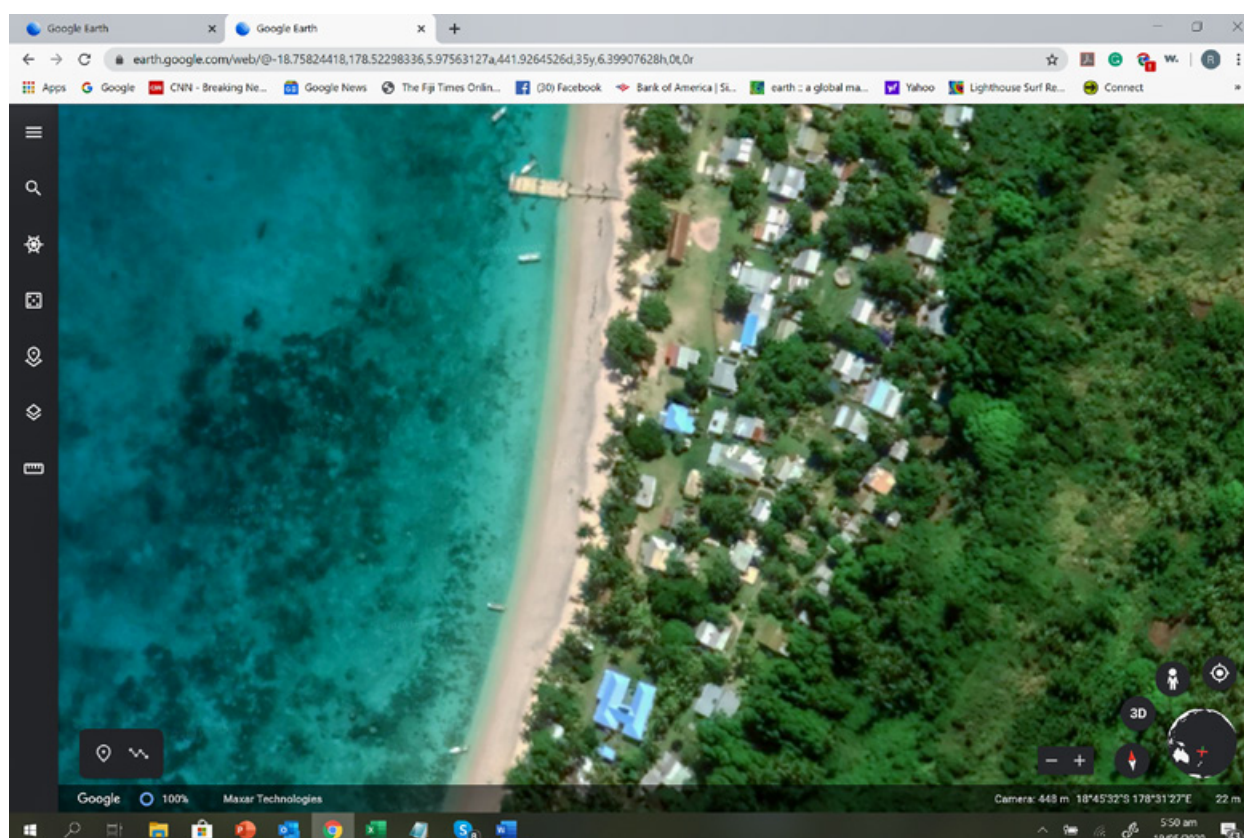


Figure 1. Google Earth image showing five boats anchored off Dravuni, Kadavu, Fiji.

Table 1. Other methods used to estimate the number of coastal fishing vessels in Fiji.

Approach	Estimate of vessel number	Comment
The experience of senior officers of the Ministry of Fisheries in the geographic divisions indicate that the actual number of fishing vessels operating is two to three times the number of registered vessels	2552 to 3828 vessels in 2008	The last time the number of registered vessels was given in an annual report was in 2008 (1276 registered vessels in all four divisions).
Estimates from Fiji boatbuilders of boat production combined with boat longevity	About 3000 fibreglass boats plus several hundred non-fibreglass boats	Estimates of vessels produced by “backyard boatyards” and vessels imported are really semi-educated guesses.
My experience at observing the number of vessels on the beach or moored near coastal villages in most parts of Fiji	3400 vessels	An average of about 4 vessels per coastal village; 850 coastal villages in Fiji.
Estimate of pre-cyclone number of vessels in a post-cyclone survey	4250 vessels	The survey showed 774 boats in 154 villages (average of 5 boats/village). That average is multiplied by Fiji’s 850 coastal villages. The average number of boats per village could be distorted by the high number in Ba Province.

Nevertheless, it is the only estimate available in recent years, and 4.7 times greater than the number of small fishing vessels estimated by a 2005 fisheries sector study (Hand et al. 2005).

## For the future

For the future the study concluded that the least expensive and most practical options for improving vessel estimates would be to include questions on vessel numbers in each population census and/or agriculture census – as done by several other Pacific Island countries, such as Cook Islands and Vanuatu. In order for this to happen, fisheries officers need to be proactive and attend census planning meetings at the national statistics agencies to ensure those surveys collect the desired information.

## References

- Gillett R. 2020. Estimating the number of coastal fishing vessels in Fiji. Gillett, Preston and Associates for Fiji's Ministry of Fisheries. 20 p.
- Hand T., Davis D. and Gillett R. 2005. Republic of the Fiji Islands: Fisheries sector review. Manila, Philippines: Asian Development Bank. 95 p.
- McCoy M. 1991. Safety at sea in Pacific Island fisheries. Suva: Food and Agriculture Organization/United Nations Development Programme Regional Fisheries Support Programme. 75 p.
- Takali E. 2018. Western Division market field data collection [Tavua – Nadi] marine fish movement within the Province of Ba. Suva: World Wildlife Fund – Pacific. 12 p.
- Welch D. 2016. A small-scale vessel registration system for Pacific Island countries and territories. Noumea, New Caledonia: Pacific Community. 14 p.





## Using local knowledge to guide coconut crab science in Fiji

Epeli Loganimoce,<sup>1\*</sup> Max Tukana,<sup>1</sup> Viliame Bainivesi,<sup>2</sup> Prakriti Rachna,<sup>2</sup> Volau Titoko<sup>2</sup> and George Shedrawi<sup>3</sup>

*From 22 June to 14 July 2020, the University of the South Pacific PEUMP<sup>4</sup> team – in collaboration with Fiji's Ministry of Fisheries Research Division – conducted a coconut crab hunter's survey on Nagelelevu Island and in the Vanua Balavu Isles, which are part of the Cakaudrove and Lau provinces, respectively. The objective of the survey was to bring together as much information as possible on hunters' experiences and perceptions on the local behaviour of coconut crabs. Information from hunters will aid in determining the timing and location for conducting fishery-independent surveys of coconut crab populations across the region. Information in the form of seasonal variation in abundance, breeding, aggregations and hunting pressure will be pertinent to correctly planning and implementing a baseline survey that can be used to introduce efficient and effective management of coconut crab populations across Fiji.*

### Background

The coconut crab (*Birgus latro*), locally named *ugavule*, is a crustacean that is closely related to hermit crabs. Coconut crabs have evolved to become the largest and least marine-dependent of the land crabs, with females only using the ocean to release larvae that stay in the ocean for three to four weeks before returning to land. In Fiji, *ugavule* are a local delicacy that are sold in local restaurants and hotels as an exotic choice for tourists. Their ease of capture, however, has made them vulnerable to overharvesting.

Coconut crabs have been reported on the far northeast and southeast boundary of Fiji's limestone islands, including parts of Yadua Island and Aiwa Island, Cikobia Island in Macuata, Cikobia Island in Lau, Kabara Island and Nagelelevu Atoll in the Ringgold Isles, and in a few privately owned

islands. Similar to observations made in Niue and Mauke Island, the occurrence of coconut crabs appears to be associated with island habitats with uplifted limestone, availability of food and undisturbed habitats.

Fiji's coastal fisheries resources are under increasing pressure and with the current global COVID-19 pandemic, it is predicted that changes to the reliance on natural resources for subsistence and income will intensify these pressures. Despite these pressures on coconut crabs, no current management plan is in place to ensure the sustainable use of this important resource. Fiji's Ministry of Fisheries is aware that stocks of coconut crabs are being excessively harvested, and there is an urgent need for baseline population information.

In Fiji, the Endangered and Protected Species (Amendment) Act (2017) under Schedule 1 (Section 3), Part 9

<sup>1</sup> Institute of Marine Resources, Faculty of Science, Technology and Environment, The University of the South Pacific, Suva, Fiji

<sup>2</sup> Research, Resource Assessment and Development Division, Ministry of Fisheries, Suva, Fiji

<sup>3</sup> Pacific Community, Coastal Fisheries Programme, Fisheries Aquaculture and Marine Ecosystems Division, Noumea, New Caledonia

<sup>4</sup> Funded by the European Union and the Government of Sweden, the EUR 45 million Pacific-European Union Marine Partnership (PEUMP) programme promotes sustainable management and sound ocean governance for food security and economic growth, while addressing climate change resilience and the conservation of marine biodiversity. It follows a comprehensive approach, by integrating issues related oceanic fisheries, coastal fisheries, community development, marine conservation and capacity building under one single regional action.

\* Author for correspondence: [epeli.loganimoce@usp.ac.fj](mailto:epeli.loganimoce@usp.ac.fj)

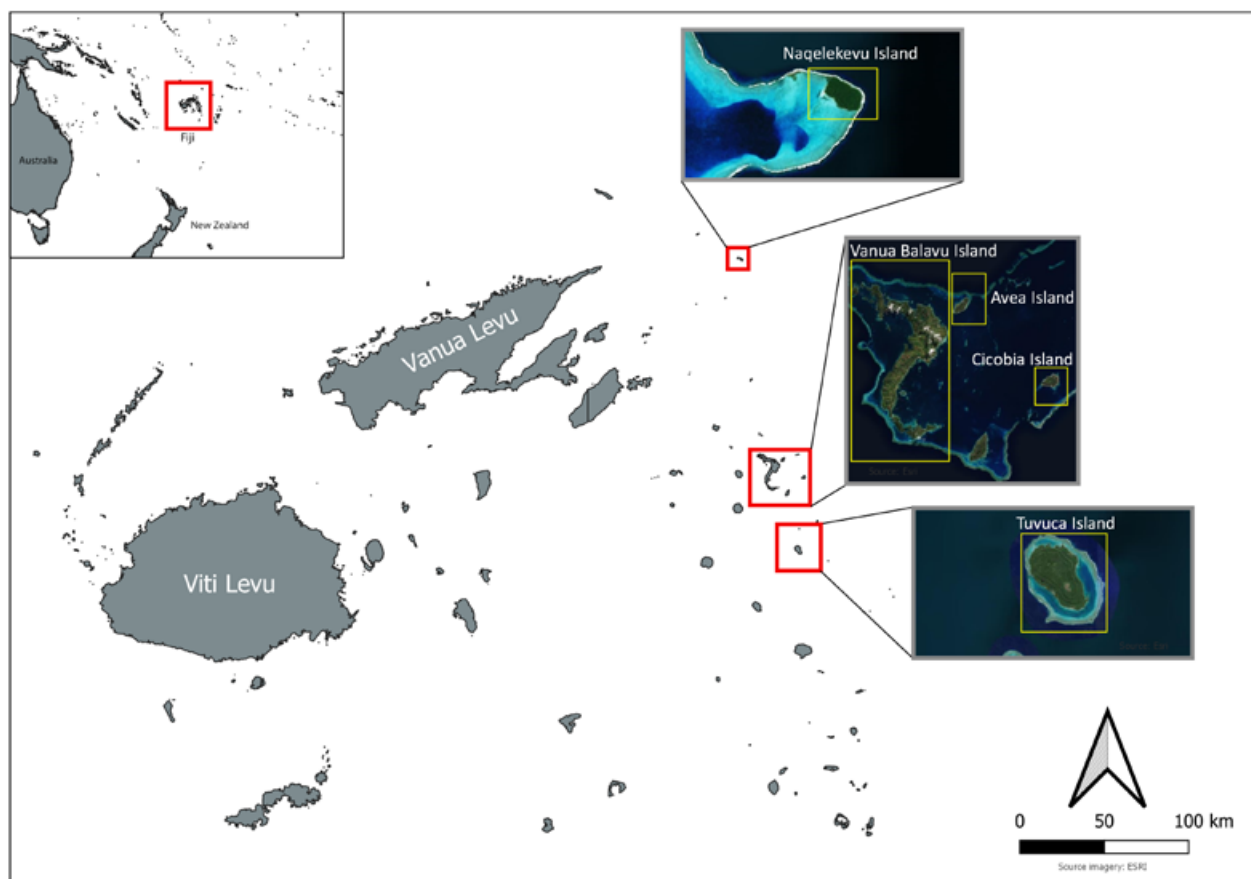


Figure 1. Coconut crab survey areas.

prohibits the sale of coconut crab sales unless the fisher is registered with the Fiji Islands CITES Management Authority. However, enforcement of this provision has been particularly poor over recent years, which is likely to have facilitated undocumented declines in coconut crab populations. Countries such as Niue and Cook Islands have adopted some sort of management regulation to safeguard their coconut crab stocks. The priority for Fiji is to first ascertain baseline information via a stock assessment survey across selected sites. An often-overlooked source of information are local community members' knowledge of coconut crab demographics and movements to guide natural resource management.

## Purpose and methods of the survey

We surveyed local hunters to gather vital information on the behaviour of coconut crabs to inform the baseline stock assessment survey and development of a management plan. Focused interviews were conducted with coconut crab hunters from Naelelevu Island in Cakaudrove Province, and the Vanua Balavu islands in Lau Province (Fig. 1). Each interview took approximately 20 minutes to complete, and the information provided by each hunter were collated and summarised to gauge coconut crab activity between seasons and locations.

## Findings and discussion

The team interviewed 28 hunters across six villages (Naelelevu, Cikobia, Namalata, Susui, Daliconi and Tuvuca) in two provinces (Lau and Cakaudrove) (Fig. 2). Males made up the majority of hunters although this was likely due to the conventional norms surrounding women's roles, which limit their involvement in this hunting activity. More than 50% of the hunters interviewed were 50 years of age and older, and the combined experiences of individuals older than 50 offered valuable insights into coconut crab behaviour. For example, a single respondent in Tuvuca had over 30 years of coconut crab hunting experience and informed us that after moulting, the emergence of crabs from their burrows coincides with the harvesting time of two locally grown yams (*kawai*: *Dioscorea esculenta* and *tivoli*: *Dioscorea nummularia*).

A boat with an outboard engine was used to access most areas. The fuel used ranged from 5–8 litres in Namalata and Avea villages to 20–25 litres in Daliconi and Tuvuca villages. Naelelevu hunters used the most fuel at approximately 200 litres for one hunting session. Hunters usually spent, on average, a week in the island hunting for crabs before they returned with their catch to Taveuni Island. The frequency of hunting sessions is also dependent on accessibility via the monthly ferry service to both Vanua Balavu and Naelelevu



islands, with hunting sessions increasing approximately 10 days prior to the ferry service. This is because not all hunters have access to boats, and the ferry provides a means of transporting catches. Within this period, hunting sessions can range from four to five days a week, and up to 12 hours a day in some locations (e.g. Tuvuca Island). Crabs are mainly for subsistence but are also sold to families and nearby restaurants in Taveuni for cost recovery. Prices of a single coconut crab are based on its size and can be as low as FJD 10 or as high as FJD 50.<sup>5</sup>

Weather conditions and specific periods of the day usually determine the frequency and timing of hunting sessions. Most hunters prefer hunting from the evening until midnight (18:00–24:00) or very early in the morning (03:00–05:00). This is when coconut crabs emerge to feed, and hunters can potentially catch more individuals in a single hunting session. The wet and dry seasons were also reported to be important periods for determining catch rates, with the wet period usually resulting in a greater number of catches than the dry season.

Behavioural patterns that are particularly crucial in planning the baseline stock assessment survey were highlighted by hunters. For example, the mating behaviour, occurrence of berried females, the release of eggs from berried females, and the period when crabs undergo moulting. Hunters confirmed (48.9% of respondents) that moulting begins around the end of the second quarter from April to June, and continues towards the third quarter (July to September) in a calendar year (according to 42.6% of respondents). During moulting, there is an increase in the number of crab burrows and a lower abundance of bigger sized individuals. Some hunters use long sticks or metals rods to poke into areas surrounding the burrow in an attempt to pierce a newly moulted individual. In most cases, this technique failed to find coconut crabs, which was only performed on relatively large burrows.

Larger sized coconut crabs take a significantly longer time to moult compared with smaller individuals. Following the moulting process, hunters believe that crabs progress into mating, however, very few hunters witnessed the process of

<sup>5</sup> FJD 1.00 = AUD 0.65 as of August 2020.

Figure 2. Volau Titoko, a Fisheries Officer in Charge at the Fiji Ministry of Fisheries, carries out a hunter's interview in Daliconi village, Vanua Balavu, Lau Province. (Image: ©Epeli Loganimoce, IMR USP)





copulation. Also, mating was inferred from changes in the behaviour of the majority of larger sized individuals around the third quarter of the year. Most hunters did not know that the pleopods are used to differentiate female from male coconut crabs (Fig. 3), but they knew that the occurrence of two large individuals close to each other is most likely an initial step towards the mating and copulation process. Hunters reported that two adults in close proximity usually results in fighting and territorial defence; and when two large individuals are in close proximity without these fight responses, it is likely due to mating behaviour and courtship. Approximately 70.0% of respondents confirmed that this mating behaviour occurs around the third quarter of the year, from July to September; 68.7% of respondents reported that berried females are normally observed throughout the last quarter, from October to December, and 19.0% reported observations of this behaviour in the first quarter, from January to December. The majority of the responses confirmed that November is when females begin to carry eggs. These females release their eggs in the last weeks of December through to early January. The process of releasing eggs takes place during high tide along the rocky shores. In this period, hunters have seen berried females hanging from rock cliffs as they allow the splashing waves to wash their eggs into the sea. On Tuvuca Island, respondents

have seen berried females of various sizes migrating towards the shores at the very front of the village to release their eggs, making them easily accessible to hunters.

The outcomes of this survey illustrate the importance of using local knowledge of hunters and fishers to gather information on the biology and behaviour of fisheries resources. The data suggest there is agreement between hunters on mating behaviour, the occurrence of berried females, the release of eggs from berried females, and the period when crabs most likely undergo moulting. An additional and critical result coming from this survey was that it provided an opportunity to establish contacts and a network within communities. Throughout the sites surveyed, the team conducted informal discussions and was able to increase awareness around the current project and communicate to hunters and others within the community about the importance of having a well-managed sustainable coconut crab resource.

## Next steps

The crucial information collected in this hunter survey will be instrumental in implementing the baseline stock assessment survey of coconut crabs across Fiji, which will be used

Figure 3. A female coconut crab from Nagelelevu Island, Cakaudrove Province, Fiji, with noticeable pleopods.  
(Image: ©Epeli Loganimoce, IMR USP)







Coconut crabs tied up after a morning hunting session on Nagelelevu Island, Cakaudrove Province, Fiji.  
(Image: ©Epeli Loganimoce, IMR USP)

to develop management guidelines and tools. Management guidelines will need to be put in place to ensure the sustainable utilisation of coconut crabs whilst ensuring that coconut crabs continue to survive. To do this, communities need to be involved at the initial stages of developing management strategies through a community consultation process.

Two main operations are currently in the process, which include training provided by the Pacific Community via a virtual workshop where the team from USP and Fiji's Ministry of Fisheries are trained on collating and managing field data and conducting a baseline stock assessment across Fiji.

## Acknowledgement

This survey was funded through the PEUMP Programme. USP is one of four key implementing partners – along with SPC, the Pacific Islands Forum Fisheries Agency and the Secretariat of the Pacific Regional Environment Programme – of the PEUMP Programme, a EUR 45 million initiative funded by the European Union and the Government of Sweden.

## Suggested further reading

Fletcher W. and Amos M. 1994. Stock assessment of coconut crabs. Canberra: Australian Centre for International Agricultural Research. 32 p.

Fletcher W.J., Brown I.W. and Fielder D.R. 1990. Growth of the coconut crab *Birgus latro* in Vanuatu. *Journal of Experimental Marine Biology and Ecology* 141:63–78.

Helagi N., Tafatu J., Bertram I., Moore B., Linawak M. and Pakoa K. 2015. Status of the coconut crab *Birgus latro* in Niue. Noumea, New Caledonia: Pacific Community. 38 p. Available at: <http://purl.org/spc/digilib/doc/suyys>

Lee S., Lewis A., Gillett R., Fox M., Tuqiri N., Sadovy Y., Batibasaga A., Lalavanua W. and Lovell E. 2018. Coconut crab. p. 30–33. In: Mangubhai S., Lee S., Gillett R. and Lewis T. (eds). *Fiji fishery resource profiles; Information for management on 44 of the most important species groups*. Suva: Gillett, Preston and Associates.

Matamaki T., Munro E., Helagi N., Bertram I. and Samuel R. 2016. Assessment of the coconut crab (*Birgus latro*) in Mauke, Cook Islands. Noumea, New Caledonia: Pacific Community (SPC). 21 p. Available at: <http://purl.org/spc/digilib/doc/u4wyf>

Qounadovu S. 2017. Coconut crabs at risk. Suva: The Fiji Times Available at: <https://www.fijitimes.com/coconut-crabs-at-risk/> (Accessed 13 August 2020).



# Developing participatory monitoring of community fisheries in Kiribati and Vanuatu

Neil Andrew,<sup>1\*</sup> Brooke Campbell,<sup>1</sup> Aurelie Delisle,<sup>1</sup> Owen Li,<sup>1</sup> Pita Neihipi,<sup>2,3</sup> Beia Nikiari,<sup>4</sup> Abel Sami,<sup>3</sup> Dirk Steenbergen<sup>1</sup> and Tarateiti Uriam<sup>4</sup>

## Introduction

Securing a sustainable supply of coastal fish has been prioritised by national governments in a series of regional policy statements, notably the Vava'u Declaration (2007),<sup>5</sup> The Apia Policy,<sup>6</sup> the Melanesian Spearhead Group's Roadmap for inshore fisheries management and sustainable development 2014–2023,<sup>7</sup> the Pacific Islands Forum Secretariat's Framework for a Pacific Oceanscape,<sup>8</sup> and the 2014 Palau Declaration – The Ocean: Life and Future.<sup>9</sup>

A major milestone in giving effect to these aspirations came in 2015 with the publication of “A New Song for Coastal Fisheries – Pathways to Change: The Noumea Strategy” (the New Song Strategy),<sup>10</sup> and the workshops that led to its release. In the five years since the publication of the New Song, coastal fisheries are now firmly on national agendas, and there is increasing investment in national programmes to support policy and management. In Kiribati and Vanuatu, for example, roadmaps have been developed to operationalise the visions provided in the New Song and in national fisheries and development documents (MFMRD 2019; VFD 2019).

The New Song powerfully articulates the need for new directions and innovations in realising regional leaders' visions, and is clear about the challenges in doing so. Reversing declines in fisheries and increasing their contribution to food security and economic development is made difficult by geography and a lack of infrastructure: many islands and communities are small and isolated, and alternative sources of food and income are limited.

These challenges are evident when considering Outcome Two of the New Song: “adequate and relevant information to inform management and policy”. By their nature, the thousands of small, complex fisheries in rural regions of Pacific

countries defy the application of generic approaches and methods to achieve outcome two. There is no simple rubric or toolbox that can be applied to all situations and objectives and data are scarce. Programmes designed to serve global, regional and national reporting obligations or national commodity fisheries will not, for example, serve communities seeking to manage their resources better. For all purposes, financial constraints and capacity will further limit what is possible. The 2019 Pacific Community (SPC) Coastal Fisheries Report Card indicates that the extent to which coastal harvests are sustainable, and the degree to which the management of those harvests is informed by scientific evidence, remains poorly known across the region (SPC 2019).

Here we introduce a fishery monitoring programme developed to support community-based fisheries management (CBFM) in Kiribati and Vanuatu as part of the Pathways project. Pathways is a collaboration among national fisheries agencies in Kiribati, Solomon Islands and Vanuatu, the Pacific Community, the University of Wollongong and WorldFish. The project joins a long history of CBFM in the Pacific region (e.g. Ruddle 1998; Govan 2009; Schwarz et al. 2011; Cohen and Foale 2013; Leopold et al. 2013; Jupiter et al. 2014; Cohen and Steenbergen 2015; Webster et al. 2017; and references therein), and interest is growing in these initiatives as food and nutritional security issues in rural communities come to the fore, most sharply in the last four months with the advent of COVID-19 (e.g. Farrell 2020; Eriksson et al. 2020; Steenbergen et al. 2020). With increasing investment, comes more attention to the performance and evaluation of CBFM and the production of generalisable lessons. The project has engaged with 134 communities and established new fisheries management plans in 45, with a further 18 under development.

The fisheries in the communities we worked with are remarkably diverse in, for example, fishing gear, seasonality,

<sup>1</sup> Australian National Centre for Ocean, Resources and Security, University of Wollongong, Wollongong, Australia

<sup>2</sup> Vanuatu Fisheries Department, Port Vila, Vanuatu

<sup>3</sup> The Pacific Community, Noumea, New Caledonia

<sup>4</sup> Ministry of Fisheries and Marine Resources Development, Tarawa, Kiribati

<sup>5</sup> <https://www.forumsec.org/2007/04/20/the-vavau-declaration-on-pacific-fisheries-resources-our-fish-our-future/>

<sup>6</sup> <http://purl.org/spc/digilib/doc/mgtfs>

<sup>7</sup> <http://purl.org/spc/digilib/doc/fmc3e>

<sup>8</sup> <https://www.forumsec.org/wp-content/uploads/2018/03/Framework-for-a-Pacific-Oceanscape-2010.pdf>

<sup>9</sup> <https://www.hokulea.com/wp-content/uploads/2016/08/Palau-Declaration-on-The-Ocean-Life-and-Future.pdf>

<sup>10</sup> <http://purl.org/spc/digilib/doc/b8hvs>

\* Author for correspondence: [nandrew@uow.edu.au](mailto:nandrew@uow.edu.au)

tide state, gendered patterns in fishing, cultural demands for fish, external forcing of demand, markets, weather, skill, politics, availability of outboard motors, and the presence of ciguatera (Adams 2012; Sulu et al. 2015; Bell et al. 2018; Gillett and Tauati 2018). In contrast, some fisheries target one or several species with a single gear type. Capturing the essence of fisheries in ways that are useful for communities to better manage their resources is reminiscent of the Indian parable about a group of blind people describing an elephant; all our truths are partial and there are a thousand ways to be wrong.

This complexity notwithstanding, there is an imperative to contribute to better informing management. Our purpose in this initiative was to evaluate the performance of community management plans in achieving their objectives. We note that CBFM can take many forms and may or may not be codified in a formal management plan. This diversity is evident among the communities we engage with, but for the purposes of developing our monitoring, we selected a subset of communities that have formalised their management aspirations in a written plan.

We were not, primarily, concerned with evaluating national policy, reporting on progress against the Sustainable Development Goals, or even against the New Song. Nor were we concerned with evaluating the performance of national commodity fisheries targeting, for example, beche de mer, tuna or deep-water snappers. Of course, the sampling programme will secondarily contribute to these goals, and to the pool of knowledge on species diversity, size structure of catches and so forth, but those were not the primary goals.

With this purpose in mind, the design process becomes a series of choices and compromises that balance practicalities and ambitions for information. Below we highlight some of those choices made to design a monitoring programme that was legitimate, simple, practical and useful for our purpose. Those choices build on the lessons and insights made by other programmes but may not be the decisions made in other contexts and with different objectives. In this and the companion national case study from Vanuatu, we focus on the data collection process, leaving other elements of the programmes to future articles.

More data is usually a good thing and a recurrent theme in the literature on fishery monitoring, and in small-scale fisheries in particular, it is the challenge of assessing data limited fisheries (see Halls et al. 2005 and Dowling et al. 2019). There is an enormous amount of literature to guide making the many compromises needed to implement a useful programme (Halls et al. 2005; Dowling et al. 2019), including many insights from the Pacific region (e.g. Dumas et al. 2009; Govan 2014; SPC 2016). There are many dimensions to these challenges relating to, for example, cost, simplicity, appropriateness, feasibility, scalability, legitimacy and adaptability. Below we highlight four dimensions and the challenges and compromises made to design a fit-for-purpose fishery

monitoring programme. Each choice brings with it opportunity costs in terms of information collected or not collected, and both financial and time consequences.

## Monitoring embedded in a larger process

Our approach positions the monitoring and evaluation process within, and subservient to, a deeper engagement with communities to support CBFM. This approach moves the fisheries biologist from centre stage and instead places more emphasis on other disciplines within a transdisciplinary approach to evaluation. A starting premise – based on our reading of the literature and experiences in rural development, fisheries and policy – was that sustainability may be more determined by the willingness of community members to decide a course of action, and develop and follow rules than by the robustness of assessment data. Baldly, science and data as a Western construct, may or may not be critical in that evolution of collective commitment. The purpose of the monitoring is to catalyse and support community-led conversations and to bridge worldviews of community members to those of national agencies and their partners.

As a consequence, we prioritised our relationship with communities, on mutual understandings of our role, and on the legitimacy of management institutions. Key in this was the process of engaging with communities, co-development of the monitoring programme, their ownership of data generated, and reporting back and translating results to make them useful to the community.

Based on established relationships and a common purpose, the monitoring and evaluation programme has three stages (Fig. 1). Before communities are visited, enumerators (project staff, fisheries officers and community members) were trained in the use of the survey instruments. Monitoring trips are “socialised” prior to visits to communities, and data collection teams spend their first day in communities discussing the monitoring activity and its role in supporting CBFM, upcoming or past activities, answering questions, recruiting interested participants, and addressing concerns. These activities are intended to foster community willingness to participate – through building an understanding of how important the participation of each fisher is – in developing a robust understanding of how the activity supports the community’s CBFM aspirations.

Importantly, the findings resulting from collected data are reported back to each community after each round of data collection. Initial reports contain information about general trends and catch composition, as well as information tailored to each community’s specific management efforts. The next step is to feed the data collected by this monitoring programme back into the management cycle, so that communities can use it to review their CBFM plans (or community rules) and make decisions about whether the plan needs adjusting. Respecting that government agencies



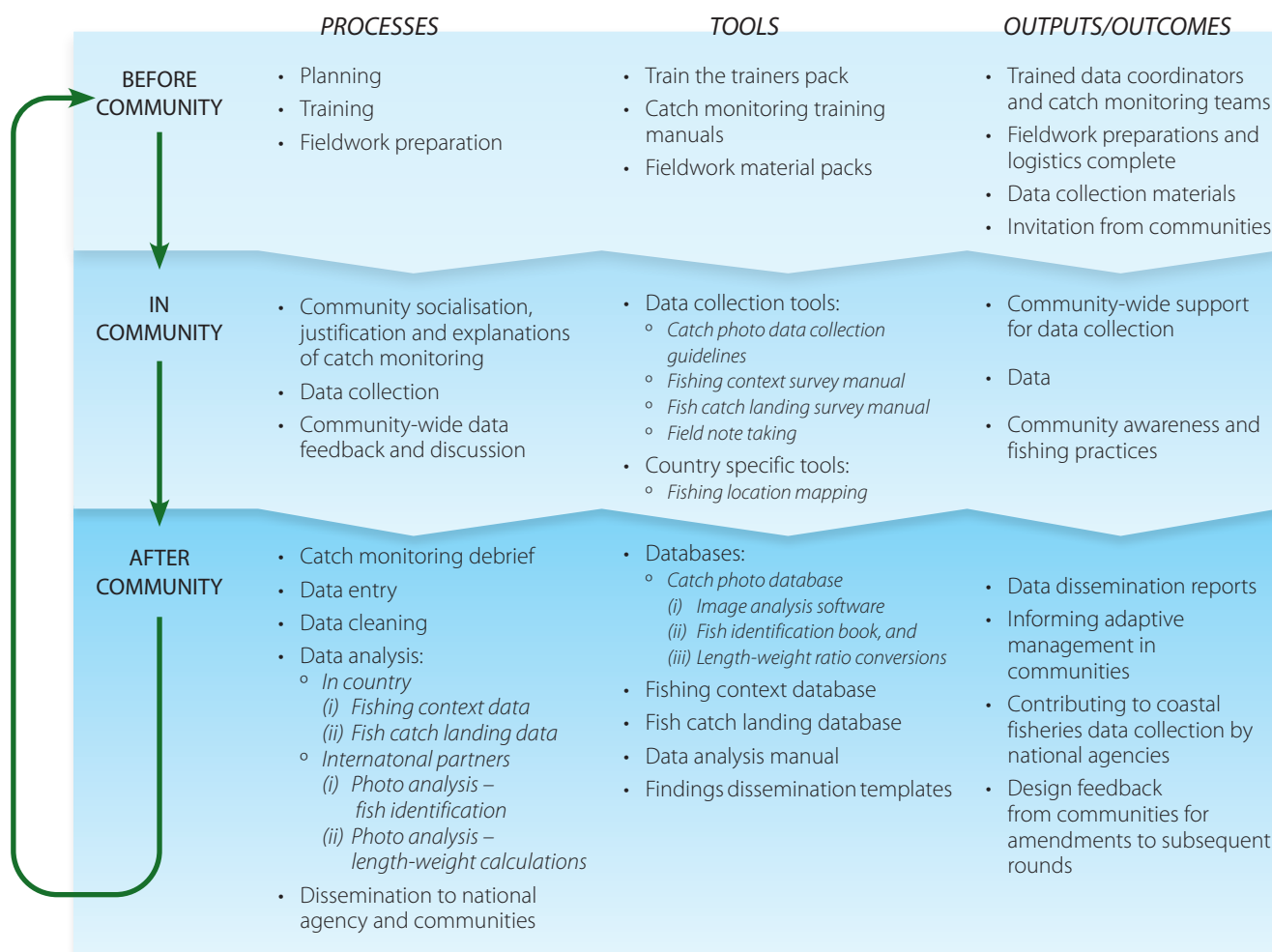


Figure 1. Components of the fishery monitoring programme.

are partners in CBFM, reports are also prepared for national government agencies, based on an awareness of their own reporting, management and policy needs.

## Mixed methods

We use a mixed methods approach (Creswell and Creswell 2018) to capture snapshots of fisheries using four data collection tools: 1) a catch and effort survey, 2) a fishing context survey, 3) photographs of catch, and 4) catch monitor field notes. The fishing context survey used a recall method to understand fishing habits over the past seven days, travel times to main fishing grounds, perceptions of observed changes to fish and invertebrate resources over a defined timeframe, awareness of local management rules and their adherence, and any resource concerns. Where appropriate, questions were designed to replicate those in a range of national and SPC survey instruments, including household income and expenditure surveys, Tails+<sup>11</sup> and research

surveys held by Pathways staff (see also Kaly et al. 2016; Molai et al. 2020).

These tools were tested in 10 communities implementing CBFM plans, each sampling trip lasting about two weeks, depending on logistics. Thus far, 7891 fish (313 species) from 295 fishing trips have been measured, and 279 fishers interviewed. Surveys are planned to be done quarterly for the next year and then reviewed. The surveys are currently paper based while catch monitors become familiar with the forms and while the design and questions are tweaked. Future iterations will integrate the photograph and the survey modules as a tablet-based tool.

## Length, not weight (or both)

An early choice was to estimate the lengths of fish rather than their weight. The experiences of SPC colleagues and others suggested that, in a community-based programme

<sup>11</sup> Tails is a tablet application which facilitates the collection of tuna, deep bottom snapper and reef fish catch data from small scale fishers and allows for the data to be uploaded to a central database for analysis (for more information see <https://oceanfish.spc.int/en/ofpsection/data-management/spc-members/dd/505-tails-application>). Tails+ refers to the amended version of Tails that makes it suitable to address needs of the Vanuatu coastal fisheries context.

where a range of enumerators from fisheries officers to community members could collect data, the maintenance of reliable and accurate scales would be expensive and problematic. Further, in many instances the weights of fish were unreliable because the fish were gutted or bled prior to landing and/or had lost significant fluid during the course of the fishing trip if they were speared and/or left on the deck.

With known length-weight relationships for many fish species, estimates of weight could be derived in almost all instances. The database of length-weight relationships curated by SPC was an important source of information in this regard. Ongoing work by SPC's Fisheries, Aquaculture and Marine Ecosystems Division is rapidly increasing the reliability of the estimates. Although not sought by communities at this stage, length-based information has the potential to support length-based methods to set size limits for fish species (Hordyk et al. 2015; Prince et al. 2015; but see Dowling et al. 2019 on cautions in the search for generic methods).

## Photographs of the catch, not of individual fish

Another early choice was to use photographs of catches rather than measure or photograph individual fish in the time-honoured creel survey tradition. Catches were either laid out on gridded mats or arranged beside a reference

object of known length and a photograph taken with a tablet, phone or conventional camera (Fig. 2, see also Cohen and Alexander 2013).

There are significant advantages and disadvantages in this choice. The method minimises irritation for participating fishers at the end of their day's work, and reduces damage to the catch from prolonged exposure to the elements. Taking a photograph also creates a permanent record of the catch for error checking and as yet unimagined purposes. Taking photos also gives more control over the accuracy and consistency of the fish identification. Thus far more than 300 species of fish have been recorded in the catches. Because we anticipate the method may be used by a diverse range of enumerators, adequate species recognition would place a significant training burden on project and national agency resources. Conversely, the method requires that catch monitors take good images, curate the photographs and maintain the tablets.

Using photographs shifts time-consuming aspects of the process from the beach to the office. Data entry and curation of forms were managed in-country, with images processed at University of Wollongong using ImageJ (Rasband 2018) to provide information on species diversity, length and (by calculation) weights. Sending the digital files from Kiribati and Vanuatu was not problematic and, as ICT coverage continues to improve in the region (Cave 2012; Hunt



Figure 2. An example of a catch from Kiribati. This catch consists of small fish from only two families: tropical snappers (*Lutjanidae*) and tropical emperors (*Lethrinidae*).



2016, 2019), files will increasingly be able to be sent directly from rural areas. Image processing is an exacting and time-consuming task. Recent work at SPC and by James Cook University with the World Wildlife Fund offers the potential for greater automation of image processing, including through mobile apps for field-based identification and measurement (Andrew Halford, Senior Coastal Fisheries Scientist, SPC and Michael Bradley, Postdoctoral Research Fellow, James Cook University, pers. comm.).

## Invertebrates

Many CBFM plans and research on coral reef fisheries focus on fish. Invertebrates are much less understood and pose particular and largely unresolved challenges for monitoring and evaluation of CBFM plans (Fig. 3). Invertebrates are an important part of catches in many parts of the region and we found this to be the case in Kiribati and parts of Solomon Islands, in particular. During one visit to a community in Kiribati, 75 catches consisted entirely of invertebrates, with only 29 containing fish. Descriptions of catches for some invertebrates such as *Trochus*, clams and whelks are relatively

straightforward, but soft-bodied taxa such as holothurians, polychaetes, octopus and squid present major challenges. Seaweeds would similarly pose problems for both size estimation and image processing. We have recorded many photographs of invertebrate catches and are working with SPC to find solutions for capturing invertebrate data so that it can be used to inform community management. Another limitation is the use of non-standard units of measurement such as strings or buckets. We are also working on establishing proxies for non-standard units, which would reduce the need for enumerators to lay out the entire contents of a bag or bucket.

## Conclusions

Based on the pilot work outlined here and in the companion article by Abel Sami and colleagues from Vanuatu, the sampling methods described appear to offer a fit-for-purpose compromise for describing catches and characterising fisheries in CBFM communities. The survey instruments and training materials developed are available upon request from the authors. The next steps will be to refine methods, further integrate sampling into management cycles with



Figure 3. A composite image of invertebrates collected from Kiribati and Vanuatu presented in the way that they are usually harvested. Clockwise from top left: Strings of peanut worms (*Sipuncula* sp.); a string of shucked giant clams (*Tridacna* sp.); a collection of snails and chitons; and an octopus.

communities, design a larger programme to cover more communities nationally, and to describe fishing patterns over time. Ultimately, these methods may contribute to systems of reporting against national goals and the New Song outcomes.

## Acknowledgements

We are grateful to participating fishers and community members for generously sharing their time and wisdom in the course of the sampling. We thank our colleagues Rutiana Tebaba, Kobaia Teitiaki, Matereiti Buren, Teitikai Kamaie, Iutita Karekennatu, Iakobwa Ierutia and Toaiti Vanguna (all from the Kiribati Ministry of Fisheries and Marine Resource Development), and Douglas Koran, Vasemaca Malverus, Regina Ephraim, Ada Sokach and Lucy Joy (all from the Vanuatu Fisheries Department) for insights and taking on the enumerator burden. Hampus Eriksson and Pip Cohen (WorldFish), Brad Moore (New Zealand National Institute of Water and Atmospheric Research), Hugh Govan (LMMA), and Andrew Halford, Pauline Bosserelle and George Shedrawi (SPC's Fisheries, Aquaculture and Marine Ecosystems Division), shared advice and discussion. This research was funded by the Australian Government through Australian Centre for International Agricultural Research project FIS/2016/300.

## References

- Adams T. 2012. The characteristics of Pacific Island small-scale fisheries. SPC Fisheries Newsletter 138:37–43.
- Bell J.D., Cisneros-Montemayor A., Hanich Q., Johnson J.E., Lehodey P., Moore B.R., Pratchett M. S., Reygondeau G., Senina I., Virdin J. and Wabnitz C. 2018. Adaptations to maintain the contributions of small-scale fisheries to food security in the Pacific Islands. *Marine Policy* 88:303–314.
- Cave D. 2012. Digital Islands: How the Pacific ICT revolution is transforming the region. Online article 21 November, 2012. Sydney, Australia: Lowy Institute. Available at: <https://www.lowyinstitute.org/publications/digital-islands-how-pacific-ict-revolution-transforming-region>
- Cohen P.J. and Alexander T.J. 2013. Catch rates, composition and fish size from reefs management with periodically-harvested closures. *PLoS ONE* 8:e73383.
- Cohen P.J. and Foale S. 2013. Sustaining small-scale fisheries with periodically harvested marine reserves. *Marine Policy* 37:278–287.
- Cohen P.J. and Steenbergen D. 2015. Social dimensions of local fisheries co-management in the Coral Triangle. *Environmental Conservation* 42(3):278–288.
- Creswell J.W. and Creswell J.D. 2018. Research design: Qualitative, quantitative, and mixed methods approaches. 5th edition. Thousand Oaks, California: Sage Publications Inc.
- Dowling N.A, Smith A.D.M., Smith D.C., Parma A.M., Dichmont C.M., Sainsbury K, Wilson J.R., Dougherty D.T. and Cope J.M 2019. Generic solutions for data-limited fishery assessments are not so simple. *Fish and Fisheries* 20(1):174–188.
- Dumas P., Jimenez H. and Leopold M. 2009. Training in community-based monitoring techniques in Emau Island, North Efate, Vanuatu. Noumea, New Caledonia: Coral reef initiatives for the Pacific (CRISP).
- Eriksson H., Ride A., Boso D., Sukulu M., Batalofo M., Siota F. and Gomese C. 2020. Changes and adaptations in village food systems in Solomon Islands: A rapid appraisal during the early stages of the COVID-19 pandemic. Program Report: 2020–22. Penang, Malaysia: WorldFish.
- Farrell P., Thow A-M., Tutuo Wate J., Noga N., Vatucawaqa P., Brewer T., Sharp M., Farmery A., Trevena H., Reeve E., Eriksson H., Gonzalez I., Mulcahy G., Eurich J.G. and Andrew N.L. 2020. COVID-19 and Pacific food system resilience: Opportunities to build a robust response. *Food Security* 12:783–791.
- Gillett R.E. and Tauati M.I. 2018. Fisheries of the Pacific Islands: Regional and national information. Food and Agriculture Organization Technical Paper No. 625. Apia, Samoa: FAO Fisheries and Aquaculture. 279 p.
- Govan H. 2009. Achieving the potential of locally managed marine areas in the South Pacific. SPC Traditional Marine Resource Management and Knowledge Information Bulletin 25:16–25.
- Govan H. 2014. Monitoring, control and surveillance of coastal fisheries in Kiribati and Vanuatu. Part I: Priorities for action. Report for Secretariat of the Pacific Community, FAME Division. 27 p.
- Halls A.S., Arthur R., Bartley D., Felsing M., Grainger R., Hartmann W., Lamberts D., Purvis J., Sultana P., Thompson P. and Walmsley S. 2005. Guidelines for designing data collection and sharing systems for co-managed fisheries. Part 2: Technical guidelines. Food and Agriculture Organization Fisheries Technical Paper. No. 494/2. Rome: FAO. 108 p.
- Hordyk A.R., Ono K., Valencia S.R., Loneragan N.R. and Prince J.D. 2015. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES Journal of Marine Science* 72:217–231.



- Hunt A. 2016. Mobile phone data collection app for artisanal fisheries makes debut in Funafuti, Tuvalu. SPC Fisheries Newsletter 149:2.
- Hunt A. 2019. 20,000<sup>th</sup> Tails logsheet uploaded. SPC Fisheries Newsletter 157:8.
- Jupiter S.D., Cohen P.J., Weeks R., Tawake A. and Govan H. 2014. Locally managed marine areas: Multiple objectives and diverse strategies. *Pacific Conservation Biology* 20:165–179.
- Kaly U., Preston G., Yeeting B., Bertram I., Moore B. 2016. Creel and market surveys: A manual for Pacific Island fisheries officers. Noumea, New Caledonia: Pacific Community. 136 p. Available at: <http://purl.org/spc/digilib/doc/izw66>
- Leopold M., Beckensteiner J., Kaltavara J., Raubani J. and Caillon S. 2013. Community-based management of nearshore fisheries in Vanuatu: What works? *Marine Policy* 42:167–176.
- MFMRD (Ministry of Fisheries and Marine Resource Development). 2019. Kiribati National Coastal Fisheries Roadmap 2019–2036. Tarawa, Kiribati: Ministry of Fisheries and Marine Resource Development.
- Molai C., Bosserelle P., Kinch J., Shedrawi G. and Halford A. 2020. Creel surveys increase understanding of fisher patterns across three atolls in Kiribati. SPC Fisheries Newsletter 160:55–64.
- Prince J.D., Victor S., Kloulchad V. and Hordyk A.R. 2015. Length-based SPR assessment of eleven Indo-Pacific coral reef fish populations in Palau. *Fisheries Research* 171:42–58.
- Rasband W.S. 2018. ImageJ, 1997–2018. US National Institutes of Health, Bethesda, MD, USA. Available at: <https://imagej.nih.gov/ij/>
- Ruddle K. 1998. The context of policy design for existing community-based fisheries management systems in the Pacific islands. *Ocean and Coastal Management* 40:105–126.
- Schwarz A.M., Béné C., Bennett G., Boso D., Hilly Z., Paul C., Posala R., Sibiti S. and Andrew N. 2011. Vulnerability and resilience of remote rural communities to shocks and global changes: Empirical analysis from Solomon Islands. *Global Environmental Change-Human and Policy Dimensions* 21:1128–1140.
- SPC (Pacific Community). 2016. Creel and market surveys: A manual for Pacific Island fisheries officers. Noumea, New Caledonia: the Pacific Community. 136 p.
- SPC (Pacific Community). 2019. Future of Fisheries – Coastal Fishery Report Card 2019. The Pacific Community (SPC), Noumea, New Caledonia. Available at: <https://fame1.spc.int/en/publications/roadmap-a-report-cards>
- Steenbergen D.J., Neihapi P., Koran D., Sami A., Malverus V., Ephraim R. and Andrew N. 2020. COVID-19 restrictions amidst cyclones and volcanoes: a rapid assessment of early impacts on livelihoods and food security in coastal communities in Vanuatu. *Marine Policy* 104:199.
- Sulu R.J., Eriksson H., Schwarz A.-M., Andrew N.L., Orirana G., Sukulu M., Oeta J., Harohau D., Sibiti S., Toritela A. and Beare D. 2015. Livelihoods and fisheries governance in a contemporary Pacific Island setting. *PLoS ONE* 10(11): e0143516.
- VFD (Vanuatu Fisheries Department). 2019. Vanuatu National Roadmap for Coastal Fisheries: 2019–2030. Port Vila, Vanuatu: Vanuatu Fisheries Department. 24 p. Available at: <http://purl.org/spc/digilib/doc/bhawm>
- Webster F.J., Cohen P.J., Malimali S., Tauati M., Vidler K., Mailau S., Vaipuna L. and Fatongiatau V. 2017. Detecting fisheries trends in a co-managed area in the Kingdom of Tonga. *Fisheries Research* 186:168–176.

# A novel participatory catch monitoring approach: The Vanuatu experience

Abel Sami,<sup>1</sup> Pita Neihapi,<sup>1,2</sup> Douglas Koran,<sup>1</sup> Vasemaca Malverus,<sup>1</sup> Regina Ephraim,<sup>1</sup> Ada Sokach,<sup>1</sup> Lucy Joy,<sup>1\*</sup> Owen Li<sup>3</sup> and Dirk Steenbergen<sup>3</sup>

*This paper presents the preliminary experiences of implementing a participatory catch monitoring programme in Vanuatu. The monitoring programme utilises a mixed-methods approach, involving photo identification combined with qualitative and quantitative surveys. It was designed to be efficient, inclusive, and implementable with domestic resources and capacity. It puts local participation front and centre to strengthen and foster people's engagement in fisheries management. As such, the programme attaches itself to larger sets of ongoing activities under community-based fisheries management practices. Although preliminary, the findings of the first round of data collection reveal highly diverse catches and new fishing techniques, and have facilitated community discussions wherein previous anecdotal evidence of management impact were both supported and challenged.*

## Introduction

Healthy and productive coastal fisheries resources are critical for Vanuatu (Hickey 2008; Raubani et al. 2017), not only for coastal communities but also for urban and inland populations. Given that Vanuatu is exceptionally disaster-prone (Day et al. 2019), fish are also an important fallback food source, as experienced during COVID-19 and Tropical Cyclones Pam and Harold in 2015 and 2020, respectively (Eriksson et al. 2017; Steenbergen et al. 2020).

To sustainably harness coastal fisheries for the health and wellbeing of all ni-Vanuatu, Vanuatu's National Roadmap for Coastal Fisheries 2019–2030 sets out the pathways for development in the coastal fisheries sector (Vanuatu Fisheries Department 2019). Implementation falls under the coordination of the Vanuatu Fisheries Department (VFD), and the roadmap clearly articulates that community-based fisheries management (CBFM) is the primary approach to ensure the sustainable management of coastal fisheries. One of the central directives under the roadmap is to generate consistent and reliable data on coastal fisheries. Furthermore, in recognising that local management starts with active participation, it is critical to generate data in ways that strengthens local motivation to manage resources. In this context, a community-based catch monitoring approach is being piloted under one of VFD's bilateral coastal fisheries programmes, the Pathways Project.

The community-based catch monitoring approach contributes to VFD's directive to integrate catch monitoring for better evidence-based management in communities and fits with existing initiatives, including community solar freezer monitoring, tailored revisions to the Tails catch monitoring mobile application designed by the Pacific Community (SPC),<sup>4</sup> and fish market monitoring. To address the need for relevant data, the new approach captures both quantitative and qualitative aspects of fishing practices to ensure the inclusion of a broad range of catch types. This allows for data from fishing-active people in communities who too often are not adequately included in fishery monitoring, mainly women. The community-based dimension integrates mechanisms for local participation and for closer engagement between communities and fisheries authorities as such relationships and dialogues are imperative for decentralised fisheries management to work. The approach, moreover, allows results and recorded changes to be fed into local management decision-making. Beyond the community level, the sampling methods have been designed to be complementary with and in support of broader national monitoring innovations, and is deliberate in that it will allow for the uptake of lessons learned into national data systems such as Tails+.

We present preliminary findings of the first round of data collection and reflect on opportunities and challenges of this approach. Our description draws on the outline of the method in the companion article (Andrew et al. 2020).

<sup>1</sup> Vanuatu Fisheries Department (VFD), Port Vila, Vanuatu

<sup>2</sup> The Pacific Community (SPC), Noumea, New Caledonia

<sup>3</sup> Australian National Centre for Ocean, Resources and Security (ANCORS), University of Wollongong, Wollongong, Australia

<sup>4</sup> Tails is a tablet application which facilitates the collection of tuna, deep bottom snapper and reef fish catch data from small scale fishers and allows for the data to be uploaded to a central database for analysis (for more information see <https://oceanfish.spc.int/en/ofpsection/data-management/spc-members/dd/505-tails-application>). Tails+ refers to the amended version of Tails that makes it suitable to address needs of the Vanuatu coastal fisheries context.

\* Author for correspondence: [ljoy@vanuatu.gov.vu](mailto:ljoy@vanuatu.gov.vu)



## Implementation of the community catch monitoring modality in Vanuatu

Data were collected by enumerator teams across five sites simultaneously. Each team was made up of a VFD observer and a recruited community member. VFD's fisheries observer unit is large and has a significant portion of staff on standby waiting for deployment. In agreement with VFD, 10 observers were invited to participate in the programme (double the amount needed per round to ensure enough observers would be available for any round).

All enumerators (both VFD and community recruits) were trained in Port Vila before travelling to communities for the first time. The training involved a thorough run-through of the objectives, procedures and tools. Scenario role playing was done to familiarise enumerators with the sampling protocol, but also to agree on standardised ways to address potential challenges in the field. In subsequent data rounds, the five VFD catch monitors will have a refresher and they, in turn, will train their community counterparts.

Once permission to visit was obtained and dates were finalised, teams travelled to communities and held meetings to explain the purpose of the catch monitoring and how it related to the existing CBFM work in the community. Subsequent data collection rounds will use this initial community meeting to also present back data findings from the previous round of data collection. Data collection lasted up to 14 consecutive days with a minimum target of 10 days, and depended, in part, on flight schedules. All "catch events" encountered were recorded, including gleaning excursions. This involved collecting data from women, men and youth. When confronted with multiple fish landings at once, priority was given to fishing that took place within the defined territory in the CBFM plan.

On completion of the data collection, the monitoring team debriefed with community leaders in order to reflect on activities and get feedback. On return from the field the Port Vila-based coordinating team transcribed data and curated the photographs before sending them to the University of Wollongong for image processing. Templates for more detailed feedback to communities and to VFD have been developed and used to standardize reporting.

## Site selection and sampling

Five sites were selected with relatively even geographical spread and were active fishing communities with which VFD has ongoing collaborative arrangements under the Pathways Project. From south to north these included two communities in Tafea Province (on Aniwa and south Tanna), one in Shefa Province (on north Efate), one in Malampa Province (southeast Malekula) and one in Sanma Province (north-east Santo). The sites range in their remoteness, with the

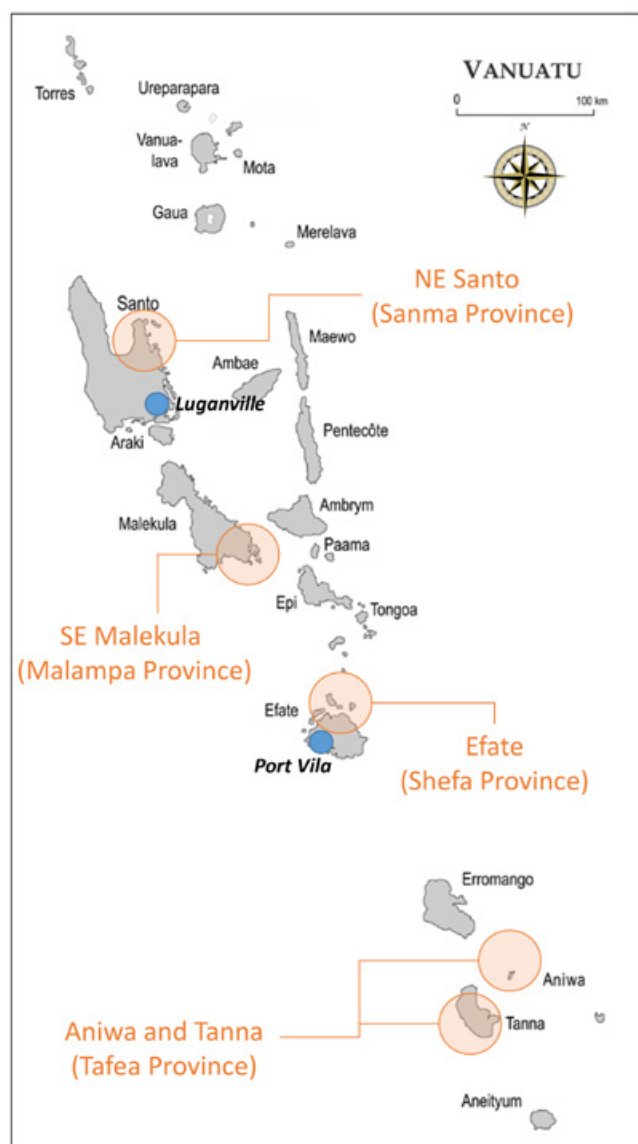


Figure 1. The catch monitoring sites in Vanuatu.

outer island community sites being the least connected by telecommunications and/or to markets or administrative centres. Communities on larger islands with capitals (Santo and Efate) were the most connected (Fig. 1). Fishing activity differed among sites, being market-driven in some places and subsistence-driven in others. This translated to varying types of fishing gear used and habitats targeted.

## Ensuring institutional embeddedness

Implementation was guided by VFD's Coastal Fisheries Division in order to aid its integration into the national programme. The implementation plan was co-designed to ensure that: 1) it complemented other data monitoring initiatives, 2) data access and sharing arrangements were in place, and 3) activities were streamlined to make the best use of shared resources (e.g. using VFD fishery observers to lead the enumerator teams).

## Preliminary findings and discussion

### Characterising fisheries

In total, 132 people – 33 women, 98 men, and one respondent whose gender was not noted – were interviewed using the qualitative survey forms (each of these was only filled out once), while 194 and 42 fish catch landings were recorded by men and women, respectively. Catch photos collected during fieldwork allowed identification and measurement of 3497 fish from 262 species and belonging to 116 genera and 45 families (Table 1). These data start to allow characterisation of communities' diverse fisheries.

The catches recorded in each community differed in quantity, diversity, and the most commonly harvested species. However, to account for seasonality and contextual anomalies during data collection, several rounds of data collection will be necessary. On Aniwa, for example, data collection partially coincided with the island's annual custom fishing period when fishing practices follow strict customary rules. Women spend all their time tending the yam crops and do not fish or glean. Catches, therefore, involved few reef species. Instead, mostly deep-bottom and pelagic species were recorded because men continued to fish offshore.<sup>5</sup> The Aniwa site was also the only site to record flying fish (Exocoetidae), which reflects not only oceanic conditions but also the customary night fishing carried out during this period.

In contrast, fishers of the southeast Malekula site, who supply important quantities of reef fish to local and urban markets, rely more heavily on coastal and fringing reefs for their catches. This is reflected in the tremendous diversity of catches (Table 1 and Fig. 2). Catches recorded at the Tanna site were small and caught in the immediate coastal zone, indicative of the primarily subsistence fishing done here (Fig. 3). Tanna was the only site where hawkfish (Cirrhitidae) and damselfish (Pomacentridae) made up a significant proportion of landings (Table 1). It will be interesting to observe whether the new tar-sealed road that is soon to open will change the species mix to more market-driven fish.

Surveys picked up unusual fishing methods that are often not included in standardised catch monitoring programmes but which are critical to inform local management. At the Tanna site, data collection coincided with neap tides and fishing using spears and machetes to kill fish driven into rock pools at night (Fig. 4). Other fishers caught fish and invertebrates by hand while free diving at night.

Localising the use of data by having fishers and fisheries officers understand the diversity of species being harvested and the methods used, helps to identify key species that warrant specific management. The catch monitoring programme can, therefore, contribute to strengthening community-led management by helping to establish local baselines, flagging issues that warrant more in-depth investigation, and gauging whether management interventions are effective.

Table 1. A breakdown of the catch diversity within and between the five sites during round 1.

	Islands of community sites				
	Aniwa	southeast Malekula	Efate	Tanna	northeast Santo
No. fish	174	1946	504	429	411
No. families	19	33	23	18	13
No. species	45	191	81	43	46
Three most prevalent families	Flying fish (Exocoetidae; n = 40)	Emperors (Lethrinidae; n = 410)	Goatfish (Mullidae; n = 94)	Wrasses (Labridae; n = 277)	Herrings, shads, sardines (Clupeidae; n = 223)
	Soldierfish, squirrelfish (Holocentridae; n = 32)	Soldierfish, squirrelfish (Holocentridae; n = 309)	Emperors (Lethrinidae; n = 83)	Hawkfish (Cirrhitidae; n = 62)	Parrotfish (Scaridae; n = 72)
	Bigeyes (Priacanthidae; n = 14)	Wrasses (Labridae; n = 302)	Halfbeaks (Hemiramphidae; n = 75)	Damselfish (Pomacentridae; n = 27)	Surgeonfish (Acanthuridae; n = 49)

<sup>5</sup> Custom fishing on Aniwa involves men fishing for pelagic species at night. During the day some men continued their deep-bottom fishing.





Figure 2. A catch from the southeast Malekula site, comprising nine species from five families, including five species of soldierfish/squirrelfish (Holocentridae), one species of emperors (Lethrinidae), one of goatfish (Mullidae), one of parrotfish (Scaridae), and one of groupers (Serranidae).



Figure 3. A catch from the Tanna site, where fishing predominantly supplies subsistence demand. Note that fish are small (grid squares measure 10 cm x 10 cm) and only four species from two fish families were present, including one species of hawkfish (Cirrhitidae) and three of wrasses (Labridae).

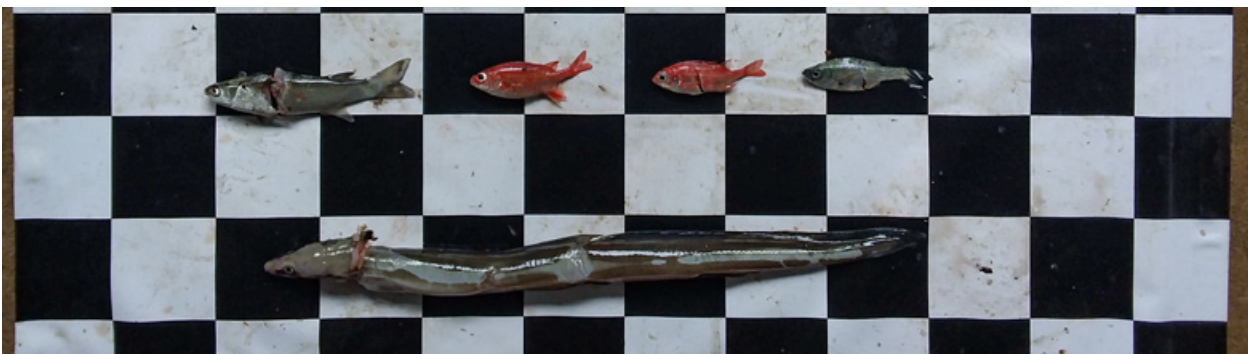


Figure 4. Fish caught at the Tanna site during neap tide fishing, showing slashes on each fish.



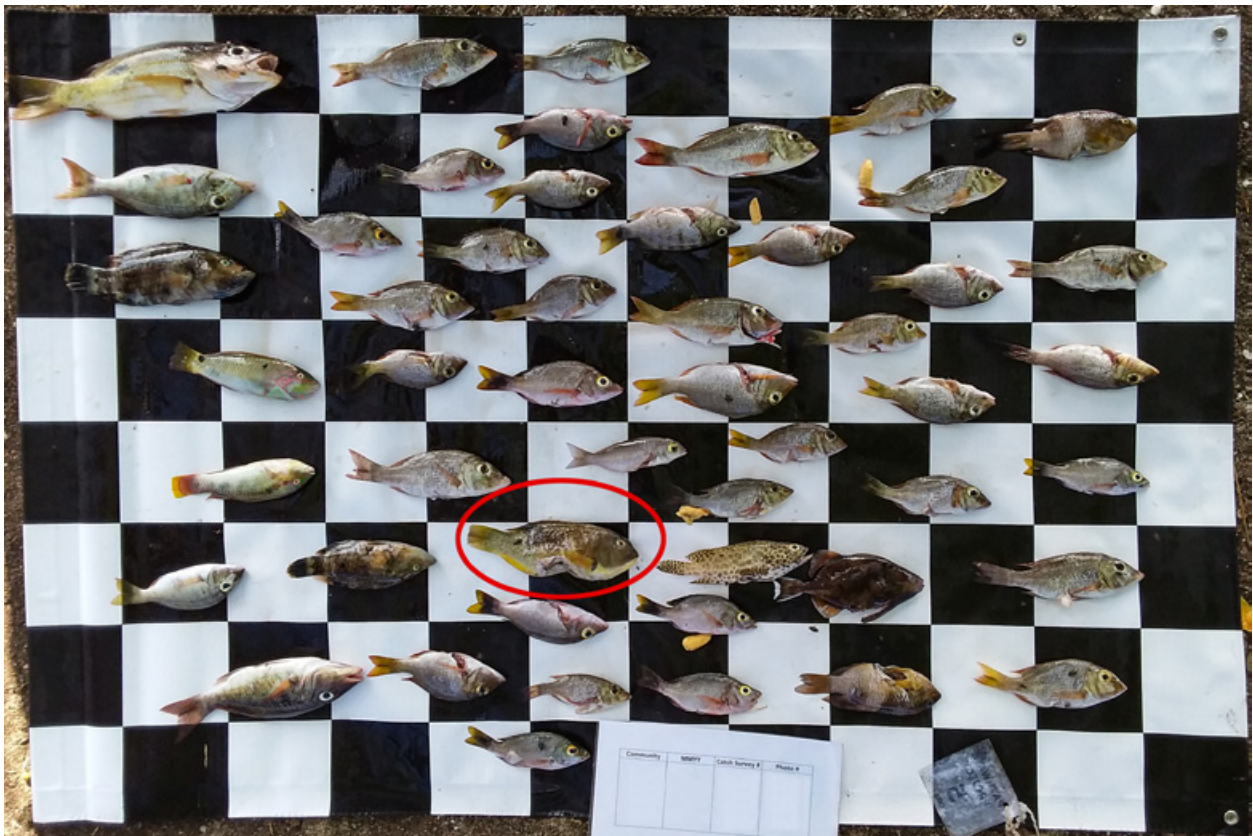


Figure 5. The only tuskfish (*Choerodon* sp.) reported among fish caught at the southeast Malekula site in round one of data collection ( $n = 1946$ ). Fishers suggested that this fish's reappearance after 10 years of absence, could be a result of the tabu area established three years prior.

## Greater community engagement

Participation was high, as evidenced by the focused and informed discussion about fisheries practices and management before, during and after data collection. Teams noted that the catch monitoring training was critical to ensuring enumerator teams confidently translated important, but often technical, methodological details to fishers and community leaders. Given that scientific concepts and fisheries management jargon are often new to community members, the close engagement of the enumerators with the respective community fisher associations, regular training refreshers, and the feedback of the findings cumulatively helped people understand why such monitoring is beneficial.

Community members were very interested to see the results, emphasising that the sharing of data proved to be a primary motivator for participation. The catch photos in particular generated a lot of discussion about the changes people experienced in their fisheries and what should be done. One catch photo from the southeast Malekula site included a species of tuskfish (*Choerodon* sp.) that fishers had not seen in 10 years (Fig. 5). In sharing the photographs during discussions, fishers made specific note of this fish and reflected on the improving state of the reef and whether their fisheries management

measures contributed to that. The photos were anonymised to enable sharing among fishers otherwise reluctant to engage.

Greater community engagement also allows for scrutiny and scepticism within the community to be addressed openly. During a presentation of initial results to the fishers association in southeast Malekula, for example, some fishers were concerned about how the data would be used afterwards, “*you are collecting these data, and some of us are asking if those data will lead to the government setting quotas on our fishing*”. Discussions that followed clarified that in order for management, let alone fisheries legislation, to ensure long-term productivity, any potentially restrictive measures needed to be evidence based, fair and relevant to the local context. To make a case for such measures requires reliable data. From this discussion, an agreement was reached whereby data could only be used by external parties with explicit permission from the community.

## Challenges

Achieving adequate gender representation was difficult in the first round of data collection. The catch monitoring teams consisted of two males at each site, and this



significantly reduced the willingness of women to participate. Capturing women's contributions to fishing is often overlooked, despite the fact that the fish and invertebrates women gather are more likely to be eaten within the community than larger reef and pelagic fish species caught by men in boats, which are often sold at markets (see Andrew et al. 2020 for further details on challenges associated to capturing and measuring invertebrates). So, from a food and nutrition security perspective it is imperative to capture women's catches, and equally so from a fisheries management perspective. Management measures, such as tabu areas, are usually established within immediate coastal zones of a village. This disproportionately limits gleaning and fishing activities of women compared with offshore fishing by men. In the interest of striving for equity, better understanding is required about how women use coastal areas and the importance of that to food, culture and livelihoods in a community. To address this, a woman catch monitor will be recruited in subsequent data rounds.

With regards to recruiting community members as part of data collection teams, a person's social standing, formal role and relationships in a community determines their ability to be an objective data collector. As experienced at one site, following discussion with leaders, it was decided to appoint the community's authorised fisheries officer, a formal position responsible for local monitoring and enforcing national regulations. Unsurprisingly, fishers did not treat the appointed catch monitor any differently than his official role – they hid their catch in fear of potential enforcement action. Reflecting on this, the way people interact with a community catch monitor is likely to be based far more on their familiar role in the community, than on any new title. The catch monitor in that community has since been replaced following community discussion.

## Impacts of COVID-19 and the programme's response

While not completely immune to COVID-19, using national staff to carry out data collection activities has made the programme relatively resilient. In implementing the second round of data collection in April 2020, an initial delay was experienced when the Vanuatu government declared a state of emergency. Once domestic travel eased, however, the programme resumed and was able to function independent of outside involvement. Collaborative data management, analysis and exchange involving international bilateral programme partners is also still possible through internet and phone.

The programme offers means to institutionalise community-based capacity for monitoring, which can catalyse a complete transition in the long-term to local data collection with minimal fisheries officer involvement on the ground. Integrating innovative technology may, over time, allow community enumerators to independently gather data and

submit them digitally. A monitoring programme such as this one could then continue largely uninterrupted even during complete lockdowns.

## Conclusion

Engaging fishers in management and monitoring of coastal fisheries in Vanuatu is a persistent challenge (Tavue et al. 2016; Raubani et al. 2019). Fishers often request evidence of whether, and how, their management measures are improving local fisheries. Preliminary implementation of the community catch monitoring programme has contributed to continual engagement between VFD and communities. This stands to strengthen collaboration and frequent interaction, which cumulatively can enhance people's understanding and participation in fisheries management. Data from the first round of collection have already shown promise in demonstrating which interventions contribute to enhancing productivity.

The method's design aimed to improve efficiency, inclusiveness and participation, and sought to function around and build national capacity. It does not require the presence of international fish and invertebrate taxonomy experts. Moreover, the time taken to collect data was drastically reduced, thus shifting the burden of time and resourcing typically associated with catch monitoring away from communities and fishers, and instead placed them with better-equipped stakeholders such as VFD. The speed at which data are collected means that monitors can move faster onto the next fisher, thus improving response rates and survey coverage. Finally, minimal handling of fish meant the freshness of fishers' catches was not compromised, an important consideration for participating fishers.

The strength of this monitoring programme is that it puts local participation front and centre. Its efficiency makes it ideal to characterise community fisheries and gauge the impact of management interventions. The data collected not only will benefit the communities where it is collected, but will also fit into Vanuatu's national strategy for coastal fisheries. The extremely diverse species-level data, for example, may usefully inform decision-making regarding which species are likely to require regulation, regular stock assessments or other interventions. This catch monitoring programme offers useful insights and innovations for VFD to incorporate into existing data programmes.

## Acknowledgements

The authors would like to thank the Director, Deputy Director Coastal, and other senior staff at VFD for their support and input towards improving catch monitoring in Vanuatu's coastal fisheries sector. Further thanks are owed to the Pathways CBFM teams in Kiribati and Solomon Islands, for their inputs into the design and

implementation. The development and implementation of the monitoring programme was funded by the Australian Government through ACIAR project FIS/2016/300 and the Vanuatu Fisheries Department.

## References

- Andrew N., Campbell B., Delisle A., Li O., Neihapi P., Nikiari B., Sami A., Steenbergen D. and Uriam T. 2020. Participatory monitoring of community fisheries in Kiribati and Vanuatu. *SPC Fisheries Newsletter* 162:34–40.
- Day J., Forster T., Himmelsbach J., Korte L., Mucke P., Radtke K., Thielbörger P. and Weller D. 2019. *World risk report 2019*. Berlin, Germany: Bündnis Entwicklung Hilft and Ruhr University Bochum – Institute for International Law of Peace and Armed Conflict.
- Eriksson H., Albert J., Albert S., Warren R., Pakoa K. and Andrew N. 2017. The role of fish and fisheries in recovering from natural hazards: Lessons learned from Vanuatu. *Environmental Science and Policy* 76:50–58.
- Hickey F.R. 2008. Nearshore fisheries and human development in Vanuatu and other parts of Melanesia. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin* 24:9–18. Available at: <http://purl.org/spc/digilib/doc/3omsx>
- Raubani J., Eriksson H., Neihapi P.T., Baereleo R.T., Amos M., Pakoa K., Gereva S., Nimoho G. and Andrew N. 2017. Past experiences and the refinement of Vanuatu's model for supporting community-based fisheries management. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin* 38:3–13. Available at: <http://purl.org/spc/digilib/doc/ixv86>
- Raubani J., Steenbergen D. J. and Naviti W. 2019. A roadmap for managing Vanuatu's coastal fisheries in the future. *SPC Fisheries Newsletter* 158:25–26. Available at: <http://purl.org/spc/digilib/doc/g6j5j>
- Steenbergen D.J., Neihapi P.T., Koran D., Sami A., Malverus V., Ephraim R. and Andrew N. 2020. COVID-19 restrictions amidst cyclones and volcanoes: a rapid assessment of early impacts on livelihoods and food security in coastal communities in Vanuatu. *Marine Policy* : 104199.
- Tavue R.B., Neihapi P., Cohen P.J., Raubani J. and Bertram I. 2016. What influences the form that community-based fisheries management takes in Vanuatu? *SPC Traditional Marine Resource Management and Knowledge Information Bulletin* 37:22–34. Available at: <http://purl.org/spc/digilib/doc/jecdvd>
- Vanuatu Fisheries Department. 2019. *Vanuatu National Roadmap for Coastal Fisheries: 2019–2030*. Port Vila, Vanuatu, Ministry of Agriculture, Livestock, Forestry, Fisheries and Biosecurity. Available at: <http://purl.org/spc/digilib/doc/bhawm>



# Population genetics: Basics and future applications to fisheries science in the Pacific

Giulia Anderson,<sup>1</sup> Jed Macdonald,<sup>2</sup> Joe Scutt Phillips<sup>3</sup> and Simon Nicol<sup>4</sup>

*Quantitative genetics and genomics provide an under-utilised avenue for monitoring capture fisheries. While most fisheries assessment tools use macro-scale observations as a proxy for the health, distribution and delineation of fish stocks, genetics directly measures the in situ molecular footprint of population health and structure. Genetics does not replace other forms of fisheries monitoring, rather it provides clarity and quantification of previously qualitative observations. As the Pacific region increasingly assimilates population genetics into its research toolkit, it is useful to briefly review population genetic analyses and their likely application in the fisheries science undertaken for member countries and territories of the Pacific Community.*

## Introduction

An individual's DNA<sup>5</sup> serves as inherited genetic instructions for development, functioning, growth and reproduction. DNA very occasionally mutates, creating variation in these instructions. Each instance of variation contributes to genetic diversity at the individual and population scale. In turn, genetic diversity is the basis of most genetic inferences. Some types of variation produce differences in an individual's physical characteristics or fitness, while other types have no measurable consequences. Variations can be as small as the switch of a single nucleotide (the building block unit of DNA) in the genetic code, as complicated as the inversion of a DNA sequence, or involve the duplication (or deletion)

of entire segments of the genetic code. Because there are so many different ways for DNA to vary, the overall genetic code is unique per individual. There are also two different genomes contained within a cell, nuclear and mitochondrial, each with different patterns of variation. Genetic analyses take advantage of all of these characteristics. Moreover, the processes that generate and spread new mutations in DNA provide a basis for understanding how species evolve, and how populations develop differing traits and adapt to changing environments and stressors.

At its most conservative, DNA diagnostics can provide an accurate identification of a specimen's species, which is useful when other taxonomic features are missing (Fig. 1).

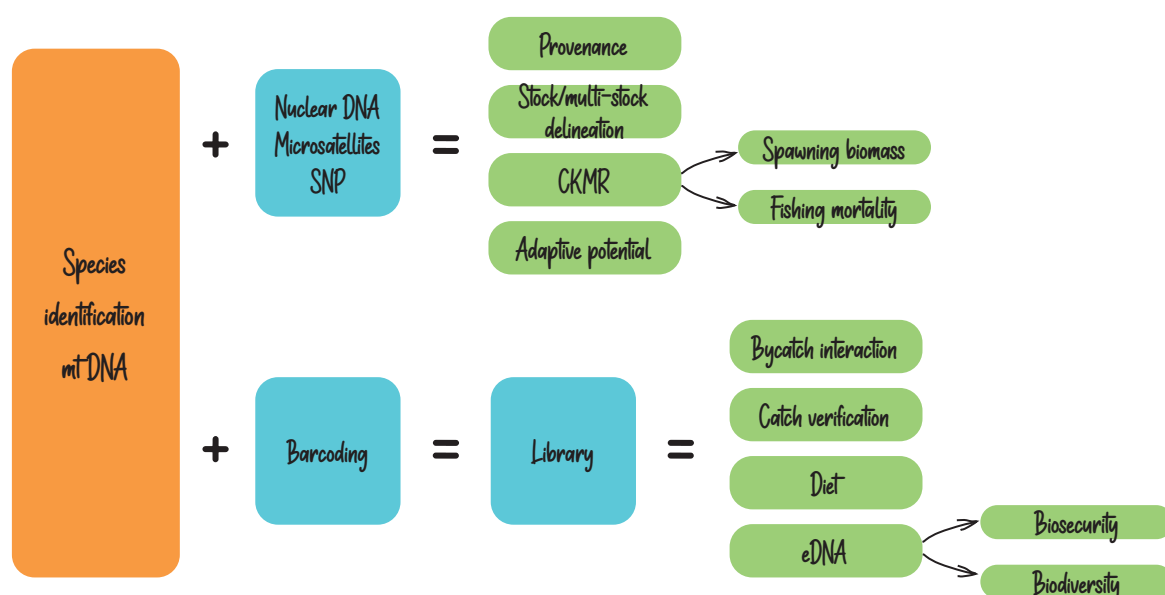


Figure 1. Schematic of fundamental applications of genetics.

<sup>1</sup> Fisheries Molecular Geneticist, SPC. Author for correspondence: GiuliaA@spc.int

<sup>2</sup> Senior Fisheries Scientist (Tuna Biology and Ecology), SPC

<sup>3</sup> Senior Fisheries Scientist (Statistical Modelling), SPC

<sup>4</sup> Principal Fisheries Scientist (Fisheries and Ecosystem Monitoring and Analysis), SPC

<sup>5</sup> The definition of DNA and other words or acronyms specific to genetics can be found in the glossary at the end of this article.

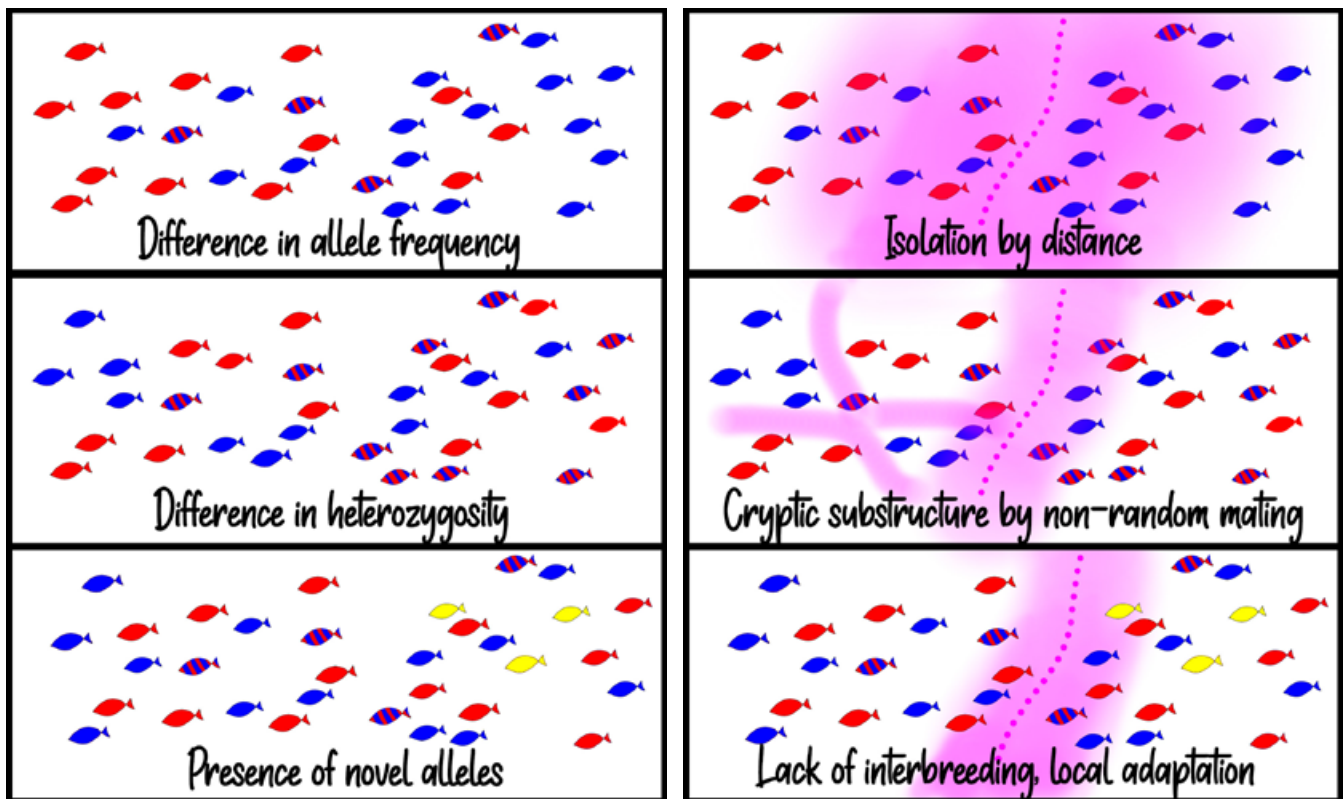


Figure 2. Examples of genetic patterns that indicate the presence of population structure (left panel), and how they might be interpreted (right panel). Different coloured fish represent the expression of different alleles. Dotted pink lines indicate proposed stock delineations; pink gradient indicates degree of uncertainty in where the actual divisions lie.

In more complex applications, genetic information can be used to evaluate the differences among individuals of the same species (Fig. 2), with implications for delineating the boundaries and estimating the degree of connectivity among populations. At its most powerful, the theory of population genetics provides an in-depth understanding of the relatedness of individuals and can directly estimate population size and mortality (Fig. 1).

The increased feasibility of incorporating a genetic perspective into fisheries monitoring, stems from the recent development and commercialisation of “high throughput” DNA sequencing technologies. The resulting increase in DNA processing capacity, reduction in cost, and greater quantities of data output make genetic assessment accessible, convenient and informative. An appealing argument for incorporating molecular approaches in fisheries science is the ability to avoid steps in data collection and analyses associated with other approaches that often introduce bias or weaken inference. However, molecular methods are also only effective if applied accurately and with appropriate expectations of how results can be interpreted.

Here we provide an introduction on genetic applications for fisheries management.

## What are the steps in DNA analysis?

Studies that wish to incorporate DNA analyses have many protocols available, and these can be broadly classified into one of two methods of collecting information. *Traditional* methods rely on variations in the length of key fragments of DNA that indicate differences in the underlying genetic code. *Sequencing* methods (most notably next generation sequencing, or NGS) directly assess the genetic code itself. Some basic steps and details are common to both methods (see also Fig. 3).

- **Common Step 1.** Extract a sample of tissue that is not contaminated by foreign DNA. Because genetic analyses focus on genetic diversity, and the introduction of foreign DNA also introduces foreign genetic variation, analyses using contaminated samples will be seriously compromised. Contamination can easily occur by touching tissue samples taken from one organism with equipment that previously came in contact with other individuals of the same or similar species, or other, non-sterile surfaces.
- **Common Step 2.** Extract the DNA. This can be done with commercially available kits and a few specialised pieces of equipment, or can be outsourced to specialised facilities for automated, high-volume sample processing.



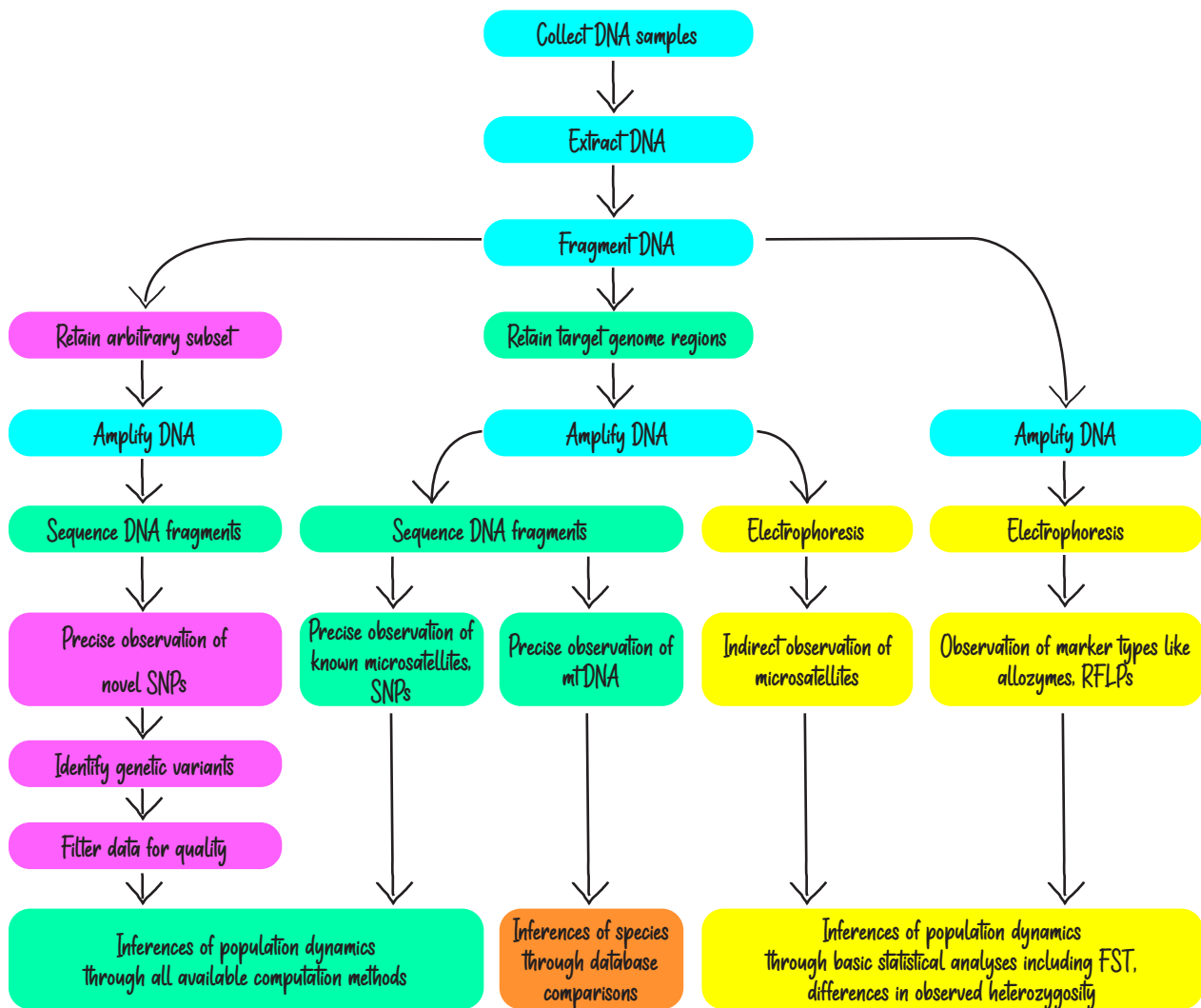


Figure 3. Basic steps in genetic analyses.

- Blue = common steps
- Yellow = traditional marker types/studies
- Green = sequencing marker types/studies
- Pink = NGS *de novo* sequencing (best method for producing maximum inference with limited existing information/initial investment)
- Orange = analyses specific to mitochondrial DNA (mtDNA) sequence data.

- ◆ **Common Step 3.** Fragment DNA. Traditional and NGS protocols use the same techniques to cut DNA into fragments, although for different reasons. Traditional methods directly infer the presence of genetic variation based on fragments produced in this step; next generation technology carries physical limits in the length of DNA strands that can be sequenced, and so requires that DNA be cut to a particular size. Both methods can also use fragmenting strategically to target (to either cut or not cut) particular genetic regions.
- ◆ **Optional Step 3b.** Select a subset of DNA for further analysis. This can be done by either targeting key regions of interest (especially in conjunction with targeted fragmenting), or filtering DNA fragments based

on arbitrary parameters (e.g. a particular length). Benefits of subsetting include discarding low-quality or uninformative DNA fragments that otherwise introduce “noise” into the data, and streamlining resources, effort and monetary investments associated with DNA processing.

- ◆ **Common Step 4.** Amplify the DNA. All protocols use some variation of polymerase chain reaction (PCR) to make many more copies of each DNA fragment. Although this is not an essential step in numerous traditional protocols, it makes it easier to identify genetic bands later. PCR is essential to NGS. In all cases, this amplification also reduces the need for large original volumes of tissue.

Traditional and NGS protocols begin to deviate at this point.

- **Traditional Step 5.** Visualise DNA fragments using gel electrophoresis. DNA will separate in isolated bands along the gel based on length and electric charge.
- **Traditional Step 6.** Call genotypes (often short-handed by turning “genotype” into a verb: e.g. “submit the raw data for genotyping”). Genetic variation among specimens can be inferred from the differences in distribution of DNA fragments across the gel. Each variable DNA fragment on the gel is interpreted as a version of that genetic segment (a variant or allele at that locus). It is also noted if each specimen carries one or two versions per segment, which determines if it is homozygous (one allele) or heterozygous (two alleles) at that locus.
- **Traditional Step 7.** Analyse data.

Because marker types associated with traditional methods produce limited data, they can only be analysed with simple statistics that produce low-resolution inferences. If using NGS methods, sequencing, genotyping and interpreting data are all much more involved.

- **NGS Step 5.** Sequence selected DNA fragments, nucleotide by nucleotide. This amounts to reading the very building blocks of the genetic code, brick by brick. Currently, the most popular protocol is genotyping-by-sequencing. The technology involved in this step is quintessential to the high-throughput sequencing revolution. Conveniently, it is standard to outsource NGS work to industrial laboratories.
- **NGS Step 6.** Identify variable genetic regions and call genotypes using automated software. The process requires tremendous computing power and is typically done using a “supercomputing” cluster as part of a sequencing laboratory’s standard services.
- **NGS Step 7.** Quality check and filter variant data. Datasets are subjected to a series of tests with thresholds determined by the available data quality and intended analyses.
- **NGS Step 8.** Analyse data.

NGS produces large volumes of data that can improve statistical power, and allows for in-depth analyses that capture the complex patterns that exist in DNA variation. Analyses that benefit from or depend on increased computational power include clustering algorithms, principle component analyses, multivariate analyses, analyses of variance tuned to molecular data (AMOVA), migration and bottleneck estimations, population assignment, and species identification.

## What are the types of markers and analyses?

Variation in the genome occurs in multiple dimensions that are measured using different tools or marker types. For example, allozymes mark genetic variation based on the final structure of produced proteins. Microsatellites observe patterns of repeating nucleic sequences for variation in physical length. Single nucleotide polymorphisms (SNPs) identify nucleotide substitutions in the genetic code itself. Each type of variation, and the associated marker type, differs in characteristics such as mutation rate, evolutionary selective pressure, and the number of possible variants per locus. The differences determine what type of marker is useful to a research question. For example, microsatellites have a higher mutation rate than SNPs, making microsatellites useful indicators of recent demographic changes, and SNPs more useful for exploring historical patterns. Alternatively, many loci in mtDNA have such a high mutation rate that when tested in very large populations (typical of tunas), they predictably return an overload of genetic variation that is impossible to parse into meaningful patterns. However, mtDNA’s extreme variability, paired with its stepwise mutation pattern, makes it very useful in devising phylogenetic trees at the species level. Figure 4 describes the practical applications of the most popular traditional and NGS-relevant marker types, along with the relative investment needed and information gained from each.

Cost is almost always the limiting factor in genetic research. The protocols that produce each marker type require specialty equipment, human effort and expertise, which drive the associated expense. The number of loci to be genotyped per specimen, the number of specimens to be processed, and the number of tissue specimens to be collected, all impact the final cost, which also means that limited funding caps the volume of data that can be produced.

Inferential power per locus correlates with the number of possible genetic variants. A single microsatellite with 20 possible variants (alleles) carries roughly as much information as 10 bi-allelic SNPs. Studies using marker types with low information content can still produce statistical power if enough loci are observed, as is the case with NGS protocols that produce thousands to millions of SNPs. Ultimately, it is the total volume of data a study produces that determines what kind of analyses are appropriate to apply (Fig. 5).

Multiple algorithms are available within each analysis type that might be more or less applicable per species and study design. However, in general, studies using more and more informative marker types have access to more data-demanding analyses that also produce higher confidence and precise observations. Heterozygosity assessments are exempt from the trend because, while the nuance provided is very marginal, the information is the basis of almost all other analyses and is the gateway assessment to justify if further data exploration is worthwhile.



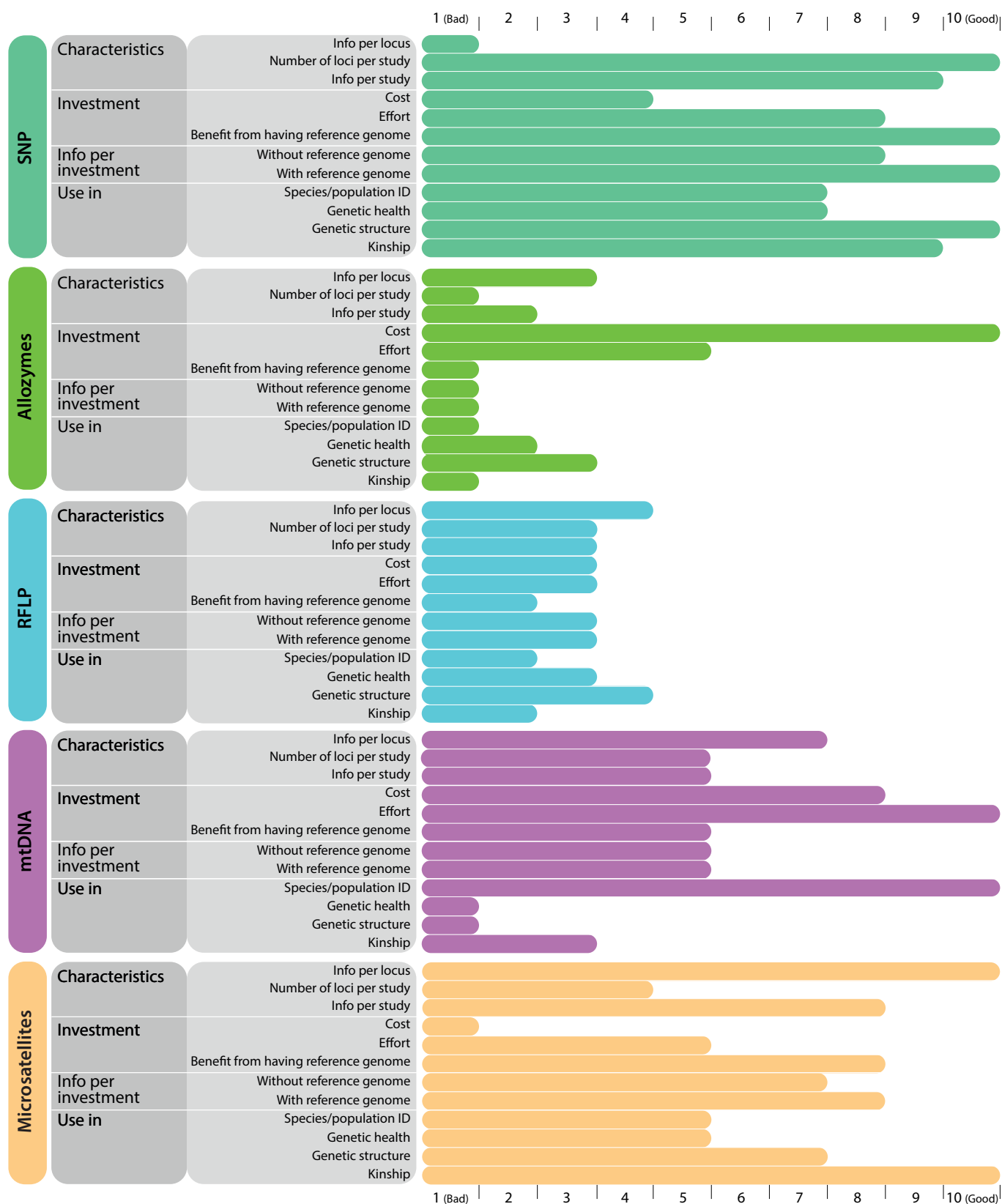


Figure 4. Comparative performance of the five most popular marker types across various parameters that commonly drive a researcher's choice of markers for a given study.

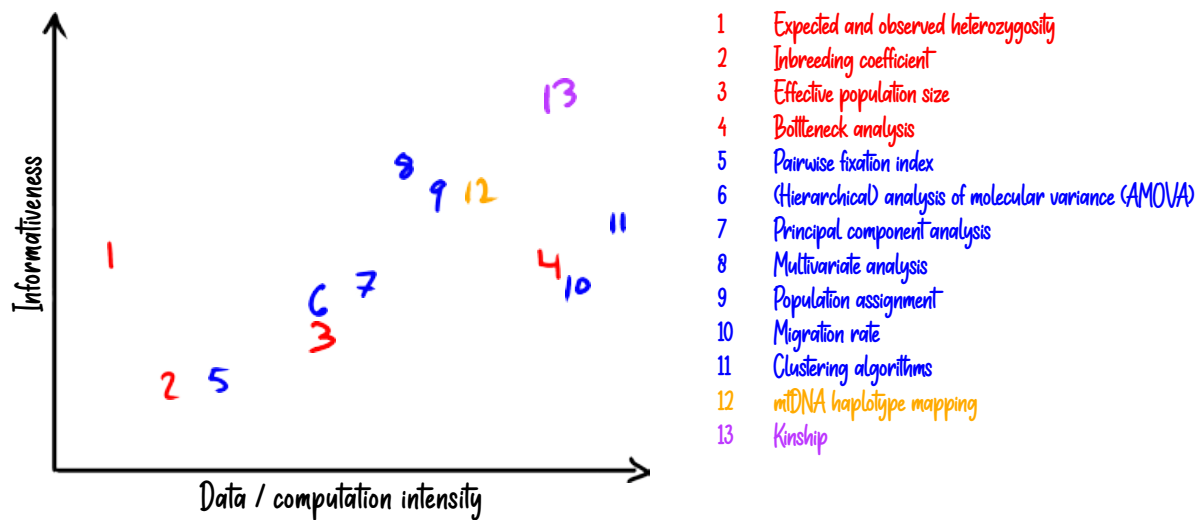


Figure 5. Information gained versus computational demands for a range of genetic data analyses. Analyses in red assess genetic diversity, those in blue assess population structure, those in orange assess species-level questions. Kinship is a unique bridge between diversity (when considered at the individual level) and structure (when zoomed out to the population level).

Data analysis in population genetic assessments has evolved in line with genotyping protocols. Originally, studies observing a handful of allozymes, each with a few alleles, used a simple statistical test to quantify differences in the proportion of each allele and the proportion of heterozygotes per marker per population. More informative analyses compared proportions of heterozygotes and homozygotes (statistics like the inbreeding coefficient  $F_{IS}$ , and the fixation index  $F_{ST}$ ). As improved DNA sequencing protocols enabled studies to produce orders of magnitude more datapoints, it became feasible, if not essential, to synthesise data based on variance among loci, averaged trends, and probability assignments, among others, in order to recognise useful patterns.

Although high-volume datasets still pay homage to baseline statistics such as  $F_{IS}$  and  $F_{ST}$ , they invariably take advantage of the improved nuance of more computationally intensive analyses such as clustering algorithms, which trial thousands of iterations of potential specimen groupings in order to recommend the most parsimonious network among observed individuals.

To summarise the generic relationships driving study design, a study's chosen genetic marker type and analysis type(s) build off one another. Choice in marker type predicts the amount of data that will be produced, which in turn influences the types of analyses that can be performed. Anticipating the statistical power necessary to capture biological patterns of interest determines the type of analyses that should be applied and the type of markers that can provide the required volume of data. External considerations, such as cost of DNA processing for the various marker types, often dictate that a compromise is reached between the most informative and most economical research methods.

The unique characteristics of each marker type, which extend beyond the amount of genetic information they commonly generate, influence their utility for particular research questions. In short:

- mtDNA sequence interpretation is best suited for identifying species;
- microsatellites are adequate for assessing kinship and recent population structure;
- SNPs are the king/queen of marker types, and match or out-perform all other marker types in most types of analyses (with the exception of species ID) given a large enough number of markers; and
- Allozymes and RFLPs remain relevant as options when NGS is not feasible.

## Applications to fisheries

Genetic analyses can be applied to a wide range of fisheries-related questions (Table 1). Some basic rules can help to navigate how genetics terminology translates to such questions. Concerns related to population sustainability, including overfishing, appropriate fishing quotas, or stock robustness in the face of climate change, can be addressed by studies of population genetic health. Questions related to fish distribution, movement, intermixing, schooling and population dynamics, can be addressed through analyses of population genetic structure.

In reality, the division between genetic health and genetic structure analyses is very fine. Based on the accepted rule that large, highly connected populations tend to be more genetically robust, studies of genetic health can validate



Table 1. Summary of common fisheries topics and the related information provided by genetic studies.

	Fisheries applicable topics	Possible inferences	Limiting factors
Genetic diversity/health	Absolute stock abundance	Quantitative estimation of the number of adults in a population	Depends on close-kin mark-recapture (CKMR), a new technique that has been tested in a limited number of species with only a moderate number of spawning adults.
	Fishery sustainability Overfishing and recovery status Need for fishing quota adjustments	Presence of past or current reductions in population size, whether due to overfishing or natural causes Presence and degree of inbreeding and loss of population-wide genetic diversity	Ability to sense historical reduction events varies with type of genetic marker Potential for confounding factors to replicate patterns associated with overfishing Not possible to isolate fishing mortality from natural mortality
	Adaptive capacity Future sustainability	Likelihood of population stability in the face of climate change and other environmental variability	Genomic adaptive capacity is fairly straightforward to quantify, but wholistic adaptive capacity also needs to consider ecological input, behaviour, phenotypic plasticity, etc
Population structure	Stock number and boundaries	Presence and strength of population structure, with implications for identifying underlying drivers	Depends on effective sampling to capture spatial and temporal differentiation; cannot make confident inferences about locations and times that were not sampled
	Stock sub-structuring	Presence and strength of more subtle, dynamic, or small-scale population structure Different kinds of potential patterns include isolation by distance, metapopulations, temporally variable structure due to migration, etc Drivers could include moderately strong site fidelity, other reductions in mobility, non-random mating, environmental selection, behaviour, etc	Extremely diverse calculations are available, with subtle differences in assumptions; selecting inappropriate equations/models can produce erroneous results As structure gets more subtle, differentiating biologically significant patterns from noise in the data is more challenging and subjective; likewise, isolating drivers with similar patterns becomes more complex.
	Mobility, connectivity	Degree of reproductive mixing between groups Potential underestimation of stock separation reported by other genetic tools, based on the disproportionate moderating effects a few migrants can have on genetic structure	Significant diversity exists among algorithms intended to infer migration rates, which often introduce assumptions about stock structure. Inappropriate model selection can significantly impact results
	Specimen provenance	Extent of admixture between different stocks Individual mobility when calibrated with catch location	Confidence of population assignment depends on extent of differentiation between populations
Conservation/Management	Species identification	Confirmation of species that are difficult to identify morphologically Hybridisation between species	Requires pre-existing data in global databases for comparison; can be limited for non-model species
	Recognising conservation concern	Intensity of necessary response based on reduction of adaptive capacity, presence of inbreeding, low genetic diversity, population fragmentation, etc	Acquiring enough specimens can be difficult in rare species
	Recommendation of appropriate action	Best practices to avoid introducing outbreeding depression or other negative consequences through conservation initiatives	Genetic analyses can easily recognise when population differentiation exists or not, but require much greater investment to predict if mixing two differentiated groups will produce maladapted offspring
	Effectiveness of ongoing conservation and management policies	Change over time in depth of genetic diversity, heterozygosity, and other measures of adaptive capacity	Depleted populations often violate assumptions that underly genetic assessment algorithms, skewing and introducing subjectivity into results
Behaviour	Migration patterns	Can confirm if fish sampled on and off an expected migration route are from the appropriate stock	Genetics does not provide indicators of previous travel; better assessed using tagging and otolith chemistry and confirmed genetically if appropriate
	Spawning locations Spawning times	Presence and number of distinct migratory spawning sites in species that are known to undertake spawning migrations Presence of non-random mating in mixed stock spawning grounds	Genetics only provides inferences based on patterns of population structure; spawning locations and times are better assessed using tagging, catch data, etc
	Future responses to unprecedented stress (especially climate change)	Extent of genetic adaptive capacity Presence of potentially advantageous genetic variations that would allow individuals to withstand new stress	Inappropriate to rely on genetic features to predict individual behaviour in complex organisms such as teleost fish; better assessed using modelling

Confidence levels:

Green High confidence assessment using predominantly genetic tools

Yellow Moderate confidence from genetic assessments; high stakes decisions should incorporate external research tools, but genetic inferences are sufficient for basic understanding

Grey Marginal confidence from genetic assessments; strongly recommended to incorporate external techniques before drawing conclusions

results against known population structure. Conversely, observations of unexpectedly low genetic diversity (and consequently health) in a large population can indicate the presence of previously unrecognised population substructure. Especially when a research question carries high stakes, such as informing conservation of a vulnerable species or recommending management changes to an important fishery, it is common to incorporate as many analytical approaches as possible to maximise confidence in the results.

Trust in inferences based on genetic data is generally high, but still not unequivocal. Genetic health is directly dependent on genetic diversity, which in turn is directly quantified using genetics tools; therefore, confidence in these types of analyses can be very high. However, structure analyses are more involved assessments of these same data, and are used to draw conclusions about a broader diversity of topics. For example, it often falls on the data interpreter to determine if heterozygosity in a sample group is lower than expected because of the presence of cryptic population structure, an abrupt isolation event in the distant past, migration patterns, or inadvertent biases in sampling of a mixed stock, among other options. Context usually provides clues to elevate one explanation over others, but brings its own potential for misinterpretation. In short, structure analyses carry relatively more possibility of inaccurate representation than baseline genetic health assessments, yet it is important to note that all genetic analyses depend on collecting samples that are both representative of the larger population being studied, and free of contamination.

The single greatest determining factor in the success of population-level genetic research is appropriate sample collection. Genetic analyses present snapshots of population parameters based on where and when individuals were sampled. Even when sample groups are accurate representations of the population, if they are not taken in a pattern that captures the phenomena of interest, results will be inconclusive. This is especially relevant for highly mobile pelagic species. For example, such species might comprise multiple populations that use the same spawning ground asynchronously, each occupying the same location at different times of year. If samples are taken annually but not seasonally, there will be no evidence of sequential habitation. Likewise, inferences made using a specific sample set may not apply to unobserved locations, times, life stages, or parts of the genome. Sample groups of mature adults consist of the tiny fraction of multiple cohorts that survived to that point, whereas juvenile sample groups contain more individuals from only a few cohorts and have not yet experienced the full range of environmental pressures. Applying patterns derived for one group to the other will likely produce inappropriate interpretations. The onus lies with the research team to collect samples in a pattern that can produce informative and accurate conclusions regarding the question that they wish to ask.

There are also blind spots in the types of inferences that are safe to derive from genetics. Unlike otolith chemistry

or other biomarkers, DNA remains stable across an individual's life and, therefore, carries no information about the behavioural or movement history of the individual. However creative applications are possible. For example, at a group level, the shared spawning location of related individuals can be inferred from DNA. Thus, genetics does have the capacity to verify pre-existing hypotheses concerning behaviour and migration.

## When it doesn't go smoothly...

The biggest challenge to the success of genetic studies occurs when there is insufficient capacity or funds to collect the appropriate number and distribution of specimens, and to extract enough genetic data from each to answer questions with confidence. However, other hiccups can also occur that threaten to compromise a study's integrity and success.

Examples include a study design that fails to sample in a pattern that captures the true pattern of genetic variability. Even given an appropriate study design, non-random or inadequate collection of specimens will result in sample groups that do not represent the larger population. Further, poor sample collection and storage protocols, and mishandling during DNA processing can allow DNA to degrade or be contaminated, leading to information loss or, in the case of unidentified contamination, the risk of interference with biologically relevant trends in the data. Even given successful extraction of genetic data, use of inappropriate statistical analyses, or failure to recognise the limits of such analyses, can lead to misinterpretation and inaccurate conclusions.

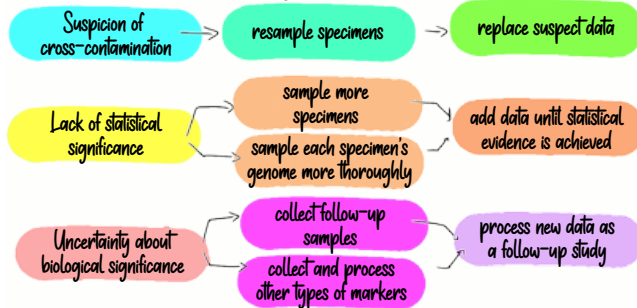
Fortunately, most issues can be avoided or corrected. Figure 6 provides potential avenues around some of the most common complications.

Some basic awareness during the study design and implementation phases can help avoid many obstacles.

- Knowing a species' life history first informs expectations of results, allowing researchers to anticipate the statistical power (and, therefore, the number of specimens and amount of genetic data per specimen) needed to generate accurate and conclusive results.
- Second, life history drives the sample collection strategy. In a classic example of non-random sampling, if a study intends to address broad-scale population dynamics but accidentally samples kin groups or other forms of local population substructure, it will produce inferences that are appropriate to the sample subgroup but distorted when projected onto a larger population. Anticipating the extent to which such substructure exists helps a researcher select an appropriate specimen collection strategy and avoid introducing noise into datasets focused on a specific question.



## Problem solving with adequate funds



## Problem solving without adequate funds



Figure 6. An incomplete list of examples of how studies might respond to common complications. The exact method of recourse depends on available resources, and not all methods succeed equally in regaining confidence in conclusions.

- Life history also informs the selection of the most appropriate downstream analyses. Complex analyses like clustering algorithms carry assumptions about the underlying model of population structure (e.g. metapopulation versus isolation by distance) upon which all other projections are built. Inappropriate assumptions will bias results and produce artefacts from an otherwise good-quality dataset.
- Comparing new data with existing data is standard practice to provide global context to current observations, and can improve inference power by incorporating compatible, published information into the new dataset. However, it is best to premeditate major comparisons and build study designs around that compatibility, otherwise the probability of two separate studies incidentally inventing parallel designs is low to non-existent. Incongruencies between any part of study design can

introduce artificial differences in results and reduce confidence in the biological significance of observations.

- Access to a reference genome, which consists of the published, nucleotide-by-nucleotide sequence of the entire genome of a species, potentially adds tremendous value to a study because it improves confidence in the selection of informative loci and can validate otherwise blind assumptions about selective pressure on a locus or its association with functional traits. Lack of a reference genome means conclusions depend exclusively on the accuracy of general population genetic theory, and especially limits confidence in assessments of local adaptation.
- A reference genome also aids in efficient budgeting. Just as sampled specimens only provide information from those locations and times, sampled genomic regions

only demonstrate patterns relevant to those exact loci. Knowing what parts of the genome will be informative to a research question (perhaps a particular gene, or a sex chromosome) allows for targeted genetic sampling, which limits costs from extraneous genetic sampling and reduces noise in the data.

- Cross-contamination among samples is a perpetual concern in genetic analyses and, once it occurs, it is difficult to correct. Vigilance in following sterilisation protocols from sample collection to sequencing is an essential point, and minimises the risk of needing to discard hard-earned data later.

## Pacific resources

Because of the significant bioinformatics focus of modern genetic assessments, the global genetics research community has developed robust support networks that stem from or mirror other computer science-associated fields. Many genetic assessment software programs exist on free platforms like R and Github. Online chatrooms such as Bio-stars, Stacks and ResearchGate have a wealth of discussion fora for troubleshooting specific software and interpreting results. Software developers are often very responsive to direct email contact regarding the performance of their published code.

It is also standard practice to outsource next generation DNA sequencing work to specialised, commercial laboratories. International shipment of tissue and preliminarily processed DNA is, therefore, common.

That said, working within the region generally reduces logistics, and potentially cost. The MOANA Labs at the University of the South Pacific in Suva, Fiji, has in-house capacity for small-scale projects using basic DNA extraction and traditional protocols. New Zealand Genomics Limited, a collaborative effort of several universities with government support, is Illumina-Propel certified to conduct NGS protocols at its University of Otago campus. Diversity Arrays Technology in Australia has developed an independent and highly popular NGS protocol, DArTseq. Many other, similarly equipped labs exist across the Pacific region.

## The Pacific Community in focus

The Pacific Community (SPC) has supported collaborations with other Pacific organisations, including the University of the South Pacific and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), to conduct preliminary population genetic structure and genetic health assessments of albacore, bigeye, skipjack and yellowfin tunas. These applications have identified the need for further research to investigate substructure driven by uneven reproductive success, the presence of kin in schools, and local adaptation. Other collaborations are developing and expanding new bioinformatic applications of genetic data, such as the close-kin mark-recapture concept, which infers absolute population size. Metabarcoding methods have also been applied for identifying tuna and seabird diets (with the University of Canberra and the Institute of Research for Development).

To progress these projects, SPC has recently commenced work on a design study to define the analytical tools, sampling coverage and investment required to resolve long-standing ecological questions for tropical tuna species in the western and central Pacific Ocean. To assist with this design study, SPC has also initiated the establishment of an informal advisory panel. While the initial role of this panel is to advise on the question of tuna stock structure, it is expected to evolve in scope to comment on the implementation of molecular genetics studies undertaken by SPC. Panel participants include experts in the application of molecular genetics and sample collection in the Pacific region. While the advisory panel is informal, SPC is utilising it as a first step in ensuring science quality and appropriate peer-review for molecular genetics applications in the region.

Here, we have aimed to demystify some of the key aspects of genetic analyses in the context of fisheries research. In developing genetics research capacity for the region, including logistical support for other Pacific research groups and in-house technical expertise for data assessment and interpretation, SPC hopes to foster knowledge exchange and encourage the wider application of genetic tools within Pacific fisheries management frameworks.

## Glossary

<b>allele:</b>	An allele is a variant form of a given gene, meaning it is one of two or more versions of a known mutation at the same place on a chromosome. Source: <a href="https://en.wikipedia.org/wiki/Allele">https://en.wikipedia.org/wiki/Allele</a>
<b>allozyme:</b>	Allozymes are variant forms of an enzyme that differ structurally but not functionally from other allozymes coded for by different alleles at the same locus. Source: <a href="https://www.genome.gov/genetics-glossary/r#glossary">https://www.genome.gov/genetics-glossary/r#glossary</a>
<b>CKMR:</b>	Close-kin mark-recapture (CKMR) is a recently developed method for estimating abundance and demographic parameters (e.g. population trends, survival) from kinship relationships determined from genetic samples. Source: <a href="http://afstws2019.org/sessions/">http://afstws2019.org/sessions/</a>
<b>DNA:</b>	Deoxyribonucleic acid (DNA), is a complex molecule that contains all the information necessary to build and maintain an organism. All living things have DNA within their cells. In fact, nearly every cell in a multicellular organism possesses the full set of DNA required for that organism. Source: <a href="https://www.nature.com/scitable/topicpage/introduction-what-is-dna-6579978/">https://www.nature.com/scitable/topicpage/introduction-what-is-dna-6579978/</a>
<b>eDNA:</b>	Environmental DNA (eDNA) is DNA obtained from environmental samples (e.g. soil, seawater, air), rather than directly from the organisms themselves. When organisms interact with their environment, DNA from, for example, sloughed tissue or scales (in fish), body mucus, or blood is expelled, accumulates and can be measured by sampling that environment. Source(s): <a href="https://www.sciencedirect.com/science/article/pii/S0006320714004443?via%3Dihub">https://www.sciencedirect.com/science/article/pii/S0006320714004443?via%3Dihub</a> <a href="https://onlinelibrary.wiley.com/doi/full/10.1002/edn3.132">https://onlinelibrary.wiley.com/doi/full/10.1002/edn3.132</a>
<b>heterozygosity:</b>	Heterozygosity is the condition of having two different alleles at a locus. Fundamental to the study of genetic variation in populations. Source: <a href="https://www.oxfordbibliographies.com/view/document/obo-9780199941728/obo-9780199941728-0039.xml">https://www.oxfordbibliographies.com/view/document/obo-9780199941728/obo-9780199941728-0039.xml</a>
<b>locus (loci):</b>	A locus is the specific physical location of a gene or other DNA sequence on a chromosome, like a genetic street address. The plural of locus is "loci". Source: <a href="https://www.genome.gov/genetics-glossary/r#glossary">https://www.genome.gov/genetics-glossary/r#glossary</a>
<b>microsatellite:</b>	A microsatellite is a tract of repetitive DNA in which certain DNA motifs (ranging in length from one to six or more base pairs) are repeated, typically 5–50 times. Source: <a href="https://en.wikipedia.org/wiki/Microsatellite">https://en.wikipedia.org/wiki/Microsatellite</a>
<b>mtDNA:</b>	Mitochondrial DNA (mtDNA) is the DNA located in mitochondria, cellular organelles within eukaryotic cells that convert chemical energy from food into a form that cells can use. Source: <a href="https://en.wikipedia.org/wiki/Mitochondrial_DNA">https://en.wikipedia.org/wiki/Mitochondrial_DNA</a>
<b>NGS:</b>	Next generation sequencing (NGS) is any of several high-throughput approaches to DNA sequencing using the concept of massively parallel processing. Source: <a href="https://en.wikipedia.org/wiki/Massive_parallel_sequencing">https://en.wikipedia.org/wiki/Massive_parallel_sequencing</a>
<b>RFLP:</b>	Restriction fragment length polymorphism (RFLP) is a type of polymorphism that results from variation in the DNA sequence recognised by restriction enzymes. These are bacterial enzymes used by scientists to cut DNA molecules at known locations. Source: <a href="https://www.genome.gov/genetics-glossary/r#glossary">https://www.genome.gov/genetics-glossary/r#glossary</a>
<b>SNP:</b>	A single-nucleotide polymorphism (SNP) is a substitution of a single nucleotide at a specific position in the genome, that is present in a sufficiently large fraction of the population (e.g. 1% or more). Source: <a href="https://en.wikipedia.org/wiki/Single-nucleotide_polymorphism">https://en.wikipedia.org/wiki/Single-nucleotide_polymorphism</a>



## Appendix 1. Some publications related to the use of genetics in fisheries

Fisheries applicable topics		Examples
Genetic diversity /health	Absolute stock abundance	Bravington M., Grewe P. and Davies C. 2016. Absolute abundance of southern bluefin tuna estimated by close-kin mark-recapture. <i>Nature Communications</i> 7:1–8. Hillary R. et al. 2018. Genetic relatedness reveals total population size of white sharks in eastern Australia and New Zealand. <i>Scientific Reports</i> 8:1–9.
	Fishery sustainability	Pinsky M.L. and Palumbi, S.R. 2014. Meta-analysis reveals lower genetic diversity in overfished populations. <i>Molecular Ecology</i> 23:29–39.
	Adaptive capacity Future sustainability	Ehlers A., Worm B. and Reusch T.B.H. 2008. Importance of genetic diversity in eelgrass <i>Zostera marina</i> for its resilience to global warming. <i>Marine Ecology Progress Series</i> 355:1–7. Nicotra A.B., Beever E.A., Robertson A.L., Hofmann G.E. and O'Leary J. 2015. Assessing the components of adaptive capacity to improve conservation and management efforts under global change. <i>Conservation Biology</i> 29:1268–1278. Foo S.A. and Byrne M. 2016. Acclimatization and adaptive capacity of marine species in a changing ocean. <i>Advances in Marine Biology</i> 74:69–116.
Population structure	Stock number and boundaries	Pecoraro C. et al. 2018. The population genomics of yellowfin tuna ( <i>Thunnus albacares</i> ) at global geographic scale challenges current stock delineation. <i>Scientific Reports</i> 8:13890.
	Stock substructuring	Knutsen H. et al. 2011. Are low but statistically significant levels of genetic differentiation in marine fishes 'biologically meaningful'? A case study of coastal Atlantic cod. <i>Molecular Ecology</i> 20:768–783. Selkoe K.A. et al. 2010. Taking the chaos out of genetic patchiness: seascape genetics reveals ecological and oceanographic drivers of genetic patterns in three temperate reef species. <i>Molecular Ecology</i> 19:3708–3726. Liu B.J., Zhang B.D., Xue D.X., Gao T.X. and Liu J.X. 2016. Population structure and adaptive divergence in a high gene flow marine fish: The small yellow croaker ( <i>Larimichthys polyactis</i> ). <i>PLoS One</i> 11:1–16. Eldon B., Riquet F., Yearsley J., Jollivet D. and Broquet T. 2016. Current hypotheses to explain genetic chaos under the sea. <i>Current Zoology</i> 62:551–566. Anderson G., Hampton J., Smith N. and Rico C. 2019. Indications of strong adaptive population genetic structure in albacore tuna ( <i>Thunnus alalunga</i> ) in the southwest and central Pacific Ocean. <i>Ecology Evolution</i> doi:10.1002/ece3.5554 Hoey J.A. and Pinsky M.L. 2018. Genomic signatures of environmental selection despite near-panmixia in summer flounder. <i>Evolutionary Applications</i> 11: 1732–1747. Grewe, P. et al. 2015. Evidence of discrete yellowfin tuna ( <i>Thunnus albacares</i> ) populations demands rethink of management for this globally important resource. <i>Scientific Reports</i> 5:1–9.
	Mobility, connectivity	Hedgecock D., Barber P.H. and Edmands S. 2007. Genetic approaches to measuring connectivity. <i>Oceanography</i> 20:70–79. Manel S. et al. 2007. A new individual-based spatial approach for identifying genetic discontinuities in natural populations. <i>Molecular Ecology</i> 16:2031–2043.
	Specimen provenance	Benestan L. et al. 2015. RAD genotyping reveals fine-scale genetic structuring and provides powerful population assignment in a widely distributed marine species, the American lobster ( <i>Homarus americanus</i> ). <i>Molecular Ecology</i> 24:3299–3315. Kerr Q., Fuentes-Pardo A.P., Kho J., McDermid J.L. and Ruzzante D.E. 2019. Temporal stability and assignment power of adaptively divergent genomic regions between herring ( <i>Clupea harengus</i> ) seasonal spawning aggregations. <i>Ecology Evolution</i> 9: 500–510.
	Species Identification	Amaral C.R.L. et al. 2017. Tuna fish identification using mtDNA markers. <i>Forensic Science International: Genetics Supplement Series</i> 6, e471–e473.
	Recognising conservation concern	von der Heyden S. 2009. Why do we need to integrate population genetics into South African marine protected area planning? <i>African Journal of Marine Science</i> 31:263–269.
Conservation/management	Recommendation for action	Flanagan S. and Jones A.G. 2017. Constraints on the F <sub>ST</sub> – Heterozygosity Outlier Approach. <i>Journal of Heredity</i> 561–573. doi:10.1093/jhered/esx048
	Effectiveness of ongoing policies	Flanagan S. and Jones A.G. 2017. Constraints on the F <sub>ST</sub> – Heterozygosity Outlier Approach. <i>Journal of Heredity</i> 561–573. doi:10.1093/jhered/esx048 Dann T.H., Habicht C., Baker T.T. and Seeb J.E. 2013. Exploiting genetic diversity to balance conservation and harvest of migratory salmon. <i>Canadian Journal of Fisheries and Aquatic Sciences</i> 793:785–793.
Behaviour	Migration patterns	Arai T., Kotake A. and Kayama S. 2005. Movements and life history patterns of the skipjack tuna <i>Katsuwonus pelamis</i> in the western Pacific, as revealed by otolith Sr: Ca ratios. <i>Journal of the Marine Biological Association of the United Kingdom</i> 1211–1216. doi:10.1017/S0025315405012336
	Spawning activity	Richardson D.E. et al. 2016. Discovery of a spawning ground reveals diverse migration strategies in Atlantic bluefin tuna ( <i>Thunnus thynnus</i> ). <i>Proceedings of the National Academy of Sciences</i> 113:3299–3304.
	Future responses to stress	Beever E.A. et al. 2016. Improving Conservation Outcomes with a New Paradigm for Understanding Species' Fundamental and Realized Adaptive Capacity. <i>Conservation Letters</i> 9:131–137. Nicotra A.B., Beever E.A., Robertson A.L., Hofmann G.E. and O'Leary J. 2015. Assessing the components of adaptive capacity to improve conservation and management efforts under global change. <i>Conservation Biology</i> 29:1268–1278.

# Spawning potential surveys in Solomon Islands' Western Province

Jeremy Prince,<sup>1</sup> Andrew Smith,<sup>2</sup> Minnie Raffe,<sup>3</sup> Shannon Seeto<sup>3</sup> and Jim Higgs<sup>4</sup>

## Summary

Since 2014, the World Wide Fund for Nature has worked with local fishing communities around Ghizo Island, in the Western Province of Solomon Islands to assess the status of the reef fish stocks and inform sustainable management. This article describes the results of their catch sampling programme and the assessments completed. A following article will describe how these data have informed the development of a system of four minimum size limits that could make reef fish catches sustainable. A relatively new methodology, length-based spawning potential ratio (LBSPR) assessment, successfully estimated the spawning potential ratio (SPR) of stocks, thereby providing an indication of whether they are likely to decline, increase or remain stable. Prior to this study, size at maturity had been estimated for only four reef fish species in Solomon Islands and no stocks had been assessed. Between February 2014 and June 2018 this project measured 8476 fish from 290 species, enabling the size at maturity of 63 species to be estimated and 61 species assessed, comprising ~84% of the sampled catch by number.

The assemblage of small- and medium-bodied reef fish around Ghizo Island appears to be less depleted than estimated by parallel studies in Palau and Fiji. The average SPR of around ~35% is currently within the target range (30–40%) used internationally as a proxy for the level likely to produce maximum sustainable yields, although we also found evidence of localised depletions of some species by night-time spearfishing. These results need to be interpreted within the context of a lack of any effective management of reef fish, and our inability to assess more highly prized large-bodied serranids, labrids and parrotfish because their prevalence in the catch has already declined. Our study would have been likely to estimate lower levels of spawning potential if we had assessed these larger-bodied species. Without any management, it is likely that the current levels of SPR in small- and medium-bodied species will only be a transitional phase as reef fish stocks in the region continue to be overfished.

## Introduction

Globally, the lack of biological information and catch data for reef fish and other small-scale fisheries, has been a long-term challenge for their assessment and management (Andrew et al. 2007; SPC 2015). With the aim of supporting community-based fisheries management around Ghizo Island in Solomon Islands' Western Province, the World Wide Fund for Nature (WWF) has been working with local fishing communities since 2014 to assess the status of reef fish stocks and facilitate the development of sustainable management policies and practices. This article describes the results of the catch sampling programme and the assessments completed through this project. A future article will describe how these data have been used to develop a simple system of size limits that could make reef fish catches sustainable.

In most Pacific Island countries and territories, there are many reef fish species but data on catch trends and biology are insufficient for applying standard methods for assessing trends in biomass (total weight). A relatively new technique, called the length-based spawning potential ratio (LBSPR)

assessment, has been developed specifically for fish stocks for which only data on catch size and composition can feasibly be collected (Hordyk et al. 2015a, b; Prince et al. 2015a). By comparing the size composition of catches to the size at which fish mature, the LBSPR methodology estimates the spawning potential ratio (SPR) of a fish population, thus providing an indication of whether those stocks are declining, stable or increasing. Left unfished, fish complete their full life span and complete 100% of their natural reproductive (spawning) potential. Fishing reduces the average life span of fish thus reducing their reproductive, or spawning, potential below natural unfished levels (<100%). SPR is the proportion of the natural unfished spawning potential remaining in a population that is being fished.

The concept of SPR for fished stocks is similar to the human reproductive index (HRI) for human populations, which is the average number of children per couple that survive to adulthood. With 2.1 children surviving through to adulthood, human couples replace themselves and those around them without children, thereby ensuring population stability. An HRI above 2.1 ensures population growth, while

<sup>1</sup> Biospherics Pty Ltd, POB 168 South Fremantle, WA 6162 Australia. Email: biospherics@ozemail.com.au

<sup>2</sup> Pacific Community, BP D5, 98848 Noumea Cedex, New Caledonia

<sup>3</sup> WWF Solomon Islands Programme Office, Honiara Hotel Building, POBox 1373, Chinatown, Honiara, Guadalcanal, Solomon Islands.

<sup>4</sup> WWF Australia, 17/1 Burnett Lane, Brisbane QLD 4000 Australia

below that the population declines. Studies from around the world have shown that in marine populations, 20% SPR is the equivalent of the HRI replacement level of 2.1 surviving children per couple; both are pivotal reference points around which populations of humans and fish either increase or decrease. Down to around 20% SPR, fish populations retain the capacity to rebuild their numbers after fishing, although the rate at which stocks can rebuild declines as SPR falls towards 20% (Mace and Sissenwine 1993). Below 20% SPR, the supply of young fish to populations is expected to decline over successive years, while 10% SPR is commonly called 'SPR crash' because populations below this level are likely to decline rapidly towards local extinction.

## Methods

The LBSPR assessment methodology compares the size of the fish being caught with the size at which they reach sexual maturity. If fish are all caught before reaching sexual maturity their populations have little spawning potential (i.e. ~0% SPR). On the other hand, with low fishing pressure, fish live close to their natural life spans, enabling them to grow much larger than their size at maturity, with many even attaining the natural average maximum size for their population ( $L_{\infty}$ ). When this happens, SPR will be close to 100% of the natural unfished level. The LBSPR algorithm enables the information in catch size composition, relative to size at maturity, to be quantified in terms of SPR and the relative fishing pressure on a population:  $F/M$ , where  $F$  is the rate at which fish are caught ("fishing mortality"), and  $M$  is the rate at which fish die due to natural causes ("natural mortality").

The data inputs required for the LBSPR methodology are:

- Catch size composition data that are indicative of the size of the adult fish in a population. If the type of fishing being conducted fails to catch the largest size classes of a fish species, then SPR will be underestimated.
- Estimates of size at maturity, which is defined by  $L_{50}$  and  $L_{95}$ , the sizes at which 50% and 95%, respectively, of a population become mature.
- The two life history ratios (LHR) that characterise each family and species of fish are:
  - ⊗  $L_m/L_{\infty}$  the relative size at maturity, which is  $L_{50}$  divided by  $L_{\infty}$ ; and
  - ⊗  $M/K$  which is a species' natural rate of mortality ( $M$ ), divided by the von Bertalanffy growth parameter  $K$ , a measure of how quickly each species grows to the average maximum size ( $L_{\infty}$ ).

The first two of these data inputs need to be measured locally for each species because they vary from place to place; but, the more technically challenging LHR can be estimated generically from the scientific literature because they are shared by families and species across their entire range (Holt 1958; Prince et al. 2015a,b).

For this analysis the algorithms needed to apply the LBSPR methodology were accessed at the freely available website: <http://barefootecologist.com.au>

## Data inputs

### Life history ratios

Estimates of LHR used for this assessment (Table 1) were developed through a meta-analysis of all available age, growth and maturity studies for Indo-Pacific reef fish species (Prince et al. in prep).

Table 1. Life history ratios assumed for reef fish families.

Family	M/k	$L_m/L_{\infty}$
Acanthurid	0.52	0.79
Caesionid	1.28	0.61
Serranid	0.64	0.64
Scarid	0.94	0.65
Labrid	1.43	0.48
Lethrinid	0.87	0.70
Lutjanid	0.75	0.74
Mullid	1.87	0.59
Carangid	1.28	0.61
Siganid	1.65	0.59
Sphyraenid	1.47	0.48

### Collection of length and maturity data

Data collection was initiated on 6 February 2014 and this analysis is based on data collected through to 27 June 2018. The majority of catches were sampled in Gizo township by having local fishers bring their catches for inspection, prior to taking them to the market to sell later in the day. Fishers were offered 15 Solomon Island dollars (SBD) per cooler of fish measured (~AUD 2.00), and a top-up of fresh ice afterwards, to assist WWF measure their fish. Researchers were also able to select, and pay market prices for, any samples they wanted to dissect for gonad examination. Fish were identified to the species level and measured in millimetres from the snout to the outer edge of the middle of the tail. Time and method of capture were recorded. Almost all the fish measured were photographed so that pictures could later be matched to data entries, and species identifications could be confirmed. Only a subsample of the most commonly caught species were purchased for gonad inspection.

At the time of sampling, fuel prices were high and there were relatively few outboard motors in the communities so fishers mainly fished from canoes propelled by paddle and sail, and the fish measured in Gizo township were caught relatively close to Ghizo Island. One main source



of samples was the fishing village of Saeraghi, located at the northwestern end of Ghizo Island where fishing was mainly with hook and line. The second principle source of samples measured in Gizo was Rarumana, a small island to the east of Ghizo Island where the community primarily spearfished at night.

A third main source of samples were the communities around Nusatuva on Kolombangara Island, several hours by motorboat east of Ghizo Island and too remote for fish to be transported to the market in Gizo. Local fishers from the communities around Nusatuva were periodically asked to catch fish and bring them to Nusatuva to sell to WWF. These fish were caught by either hook-and-line or night-time spearfishing. As these fish were purchased by WWF, almost all were dissected for gonad inspection.

#### Size at maturity estimation

To the extent possible, fish were opened and their gonads inspected so that they could be macroscopically gauged as immature or mature, male or female, and so that size at maturity could be estimated. We applied a basic protocol developed for general utility across coral reef species, which can be taught to artisanal fishers (Prince et al. 2015b). The primary features for classifying gonads as being are:

- distinct, three-dimensional shape; lobed, and triangular in cross section, for testis, or sausage, tube, or sack-like for ovaries; and
- the length of the gonad is longer than one-third of the length of the body cavity.

Where possible, these macroscopic examinations were used to estimate the proportion of mature fish by size class, and a logistic curve was fitted to estimate  $L_{50}$  and  $L_{95}$ . Many Indo-Pacific reef fish species exhibit ontogenetic habitat shifts, with juveniles growing up in shallow nursery habitats, such as shallow mangroves, seagrass beds or coral rubble reef flats, and only moving out into the coral reef habitat as they mature (Nakamura et al. 2008; Grol et al. 2011). This behaviour can mean juveniles are rarely found in catches from coral reef habitats, and makes it difficult or impossible to define the transition from 0 to 100% mature, thus preventing the estimation of size at maturity (e.g. Williams et al. 2008; Currey et al. 2013; Moore et al. 2015; Taylor et al. 2018). Caillart et al. (1994) and Prince et al. (2008) suggested turning this difficulty to advantage by using the size of the smallest fish caught in the adult habitat to approximate size at maturity. A recent study completed in Palau by Prince et al. (in prep.) demonstrates how this can be done by converting the left-hand side of the catch length-frequency histogram into a cumulative frequency curve, as the 50<sup>th</sup> percentile of that curve approximates histological estimates of size at maturity. Using this principle, we fitted logistic curves to the left-hand side of the main mode in the length-frequency histograms, and in this way developed alternative estimates of  $L_{50}$  and  $L_{95}$ . Where our

inspection of a species' gonads revealed a high and trendless proportion of each size class that were mature, causing the macroscopically derived size at maturity curve to be poorly defined, or entirely undefined, we preferred these length-based estimates of size at maturity.

## Results

### Data collection

Some 8476 fish from 290 species were in the database we analysed, evidence of the remarkably diverse reef fish fauna of the region. With such diversity, sample sizes for most species were relatively small, with  $n > 1000$  only being achieved for one species (*Lutjanus gibbus*). Sample sizes were  $n = 300$ – $1000$  for 4 species,  $n = 100$ – $300$  for 16 species, and  $n = 30$ – $100$  for 40 species.

### Catch composition of different fishing methods

A total of 4071 fish from 197 species were sampled from catches by night-time spearfishers, and 4405 fish from 200 species from hook-and-line catches.

By number of fish, the hook-and-line catch (Table 2) was dominated by just seven species comprising ~52% of the catch; two snappers *Lutjanus gibbus* (~27%) and *L. bohar* (~3%), 5 species of emperor *Lethrinus lentjan* (~7%), *L. erythropterus* (~5%), *L. obsoletus* (~4%), *L. xanthurus* (~3%) and *L. microdon* (~3%).

In contrast, the spearfishing catch (Table 2) was more heterogeneous, with a similar 52% of the catch comprising 12 species; goatfishes *Parupeneus barberinus* (~9%) and *Mulloidichthys vanicolensis* (~2%), surgeonfishes *Acanthurus nigricauda* (~8%) and *A. lineatus* (~7%), parrotfishes *Hippocampus longiceps* (~4%), *Scarus dimidiatus* (~3%), *S. niger* (~2%) and *S. psittacus* (~2%), rabbitfishes *Siganus doliatus* (~4%) and *S. argenteus* (~3%), as well as the fusilier *Caesio caerulea* (3.4%), the snapper *Lutjanus gibbus* (2.85%) and humpnosed bigeye seabream *Monotaxis grandoculis* (2.38%).

### Regional differences

The catch composition was only subtly different between the two main sampling locations. Larger-bodied predatory species of snappers and groupers, such as *Lutjanus malabaricus*, *L. argentimaculatus*, *Plectropomus aeorolatus*, *Epinephelus coioides*, *E. fuscoguttatus* and *E. polyphkadian*, were more commonly sampled at Nusatuva, although still relatively rarely, suggesting the fish in that area, which is farther from the market, have been somewhat less impacted by fishing than fishing grounds closer to the market around Ghizo Island. We cannot, however, exclude differences in habitat which could also contribute to this subtle difference.

Table 2. The 30 most frequently sampled reef fish species caught by spearfishing (left) and hook-and-line (right), and the relative importance of each species (in percentage of the total number of individuals caught) for each fishing method.

Spearfishing n = 4071		Hook-and-line n = 4405	
Species	% of total number of fish caught	Species	% of total number of fish caught
<i>Parupeneus barberinus</i>	9.24	<i>Lutjanus gibbus</i>	26.88
<i>Acanthurus nigricauda</i>	8.33	<i>Lethrinus lentjan</i>	6.72
<i>Acanthurus lineatus</i>	6.63	<i>Lethrinus erythropterus</i>	4.93
<i>Hipposcarus longiceps</i>	4.42	<i>Lethrinus obsoletus</i>	4.15
<i>Siganus doliatus</i>	3.76	<i>Lethrinus xanthurus</i>	3.75
<i>Caesio caerulea</i>	3.39	<i>Lutjanus bohar</i>	3.13
<i>Scarus dimidiatus</i>	3.37	<i>Lethrinus microdon</i>	2.57
<i>Siganus argenteus</i>	3.02	<i>Caesio cuning</i>	2.29
<i>Lutjanus gibbus</i>	2.85	<i>Selar boops</i>	2.11
<i>Monotaxis heterodon</i>	2.38	<i>Sphyrna forsteri</i>	2.11
<i>Mulloidichthys vanicolensis</i>	1.87	<i>Lethrinus atkinsoni</i>	1.98
<i>Scarus niger</i>	1.74	<i>Lutjanus monostigma</i>	1.88
<i>Scarus psittacus</i>	1.72	<i>Lutjanus rufolineatus</i>	1.75
<i>Monotaxis grandoculis</i>	1.67	<i>Lutjanus semicinctus</i>	1.50
<i>Acanthurus xanthopterus</i>	1.65	<i>Lethrinus olivaceus</i>	1.43
<i>Scarus quoyi</i>	1.65	<i>Lethrinus erythracanthus</i>	1.34
<i>Scarus rivulatus</i>	1.60	<i>Lutjanus malabaricus</i>	1.32
<i>Parupeneus crassilabris</i>	1.25	<i>Myripristis pralinia</i>	1.23
<i>Lethrinus erythropterus</i>	1.23	<i>Lutjanus kasmira</i>	1.20
<i>Naso vlamingii</i>	1.13	<i>Monotaxis grandoculis</i>	1.04
<i>Naso lituratus</i>	1.11	<i>Lethrinus ornatus</i>	1.02
<i>Scarus ghobban</i>	1.11	<i>Lutjanus quinquelineatus</i>	0.77
<i>Siganus punctatus</i>	1.06	<i>Lutjanus fulvus</i>	0.75
<i>Choerodon anchorago</i>	1.03	<i>Lethrinus rubrioperculatus</i>	0.73
<i>Siganus puellus</i>	1.03	<i>Myripristis berndti</i>	0.68
<i>Parupeneus cyclostomus</i>	1.01	<i>Pristipomoides multidens</i>	0.68
<i>Caesio lunaris</i>	0.98	<i>Epinephelus fasciatus</i>	0.64
<i>Lethrinus obsoletus</i>	0.96	<i>Lethrinus harak</i>	0.64
<i>Chlorurus bleekeri</i>	0.86	<i>Lethrinus semicinctus</i>	0.61
<i>Cephalopholis cyanostigma</i>	0.84	<i>Lutjanus argentimaculatus</i>	0.61

### Size at maturity estimates

Size at maturity was estimated for the 61 most frequently sampled species. Table 3 provides the estimated size at maturity parameters derived, where possible, with macroscopic inspection of gonads, and with the length-based approach. Our preferred estimate used for LBSPR

assessment is shown in bold. For many species, both techniques produced similar estimates, which enhanced our confidence in those estimates.

There apparently are only four pre-existing size at maturity estimates for reef fish in Solomon Islands: 1) *Bolbometopon muricatum* by Hamilton et al. (2008), 2) *Hipposcarus*

*longiceps* (Brett Taylor, B.M. Australian Institute of Marine Science, pers. comm.), 3) *Thalassoma lunare* by Ackerman (2004), and 4) *Scarus ghobban* by Sabetian (2010). Two of these previous estimates are for species for which we estimated size at maturity and were made using samples collected around Ghizo Island, thus enabling a direct comparison. The size at maturity estimate of 260 mm for *H. longiceps* produced with microscopic techniques by Taylor (unpubl.) is very close to our preferred length-based estimate of 249 mm. However, our length-based estimate of 217 mm for *S. ghobban*, which was based on a sample of just 55 individuals, is much smaller than the 260 mm estimated microscopically by Sabetian (2010). In this case, we preferred the Sabetian estimate for our LBSPR assessment.

### LBSPR assessments

The multiplicity of small samples sizes presents a challenge for the application of the LBSPR methodology. Ideally, sample sizes greater than 1000 individuals would always be available for analysis so that the largest individuals in each population are fully represented (Hordyk et al. 2015b). The LBSPR method is strongly influenced by the size of the largest fish in a sample, relative to the average maximum size inferred from the size at maturity and the ratio  $L_m/L_\infty$ . The largest individuals in a population are always the rarest, meaning there is a high chance that small samples will fail to fully represent them. Statistical studies show that sample sizes of 1000 are required to ensure that the largest individuals are fully represented (Erzini 1990). Under-representation of the largest size classes results in downwardly biased estimates of SPR, and upwardly biased estimates of  $F/M$ . In the real world of reef fish assessment, sample sizes greater than 1000 individuals are extremely difficult to accumulate, and it is necessary to use whatever data are available. During the development of LBSPR, simulation testing with much smaller sample sizes ( $n > 30$ ) demonstrated that indicative assessments (i.e. heavily fished, moderately fished or lightly fished) could often be derived with smaller sample sizes (Hordyk et al. 2015b). While our previous experience applying the methodology to reef fish (Prince et al. 2015b, 2018) has shown that sample sizes of ~100 individuals, which coherently describe the mode of adult fish, produce robust indicative results. Experiences replicated by Babcock et al. (2018) and Hommik et al. (2020) who applied the technique to samples of reef fish as small as ~60 individuals. Although estimates of SPR are expected to increase marginally, and  $F/M$  to decrease slightly, if sample sizes can be subsequently enlarged (Hordyk et al. 2015b).

In this context, and confronting a multiplicity of small samples, we applied the LBSPR methodology to all species, with ~30 individuals, and samples sizes as small as  $n = 23$  being analysed. Quality control criteria were subsequently applied to the results with the aim of culling the least reliable assessments. In our other applications of LBSPR to reef fish assemblages (Prince et al. 2015b, 2019) we have observed coherent patterns arising from the

aggregate of multiple assessments, and this was our hope here, that while the individual assessments based on small sample sizes may not be particularly accurate or reliable in themselves, together they might still contribute to a coherent bigger picture of the status of the reef fish resource in Solomon Islands' Western Province.

### Site differences in LBSPR assessments

Sample sizes were considered large enough for only three species to make it potentially worthwhile to assess the two sampling locations – Gizo and Nusatuva – separately, to determine if any difference could be detected (*Acanthurus nigricauda*  $n = 340$  and  $150$ , *Lethrinus erythropterus*  $n = 83$  and  $175$ , *Lutjanus gibbus*  $n = 970$  and  $330$ ). Only in the case of *Lutjanus gibbus*, with the largest samples, was a difference detected that approached significance, with the estimated confidence intervals overlapping but not with the average estimates. As expected, the Nusatuva sample looked to have the lower fishing pressure, producing a higher estimate of SPR (0.86 cf. 0.62) and lower estimate of  $F/M$  (0.15 cf. 0.50).

### Aggregated LBSPR assessments

Given the inability to detect a significant difference between sampling locations, and the general context of small sample sizes, all species samples were aggregated across both sites for the purpose of our assessments. The length data and size at maturity estimates (Table 3) were used along with estimates of life history ratios (Table 1) to make LBSPR assessments for 61 species (Fig. 1).

Across all assessments conducted, the estimated average SPR was 0.41 (SD = 0.24,  $n = 61$ , range = 0.03–1.0) and the average relative fishing mortality ( $F/M$ ) was 2.32 (SD = 1.49,  $n = 43$ , range = 0.32–5.0). The confidence intervals computed around many of the estimates were very wide, indicating many are imprecise and relatively uninformed by the data; predictably so, in the context of the many small sample sizes.

Two forms of quality control were used to identify the more reliable assessments and to cull the least reliable:

1. Medium quality assessments were selected on the basis of their estimated 95% confidence intervals around the SPR estimate being  $< 0.5$ ; and
2. The highest quality assessments were selected on the basis of their estimated 95% confidence intervals around the SPR estimate being  $< 0.5$ , and their samples size being  $n > 100$ .

After applying the former criterion 43 species with medium and highest quality assessments were left in the sub-sample producing an average SPR estimate of 0.33 (SD = 0.16,  $n = 43$ , range = 0.03–0.77; solid line in Fig. 1) and an average  $F/M = 2.32$  (SD = 1.49,  $n = 43$ , range = 0.32–5.0).



Table 3. Estimated size at maturity parameters ( $r$  = steepness;  $L_{50}$  = size class at which 50% are mature;  $L_{95}$  = size class at which 95% are mature;  $n$  = number of species examined for maturity) estimated through dissection and macroscopic staging and/or analysis of the left-hand side of the main mode in the length-frequency histogram. The preferred estimates used in the assessment of each species are shown in bold.

Species	Macroscopic				Length-based				Species	Macroscopic				Length-based			
	$r$	$L_{50}$	$L_{95}$	$n$	$r$	$L_{50}$	$L_{95}$	$n$		$r$	$L_{50}$	$L_{95}$	$n$	$r$	$L_{50}$	$L_{95}$	$n$
<i>Acanthurus lineatus</i>	0.26	172	185	59	0.19	<b>162</b>	<b>178</b>	270	<i>Lutjanus kasmira</i>					0.13	174	195	58
<i>Acanthurus nigricauda</i>	0.14	<b>180</b>	<b>200</b>	244	0.10	184	215	313	<i>Lutjanus malabaricus</i>	0.04	325	410	55	0.09	<b>462</b>	<b>500</b>	58
<i>Acanthurus xanthopterus</i>	0.03	<b>322</b>	<b>450</b>	27	0.06	245	300	67	<i>Lutjanus monostigma</i>					0.08	234	275	97
<i>Caesio caerulea</i>					0.22	166	180	156	<i>Lutjanus quinquelineatus</i>					0.42	181	188	34
<i>Caesio cuning</i>	0.10	<b>165</b>	<b>195</b>	94	0.30	158	168	112	<i>Lutjanus rufolineatus</i>	0.05	174	235	38	0.16	<b>175</b>	<b>195</b>	74
<i>Caesio lunaris</i>					0.12	188	215	40	<i>Lutjanus semicinctus</i>	0.10	<b>216</b>	<b>247</b>	24	0.82	205	209	87
<i>Carangoides plagiotaenia</i>	0.013	<b>217</b>	<b>450</b>	21	0.03	208	300	28	<i>Monotaxis grandoculis</i>	0.17	<b>201</b>	<b>220</b>	41	0.10	165	195	114
<i>Cephalopholis cyanostigma</i>					0.25	216	228	40	<i>Monotaxis heterodon</i>					0.10	161	194	103
<i>Chlorurus bleekeri</i>	0.10	<b>207</b>	<b>237</b>	45	0.33	200	209	51	<i>Mulloidichthys vanicolensis</i>	0.49	189	195	22	0.12	<b>178</b>	<b>202</b>	76
<i>Choerodon anchorago</i>	0.11	<b>247</b>	<b>275</b>	13	0.05	204	260	48	<i>Naso lituratus</i>	0.04	198	275	13	0.08	<b>171</b>	<b>210</b>	46
<i>Epinephelus corallicola</i>					0.06	267	315	24	<i>Naso vlamingii</i>					0.11	177	230	47
<i>Epinephelus fasciatus</i>					0.48	180	186	28	<i>Parupeneus barberinus</i>	0.90	250	290	78	0.15	<b>176</b>	<b>195</b>	386
<i>Epinephelus ongus</i>	0.02	300	450	27	0.15	<b>215</b>	<b>235</b>	39	<i>Parupeneus crassilabris</i>					0.22	162	175	51
<i>Epinephelus polyphekadion</i>					0.03	329	420	22	<i>Parupeneus cyclostomus</i>	0.35	197	260	19	0.12	<b>194</b>	<b>220</b>	43
<i>Hipposcarus longiceps</i>	0.04	260	340	95	0.05	<b>250</b>	<b>310</b>	180	<i>Parupeneus multifasciatus</i>					0.42	162	169	31
<i>Lethrinus atkinsoni</i>					0.07	<b>206</b>	<b>250</b>	115	<i>Plectropomus aeoratus</i>	0.17	<b>341</b>	<b>360</b>	21	0.45	303	310	31
<i>Lethrinus erythracanthus</i>	0.03	<b>287</b>	<b>380</b>	30	0.07	218	260	67	<i>Scarus dimidiatus</i>					0.11	190	218	140
<i>Lethrinus erythropterus</i>	0.08	<b>171</b>	<b>238</b>	213	0.09	206	238	267	<i>Scarus ghobban</i>	1.47	187	190	51	0.08	<b>217</b>	<b>255</b>	55
<i>Lethrinus harak</i>					0.15	193	215	36	<i>Scarus niger</i>	0.55	160	166	11	0.20	<b>206</b>	<b>220</b>	71
<i>Lethrinus lentjan</i>	0.12	223	250	121	0.12	<b>220</b>	<b>280</b>	317	<i>Scarus oviceps</i>					0.16	190	210	31
<i>Lethrinus microdon</i>	0.08	237	275	99	0.06	<b>288</b>	<b>340</b>	127	<i>Scarus psittacus</i>	0.12	186	195	52	0.12	<b>186</b>	<b>210</b>	71
<i>Lethrinus obsoletus</i>	0.21	<b>224</b>	<b>238</b>	99	0.29	232	242	222	<i>Scarus quoyi</i>	0.05	<b>201</b>	<b>260</b>	59	0.19	185	200	67
<i>Lethrinus olivaceus</i>	0.02	373	510	52	0.03	<b>404</b>	<b>510</b>	65	<i>Scarus rivulatus</i>					0.07	208	250	80
<i>Lethrinus ornatus</i>					0.13	195	220	57	<i>Selar boops</i>					0.26	183	195	93
<i>Lethrinus rubrioperculatus</i>	0.03	222	275	15	0.09	<b>195</b>	<b>230</b>	48	<i>Siganus argenteus</i>	0.05	<b>193</b>	<b>210</b>	87	0.12	174	200	123
<i>Lethrinus semicinctus</i>	0.71	176	180	5	0.79	<b>180</b>	<b>184</b>	27	<i>Siganus canaliculatus</i>					0.07	197	240	26
<i>Lethrinus xanthochilus</i>	0.02	<b>358</b>	<b>500</b>	134	0.03	252	375	183	<i>Siganus doliatus</i>	0.12	<b>158</b>	<b>182</b>	79	0.14	166	188	157
<i>Lutjanus biguttatus</i>					0.47	155	161	22	<i>Siganus lineatus</i>	0.08	<b>213</b>	<b>325</b>	13	0.07	214	260	29
<i>Lutjanus bohar</i>	0.02	<b>267</b>	<b>390</b>	67	0.05	186	245	147	<i>Siganus puellus</i>	0.05	220	275	21	0.11	<b>173</b>	<b>200</b>	47
<i>Lutjanus ehrenbergii</i>	0.08	<b>213</b>	<b>238</b>	17	0.47	211	217	27	<i>Siganus punctatus</i>	0.06	<b>236</b>	<b>290</b>	29	0.18	204	220	49
<i>Lutjanus fulvus</i>					0.27	182	194	60	<i>Sphyræna forsteri</i>					0.06	386	438	101
<i>Lutjanus gibbus</i>	0.06	198	245	520	0.07	<b>209</b>	<b>250</b>	1294									

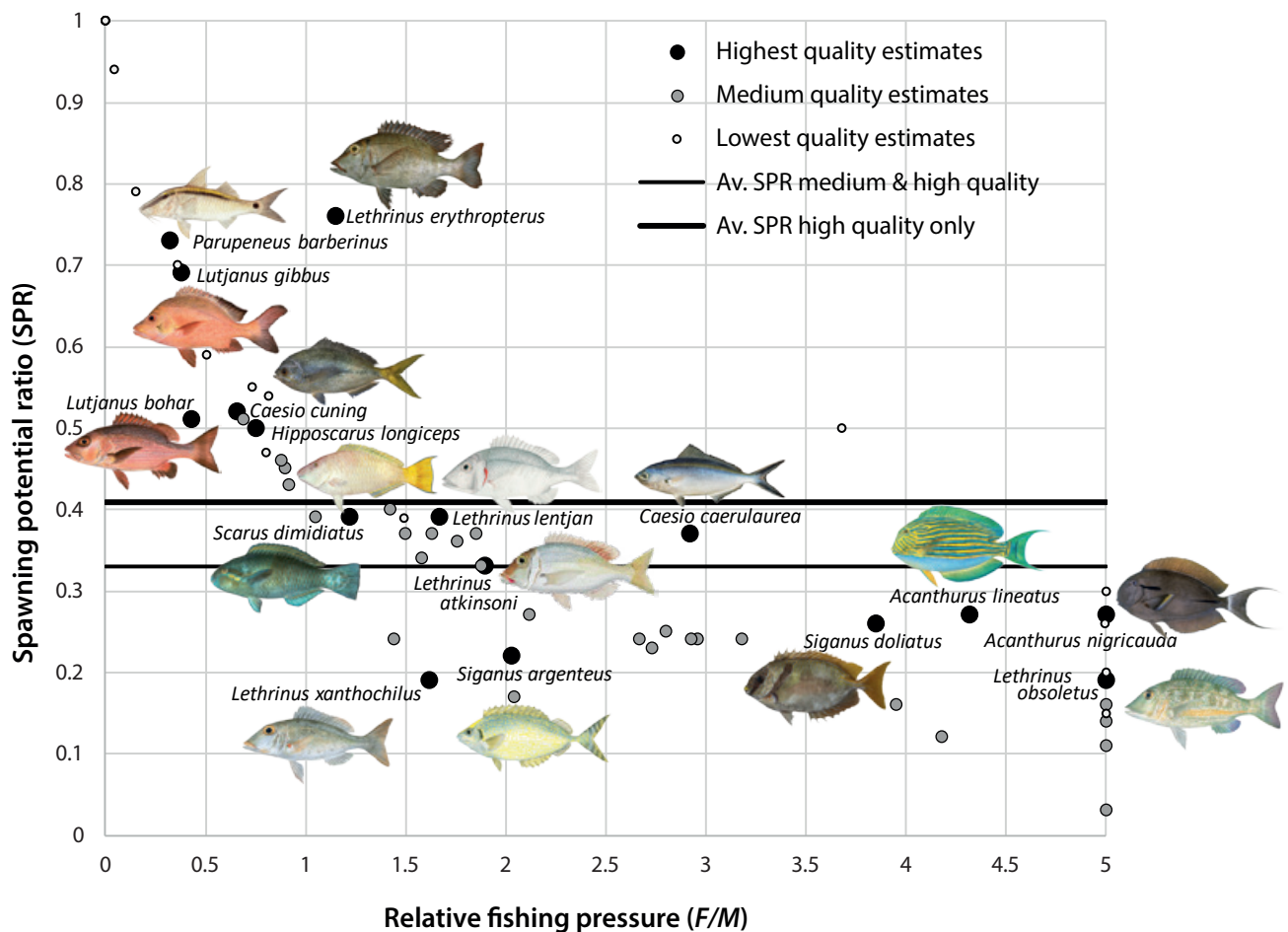


Figure 1. The results of all 61 assessments with estimates of relative fishing pressure ( $F/M$ ) plotted along the x-axis and spawning potential (SPR) plotted up the y-axis. Highest quality assessments plotted as large black circles and identified with species names, medium quality assessments plotted as un-named medium-sized grey circles, and lowest quality assessments as un-named small points. Average SPR of highest quality assessments shown as a dashed line. Average SPR of highest and medium quality assessments shown as a solid line. Note that the maximum  $F/M$  has been constrained to a value of 5.

Applying the latter criteria left 16 species highest quality assessments in the subsample (Table 4) producing an average SPR = 0.41 (SD = 0.19,  $n = 16$ , range = 0.15–0.76; dashed line in Fig. 1) and an average  $F/M = 2.08$  (SD = 1.64,  $n = 16$ , range = 0.32–5.0).

Comparison of average SPR for hook-and-line-caught species (SPR = 0.35 SD = 0.20,  $n = 17$ ) and night-time spear-fished species (SPR = 0.32 SD = 0.14,  $n = 30$ ) revealed little difference in status between these two subsets of species.

## Discussion

The stability and homogeneity of the estimates of average SPR across the subsamples of assessments helps to build a level of confidence that in aggregate these assessments present a coherent bigger picture of the portion of the reef fish assemblage we have been able to assess. The average SPR of ~35% is within the range (30–40%) used internationally

as a proxy for the fishing level likely to produce maximum sustainable yield (MSY). A level considerably higher than that produced for similar assemblages of reef fish species in parallel studies (Prince et al. 2015b and 2019) conducted in Fiji (19% SPR across 29 species) and Palau (12% SPR across 12 species). Significantly, although the estimated average relative fishing pressure ( $F/M > 2$ ) is, by international standards, approximately double the level expected to produce MSY. There is also some interesting variation around these average estimates.

Several groups of small-bodied species emerged as apparently being particularly prone to localised depletion by night-time spearfishers. Our samples of these species came mainly from the catch of night-time spearfishers operating very locally around the small island of Rarumana just to the east of Gizo town. Their representative, who brought their catches to us for sampling, was very forthright about his concern that they were experiencing localised depletion of their fishing ground, and that this was driving his divers to

Table 4. Assessment results of the 16 assessments considered of highest quality, listed in order of descending spawning potential ratio (SPR) estimate; estimated SPR 95% confidence intervals <0.5 and samples size  $n > 100$ . Results in terms of SPR and relative fishing pressure ( $F/M$ ) along with estimated 95% confidence intervals (CI) around those estimates. Note the maximum estimate of  $F/M$  has been constrained to a value of 5.

Species	$L_{50}$	$L_{95}$	$L_{\infty}$	n - Length comp.	n - $L_{50}$	SPR	SPR CI	$F/M$	$F/M$ CI
<i>Parupeneus barberinus</i>	176	195	298	386	386	0.73	0.6–0.86	0.32	0.09–0.55
<i>Lutjanus gibbus</i>	209	250	282	1300	1300	0.69	0.61–0.77	0.38	0.23–0.53
<i>Lutjanus bohar</i>	300	320	405	151	67	0.51	0.3–0.73	0.43	0.12–0.74
<i>Caesio cuning</i>	165	195	270	113	113	0.52	0.31–0.73	0.66	0.09–1.23
<i>Hipposcarus longiceps</i>	249	320	383	181	181	0.5	0.35–0.65	0.75	0.29–1.21
<i>Lethrinus erythropterus</i>	170	238	243	267	213	0.76	0.64–0.87	1.15	0.23–2.07
<i>Scarus dimidiatus</i>	190	218	292	140	140	0.39	0.28–0.49	1.22	0.66–1.78
<i>Lethrinus xanathochilus</i>	358	500	512	183	134	0.19	0.09–0.29	1.62	0.78–2.46
<i>Lethrinus lentjan</i>	220	280	314	314	314	0.39	0.31–0.48	1.67	0.95–2.39
<i>Lethrinus atkinsoni</i>	206	250	294	115	115	0.33	0.19–0.48	1.9	0.48–3.32
<i>Siganus argenteus</i>	193	200	327	123	86	0.22	0.13–0.32	2.03	0.98–3.08
<i>Caesio caerulea</i>	166	180	272	156	156	0.37	0.12–0.62	2.92	0–6.33
<i>Siganus doliatus</i>	158	182	268	157	73	0.26	0.20–0.33	3.85	2.08–5.62
<i>Acanthurus lineatus</i>	162	178	205	270	270	0.27	0.19–0.34	4.32	2.47–6.17
<i>Acanthurus nigricauda</i>	180	220	228	342	244	0.27	0.14–0.4	5	2.04–9.44
<i>Lethrinus obsoletus</i>	224	242	320	222	99	0.19	0.13–0.25	5	4.47–11.37

expand their operations into neighbouring fishing grounds and creating conflict with those other communities. All six assessed species of rabbitfish (*Siganus argenteus*, *S. canaliculatus*, *S. doliatus*, *S. lineatus*, *S. puellus*, *S. punctatus*) produced similarly low SPR estimates (SPR = 0.22–0.26). This suite of species has long been recognised as being particularly prone to depletion despite their small body size, a factor normally expected to save species from early targeting in the process of fishing down food webs (Pauly et al. 1998). Johannes (1978) described localised aggregations of rabbitfish being sequentially extinguished around Palau during the 1970s, and attributed it to their being shallow water species that formed predictable spawning aggregations, which were easily and heavily targeted. In our assessments, a group of shallow-living, small-bodied surgeonfish (*Acanthurus lineatus*, *A. nigricauda*, *A. xanthopterus*) targeted by night-time spearfishers also produced relatively low SPR estimates (0.17–0.27) as did a group of small parrotfish (*Scarus ghobban*, *S. niger*, *S. oviceps*, *S. quoyi*) (SPR = 0.24–0.27); however, SPR estimates of several other parrotfish species were higher: *S. dimidiatus* (0.39), *Chlorurus bleekeri* (0.39), *S. psittacus* (0.46) and *Hipposcarus longiceps* (0.5). Despite these exceptions, there still emerges from our results a pattern of heavy localised impacts resulting from night-time spearfishing around Rarumana.

On the other hand, some of the most abundant species in our sampling regime, which consequently tended to produce the highest quality assessments, were estimated to still be relatively lightly exploited (Table 4 and Fig. 1); for example, the long-finned emperor (*Lethrinus erythropterus* SPR = 0.77;  $F/M$  = 1.15), the dash-and-dot goatfish (*Parupeneus barberinus* SPR = 0.74;  $F/M$  = 0.32) and the humpback snapper (*Lutjanus gibbus* SPR = 0.69;  $F/M$  = 0.38). These species are apparently less prone to the heavy localised pressure of night-time spearfishing due to being mainly caught by hook-and-line (e.g. *L. erythropterus* and *L. gibbus*) and/or occupying a broad range of depths (e.g. *L. gibbus* and *P. barberinus*).

The broader picture presented here of a moderately exploited assemblage of medium- and small-bodied species must be qualified by drawing attention to the almost complete absence from our samples of all the largest-bodied serranids, labrids and parrotfish. Species that at some time in the past would have dominated landings. Hamilton et al. (2016) documented the depletion of the largest-bodied parrotfish *Bolbometopon muricatum* through this region. Hamilton and Matawai (2006) described the depletion of the squaretail coral grouper, *Plectropomus aerolatus*, around Papua New Guinea by the live fish trade. A fishery that



undoubtedly also depleted all the most valuable large-bodied grouper species throughout the Western Province. The rarity of these species in our samples has prevented us from assessing their status. There can be little doubt that if we had been able to accumulate sufficient samples of these depleted larger-bodied species, our average estimates of SPR would have been much lower, and  $F/M$  even higher than the average estimates we have produced.

With unmanaged fishing pressure across the region, there can be no doubt that these depleted and unassessed highly prized, larger-bodied species continue to be overfished. As time passes and those more preferred larger-bodied species become even scarcer, fishing pressure previously directed almost entirely at the most preferred bigger species, will increasingly target the assemblage of smaller and medium-bodied species we could assess. Adding to that process of fishing down the food web, as the region develops, is population growth, rising demand for income from fishing to purchase consumer goods, and growing access to better fishing equipment and fish markets. So, we can be certain that fishing pressure on the species assemblage we assessed is going to continue intensifying. The relatively high levels of SPR we estimated, are unlikely to be stable, instead they most probably represent a transitional state the assemblage is passing through as it continues to be fished down. This interpretation of our results is consistent with the high average level of relative fishing pressure we estimated ( $>2$ ) twice the level likely to produce high sustainable yields. As well as with the much lower levels of SPR we have observed for this assemblage of species in Fiji and Palau where there has been better access to larger fish markets for some time (Prince et al. 2015b and 2019). In this context, and without any improvement to management, we would expect a repeat of this study in five years to find lower levels of SPR in the species we have assessed, and for some of them to have joined a growing list of species that are no longer possible to assess because sample sizes are too small.

## Conclusion

This study adds to those of Prince et al. (2015b and 2019) and Babcock et al. (2018) in illustrating the cost-effective utility of the LBSPR methodology for assessing reef fish stocks and for informing the development of management guidelines. Previous to this study, size at maturity had been estimated for only four species of reef fish in Solomon Islands and there were no quantitative estimates of stock status and fishing pressure. Through this project, 63 estimates of reef fish size at maturity were developed, and the status of 61 species assessed, accounting for ~84% of the sampled catch by number.

This study provides a snapshot of the overfishing of reef fish in Solomon Islands' Western Province and parallels observations reported from across other Pacific Island countries (e.g. Newton et al. 2007; Sadovy 2005; Sadovy de Mitcheson et al. 2013) and, indeed, the entire tropical Indo-Pacific region

(McClanahan 2011). The picture emerging from these assessments is of the reef fish stocks around Ghizo Island being more lightly fished and less depleted than parallel studies (Prince et al. 2015b and 2019) suggest for Fiji and Palau. The average SPR of around ~35% is within the target range (30–40%) often used internationally as a proxy for the fishing level likely to produce maximum sustainable yields; although we also estimated fishing pressure at double the level likely to be sustainable, and found evidence of localised depletions of some species being driven by night-time spearfishing. These results need to be appreciated in the context of the current lack of any effective fisheries management that has already permitted the depletion of all the most highly prized and largest-bodied serranids, labrids and parrotfish. Their depletion prevented us from sampling enough of those species to make an assessment possible. If we had been able to assess those larger-bodied species, we would inevitably have estimated much lower levels of SPR and higher relative fishing pressure than the averages we have produced. The relatively high levels of SPR we estimated for the assemblage of small- and medium-bodied species are unlikely to be sustainable given the context and our estimates of high fishing pressure. In the absence of effective management, we expect the reef fish food web in the region to continue being fished down.

## Acknowledgements

Our heartfelt thanks and acknowledgement to all the dedicated WWF staff, past and present, who assisted with this project: Zeldalyn Hilly, Richard Makini, Salome Topo, Dudley Marau, Dafisha Aleziru, Piokera Holland, Tingo Leve, Sara Martin, Jessica Rutherford. Solomon Islands spawning potential surveys have been financially supported by the Australian government through the Australian NGO Cooperation Program (ANCP), Simplot Australia via their seafood brand John West, and WWF Australia and WWF Netherlands supporters.

## References

- Ackerman J. 2004. Geographic variation in size and age of the coral reef fish *Thalassoma lunare* (Family: Labridae) a contribution to life history theory. PhD Thesis, James Cook University. 166 p.
- Andrew N.L., Béné C., Hall S.J., Allison E.H., Heck S. and Ratner B.D. 2007. Diagnosis and management of small-scale fisheries in developing countries. *Fish and Fisheries* 8:227–240. doi:10.1111/j.1467-2679.2007.00252.x
- Babcock E.A., Tewfik A. and Burns-Perez V. 2018. Fish community and single-species indicators provide evidence of unsustainable practices in a multi-gear reef fishery. *Fisheries Research* 208:70–85.

- Caillart B., Harmelin-Vivien M.L., Galzin René and Morize E. 1994. Reef fish communities and fishery yields of Tikehau Atoll (Tuamotu Archipelago French Polynesia) Part III. Atoll Research Bulletin, The Smithsonian Institution, Washington DC (415-PART 3):38 p. Available at: <https://doi.org/10.5479/si.00775630.415>
- Currey L.M., Williams A.J., Mapstone B.D., Davies C.R., Carlos G., Welch D.J., Simpfendorfer C.A., Ballagh A.C., Penny A.L., Grandcourt E.M., Maplestone A., Wiebken A.S. and Bean K. 2013. Comparative biology of tropical *Lethrinus* species (Lethrinidae): Challenges for multi-species management. *Journal of Fish Biology* 82:764–788.
- Erzini K. 1990. Sample size and grouping of data for length-frequency analysis. *Fisheries Research* 9:355–366.
- Grol M.G.G., Nagelkerken I., Rypel A.L. and Layman C.A. 2011. Simple ecological trade-offs give rise to emergent cross-ecosystem distributions of a coral reef fish. *Oecologia* 165:79–88.
- Hamilton R.J., Adams S. and Choat J.H. 2008. Sexual development and reproductive demography of the green humphead parrotfish (*Bolbometopon muricatum*) in the Solomon Islands. *Coral Reefs* 27:153–163.
- Hamilton R.J., Almany G.R., Stevens D., Bode M., Pita J., Peterson N.A. and Choat J.H. 2016. Hyperstability masks declines in bumphead parrotfish (*Bolbometopon muricatum*) populations. *Coral Reefs*. DOI 10.1007/s00338-016-1441-0
- Hamilton R.J. and Matawai M. 2006. Live reef food fish trade causes rapid declines in abundance of squaretail coral grouper (*Plectropomus areolatus*) at a spawning aggregation site in Manus, Papua New Guinea. *SPC Live Reef Fish Information Bulletin* 16:13–18.
- Holt S.J. 1958. The evaluation of fisheries resources by the dynamic analysis of stocks, and notes on the time factors involved. ICNAF (International Commission on North Atlantic Fisheries) Special Publication 1:77–95.
- Hommik K., Fitzgerald C.J., Kelly F. and Shephard S. 2020. Dome-shaped selectivity in LB-SPR: Length-based assessment of data-limited inland fish stocks sampled with gillnets. *Fisheries Research* 229. doi:10.1016/j.fishres.2020.105574
- Hordyk A., Ono K., Sainsbury K., Loneragan N. and Prince J.D. 2015a. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. *ICES Journal of Marine Science* doi:10.1093/icesjms/fst235
- Hordyk A., Ono K., Valencia S.V., Loneragan N. and Prince J.D. 2015b. A novel length-based estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES Journal of Marine Science* doi:10.1093/icesjms/fsu004
- Johannes R.E. 1978. Words of the lagoon: Fishing and marine lore in the Palau District of Micronesia. Berkeley, CA: University of California Press, Berkeley.
- Mace P. and Sissenwine M. 1993. How much spawning per recruit is necessary? p. 101–118. In: Risk evaluation and biological reference points for fisheries management. Smith S., Hunt J. and Rivard D. (eds). Canadian Special Publications of Fisheries and Aquatic Science 120. 222 p.
- McClanahan T.R. 2011. Human and coral reef use interactions: From impacts to solutions. *Journal of Experimental Marine Biology and Ecology* 408:3–10. Available at: <https://doi.org/10.1016/j.jembe.2011.07.021>
- Moore B., Rechellul P. and Victor S. 2015. Creel survey and demographic assessments of coastal finfish fisheries of southern Palau, September 2014. Noumea, New Caledonia: Secretariat of the Pacific Community.
- Nakamura Y., Horinouchi M., Shibuno T., Tanaka Y., Miyajima T., Koike I., Kurokura H. and Sano M. 2008. Evidence of ontogenetic migration from mangroves to coral reefs by black-tail snapper *Lutjanus fulvus*: Stable isotope approach. *Marine Ecology Progress Series* 355:257–266.
- Newton K., Cote I.M., Pilling G.M., Jennings S. and Dulvy N.K. 2007. Current and future sustainability of island coral reef fisheries. *Current Biology* 17:656–658.
- Pauly D., Christensen V., Dalsgaard J., Froese R. and Torres F. 1998. Fishing down marine food webs. *Science* 279:860–863. doi:10.1126/science.279.5352.860
- Prince J.D., Peeters H., Gorfine H. and Day R.W. 2008. The novel use of harvest policies and rapid visual assessment to manage spatially complex abalone resources (Genus *Haliotis*). *Fisheries Research* 94:330–338.
- Prince J.D., Lindfield S.J. and Harford W.J. (in prep). Using size frequency data to estimate size of maturity in fish reveals a potential mismatch between biological and functional definitions of maturity. 17 p.

- Prince J.D., Lalavanua W., Tamanitoakula J., Loganimoce E., Vodivodi T., Marama K., Waqainabete P., Jeremiah, Nalasi D., Tamata L., Naleba M., Naisilisili W., Kaloudra U., Lagi L., Logatabua K., Dautei R., Tikaram R. and Mangubhai S. 2019. Spawning potential surveys reveal an urgent need for effective management. SPC Fisheries Newsletter 158:28–36. Available at: <http://purl.org/spc/digilib/doc/y6mf4>
- Prince J.D., Hordyk A., Valencia S.V., Loneragan N. and Sainsbury K. 2015a. Revisiting the concept of Beverton-Holt Life History Invariants with the aim of informing data-poor fisheries assessment. ICES Journal of Marine Science 72(1):194–203. doi:10.1093/icesjms/fsu011
- Prince J.D., Kloulchad V.S. and Hordyk A. 2015b. Length-based SPR assessments of eleven Indo-Pacific coral reef fish populations in Palau. Fisheries Research 171: 42–58.
- Sabetian A. 2010. Parrotfish fisheries and population dynamics: A case study from Solomon Islands. PhD Thesis, James Cook University. 227 p.
- Sadovy Y. 2005. Trouble on the reef: The imperative for managing vulnerable and valuable fisheries. Fish and Fisheries 6:167–185. doi:10.1111/j.1467-2979.2005.00186.x
- Sadovy de Mitcheson Y., Craig M.T., Bertoncini A.A., Carpenter K.E., Cheung W.W., Choat J.H., Cornish A.S., Fennessy S.T., Ferreira B.P., Heemstra P.C., Liu M., Myers R.F., Pollard D.A., Rhodes K.L., Rocha L.A., Russell B.C., Samoilys M.A. and Sanciang J. 2013. Fishing groupers towards extinction: A global assessment of threats and extinction risks in a billion dollar fishery. Fish and Fisheries 14:119–136. doi:10.1111/j.1467-2979.2011.00455.x
- SPC (Secretariat of the Pacific Community). 2015. Final outcomes. A new song for coastal fisheries: Pathways to change. Future of coastal/inshore fisheries management workshop. Noumea, New Caledonia, 3–6 March 2015.
- Taylor B.M., Oyafuso Z.S., Pardee C.B., Ochavillo D. and Newman S.J. 2018. Comparative demography of commercially harvested snappers and an emperor from American Samoa. PeerJ 6:e5069; doi 10.7717/peerj.5069
- Williams A.J., Currey L.M., Begg G.A., Murchie C.D. and Ballagh A.C. 2008. Population biology of coral trout species in eastern Torres Strait: Implications for fishery management. Continental Shelf Research 28:2129–2142.