Fisheries Newsletter

166 | September–December 2021

Pacific Community
Communauté du Pacifique

ISSN: 0248-0735

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Fisheries, Aquaculture and Marine Ecosystems Division

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Cover image: Visits and controls at fish selling locations were part of the field work during MCS&E training workshops in Vanuatu. (Image: Yakar Silas)

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And… action!

When movies are our allies for capacity building and awareness raising

Some call it "infotainment", but the value of videos and podcasts to share knowledge can sometimes be overlooked as we seek to develop more ways of monitoring and assessing user interactions and progress with learning materials. Sure, the online learning platforms with all of their flashy features and expert content have amazing benefits if well-developed, but there is something closer to "the real deal" in watching someone you might know, and trust, explaining a subject with their characteristic flair in full flow. Feeling that there is a human connection can make the subject a little more accessible, perhaps. So, in an effort to increase the impact on learning, staff of the Pacific Community's Fisheries, Aquaculture and Marine Ecosystems (FAME) Division have been combining entertaining video content with other training tools within a training package. This can be particularly effective if the content is then shared through social media channels.

At the core of the work we do in FAME is our commitment to develop professional capacity in fisheries across the Pacific Islands region. Our capacity building and collaborative activities have flourished over the years through the cultivation of close professional and personal working relationships between our staff and SPC members. As the pandemic continues to restrict travel, we have had to revise our approach to delivering these fruitful activities; no longer able to benefit from the face-to-real-face interactions with the social opportunities these provide, we have resorted to online video conferencing and other platforms for training. Knowing how important it is to have that real connection with people, some of our staff embarked on producing videos to enhance their knowledge sharing. While this is not new to FAME in general, to some of the teams it has been a novel and exciting way of communicating with their partners in the Pacific. And there is not a one-size fits all approach either.

Here, we take a short tour of some of the recent video knowledge products from a few FAME teams, considering how the content and purpose of each has influenced the widely different styles. Perhaps FAME staff are not going to be leaving SPC for the bright lights of Hollywood anytime soon, but their enthusiasm for bringing the human touch and a dose of humour back into the capacity building arena is a warm reminder of the personal connections we have all missed over the past 20 months.

The "How to" take a fish apart – biological sampling technique series

Demonstrating a practical activity, such as how to extract the otoliths from a yellowfin tuna, can be tricky when done remotely. You do not get the same opportunity to stop the trainer and ask the questions you normally would. Of course, you could read a standard operating procedure (SOP) manual and follow this to the letter, but even the best written SOP manual benefits from a visual demonstration for everyone to be able to access the knowledge. Considering the different learning styles of people is key to developing a comprehensive teaching package, which is why our experts develop materials using a range of resources, such as printable information sheets, presentations, exercises, quizzes, games and practical activities.

Caroline Sanchez demonstrating how to extract otoliths from a skipjack tuna.
(Image: T. Rasoloarimanana, ©SPC)

The series demonstrates how to collect biosamples at sea and in port. (Image: T. Rasoloarimanana, ©SPC)

As a way of reaching as many fisheries officers as possible, our senior fisheries technician, Caroline Sanchez, decided to put her knowledge on film and set out to make a series of videos to show exactly what is meant by phrases such as "place your drill at an angle of 45 degrees towards the opposite eye," as this can be fairly tricky to follow if you have not done this before, so best to have a visual for this!

The objective of these step-by-step videos was to show fisheries officers how to collect samples for bioanalysis in an engaging and easy-to-follow format. These samples are curated by the Pacific Marine Specimen Bank, and the analyses are vital to FAME's work, particularly for understanding how marine ecosystems function. The information generated from these analyses feed directly into regional assessment models used to estimate stock status, so we rely on the collection of samples by our members at sea and in port. Anyone can access these videos, which are hosted on the SPC YouTube channel, and the easy-to-follow style means that you do not need to have a degree in marine biology in order to be able to follow them and collect good quality samples. To ensure that all of our partners are equipped with the know-how to collect fish otoliths, gonads, muscle, livers, stomachs and other body parts, these videos have adopted a firm, yet friendly, instructive style. The visuals are very graphic (not for the squeamish!) so the voiceover details can be clearly understood. The settings for the videos vary, accounting for at-sea or in-port sampling. The videos can be standalone instruction tools, but they will also be included as part of a module in, for example, the Pacific Island Regional Fisheries Observer training on biological sampling.

Creating a friendly atmosphere to share know-how – the fish and tips series of videos

To address the growing need to provide alternative livelihood options to Pacific Island fishing communities, the coastal fisheries team is currently developing an information toolkit on nearshore fishing practices, focusing on the more resilient pelagic species. But how do you show someone how to troll with multiple lures or how to prepare your drop stone when you cannot sit in the same fishing boat? It is a challenge, but the team is up to it. In addition to a manual, complementary short videos are being produced in an easily accessible way to reach a wide audience. Here again, the easy-to-follow style has been adopted, also making use of the four following ingredients.

- Seasons

  Considering that coastal communities have a range of backgrounds in terms of access to equipment and technical know-how, the videos are segmented into several seasons and short chapters (for example season 1 covers trolling, season 2 covers mid-water fishing). Why? So that users can skip the methods that they already know and go straight to the chapter they want.

- **Visuals**

  Visuals make use of footage on shore to show the equipment needed and at sea to demonstrate how to use gear, and with underwater shots to visualize the gear in action.

- **Repetition**

  The real-life footage is accompanied by recaps that include illustrations and diagrams of the materials and "how-to" components.

- **People with a Pacific touch of humour**

  The essential element in this series is the relaxed atmosphere in which FAME coastal fisheries experts, Ian Bertram, William Sokimi, and Watisoni Lalavanua, share their skills and knowledge. The script was carefully crafted to ensure absolute clarity alongside some light, relevant humour in places to create a warm and friendly delivery style. While this is in no way near as good as being sat in a boat with the real William, Ian or Soni, it goes some way to recreating an informal and amicable practical instruction session with these well-known characters.

This project was produced with financial support from the European Union, the Government of Sweden, and the New Zealand Aid Programme. The contents of the videos do not necessarily reflect the views of the European Union, the Government of Sweden, or the Government of New Zealand.

Converting a high-level concept into a fun movie to hook your audience: The case of the Harvest Strategies

When Marino Wichman first came to SPC as a Pacific Island Fisheries Professional, he had no idea that he would be the star of a short "action" style movie about tuna harvest strategies in the western and central Pacific Ocean (WCPO). In fact, perhaps few people could have envisaged that tuna harvest strategies could be the subject of an energetic and entertaining short film. This innovative approach to explaining a complex new concept and all of its unfamiliar terminology has been well received so far.

Having already run a number of in-country workshops across the region, team members were aware that they needed to expand their range of stakeholder engagement materials for the harvest strategy framework to support existing materials. While stakeholders understood the general idea of the harvest strategy, retaining the vocabulary around it could sometimes lead to confusion, especially when it was not always used consistently by the experts. The objective, therefore, was to come up with a script and video to raise awareness of the main components of a harvest strategy in a way that is accessible and relevant to Pacific Island countries and territories.

The concept for this video style came about when FAME's management strategy evaluation team decided that perhaps a more dynamic, story-telling style would be more effective at engaging members than a traditional show-and-tell style. This approach has the added bonus of indulging in a touch of humour, with cameo appearances from well-known faces from around the region, already making what can be quite a dry subject more accessible. Filming started in February 2021 and was completed just before the confinement period started in New Caledonia in March (and in time for the lead, Marino, to finally return to the Cook Islands). Most of the filming took place in and around SPC, making use of a green screen for the "action scene" and the amateur (or aspiring!) acting skills of SPC staff and members.

The video is not meant as a standalone knowledge product, but as an awareness-raising tool that will complement existing materials and tools to promote a regional understanding of harvest strategies. Videos explaining each component in more detail are already in the planning phase, and the team would really welcome any feedback that viewers might have to help refine the content and the scripts.

Dealing with an overly enthusiastic student can be challenging! (Image: A. Brécher, ©SPC)

William Sokimi shows how to make an inline sinker. (Image: A. Brécher, ©SPC)

This was work was supported by the New Zealand Ministry of Foreign Affairs and Trade (MFAT) funded project "Pacific Tuna Management Strategy Evaluation". You can check out the video on the SPC YouTube channel: https://www.youtube.com/watch?v=zM3B9DLmtZg

A people-centred approach in a virtual world

While these three examples of informing through entertainment (or infotainment) have different angles, all three have a common objective to engage a specific audience, hold their interest, and deliver a key message. Whether this is through a simple, step-by-step demonstration by a trusted expert, a friendly dialogue between a novice and veteran fisher, or a lively adventure to understand a management strategy, all place people at the centre to try to recapture the human touch in training. And there are other examples of such efforts within FAME's outreach portfolio, such as involving real community members in advocacy campaigns to bring others onboard to work in a new way. Trust is central to capacity building. We are adapting, and we are looking to maintain and build on the personal connections that we have built over so many years with our stakeholders.

We would love to hear your feedback on these projects, so if you would like to provide your comments on any of the materials described here, or if you have ideas for future capacity building ventures using film, then please get in touch.

Setting up the action shots with a green screen and a palm frond.
(Image: T. Holley, ©SPC)

Marino Wichman interrogates Rob Scott about management objectives. Can you identify the random fisher behind them?
(Image: T. Holley, ©SPC)

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Monitoring, control, surveillance and enforcement training for community-based authorised fisheries officers in Vanuatu

During the second half of 2021, community-based authorised officers from several provinces in Vanuatu attended three training workshops in coastal fisheries monitoring, control, surveillance and enforcement (MCS&E). The workshops were held in Tanna (Tafea Province), Luganville (Sanma Province) and Port Vila (Shefa Province), Vanuatu's capital.

Funded by the Pacific Community (SPC), the training workshops were conducted by Jeff Dunlop from the New Zealand Ministry of Primary Industries Te Pātuitanga Ahumoana a Kiwa (Partnerships in the Pacific) programme, with support from SPC's Coastal Fisheries MCS&E Adviser, Ian Freeman. Due to region-wide COVID-19-related travel restrictions, all three workshops were conducted virtually, using Zoom.

Two senior fisheries officers from the Vanuatu Fisheries Department (VFD) Compliance Section, Yakar Silas and Joby Siba, were on the ground to facilitate the training and practical exercises conducted during the workshop.

Several other members of VFD, along with members of the Vanuatu police force were also involved to support the training.

In-country, face-to-face capacity building is always the preferred approach for this type of training but due to COVID-related travel restrictions this has not been possible over the past two years. Being able to deliver such training virtually, with the strong support of local facilitators, has provided very positive outcomes with some interesting lessons learned along the way (see Box 1 for additional information).

The community-based authorised officer (CBAO) training focused on improving officers' understanding of the current Vanuatu Fisheries Act and regulations, their powers as authorised officers under the act, and how enforcing regulations will help to conserve and manage Vanuatu's coastal marine resources.

During the training, practical exercises included undertaking market and fish vendor inspections so that CBAOs received genuine workplace experience, along with structured learning lessons in basic MCS&E requirements. The training also included the use of the Authorised Officer Incident Report Book for fisheries-related inspections. This incident book was developed by the New Zealand Te Pātuitanga Ahumoana a Kiwa programme and the Pacific Community's Coastal Fisheries team for the Pacific Islands region. It provides a step-by-step guide for officers

Some of the AFO participants during the training at the Vanuatu Fisheries Training Centre in Luganville, Santo. (Image: ©Yakar Silas)

The Authorised Officer Incident Report book and its explanatory notes.

in the field, and ensures essential information and evidence is recorded to support a case file when an offence has been detected. Recording relevant information related to the offence then enables senior management officials to make an informed decision as to an appropriate enforcement outcome. This could include issuing a warning, fixed penalty notice, or even prosecution.

The incident book has proven popular with fisheries officers in several Pacific Island countries for its ease of use, and has given them confidence when dealing with minor offences detected under their coastal fisheries laws.

As part of the training sessions, the incident book was loaded onto computer tablets and given to each CBAO, along with instructions on how to enter the incident book steps directly into the tablets. This will ultimately enable CBAOs to conduct their inspection work with confidence, record the required information, and send the report directly to senior management in VFD.

Elsie Jimmy, a participant from Luganville said, "The KoBo Collect Application installed on the tablet that we have received during training will make life easier for us.[1] Once we can collect data outside in the field, we can send it directly on the spot to the office in Port Vila, breaking down that distance barrier. Making use of technology with what we already have, such as tablets and android mobile phones, is the way forward in conserving and preserving our marine resources."

Illegal confiscated product taken from markets in Port Vila. (Image: ©Yakar Silas)

CBAOs learned a lot about how the current Fisheries Act and regulations will help them conserve and preserve the currently endangered marine species in their communities, such as green snail, trochus, sea turtles, dolphins, rock lobsters, coconut crabs, conch shell and many more.

"The Authorized Fisheries Officer training this year will help me and my community, village and island to conserve and preserve our turtles, trochus and fish stocks in the years to come, as I now know that there are laws that prohibit the killing of turtles and harvesting of conch and trochus, which are prevalent in my community."

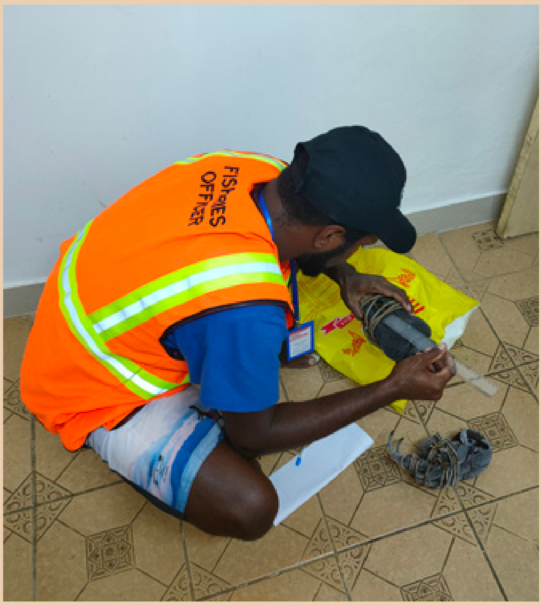
"After this training I will go back and make sure that everyone is aware of the regulations and penalties involved if anyone decides to look over the regulations," Wanga Taliban said. Wanga is from Craig Cove on Ambrym Island.

Vanuatu has 72 area councils, and the current government policy is to decentralise its services to all area councils. The appointment of CBAOs comes as part of this decentralisation policy and provides a way forward for managing and monitoring marine resources in communities or area councils.

"The government, through the VFD, will continue to train and appoint more community-based authorised officers throughout Vanuatu to work under the area councils, to make sure that we have good management and monitoring of our marine and coastal resources for us to enjoy, now

[1] A web application developed in Vanuatu, which allows the incident boook to be used on a tablet or smartphone..

Field work included visits and controls at fish selling locations. (All images: ©Yakar Silas)



Box 1: Tips for virtual training workshops

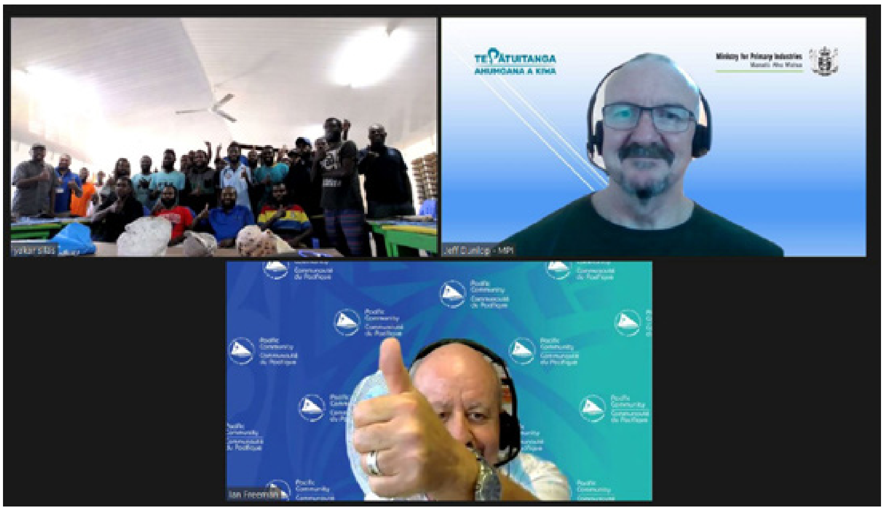
- Having in-country-based "on-the-ground" facilitators was a huge help in the training process, and produced some interesting learning outcomes as we progressed over the many days of training. Following the steps below will assist with the virtual training process.
- Make sure facilitators have a Zoom licence, otherwise you have to reconnect to a new Zoom link every 45 minutes.
- If the training is being conducted in a local language, make sure you have translators available, particularly if you are expected to provide feedback on general comments.
- Some basic training in facilitating a Zoom meeting may be useful for facilitators, such as aligning the camera, so that it shows external participants what is being presented, or a view of participants in the training room.
- Ensure that all participants are aware that many external sounds are transmitted via the microphone so the sounds of dogs barking, or roosters crowing can be very distracting.

and for our kids to enjoy in the future," said VFD's Principal Monitoring, Control and Surveillance officer, Yakar Silas.

"Community-based AFOs, basically are the eyes and ears of the Vanuatu government in the islands, and they make sure that all the marine-regulated species, like sea turtles, sea cucumbers, rock lobsters, coconut crabs and trochus shells are harvested according to the regulated size limits and quotas. Not only that, they represent VFD in their community," Silas added.

Currently, CBAOs are located in 29 council areas in the provinces of Tafea, Shefa, Malampa, Sanma, Penama and Torba. These CBAOs have all participated in MCS&E training. In 2022, SPC and Te Pātuitanga will continue the CBAO training for an additional 22 council areas located in these same provinces, and Efate. The ultimate target is for there to be three CBAOs for each council area, and this is planned to happen by the end of 2022.

SPC will also provide high-visibility vests and caps to CBAOs, along with copies of the incident report book for new CBAOs to record the details of their inspections. The delivery of these items to Vanuatu has been delayed due to COVID-19-related issues, although delivery is expected to occur in January 2022.



Tanna training participants and the trainers. (Zoom screenshots by Jeff Dunlop)

For more information or to request similar training for your country:

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“Keep fishing sustainably”: Innovative communication methods for engaging communities of Wallis and Futuna

Besides disseminating information, many awareness campaigns aim to permanently change practices and behaviour. Changing norms can only be achieved with local communities, often by jointly developing systems and key messaging. As new information and communication technology develops quickly, so do the tactics needed to engage communities, which requires innovation.

Participatory approaches and innovation

“The Sea, our Source of Life” campaign on Wallis and Futuna clearly illustrates this process. A 2020 coastal fisheries management review identified the need to strengthen ties between fisheries departments and fishers, and set up a unified information platform as prerequisites for sustainably managing coastal marine resources.

In 2021, the Wallis and Futuna Agricultural, Fisheries and Forestry Services Department (DSA) built Phase 1 of an awareness campaign on sustainable fisheries with support from the Pacific Community (SPC). The campaign is funded by the European Union through PROTEGE (Pacific Territories Regional Project for Sustainable Ecosystem Management) and the New Zealand Aid Programme through SPC’s Fisheries, Aquaculture and Marine Ecosystems Division. The campaign aims to be unequivocally focused on fishers and sea users.

Symbols and messaging

The campaign’s information kit has been translated into local languages and already contains two animated TV clips that began broadcasting August 2021, In addition, 10 exhibition panels and an anthology of poems showcase the testimony of elders or display photographs of communities. During production, DSA sounded out community representatives for their approval of the logos, symbols and messages. Phase 1 aimed at rallying communities around sea and fisheries culture.

A video challenge to trigger changes to local behaviors

The campaign introduced innovation in the form of a Facebook video challenge, using digital media and images, which ran from September to November 2021. The theme was

Contestant #6 Aleta and Granny Falai.
https://www.facebook.com/pecheurswf/videos/875579923143073/

"Keep Fishing Sustainably" and the objective to engage civil society and fishers through entertaining videos. All nine contest judges, consisting of Wallis and Futuna fisheries management stakeholders, shared short recorded testimonies explaining the issues involved in sustainable fisheries as well as the contest's rules. DSA's teaser video alone garnered nearly 25,000 views and 2000 positive comments on the campaign's Facebook page.

Campaign ambassadors

Within two months, there was a tremendous response, with 17 highly varied videos submitted by fisher associations, schoolchildren and teachers. The messages expressed in their videos were replete with colour, ideas, poetry and even a touch of humour. People became actively involved in effecting change, bearing messages from their island territory in support of sustainable fisheries.

Contestant #16 - Erwan Taufana, a spearfisher
https://www.facebook.com/pecheurswf/videos/1254682351622104

Contestant#5 - Odette Manufekai and Manuella Tuhimutu
https://www.facebook.com/pecheurswf/videos/306105218014514/

"Today, needs have changed as lifestyles on our islands have moved on [...] which is why we must remember that nothing lasts forever, and we need to learn how to fish sustainably so that we can continue living off our marine resources." Aleta and Granny Falai spoke about changing lifestyles while Odette Manufekai and Manuella Tuhimutu danced on the seashore to celebrate sustainable practices. "Let our little fishes live!" concluded the budding fisherwomen. Meanwhile, spearfisher Erwan Tufana, urged viewers not to fish too often at night.

Along with roundtable meetings and consultations with fishers, these messages will form the basis for building the awareness campaign's second phase scheduled for 2022.

While the awareness campaign's ultimate aim is to have a genuine impact on behaviour, the activity on Wallis and Futuna showed that this original awareness messaging format produced by the local community and stakeholders was successful because it earned people's trust and led to concerted action with the communities. The activity was also in line with socially and environmentally responsible principles, as it involved local communities in the Pacific Community's communication and awareness exercises.

For more information

Visit "The Sea, our Source of Life" campaign's information material
https://www.spc.int/DigitalLibrary/FAME/Collection/Campagne_WF_Te_Tai

Watch the winning video of the "Keep fishing sustainably" contest produced by Maëlann and Chloé Liufau Telesia Tiniloa
https://www.facebook.com/pecheurswf/videos/342253031008516/

Watch the artistic video of the "Keep fishing sustainably" contest made by Lano Alofiva school's Year-8 pupils
https://www.facebook.com/pecheurswf/videos/441966224101720/

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Healthy or not healthy? The status of tuna stocks in the western and central Pacific Ocean

In early December, the 21st edition of the Tuna Fisheries Assessment Report (widely known as the "TFAR") was completed and made available via the Pacific Community's website.[1] Published annually since 1999 (with the exception of 2007), the TFAR is intended to present a concise, plain-language summary of tuna fisheries in the western and central Pacific Ocean (WCPO). The report presents detailed statistics on catches of the four target tuna species – skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), bigeye (*T. obesus*) and albacore tuna (*T. alalunga*) – by the major gear typces used, which include purse-seine, longline, pole-and-line, troll and a variety of artisanal and small-scale gear types. The latest stock assessment and relevant management advice for each of the four tuna species is outlined, and the status of the stocks is summarised. The history of WCPO tuna tagging programmes, including both tagging and recapture locations, is illustrated. Information is presented on associated catch and stock status for important bycatch caught in the same fisheries, including billfish and sharks. Finally, the influence of the El Niño Southern Oscillation (ENSO) is discussed, and the latest ENSO forecast presented.

Some highlights of TFAR no. 21, which summarises the 2020 tuna fisheries, include:

- The three tropical tuna stocks (bigeye, yellowfin, skipjack) are all in a relatively healthy state, classified as not overfished and not experiencing overfishing, with sustainably high catches being taken.
- South Pacific albacore was newly assessed this year; the work was conducted jointly with the Inter-American Tropical Tuna Commission and, for the first time, covered the albacore stock across the entire Pacific Ocean.
- Encouragingly, a new assessment for blue shark in the southwest Pacific showed that while the assessment had considerable uncertainty, the stock has rebounded, and it is unlikely to be overfished. However, some other species of shark are assessed as being overfished.
- Small Island Developing States continue to increase their participation in the skipjack purse-seine fishery, with more than 50% of purse-seine vessels flagged to, or chartered by, SIDS.
- The climate pattern known as "La Niña" significantly altered fishing patterns in 2020/2021 and is expected to do so again in 2022.

The TFAR is perhaps the most recognizable regular publication from the Pacific Community's Oceanic Fisheries Programme, and is widely distributed to fisheries departments and libraries around the world. The content of the TFAR has evolved over time but the format has remained relatively constant. Responsibility for assembling the TFAR has also changed hands over the years.

The lead author for TFAR no. 1, as well as nos. 2–4, was John Hampton; subsequent lead authors include Adam Langley (nos. 5–8), Shelton Harley (nos. 9–14), Stephen Brouwer (no. 15–19) and Steven Hare (no. 20 and 21). John Hampton and Peter Williams have been co-authors in all 21 TFARs to date.

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[1] https://fame1.spc.int/en/component/content/article/251

Fourth Regional Technical Meeting on Coastal Fisheries and Aquaculture

The Fourth Regional Technical Meeting on Coastal Fisheries and Aquaculture (RTMCFA4) was held online using a virtual platform, from 12–15 October 2021. RTMCFA4 brings together coastal fisheries and aquaculture scientists and technical experts in the Pacific to discuss important technical and scientific gaps, needs, challenges and opportunities. Twenty-one Pacific Community (SPC) member countries and territories participated, with over 132 participants total, consisting of members, observers, civil society organisations (CSOs), non-governmental organisations (NGOs) and other non-state actors (NSAs).

Not only was this the first RTMCFA to be held virtually, but it was also the first meeting to include the Community-Based Fisheries Dialogue (CBFD), which was convened by, and focused on, CSOs and NSAs.[1] The purpose of the CBFD is to give CSOs and NSAs an opportunity to provide information and advice on key needs, through the RTMCFA, to the Heads of Fisheries, to assist with informing Pacific Leaders on priority issues associated with the sustainable use of coastal fisheries resources. The CBFD also provides an opportunity to share experiences and lessons from community-based initiatives to strengthen efforts to maintain productive and healthy ecosystems and their associated fisheries resources that are critical to the wellbeing of coastal communities.

The overarching theme of RTMCFA4 was to discuss and address some of the main technical issues affecting coastal fisheries and aquaculture in support of better science-based resource management and the equitable access to resources, by capturing lessons learned from the "response phase" of the COVID-19 pandemic and identifying approaches and priorities as the region transitions to the recovery phase in 2022 and beyond.

The RTMCFA4 Outcomes and Actions Report, along with all of the working and information papers and, are available on the SPC RTMCFA4 webpage.[2] The RTMCFA4 Outcomes and Actions Report includes the agreed priority issues and needs to be actioned by SPC members, provides guidance to SPC's Coastal Fisheries and Aquaculture Programme, and identifies key recommendations to be taken to the Fourteenth Heads of Fisheries (HoF14) meeting in 2022.

The meeting included technical sessions on:

- supporting the integration of e-data systems into coastal fisheries across Pacific Island countries and territories (PICTs);
- enhancing capacity for effective coastal fisheries management;
- risk planning for Pacific aquaculture;
- aquaculture needs, priorities and future directions in the Pacific Islands region; and
- scientific and technical support in a COVID-19 context.

An update on the *2021 Coastal Fisheries Report Card*[3] was also provided. The meeting has requested HoF14 to initiate a review of the regional and national indicators for the Coastal Fisheries Report Cards, in line with the *New Song for Coastal Fisheries*[4] and other regional frameworks.

A session was devoted to the integration of e-data systems into coastal fisheries across Pacific Island countries and territories. (Image: P. James, ©SPC)

[1] See article on p. 18 of this issue: purl link
[2] https://fame1.spc.int/en/meetings/253
[3] https://purl.org/spc/digilib/doc/rfxg6
[4] https://purl.org/spc/digilib/doc/b8hvs

The new CBFD session focused on establishing an appropriate administrative foundation for future CBFD meetings. Participants provided feedback, advice and recommendations for future CBFD session arrangements by reviewing the provisional terms of reference, the convening arrangements, and the processes for the selection of participants for future CBFD meetings.

The CBFD also included a session on Implementing the Pacific Framework for Action on Scaling-up CBFM. CBFD participants discussed how CSOs and NSAs could contribute to and/or further align with achieving the outcomes in the Framework for Action. They considered how implementation progress can be monitored and evaluated, and what role CSOs and NSAs can play in strengthening and improving national and regional reporting.

Summary of PICT coastal fisheries and aquaculture technical issues, needs and priorities

Prior to the meeting, participants from Pacific Islands countries and territories (PICTs) fisheries and aquaculture agencies were consulted on their national coastal fisheries and aquaculture issues, challenges and needs. This information was summarised for both coastal fisheries and aquaculture, priority technical needs, and technical issues or challenges, and presented in plenary "to set the scene" and use the information as background for RTMCFA4 discussions.

Supporting the integration of e-data systems into coastal fisheries across PICTs

The first technical session highlighted the range of e-data tools that have been developed for improving the process of data collection, analysis and reporting on coastal fisheries. SPC member countries support the use of e-data approaches, as developed by SPC, to improve the quality of coastal fisheries data collection and to continue investigating and delivering on innovative technology, such as satellites and drones, as appropriate.

The integration of socioeconomic survey capability into the available e-data tools is underway. SPC was requested to continue with the introduction of e-data systems to all interested PICTs, with a focus on sustained training and capacity development to underpin successful implementation. This should include progressively expanding training by the Pacific Community's Fisheries, Aquaculture and Marine Ecosystems (FAME) Division to include analysis of fisheries data and the use of spatial analysis software. Members agreed to work with SPC to explore effective ways to incorporate their historic data into the e-data system, subject to satisfying standard quality control issues, as outlined in SPC FAME's data policies.

Enhancing capacity for effective coastal fisheries management

Against the backdrop of the COVID-19 pandemic travel restrictions, SPC has continued to provide advisory and technical support to members, albeit remotely, to enhance members' capacity for effective management and sustainable development of their coastal fisheries. This session considered activities undertaken over the last two years. Through breakout groups and plenary discussions, members provided feedback on how SPC's support activities in the areas of policy, legislation, and monitoring, control, surveillance and enforcement (MCS&E) can be better integrated to enhance capacity for effective coastal fisheries management. Eleven key areas were identified, including, *inter alia*:

- recognising the importance of effective coastal fisheries management, including collaboration with local communities, and the use of available IT platforms and e-learning tools to build PICTs' capacity in the three broad areas of policy, legislation and MCS&E;
- facilitating the integration of data collection, policy, management, legislation and MCS&E in training opportunities offered by SPC, with support for learning exchanges within and between PICTs;
- ensuring science-based evidence for management plans and regulations, and case studies on how to link data to specific policies, and on the effectiveness of new management measures for specific fisheries;
- developing guidelines for drafting laws and regulations for coastal fisheries and aquaculture, including legal terminologies and models for legislation;
- developing guidelines for preparing coastal fisheries and community-based management plans;
- organising workshops on monitoring the implementation of management plans;
- incorporating traditional rules into local ordinances or bylaws to increase the chances of compliance by all fishers, and developing awareness materials on prohibited species harvest for communities; and
- providing training support at the community level, and developing appropriate e-tools for communities.

Risk planning for Pacific aquaculture

An update was provided on work undertaken by FAME on risks to PICTs' aquaculture production, with an overview of the kinds of risks exist. The importance of risk planning management for aquaculture was highlighted. An interactive plenary session, using a virtual whiteboard, was used to: 1) discuss and share information on the types of aquaculture risks faced within PICTs and any gaps in capacity to manage risks; 2) set priorities for development of practical management approaches to each risk type; and 3) identify what works. Risks and management strategies were identified for, as examples, seaweed, tilapia, marine fish and giant clams. Additional suggestions indicated that shrimp and coral species restoration might also make good risk management examples.

Members invited SPC to provide further guidance on the extent to which risk assessment is relevant and can be used for small-scale aquaculture at the community level for food security purposes (i.e. subsistence and artisanal). The importance of accounting for the diversity of national contexts and productions (including cultural aspects) also needs consideration, bearing in mind that most small-scale aquaculture activities in the region are not commercially oriented.

Aquaculture needs, priorities and future directions in the Pacific Islands region

The Thirteenth Heads of Fisheries meeting endorsed SPC to undertake a regional assessment of the needs, priorities and future directions of aquaculture in the Pacific Islands region. The output from the regional aquaculture assessment and its recommended future directions and priorities will form the basis for consultations with members towards the development of a regional aquaculture strategy. The meeting identified and highlighted a number of issues.

- The multiple and interdependent purposes that aquaculture can serve: food security, economic and restoration. The key importance and expected contribution of small-scale, non-commercial aquaculture to food security and livelihoods was also stressed.
- The need for SPC to continue providing tailored technical guidance (e.g. feasibility studies, cost-benefit analyses) and capacity-building (e.g. training) to meet specific PICTs' needs in setting up integrated aquaculture operations, seed production systems, as well as a relevant enabling environment (e.g. policies, plans, knowledge sharing and awareness mechanisms).
- The importance of establishing new networks, or reviving existing ones, and strengthening collaboration to allow for the exchange and transfer of aquaculture knowledge and information, within PICTs and regionally.
- The requirement for further guidance and effort on sustainable and environmentally friendly aquaculture, including culturing native species and species with low environmental impacts. Specific guidance is needed on aquatic biosecurity, as well as for robust food safety and quality standards, in respect of international norms, to increase access to local and international markets.
- The need for SPC to coordinate the development of guidelines and an aquaculture code of practice at a regional level, as well as guidelines for food safety and value-adding opportunities.
- The importance of elevating the profile of aquaculture to allow access to financial support (e.g. bank loans) for small-scale aquaculture initiatives, noting that climate-smart aquaculture relies on sustainable high-quality inputs and efficient infrastructure, including hatcheries, transport and water supply.

Scientific and technical support in a COVID-19 context

Following the COVID-19 pandemic and associated travel bans, SPC experimented with alternate ways of providing coastal fisheries and aquaculture technical support to fisheries agencies, such as video conferencing and the development of online courses and videos. SPC informed partici-

Aquaculture ponds, Fiji. (Image: A. D'Andrea, SPC) pants that online tools, on-demand modules, and training videos are available to members, and to CSOs and NSAs. Reflecting on the last year's experiences, SPC proposed a way forward using video conferencing and online training options, and invited members to provide feedback and preferences on the proposed options.

Members requested SPC to continue providing remote training and assistance through diversified and accessible e-tools and platforms, and to periodically inform them of any new training materials, applications and e-tools that could be applied at the PICT level. SPC was encouraged to further experiment with and use diverse formats to maximise and improve the long-term impact of training on the priority coastal fisheries and aquaculture topics identified during the meeting (e.g. statistical analysis, GIS, management plan drafting, MCS).

Recommendations for the Fourteenth SPC Heads of Fisheries meeting

The meeting discussed and agreed to nine recommendations to be transmitted to the Fourteenth Heads of Fisheries for their consideration in early 2022. These are included in the RTMCFA4 Outcomes and Actions Report.[5]

[5] https://purl.org/spc/digilib/doc/ezfxn

Feedback

Participants were asked to complete an online survey to rate aspects of the meeting. Unfortunately, there were only 29 responses, 86 percent of which were from member countries, with the rest coming from donor partners and observers. Participants were asked to rate the organisation of the meeting, the content, the use of Zoom and breakout groups, as well as the opportunity to provide feedback, and overall engagement. In general, these aspects were rated highly, with an average of 4.1 out 5.0. The aspects of meeting content were particularly high, with 4.4 out of 5.0. Twenty-two respondents also provided suggestions for improving future meetings.

The next RTMCFA meeting will be held in late October 2022, whether it will be a virtual, hybrid or in-person meeting will be determined by mid-2022.

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Ways for SPC to continue providing scientific and technical support during a travel ban were discussed during the meeting. (Image: ©MIMRA, Marshall Islands)

First Community-Based Fisheries Dialogue at the Fourth Regional Technical Meeting on Coastal Fisheries and Aquaculture

The Fourth Regional Technical Meeting on Coastal Fisheries and Aquaculture (RTMCFA4), held online from 12–15 October 2021, was the first meeting to include the Community-Based Fisheries Dialogue (CBFD). The meeting was convened by, and focused on, civil society organisations (CSOs) and other non-state actors (NSAs), with the Pacific Community's Division of Fisheries, Aquaculture and Marine Ecosystems (FAME) as the secretariat. The purpose of the CBFD is to give CSOs and other NSAs an opportunity to provide information and advice on key needs and issues. This is done through the RTMCFA to the Heads of Fisheries, to assist with informing ministers and Pacific leaders about priority issues associated with the sustainable use of coastal fisheries resources. The CBFD also provides an opportunity to share experiences and lessons from community-based initiatives to strengthen efforts to maintain productive and healthy ecosystems, and their associated fisheries resources, which are critical to the wellbeing of coastal communities.

The CBFD was held as a virtual meeting on 13 October 2021. The first CBFD session was facilitated by an independent convenor, Kesaia Tabunakawai from Fiji, with at least 38 representatives of CSOs and other NSAs engaged in plenary and breakout group discussions. There were over 100 participants in the CBFD session, including representatives of government agencies and other observers.

This first CBFD focused on laying the foundation for future dialogues through consideration of the CBFD Provisional Terms of Reference, and discussion of CSO and NSA contributions to the implementation of the "Pacific Framework for Action on Scaling-up CBFM".[1]

The CBFD Outcomes Report – along with all of the working, information and background papers, and presentations – are available on the SPC RTMCFA4 webpage.[2] The CBFD Outcomes Report summarises outcomes and points of consensus among CBFD participants, highlights priority issues and needs to be actioned by CSOs and other NSAs, including SPC members, provides guidance to SPC's Coastal Fisheries and Aquaculture Programme (CFAP), and identifies key recommendations to be taken to the 14th Heads of Fisheries Meeting in early 2022 via the RTMCFA4, and for transmission to the Regional Fisheries Ministers Meeting in mid-2022. During the CBFD, and from the CBFD Outcomes Report post-dialogue written feedback, several points were raised by participants requiring clarification. To ensure these were captured and available for future participants, the convenor compiled these points and responses into a "Q & A" information paper that is available on the SPC RTMCFA4 webpage.[2]

Background on the CBFD

The CBFD is a new mechanism for increasing the engagement of CSOs and other NSAs to give effect to the Pacific Island Forum Leaders' decision in relation to coastal fisheries (paragraph 10, 47th Leaders Communique, 2016).[3] The Regional Fisheries Ministers, at their Special Meeting[4] in 2019, requested the Pacific Community to commission a review of the former Coastal Fisheries Working Group (CFWG) to, in part, provide options and recommendations for a new mechanism. SPC member Heads of Fisheries, past participants in the CFWG, CSO representatives, Pacific Community staff, and other stakeholders were consulted during the external review. The final proposed mechanism (originally referred to as the "CBF session"), including draft provisional terms of reference, was reviewed and approved at the Twelfth Heads of Fisheries meeting (May 2020) and endorsed at the First Regional Fisheries Ministers Meeting (August 2020).

CBFD terms of reference and convening arrangements

As this was the first CBFD, it focused on establishing an appropriate administrative foundation for future CBFD meetings. Through plenary and breakout group discussions, participants reviewed and generally agreed on future CBFD session arrangements relating to:

- the terms of reference for the CBFD session within the RTMCFA agenda;
- convening arrangements for the CBFD session; and
- processes for selecting participants to future CBFD sessions.

[1] https://purl.org/spc/digilib/doc/yr5yv
[2] https://fame1.spc.int/en/meetings/253
[3] Forum Communiqué, 47th Pacific Islands Forum, Pohnpei, Federated States of Micronesia, 8-10 September, 2016. http://www.forumsec.org/wp-content/uploads/2016/09/2016-Forum-Communique_-Pohnpei_-FSM_-8-10-Sept.pdf
[4] Special Regional Fisheries Ministers Meeting Outcomes: https://www.ffa.int/node/2296

The convenor acknowledged that not all participants were in full agreement with all of the arrangements. Recognising this is the start of a process, it is anticipated that it will take several dialogues to ensure that effective and broadly accepted processes are in place, and will be refined after each meeting. The CBFD agreed to use the modified provisional terms of reference (included in the CBFD Outcomes Report) to organise and run the next CBFD in 2022.

The CBFD noted the following issues for ongoing consideration.

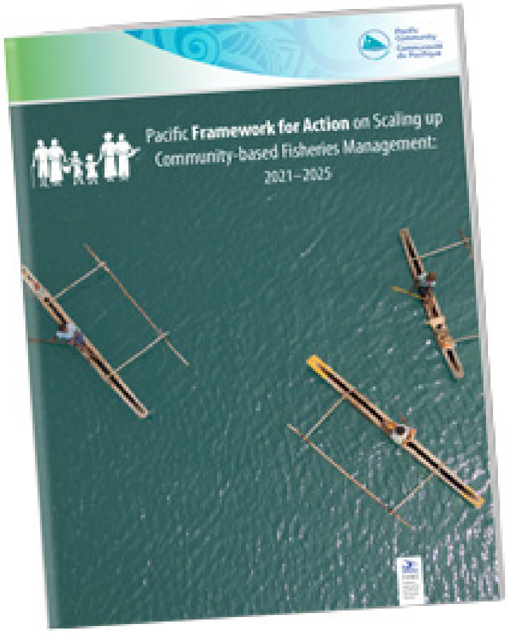
1. **Membership:** The CBFD should include members of CSOs and NSAs that are actively engaged in CBFM in Pacific Island countries and territories.
2. **Purpose:** The purpose of the CBFD should be expanded beyond community-based fisheries management to include ecosystem-based fisheries management.
3. **Preparatory work:**
   a. To increase value of the overall process, adequate resources should be assigned to preparatory time at the national level in the lead up to the CBFD.
   b. The role of national focal points needs to be clearly defined and adequately resourced.
4. **Selection of convenor and vice-convenor:**
   a. The establishment of a technical advisory group to work with FAME, the convenor and vice-convenor on agenda, report and other matters, should be considered. The role, procedure for selection, and period of appointment should be described for future consideration.
5. **Convenor and vice-convenor:**
   a. SPC is encouraged to secure funding support for these two posts.
   b. Each vice-convenor would be involved for two years – one year as vice-convenor and a second year as convenor – to assist with developing familiarity with the process and building capacity.
   c. Consideration should also be given to regional or international organisations that are working on community-based fisheries management within countries or territories, not just national groups.
   d. Consideration should be given to the option of rotating the role of convenor and vice-convenor between the three subregions of Micronesia, Melanesia and Polynesia and, that within each region, alphabetical rotation be encouraged.
6. **Selection of participants:**
   a. The number of people involved in preparatory consultations should be increased.
   b. The national selection process would be led by CSOs and NSAs, being sensitive to domestic considerations such as geography and other factors.
   c. Effective community representation is needed through representatives who are engaged in community-based fishing and can speak confidently on behalf of their constituents.
7. **Reporting:**
   a. CBFD outcomes should be reported back, in simple language, to CSOs, NSAs and community groups between the RTMCFA, Heads of Fisheries, and RFMM.
   b. The convenor and vice-convenor will accompany the chair of the RTMCFA to report to the Heads of Fisheries (HoF), and will be present at the time the HoF outcomes document to the RFMM is adopted by HoF.
   c. There is a need to provide for CSO, NSA, and minority and majority views when consensus is difficult to achieve.

Implementing the Pacific Framework for Action on Scaling-up CBFM

The CBFD included breakout and plenary sessions on "Implementing the Pacific Framework for Action on Scaling-up CBFM".[5] CBFD participants discussed how CSOs and NSAs could contribute and/or further align to achieving the outcomes in the Framework for Action. It also considered how implementation progress can be monitored and evaluated, and what role CSOs and NSAs can play in strengthening and improving national and regional reporting.

The CBFD and other RTMCFA participants highlighted the broader activities being implemented to support the Framework for Action, and raised some key support needs to strengthen future implementation, including:

- evidenced-based management information to support communities;
- government support in developing national and subnational CBFM scaling-up strategies to guide CBFM implementation in each Pacific Island country and territory;
- government and donors funding support to sustain CBFM programmes at national and subnational levels;
- CBFM capacity building at national and subnational levels; and
- strengthening legal frameworks and monitoring, control, surveillance and enforcement to support implementation and scaling up of community-based fisheries management.



The Pacific Framework for Action on Scaling-up Community-based fisheries Management

Reporting to the Fourteenth SPC Heads of Fisheries meeting

The CBFD Outcomes Report, including the revised provisional terms of reference, will be presented to the Fourteenth Heads of Fisheries (HoF14) by the CBFD convenor as part of the RTMCFA4 reporting to HoF14.

Feedback

Participants were asked to complete an online survey to rate aspects of the meeting. Only 12 participants from CSOs and NSAs, and from 11 Pacific Island countries and territories, responded to the survey. Respondents rated the meeting content highly (4.25 out of 5.0), and most participants stated that they were given the opportunity to provide feedback when they wanted. Seventy-eight per cent of respondents agreed that the purpose of each session was clear, and 82 per cent mentioned that they gained new knowledge from the CBFD. Two sets of written review comments on the draft outcomes report and provisional terms of reference were received and considered by the convenor, contributing to the "Q & A" information paper.

Participant feedback and other lessons learned from the first CBFD will be used to modify the next meeting, which will be held in conjunction with RTMCFA5, which is planned for mid- to late-October 2022. Whether it will be a virtual, hybrid, or in-person meeting will be determined by mid-2022.

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[5] See: Pacific Framework for Action on Scaling-up CBFM (https://purl.org/spc/digilib/doc/yr5yv) and Policy Brief #37 (2021): Scaling up community-based fisheries management: A regional commitment supporting Pacific island communities in sustaining coastal fisheries (https://purl.org/spc/digilib/doc/z2csz)

Case study: Luen Thai/Lian Cheng involvement in electronic monitoring of tuna fisheries in the Federated States of Micronesia

Robert Gillett[1]

Although there is general agreement that the use of electronic monitoring (EM) aboard tuna vessels could be a valuable tool for managing tuna fisheries, there is considerable discussion and debate about the most appropriate manner to initiate the uptake of EM by fishing companies. This report presents a case study of a fishing company operating in the Federated States of Micronesia (FSM) that adopted EM without being compelled to do so by government regulations. It provides some insight into motivations, concerns and opportunities associated with the adoption process, which may be applicable to fleets operating in other countries.

This report consists mainly of information supplied by the senior vice-president marketing of Luen Thai Fishing Venture (LTFV), the executive director of FSM's National Oceanic Resource Management Authority (NORMA), the Luen Thai and NORMA websites, comments from fisheries specialists, and published studies (Brown et al. 2021; Campling et al. 2017).

Backgound

The Luen Thai Group, a component of a large Hong Kong-based company, was founded in 1965 primarily for garment manufacturing in Saipan, Commonwealth of the Northern Mariana Islands. The company became involved in fishing through its subsidiary, LTFV, in 1994 when it acquired the Majuro, Palau and Pohnpei facilities of a defunct fishing company. Lian Cheng is the China-based, vessel-owning and operational component of Luen Thai.

A Lian Cheng longline vessel

Forty-seven Lian Cheng longline vessels are based in FSM. Thirty-nine are freezer boats and eight are able to carry both fresh and frozen fish. The LTFV facilities in Pohnpei consist of a dock, a processing plant leased from the government, and (soon) a cold storage facility. In Kosrae they have a transshipment base (shipping about 40 containers per month) consisting of a crane and large dock with plug-in electrical facilities for containers. In Yap, LTFV has a small offloading and transshipping operation. LTFV (or its sister companies) have leases on portions of government docks in Kosrae, Pohnpei and Yap.

[1] Director, Gillett, Preston and Associates. Email: gillett@connect.com.fj

A Lian Cheng longline vessel. (Image: © Lian Cheng)

Initial involvement in EM

LTFV has highly skilled information technology staff based in Shanghai. For some time, they have been developing systems to remotely monitor activities on their distant-water fishing vessels. About 2013, they used cameras on board their longline vessels in FSM for commercial purposes, such as fish quality control, accidents and broken gear. Other forms of EM were developed for use aboard the LTFV vessels, such as alarms for problems with onboard cold storage, and for when the monitored vessel closely approached another vessel.

On request from FSM's NORMA in 2014, five Lian Cheng vessels based in FSM participated in the "TNC-Pacific Islands Cooperative Longline EM Project", along with other vessels operating in the waters of the Marshall Islands and Palau. The aims of the project were to: 1) estimate differences between EM and logbook reporting rates for the main market tuna species (yellowfin, bigeye and albacore) and key bycatch groups (all species other than the main targeted tuna species, including sharks, turtles, billfish and other fish species); 2) compare catch rates from EM to human observer data; 3) compare EM and logbooks for species composition; 4) investigate whether EM can inform bycatch mitigation by looking at how fishing practices affect clustering of bycatch within sets; and 5) explore the representativeness of the current EM trials, to make suggestions for the utility of EM to improve monitoring coverage of different fleet components.

During the TNC project, the five Lian Cheng vessels carried two sets of EM gear: one from the project and one from LTVF. The project EM gear was carried by the vessels for five or six years.

In the EM introductory process, LTFV management indicated there was not much resistance or concern by vessel captains. There was one case of a camera being blocked in the early period, and a few cases of EM equipment failure – but those early problems appear to have been resolved. Captains seemed to have become accustomed to the EM alarms, and even appreciated the cold storage warnings.

Video cameras can be placed in several locations on a longline vessel. (Image: © Lian Cheng)

Current involvement in electronic monitoring

Since the original LTFV EM gear was installed in 2013, many improvements have been made to their system. The system now onboard the vessel is considered to be "fourth generation" with advancements made in several areas, including the use of artificial intelligence, improved video reviewing, reliability, and tamper-proofing.

All of the technical support for the LTFV EM system is provided "in-house" by technicians based in China.

Although NORMA has the EM data from the TNC project, it has not asked for the LTFV EM data. Should they ask, the company indicates that raw video data would be provided.

NORMA had people to review the video data during the TNC EM project. The company spot checks their EM data, but does not do a full review of video recordings, except for trips with incidents such as accidents or fish quality problems. The company has the attitude that the purpose of EM is to help them with technical issues, not for compliance purposes: "no point in self-policing". They did, however, do spot checks for shark finning in 2013, when finning became a major global concern. When technical issues are detected in the review process, they are reported to the chief operating officer and fleet manager.

Has EM data from Luen Thai vessels ever uncovered damaging incidents? According to Luen Thai management, during the TNC EM project, two embarrassing situations were detected by NORMA staff reviewing the EM data. One concerned the unhooking of a ray on deck, and the other was about a small whale on deck.

Why has Luen Thai embraced EM?

There are several reasons why LTFV has adopted EM without being forced to do so by the FSM government. As mentioned above, EM was originally developed as a tool for the company to monitor their distant-water fleets, and it has been quite effective for that objective. Other reasons cited by the company are:

- The low threshold requirement of 5% human observer coverage for longline vessels required by the Western and Central Pacific Fisheries Commission leaves a significant gap in monitoring logbook data that can be captured by EM.
- The Technology for Tuna Transparency (T-3) Challenge, an initiative of the FSM president to move towards full transparency in tuna fisheries, was a motivating factor in getting LTFV to be more involved in EM, consistent with being a good corporate citizen.
- LTFV is in a fishery improvement project (FIP) with the Thai Union Group, a Thailand-based producer of seafood products. The terms of that FIP stipulate that for LTFV to sell tuna to the Thai Union Group, there must be EM on the vessels within two years (i.e. by September 2023).
- Throughout the world, the management of tuna fisheries is increasingly making use of EM, and it is only a matter of time before EM is a requirement for participation in the major tuna fisheries of the central and western Pacific.
- Following from the above point, LTFV with its IT capabilities saw a future business opportunity in providing EM support (including video review services) to a large number of non-company vessels.

The above points together created a situation in which it is simply good business sense to Luen Thai to have EM onboard their vessels.

Cost considerations

According to LTVF management, the current initial cost of onboard EM gear is about USD 4000–5000 per vessel. The monthly cost of EM per vessel is about USD 1500, which is mostly for analysis for company purposes of the data generated. Luen Thai's thinking is that the company can and should bear those costs of this monitoring tool because it is being used for their own commercial purposes.

On the other hand, Luen Thai feels that the cost of the analysis of EM data (including video review) by a non-Luen Thai entity for other purposes, such as compliance, should be the responsibility of that agency. Simply stated: "If they want it, they should pay for it".

Concluding remarks

A favourable situation has come about in which Luen Thai has adopted EM on its longline vessels in FSM for its own commercial purposes, and has offered to make the raw EM data available to FSM's fisheries management agency.

In many respects, this could be considered a win-win situation. For Luen Thai, EM is both an operational tool and supports the sustainability certification (Marine Stewardship Council certification), but the company needs an independent party to verify compliance with FSM's laws and regulations. NORMA provides that independence, scrutiny and verification and, should NORMA wish, is also able to obtain raw EM data to determine compliance of the company's fishing activities with the country's legislation.

Although this arrangement seems quite positive, further consideration appears to be required in two areas:

- The issues associated with using EM for commercial monitoring purposes versus using it for compliance purposes: Can a vessel operator function properly and impartially when in control of an EM system that aims to fulfill both roles effectively?
- The costs associated with using company-generated data for compliance purposes: Will the government or non-governmental organisations be willing to shoulder the costs of the components of the EM system that are associated with compliance?

References

Brown C., Desbiens A., Campbell M., Game E., Gilman E., Hamilton R., Heberer C., Itano D. and Pollock K. 2021. Electronic monitoring for improved accountability in western Pacific tuna longline fisheries. Marine Policy 132:104664.

Campling L., Lewis A. and McCoy M. 2017. The tuna longline industry in the western and central Pacific Ocean and its market dynamics. Honiara, Solomon Islands: Pacific Islands Forum Fisheries Agency.

Quantifying illegal, unreported and unregulated fishing in the Pacific Islands region – a 2020 update[1]

Background and approach

Illegal, unreported and unregulated (IUU) fishing is a recognised global problem that undermines the integrity of responsible fisheries management arrangements, and results in lost value to coastal states (e.g. FAO 2002; Agnew et al. 2009). The first attempt at quantifying the value and volume of IUU fishing in tuna fisheries within the Pacific Islands region was undertaken in 2016 using data from 2010–2015 (MRAG Asia Pacific 2016). That study estimated the total volume of product either harvested or transshipped involving IUU activity in Pacific tuna fisheries was 306,440 t, with an ex-vessel value of USD 616 million. Nevertheless, the authors noted that the data and information underlying many of the estimates were highly uncertain and that the outputs should be seen as a "first cut".

In order to assess changes in the nature and extent of IUU fishing since that time, this study was commissioned as part of the Global Environment Facility-funded Pacific Islands Oceanic Fisheries Management Project II to undertake a 2020 update of the original estimates. The aim was to undertake an "apples vs apples" update of the original estimates, using a consistent methodology and taking into account the latest available information. The study period covered the years 2017–2019. Importantly, this preceded any COVID-19 related impacts on monitoring, control and surveillance, and IUU activity in the region.

Broadly, we used a "bottom up" approach to quantify IUU fishing activity across key IUU risks in four categories: 1) unlicensed or unauthorised fishing; 2) misreporting; 3) non-compliance with other license conditions (e.g. shark finning); and 4) post-harvest risks (e.g. illegal transhipping). Best estimate and minimum and maximum range values were generated for each risk, taking into account the best available information. Monte Carlo simulation was then used to produce probabilistic estimates of IUU activity, taking into account probability distributions assigned within the minimum and maximum range values. Using this approach, estimates of IUU volume and value were developed for each of the three main fishing sectors – purse-seine, tropical longline and southern longline – and then aggregated to produce an overall estimate for tuna fisheries in the Pacific Islands region.

While the same basic approach to estimating IUU was used between the 2016 and 2020 studies, a number of changes were made to the information underlying the estimation of individual risks. In some cases, this was driven by new information becoming available (e.g. to estimate the scope for illegal transshipment), while in other cases the information previously used to support estimates for the 2016 study was no longer available. For some risks, these changes in information had substantial impacts on the estimated volume and value between studies.

Estimated volume and value of IUU fishing

Our simulations suggest that the best estimate for the total annual volume of product either harvested or transshipped involving IUU activity in Pacific tuna fisheries during the 2017–2019 period was 192,186 t, with 90% confidence that the actual figure lies within a range of 183,809 t to 200,884 t. Based on the expected species composition and markets, the ex-vessel value of the best estimate figure is USD 333 million. The 90% confidence range is between USD 312 million and USD 358 million. For context, the estimated IUU volume figure is around 6.5% of the total Western and Central Pacific Fisheries Commission (WCPFC) Convention Area (WCPFC-CA) catch in 2019.

This result is a considerable reduction from the "first cut" estimates in the 2016 study, which were 306,440 t (276,546 t to 338,475 t), with a best estimate value of USD 616.11 milion (USD 517.91 million to USD 740 million). The reduction was primarily driven by substantial reductions in estimates for illegal transshipping and FAD fishing during the closure period (in turn driven by the use of better and different information, respectively) as well as the removal of the "unauthorised landings in foreign ports" risk. Overall, figures were also influenced by changes in fishery dynamics (e.g. catch, effort, price).

Among the four categories of risk identified here, the largest contribution to the overall IUU volume was made by misreporting, accounting for 89% of the total volume. Importantly, much of this volume was driven by misreporting and misidentifying target species in the purse-seine sector, for which challenges exist in making accurate estimates of

[1] Based on the report prepared for the Pacific Islands Fisheries Agency: MRAG Asia Pacific. 2021. The quantification of illegal, unreported and unregulated (IUU) fishing in the Pacific Islands Region – a 2020 update. 125 p. https://sustainpacfish.ffa.int/wp-content/uploads/2021/12/ZN2869-FFA-IUU-2020-Update-final.pdf

Between 2016 and 2020, the total estimated volume of tuna illegally caught or transshipped in the western and central Pacific Ocean decreased by 37%. That's good news for everyone. (Image: ©Francisco Blaha)

catch while at sea. The various types of unlicensed fishing collectively accounted for 5% of overall estimated IUU volume, while non-compliance with license conditions and post-harvest offences accounted for 3% each.

Of the three main sectors assessed, the estimated volume of IUU product was highest in the purse-seine sector, accounting for 72% of overall volume. Nevertheless, much of the estimated volume in this sector was driven by estimates for misreporting, for which mechanisms exist (through 100% observer coverage) to correct any errors in catch reports and, given the nature of access arrangements under the vessel day scheme, it is likely that economic rents associated with any misreporting would be captured anyway. This result should be seen in that context. The tropical longline and southern longline sectors accounted for 21% and 7% of the overall volume, respectively. The purse-seine fishery also contributed to slightly under half of the overall ex-vessel value of IUU product (USD 152.26 million), although the higher market value of target species in the longline fisheries meant that the tropical longline sector made a proportionally higher contribution by value (40%) than volume to overall estimates. The southern longline fishery had the lowest overall estimates of IUU product value (14%).

Of the main target species, yellowfin accounted for the highest volume of IUU product, making up 33% of the total estimated IUU volume, and 25% of the ex-vessel value. The total estimated IUU volume of yellow fin equated to around 9.4% of the estimated total yellowfin catch in the WCPFC-CA area during 2019. However, because much of the yellowfin volume is driven by misreporting in the purse-seine fishery, which is subject to 100% observer coverage, this should not result in any "unaccounted for" catch. Skipjack tuna accounted for the next highest volume, making up around 27% of overall estimated volume, but only 20% of the overall ex-vessel value given its lower market price relative to other tuna species. The total estimated IUU volume of skipjack equated to around 2.5% of the estimated total skipjack catch in the WCPFC-CA area in 2019. Bigeye tuna accounted for 17% of the overall estimated IUU volume, but 20% of the ex-vessel value. The proportionally higher contribution to the ex-vessel value total reflects the fact that much of the estimated IUU volume came from the longline sector, which achieves relatively high market prices. The total estimated IUU volume of bigeye equates to around 24.3% of the estimated total bigeye catch in the WCPFC-CA area during 2019. Importantly, this does not necessarily mean that 24.3% of additional bigeye tuna have been taken in addition to reported figures. For example, some of bigeye estimates relate to over-reporting in the purse-seine fishery. Albacore accounted for 2% of the overall estimated IUU volume and total ex-vessel IUU value. The total estimated albacore IUU volume equates to around 2.8% of the estimated total albacore catch in the WCPFC-CA area in 2019.

Analysis and main messages

Apart from the main outcomes of volume and value estimates, a number of key messages arise from the analysis:

- **The reduction in estimates since 2016 is positive but should be seen in context.** The overall volume and value of IUU estimated in this 2020 update are a substantial reduction from those of 2016. Although this is a very positive result for the region and the monitoring, control and surveillance (MCS) efforts for IUU fishing, it should be seen in context. The 2016 estimates were a first cut, with highly uncertain data across a number of key risk areas. On that basis, estimates were kept deliberately broad to account for high levels of uncertainty. For the 2020 study, new information became available to estimate some risks – most notably illegal transshipping and longline misreporting – while information previously used to quantify risks for the 2016 study were unavailable for the current study period. Broadly, it was these changes in information that produced the biggest overall changes in volume and value estimates. In addition, incorporating one new risk (exceeding effort limits) and removing another (unauthorised landing of catch in foreign ports) together with changes in fishing effort, catch rates and fish price also influenced overall estimates. In practice, the 2020 estimates should be seen as the next evolution in an ongoing process to refine approaches to quantify the nature and scale of IUU in the Pacific Islands region.

- **Cooperation works.** While IUU fishing in its various guises will require ongoing attention from members of the Pacific Islands Forum Fisheries Agency (FFA), there is little doubt that the MCS measures FFA members and their partners and/or regional secretariats have implemented over recent decades have had a profound impact on both the nature and volume of IUU fishing in the region. Cooperative, regional MCS measures – such as the establishment of the FFA Vessel Register and Good Standing requirement, the agreement of Harmonised Minimum Terms and Conditions for foreign fishing vessel access, the establishment of the FFA Vessel Monitoring System, the development of common regional data collection protocols and forms, the establishment of regional Pacific Island Regional Fisheries Observer standards and training for observers, the Niue Treaty and Subsidiary Arrangement to facilitate cooperation on MCS, including information sharing and coordinated regional operations, among others – have substantially strengthened the MCS environment across all member exclusive economic zones compared to individual members acting alone. The relatively low estimates of IUU activity in the FFA region – compared to many other parts of the world – is practical evidence of the MCS framework's success.

- **Estimates continue to be dominated by the licensed fleet.** A key outcome of the 2016 study was that estimates of IUU volume and value were dominated by the licensed fleet. The 2020 update shows a similar pattern, with unlicensed fishing accounting for only 5% of overall IUU activity.

- **Unlicensed fishing remains a marginal issue.** Unlicensed fishing continued to be a marginal issue, both figuratively and literally. Overall, evidence for unlicensed fishing by vessels on the FFA Vessel Register and/or WCPFC Record of Fishing Vessels was very limited with no confirmed instances of unlicensed fishing by these vessels detected during regional operations, and few national level detections and/or prosecutions during the study period. The main exception to this is on the fringes of the FFA region, and in particular on the western fringe adjacent to the domestic fleets of southeast Asian countries, where evidence of regular incursions was stronger.


Image: ©Francisco Blaha

Fisheries enforcement officers, as seen here in the Marshall Islands, are a key element in the fight against illegal activities in the tuna industry. (Image: ©Francisco Blaha)

- **Priorities for strengthening MCS measures in the longline sector.** Of the two main gear types operating in the Pacific Islands region, the purse-seine fleet is subject to very strong MCS arrangements, including 100% observer coverage, a requirement to tranship in port and a requirement for e-reporting under the Parties to the Nauru Agreement's vessel day scheme (VDS). Moreover, the majority of fishing effort occurs in exclusive economic zones that are subject to strong coastal state MCS arrangements. In contrast, MCS arrangements for the longline sector are weaker, with lower observer coverage, a far higher proportion of effort on high seas areas, and a higher proportion of the catch transshipped at sea, which limits opportunities for port state MCS measures. Particular focus should be on strengthening measures to monitor and validate catch both on longline vessels and as they move through the supply chain. Given the shared nature of stocks in the region, it is important that strong catch validation measures are applied across the full range of stocks, including on the high seas.

- **Estimates of illegal transshipping have come down, but monitoring and control remain a work in progress.** The availability of WCPFC transshipment declaration information, together with Global Fishing Watch's automatic identification system dataset, has provided considerably better information on the scope for unauthorised transshipment than was available to the 2016 study. This has led to a substantial reduction in overall estimates of volume and value. Nevertheless, important areas of uncertainty remain in the at-sea transshipment component of the longline supply chain, and monitoring and control remain a work in progress. In particular, improvements are required to strengthen the implementation of the observer programme such that information provided by vessels on the volume and species composition of fish transshipped can be validated against independent observer estimates.

- **IUU is not straightforward.** While the formal definition of "IUU fishing" in the International Plan of Action-IUU is relatively clear in theory, but applying it for the purposes of quantifying its nature and extent presents a range of practical challenges. In addition to the inevitable uncertainties in the underlying data, resolving what should, and should not, be considered in estimates frequently requires judgements that can significantly impact on overall volume and value figures.

- **Ex-vessel value is not a good indicator of actual loss to FFA members.** This is because the full value of the catch is not returned to coastal states under normal circumstances (only a proportion of total revenue is, typically through access fees). A better benchmark of revenue forgone by Pacific Island countries is likely to be the rent generated by vessels from IUU activity; however, even then the nature of access arrangements, such as the VDS, mean that economic rents associated with many IUU activities (e.g. misreporting) is likely to be captured anyway. Taking into account estimates of profitability during the study period in the purse-seine and longline sectors, as well as the likelihood that rents associated with some risks (notably misreporting in the purse-seine sector) are likely to be captured through the VDS, we estimate the rent associated with ex-vessel IUU value to be USD 43.18 million. This is a considerable reduction from the 2016 estimate (USD 152.67 million), but may still overestimate actual loss. More accurate estimates would require additional analyses of the unique circumstances of each IUU risk.

What additional measures can be taken to better deter and eliminate IUU fishing?

As outlined in the 2016 study, considerable efforts have been taken at the national, subregional (FFA, the Pacific Community, Parties to the Nauru Agreement) and regional levels (WCPFC) to mitigate IUU fishing in Pacific tuna fisheries. Moreover, a range of additional MCS measures have been taken since then (e.g. establishment of the Pacific Maritime Security Program, strengthening of longline unloadings monitoring coverage in FFA member ports, which have better informed the estimates of the 2020 update and contributed to lower overall estimates.

Nevertheless, ongoing uncertainties in relation to a number of key risk areas highlight priority areas for future MCS development. In the longline sector, the priority is to strengthen measures to monitor and validate the catch of licensed vessels throughout the supply chain. Despite good improvements in some areas (e.g. unloadings coverage in FFA ports), current monitoring arrangements remain limited for some fleets. Measures that could be taken to strengthen monitoring include strengthening observer coverage (for those longline fleets not meeting the 5% WCPFC benchmark, as well as FFA domestic fleets), more active cross-verification of independent data sources to identify reporting discrepancies (e.g. logsheet versus unloading), an enhanced focus on investigating reporting offences, wider use of electronic reporting and monitoring, and the development of an effective catch documentation scheme for key species. In addition, more effective monitoring and control of at-sea transshipments is required, including strengthening arrangements for the implementation of the transshipment observer programme.

In the purse-seine sector, notwithstanding recent complications arising from COVID-19 restrictions, the MCS arrangements in place are considerably stronger than those for the longline sector. Priorities include continuing efforts to validate estimates of catch composition and monitoring and control of FAD usage.

References

Agnew D.J., Pearce J., Pramod G., Peatman T., Watson R. et al. 2009. Estimating the worldwide extent of illegal fishing. PloS ONE 4(2):e4570. doi:10.1371/journal.pone.0004570

FAO (Food and Agriculture Organization of the United Nations). 2002. Implementation of the International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing. FAO Technical Guidelines for Responsible Fisheries. No. 9. Rome, FAO. 122 p.

MRAG Asia Pacific. 2016. Towards the quantification of illegal, unreported and unregulated (IUU) fishing in the Pacific Islands region. 93 p.

MRAG Asia Pacific 2021. The quantification of illegal, unreported and unregulated (IUU) fishing in the Pacific Islands region – a 2020 update. 125 p.

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Coastal fisheries and FAD monitoring project in Kadavu, Fiji: An assessment of data collected from 2017–2020

Jean-Baptiste Marre[1] and Andrew Hunt[2]

Background

In Fiji, nearshore fish aggregation devices (FADs) have been deployed by the Ministry of Fisheries (MoF) in various locations along the coasts of Suva, Gau, Kadavu, Savusavu and in the outer islands. The Pacific Community (SPC) supported MoF in implementing the monitoring and evaluation of FADs deployed in Kadavu, with the primary scope of quantifying fishing effort and catches while also providing training to community monitors in collecting landing data. Training and data collection in Kadavu started in September 2017 and have been ongoing since then. To further investigate if and to what extent FADs affected income and food security in communities, household surveys were also planned but have not been implemented yet, mainly because of the COVID-19 pandemic and associated travel restrictions. This article presents an assessment of the landing survey data collected between September 2017 and December 2020 in Kadavu, with a focus on examining the performance of FADs in terms of catch per unit effort (CPUE). It then discusses the results, and critically reflects on possible next steps.

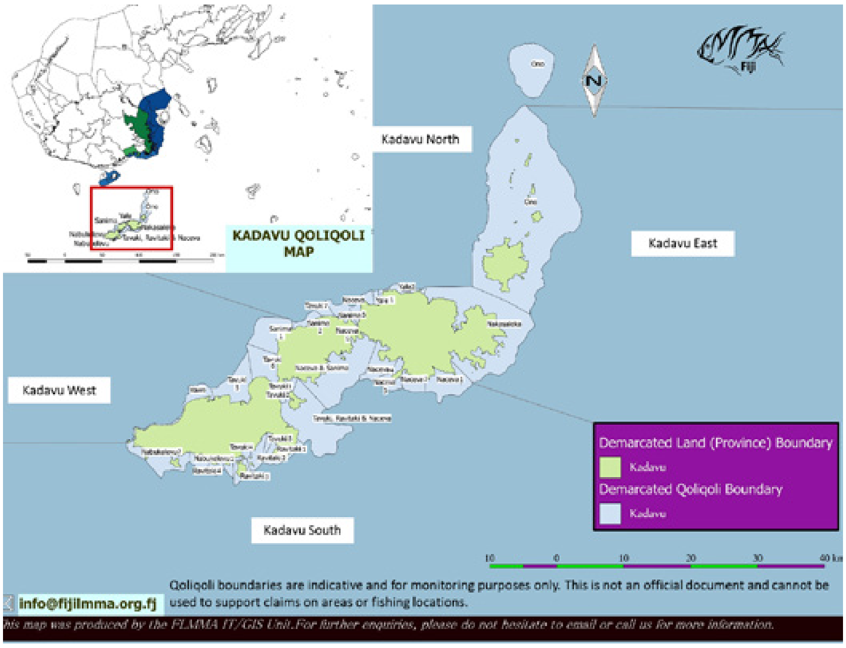

Figure 1. Fishing areas in Kadavu. (Source: LMMA Fiji)

Methodology

A landing survey protocol was developed, and data collectors were trained to use the SPC TAILS application[3] for artisanal fisheries collection and nearshore FAD monitoring by staff from SPC's Oceanic Fisheries and Coastal Fisheries programmes in August 2017. Training included fish species identification. The protocol was updated on several occasions. Landing sites were selected for data collection based on fishing areas defined on the basis of fishing rights areas, called *i-qoliqolis*. A map of Kadavu's *i-qoliqolis* is provided in Figure 1. Each village or site is unique, with different fishing habits and challenges for data collection. The sample protocol[4] was designed to work within the community context and be flexible to capture most of the fishing activity during the sample days.

Catch and effort data were regularly recorded at seven landing sites. Data collection days varied from week to week on a rolling three-day basis. Seven nearshore FADs were covered by the data collection.

The data available includes fishing activity logs and fishing logsheets. Activity logs count, according to a defined protocol, the number of boats, both paddle vessels and motor vessels, that come back from fishing each day during a defined period. Logsheets were gathered from as many fishers as possible on sample days, catch and effort data regarding each fishing trip, including fishing methods, costs, locations and catches, were recorded.

Data analysis was performed using the opensource system R version 4.0.2, installed on R-studio (R Development Core Team, 2005).

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[3] https://oceanfish.spc.int/en/ofpsection/data-management/spc-members/dd/505-tails-application
[4] The detailed protocol is available upon request.

Results

Activity logs

In total, of 5766 activity logs (including zero fishing days) and 4756 fisher logsheets were collected across the seven landing sites in 40 months. Activity log numbers are independent of fishing activity, and these are within the control of data collectors and generally governed by survey protocols; thus, numbers over time should be reasonably stable. Logsheets were collected from fishers who have been fishing, and are directly related to fishing activity and dependent on fisher behaviour; thus, numbers are expected to be less stable. The greatest number of activity logs were collected in the fourth quarter of 2018.

Fishing trips, events and catches

Table 1 provides a summary of the number of fishing trips, events and catch records sampled, as well as the total weight of catches for each landing site. A fishing event is defined by a combination of the fishing area fished and the fishing method used. A fishing trip can, therefore, contain several fishing events if the fisher changes fishing area or fishing method. For each fishing event, catches are then recorded by the species of fish caught (i.e. one catch record per species of fish caught). A fishing event can contain multiple catch records if several different species of fish have been caught during that fishing event.

Catches by categories of fish

Figure 2 presents a breakdown of catches by fish categories, excluding tuna catches, which represent the largest amount at around 51 tonnes. Emperors accounted for most of the reef fish caught (12.3% of the total catch, excluding tunas). Parrotfish, groupers and unicorn fish were the next common reef and lagoon species caught (9.3%, 9.2% and 5.1%, respectively, of the total catch weight, excluding tunas). Reef-associated species such as trevally, Spanish mackerel and barracuda also accounted for a reasonable number of the fish sampled by data collectors (14.5%, 9.4% and 7.7%, respectively, of the total catch weight, excluding tunas).

Trends in average fish weight[5] over time were also analysed for top-landed fish families or species. For most top-fished families and species, the average landed weight changed significantly over time. Despite an important variability, a decrease in average landed fish weight can be observed over time for some species (e.g. mullet, parrotfish, emperors[6]). A sustained downward trend may provide an indication of problems with fish stocks, providing that the associated fishing effort has not decreased as well. This is not the case for reef and lagoon fishing (fishing effort cannot be disaggregated at the species level, only by habitat or method), which has actually increased between 2017 and 2020.

Catch and effort by habitats fished

Table 2 below presents catch and effort data by type of habitat fished[7], including descriptive statistics for CPUE. Differences between FAD mean and others are highly significant according to t-tests (p-value < 2.2e-16). Mean CPUE is much higher for FAD as compared to other habitat fished, highlighting the effectiveness of FADs to increase catch rate. The standard deviations are quite high, reflecting the wide variations and dispersion in the weight of fish caught (e.g. well over 150 kg for some fishing events), and indicating that the median CPUE can also be a good indicator to use.

Changes in mean effort, mean catch and mean CPUE across time were examined by quarter and for each year. Figure 3 compares the mean CPUE for the different fishing habitats across each year, and Figure 4, shows this by quarter.

Table 1. Number of fishing trips, events and catch records sampled and total weight of catches per landing site.

Landing site	No. of trips sampled	No. of events sampled	No. of catch records sampled	Weight of catch sampled (kg)
Kadavu Nabukelevu Babatokalau	842	868	1621	36,520
Kadavu Naceva/Nakasaleka Babaceva	772	772	3286	20,080
Kadavu Naluvea/Galoa	638	643	3201	17,800
Kadavu Nasaila/Ravitaki District	635	688	1873	17,900
Kadavu Kavala Jetty/Fisheries/Ono	461	463	1442	21,260
Kadavu Nabukelevu Babaceva	453	457	853	9750
Kadavu Yawe/Tavuki	186	192	305	8610
Kadavu Market/Vunisea Jetty	11	11	24	250
Kadavu Vunisea Fisheries	1	2	2	10
Total	**3999**	**4096**	**12,607**	**132,180**

5 Total catch weight per species or family divided by number of fish caught from this species or family.
6 Parrotfish and emperors started being exported to Suva shortly after monitoring commenced.
7 Deep water includes seamounts and deep reef slopes. Reef and lagoon sites include coastal reefs, outer reefs, mangroves, and lagoons.

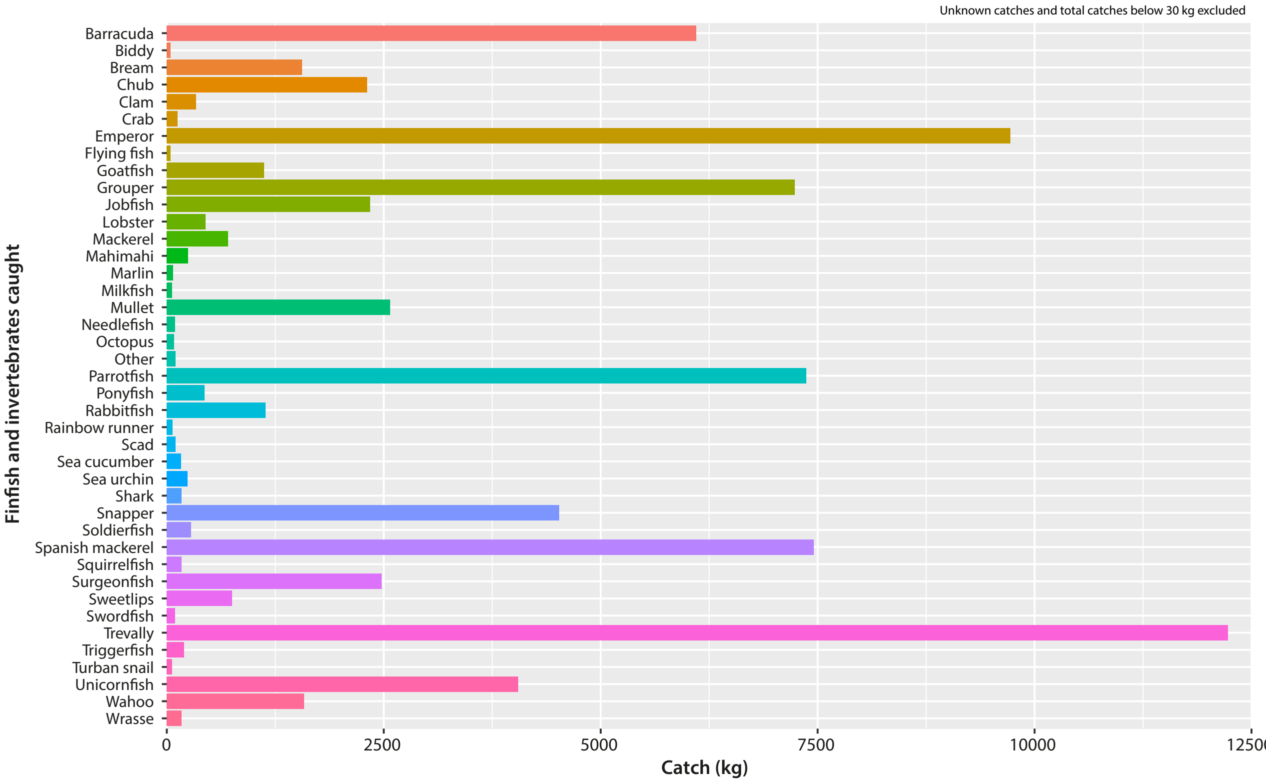

Figure 2. Total catch by categories of fish, excluding tunas. Unknown catches and catches below 30 kg were excluded.

Table 2. Catch and effort data by type of habitat fished.

Habitat type	No. of events sampled (n)	Hours	Fish weight (kg)	CPUE (kg/hour)		
				Mean	Median	SD
Deep water	138	751	6652.5	10.1	6.5	9.4
FAD	1015	2135.7	43,339	24.5	18	21.9
Open ocean	493	1382.1	15,995	12.4	8.1	14.9
Reef and lagoon	2443	12,774.1	66,046.4	6.7	4.3	8.5

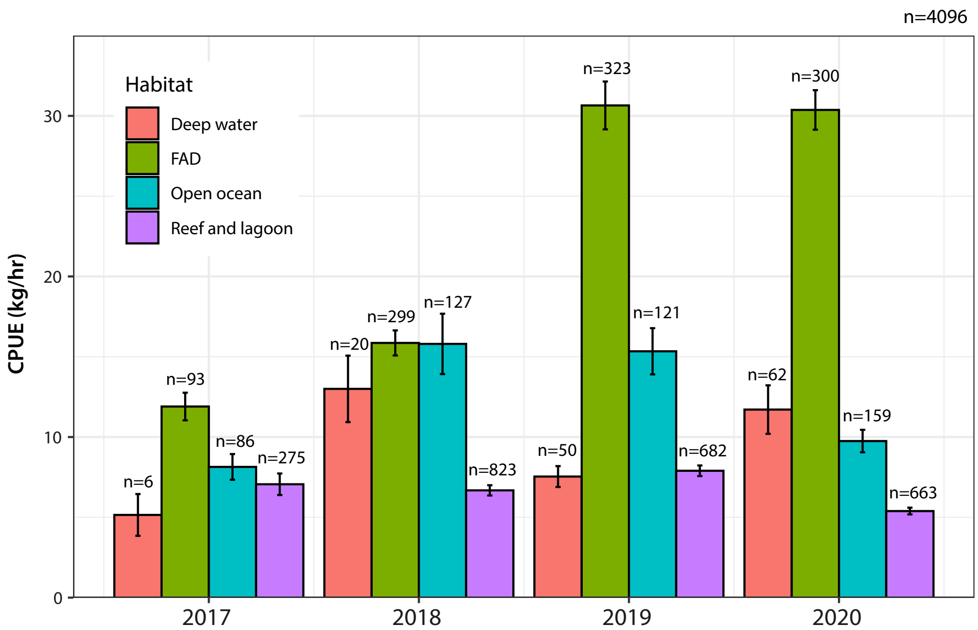

Figure 3. Mean catch per unit effort (kg/hr) by year and area fished, with standard errors. The numbers displayed are the number of fishing events sampled.

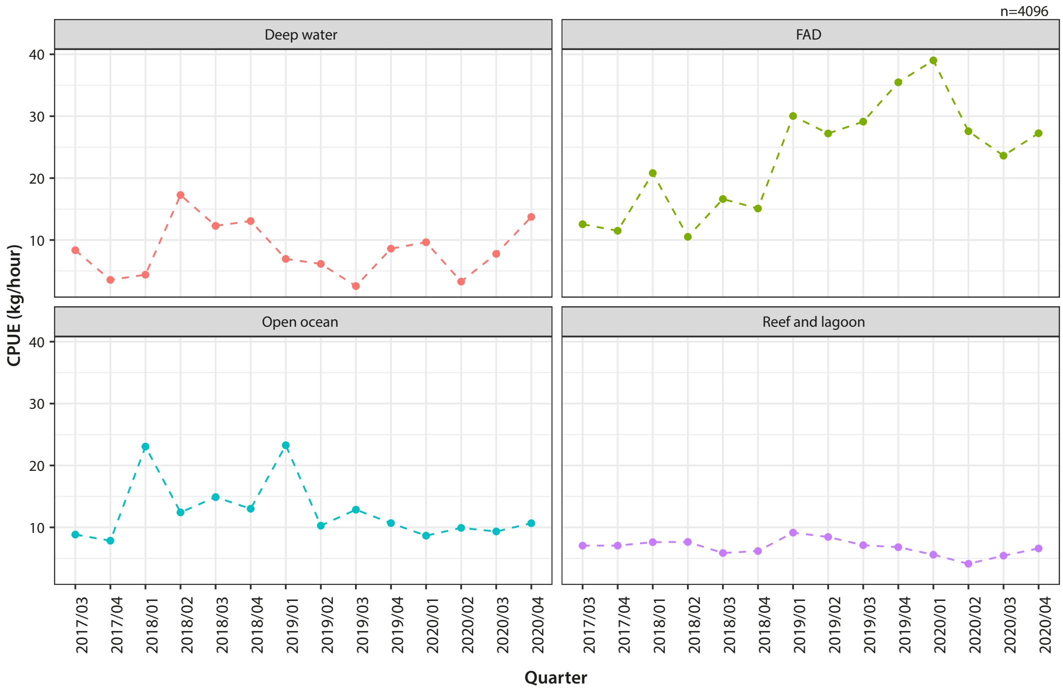

Figure 4. Mean catch per unit effort by quarter and habitat fished.

While the mean CPUE for reef and lagoon habitats remains relatively stable (Fig. 4), the mean CPUE for other habitats shows some strong variations across quarters, in particular for FADs, where an increase in the mean CPUE was observed between 2017 and 2020, with multiple peaks observed in the first quarters of every year. The sharp increase of mean CPUE in 2019 could be partly explained by the deployment of an additional FAD in Talaulia in mid-2018, following cyclone Keni, showing a particularly high mean CPUE (see Section "Catch and effort by FAD"). An examination of weight categories of yellowfin tunas caught between 2018 and 2020 shows that mostly small fish were caught in 2018, whereas much bigger fish were caught in 2019 and 2020. The different peaks of mean CPUE at FADs corresponds with tuna seasonality, with tuna being the main fish caught at FADs (see Section "Catch and effort by FAD" below).

Catch and effort by FAD

Catch and effort data were analysed for each FAD and compared to non-FAD areas. Over 30% of the catch by weight was sourced from FADs, highlighting the significance of FAD fishing in Kadavu. Nearly 90% of the fish caught at FADs were tunas, the vast majority being yellowfin (88% of tuna caught), followed by skipjack (11%). The remaining 11% of fish caught mostly consisted of barracuda (5%), wahoo (2%), snapper (1%) and emperors (1%).

Over 92% of recorded FAD fishing events occurred on two FADs, both of them located on the south side of Kadavu, with most fishing events occurring from just two landing sites. The reasons why other FADs have not been fished include their location, or the fact they were lost shortly after data collection started.

The main fishing method used at the FADs was trolling (937 fishing events). The highest mean CPUE was for trolling (26 kg/hour) followed by mid-water handlining (12 kg/hour), the latter being the cheapest fishing method used at FADs in terms of Fijian dollars per hour (costs include fuel, baits and ice). This highlights the potential interest to further develop mid-water fishing at FADs.

End use of fish

Data collectors asked fishers what the intended end use of each fish was. This allowed a characterisation of the relative importance of certain types of fish within community food security and livelihood support. The end use of marine products was split into five possible outcomes: eaten, given away, sold in the community (in the village or by the roadside), sold at a provincial market (i.e. Vunisea or similar), or sold at a urban market (i.e. Suva or export). In total, across the sampled catches, 22% of fish were eaten, 8% were given away, and the remaining 70% sold (33.5% at community level, 33.5% at a provincial market and 3% at urban markets).

End use varies significantly across species, highlighting heterogeneous contributions to both food security and livelihoods. For instance, while many reef fish species were eaten by fishers, oceanic species were predominantly sold at community or markets. This concurs with findings in Figure 5, which presents end usage of fish caught from FAD and non-FAD fishing. Most of the fish caught at FADs were sold, predominantly to the community (more than 50% of reported use). On the contrary, for non-FAD fishing, only around 20% of catches were reported to be sold to communities, and 25% were reported to be eaten by fishers. A larger proportion of non-FAD catches were also given away.

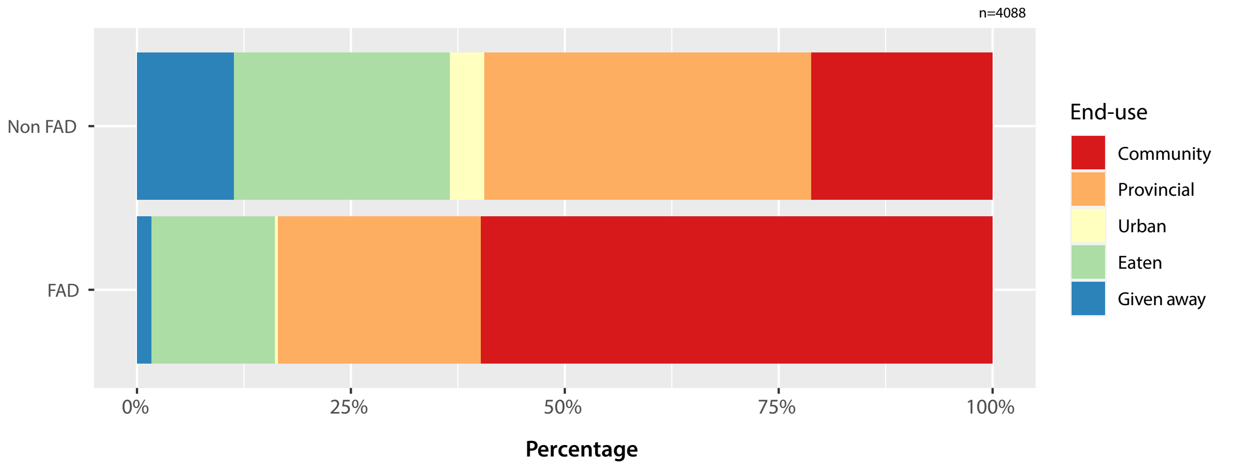

Figure 5. Proportions of reported end use of fish for FAD (three mostly fished FADs) and non-FAD fishing.

Fishing costs

Data were collected on the costs of fishing, which were largely due to fuel, ice and baits. The costs of fishing from motor vessels only were compared in the following ways: cost per hour of fishing effort by method (Fig. 6), cost per weight of fish caught by fishing location (Fig. 7) and cost per hour of fishing effort by fishing location (Fig. 8). All costs are in Fijian dollars (FJD).

The comparison by method shows that the mean cost per hour of fishing on motor vessels varied significantly from around FJD 3.5/hour for scoop nets, to FJD 24.6/hour for trolling. The relatively high mean cost of collecting by boat (only 22 motorised fishing events) can seem surprising, and is mostly due to lobster, urchin and giant clam fishing. Fishing in the open ocean was the most expensive in terms of how much it costs to obtain a kilo of fish (Fig. 7). The cost per hour of fishing in the open ocean and around FADs are higher than the cost of fishing on reefs, lagoons or deep-water grounds (100–450 m depths) (Fig. 8), which is intuitive as open ocean and FAD fishing require the motor to be running most of the time.

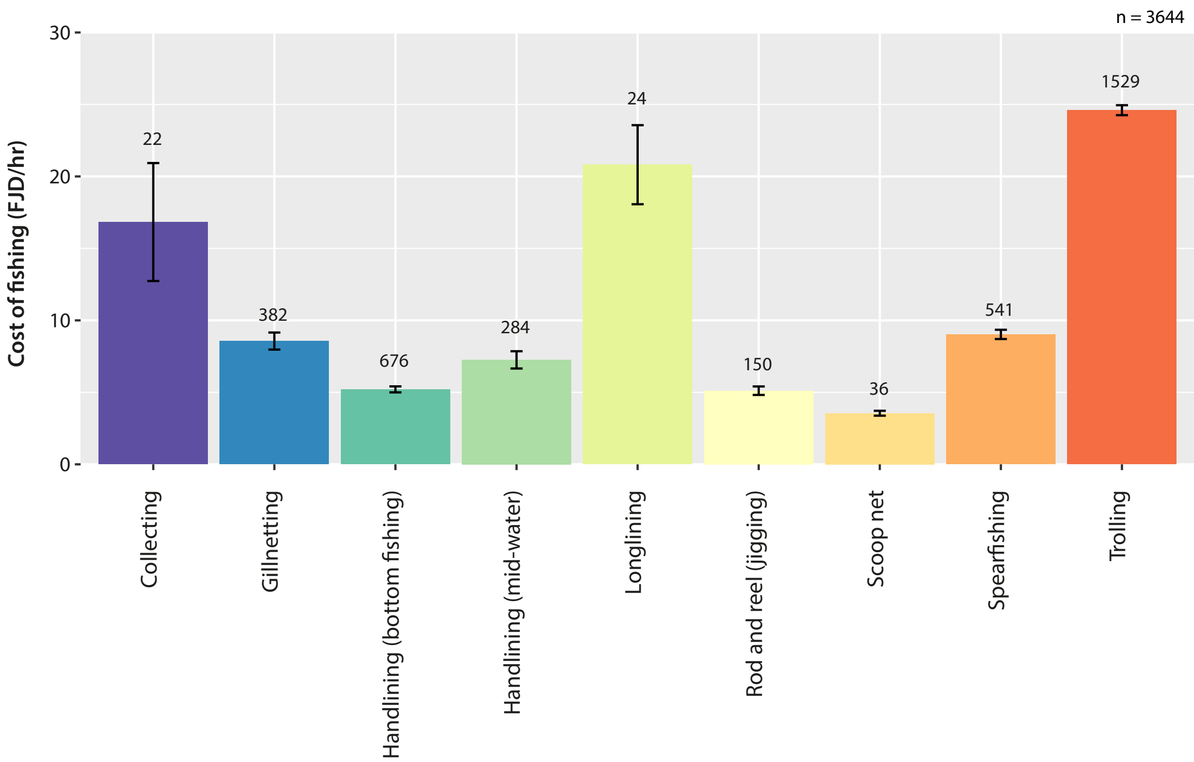

Figure 6. Relative mean costs of fishing by method for motor vessels, in FJD/hour fished, with standard errors. The numbers displayed are the number of fishing events sampled.

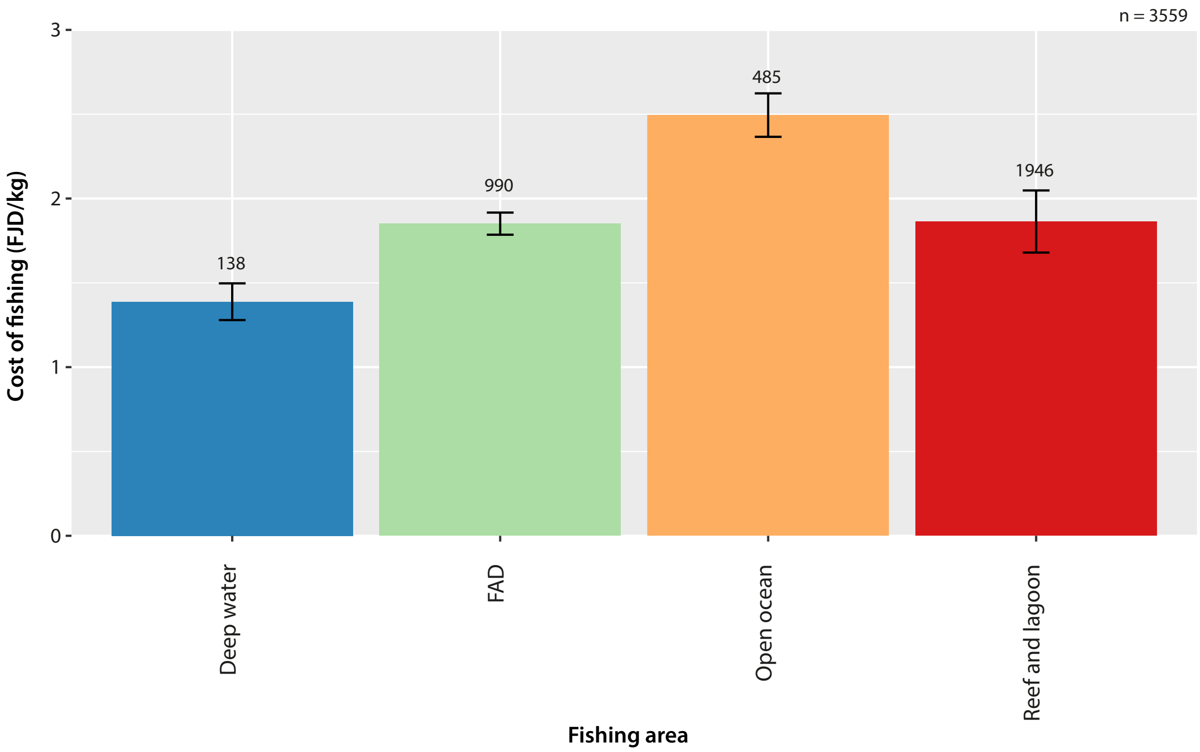

Figure 7. Relative mean costs of fishing by location for motor vessels, in FJD/kg of fish caught, with standard errors. The numbers displayed are the number of fishing events sampled.

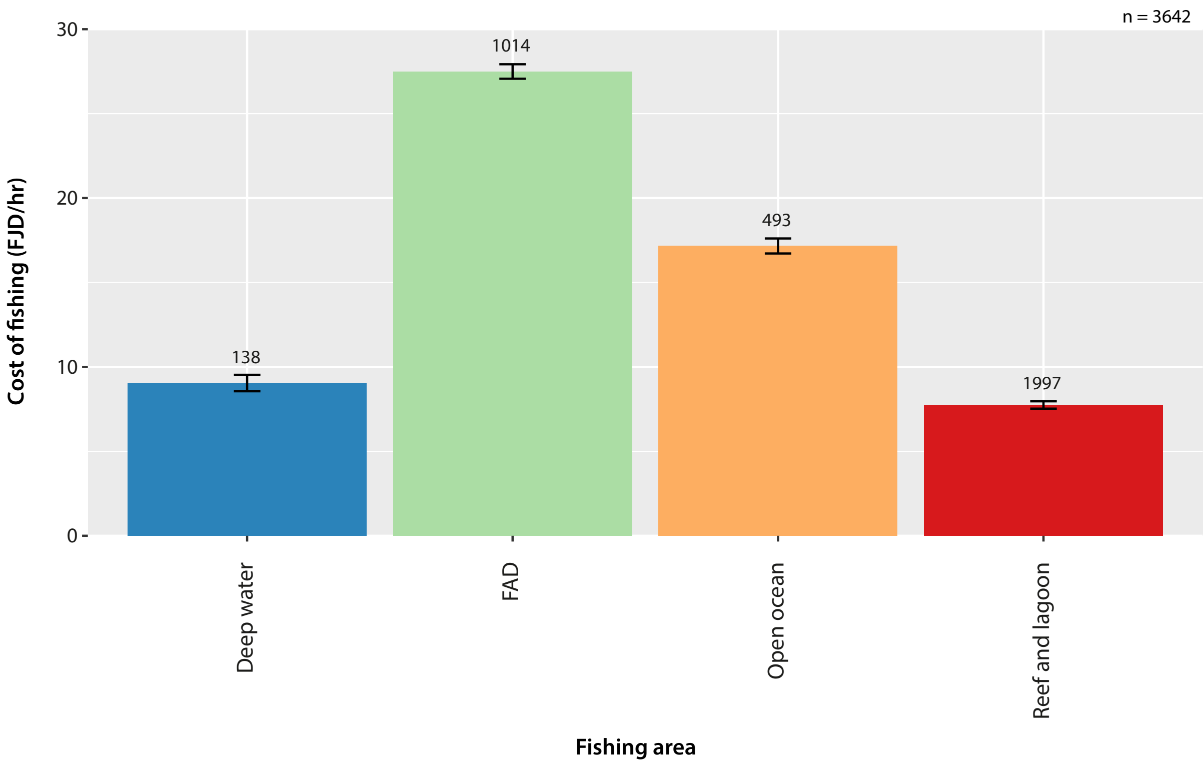

Figure 8. Relative mean costs of fishing for motor vessels by location, in FJD/hour fished, with standard errors. The numbers displayed are the number of fishing events sampled.

Gender

Table 4 presents catch and effort data by gender, including descriptive statistics for CPUE. An important point to consider when interpreting the data on gender is that 97% of the data collection on female fishers was done by one single data collector (one of two women collecting data[8]) at just one landing site.

There are almost 10 times as many records of male fishing events as there are of female fishing events. The observed fishing effort may not be representative of the actual balance between male and female fishing effort as there could be a bias induced by the difficulty of collecting data on female fishing activity. Indeed, men tend to fish from a boat and are, therefore, easy to spot when they land their catch at defined landing sites. This is not the case for women who mostly fish on foot on the reef.

Mean CPUE is much higher for male fishers than female fishers, reflecting the relative efficiency of power vessels and the differing fishing methods used by men and women.[9] Male fishers allocated 96% of their effort to using a motor vessel to fish, and only 3.5% to fishing on foot and 0.5% to using a paddle vessel. Female fishers, however, mostly fish on foot (69%), followed by using motor vessels (31%). Female fishers only targeted reef and lagoon habitats and use fewer types of methods when fishing, mostly handlining and collecting[10] (see Fig. 9 for fishing methods used by gender). This suggests that female fishers are less diverse and, therefore, potentially more vulnerable to disturbances to certain types of ecosystems. However, many of the methods logged as used by females are low technology, which could also possibly make them less vulnerable to socioeconomic impacts.

Table 4. Catch and effort data by type of habitat fished.

Gender	No. of events sampled (n)	Habitats targeted	Hours	Fish weight (kg)	CPUE (kg/hour)		
					Mean	Median	SD
Male	3567	Reef and lagoon; open ocean; deep water; FADs	15,305	6652.5	12.5	6.5	16.4
Female	391	Reef and lagoon	1344	43,339.0	6.4	4.5	7.8

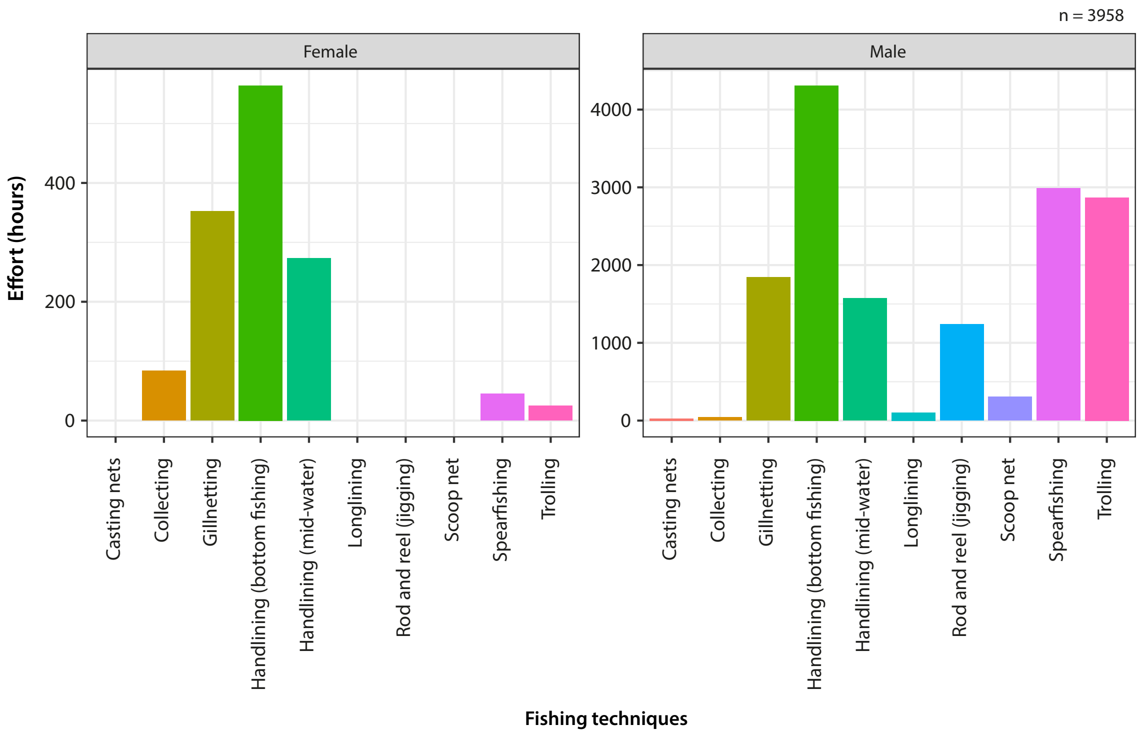

Figure 9. Fishing effort by method and gender.

[8] The other female data collector only collected data at one landing site from male fishers (mostly spearfishermen) who sell their fish for export to Suva.
[9] Mean CPUE data were also computed by fishing method. The fishing method with the highest CPUE is trolling (around 20 kg/hour), which is mostly used by male fishers.
[10] Collecting includes gleaning and collecting underwater from a motor vessel.

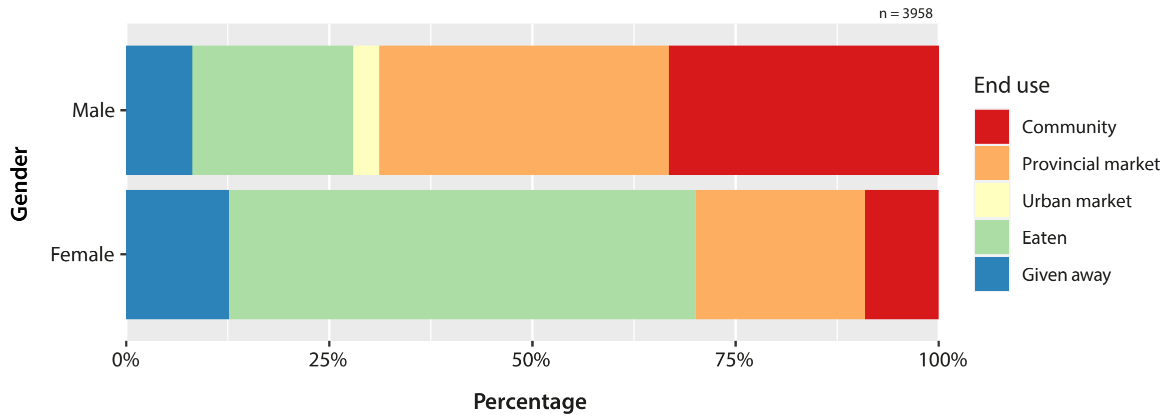

Figure 10. Proportions of reported end use of fish caught by gender.

Among policy-makers and fishery managers there is an assumption that women fishers largely fish for household consumption, while male fishers tend to fish for income and livelihood support. The data from Kadavu Province provides evidence to support this assumption (Fig. 10): 57% of the marine products fished by females were eaten at home, whereas males only used 20% of their landed catch for household consumption. Females also sold 30% of their catch locally within the community (10%) or at a provincial market (20%). Overall, this highlights the important role of female fishers in terms of food security for their own households but also on the island. As male fishers tended to sell most of their catch, they could be more vulnerable to market fluctuations over which they have no control.

Discussion and recommendations

An important point to note before discussing the monitoring results associated with the performance and effectiveness of FADs is that 98% of the monitored FAD fishing events over the four years were from only two landing sites, with 80% of them from just one site. The reasons why almost no FAD fishing occurred at the remaining five landing sites should be further investigated by the data collectors and the Ministry of Fisheries. The survey protocol may need to be amended as needed to capture information from more FAD fishing trips on the island.

The results show that FADs are effective in improving catch rate for fishers at the two landing sites where FAD fishing occurred. FADs are also less costly to fish to per kilogram of fish caught than other habitats. The results regarding reported end use suggest that FADs allow communities to access more pelagic seafood. Further assessing the effectiveness of FADs in terms of fishing profitability and overall return on investment (see Tilley et al. 2019; Sharp 2013), should it be deemed appropriate by the Ministry of Fisheries, would require further data collection on FAD costs[11] (e.g. pre-deployment scoping and survey, materials, assembly, deployment, maintenance), fishing training costs (if any), fishing costs (e.g. vessel costs, including maintenance, gear and other appropriate running costs that have not been collected) as well as fish price by species and market.

The sample protocol was designed to capture most of the fishing activity during the sample days at each landing site, which enabled the extrapolation and estimate total production, mean catch rate and reported end use for each of the landing site for the years 2018, 2019 and 2020. The protocol provides some very cursory indications on the possibility for extrapolation, and notes that scaling would need to be done carefully for most landing sites. Some additional information on the total number of vessels in each area, and discussions with data collectors and the Ministry of Fisheries on the fishing activity outside hours of monitoring would be needed to allow for robust extrapolation.

It is also not possible to know the extent to which the data is representative of coastal fisheries: 1) in areas where landing sites are located, and 2) for the entire island. Data collectors themselves log their own fishing activities (around 30% of all fishing trips are from six of the data collectors), so they are over-represented in the samples. Social connections can also be leveraged in the data collection, which can be biased towards the close contacts of the data collectors. For instance, almost all data collection on female fishers comes from one female data collector at only one landing site. These are important limits that can be dealt with through additional training and regular feedback.

To better assess representativity and extrapolate some of the results, additional information is needed on fishing activities and practices at both the landing sites and around the entire island (including number and types of operating vessels, fishing effort, catch, fishing location, gear type, end-use of catches, fish consumption). Some information, such as the number of vessels or fishers, could be obtained or

[11] Costs of FAD materials can be found in a 2018 report from the Ministry of Fisheries on FAD deployment in Kadavu.

approximated by the Ministry of Fisheries staff in Kadavu. The remaining information could be obtained in various ways, such as conducting a literature review or through existing data analyses (e.g. University of the South Pacific marine resource value assessments in Kadavu[12] or household income and expenditure surveys), focus group discussions, key informant interviews and representative household surveys at the provincial level.

In addition, ongoing monitoring does not enable the situation to be assessed prior to the deployment of FADs,[13] and does not differentiate impact versus control sites. This limits the scope of the monitoring and does not allow enable an assessment of changes due to FAD deployment. Ideally, to assess and monitor impacts from an intervention (FAD deployment in that case), indicators of interest would be sampled at multiple sites to be affected by the intervention (impact sites), and at multiple control sites, on two or more occasions before and after the intervention (Bell et al. 2015). This means that ongoing monitoring does not make it possible to assess changes due to FADs in terms of livelihood or food security. It also does not make it possible to assess whether there has been any displacement of fishing efforts, from the reef to FADs.

Most of the points raised above are important limits to using the results for assessing FADs' financial performance and effectiveness at the provincial level, and more broadly for fisheries management purposes in Kadavu. For instance, the introduction of size measurements could help to better detect possible overfishing of targeted species, which can then be used as a basis for management decisions such as minimum size limits or bans on specific species. A key recommendation is for SPC and the Ministry of Fisheries to collectively re-examine and discuss the objectives of the Kadavu FAD monitoring project to better link them with management ones, based on the ministry's needs. It could also be an opportunity to discuss how the monitoring project fits in with Fiji's FAD management plan, which is under development.

References

Bell J.D., Albert J., Andréfouët S., Andrew N.L., Blanc M., Bright P. et al. 2015. Optimising the use of nearshore fish aggregating devices for food security in the Pacific Islands. Marine Policy 56:98–105. doi: 10.1016/j.marpol.2015.02.010

Sharp M. 2014. Positive results of a FAD monitoring programme in Yap. SPC Fisheries Newsletter 143:34–38. https://purl.org/spc/digilib/doc/zxz2a

Tilley A., Wilkinson S.P., Kolding J., López-Angarita J., Pereira M. and Mills D.J. 2019. Nearshore fish aggregating devices show positive outcomes for sustainable fisheries development in Timor-Leste. Frontiers in Marine Science 6:487. doi: 10.3389/fmars.2019.00487

[12] https://www.usp.ac.fj/index.php?id=23550

[13] This would only be possible for one of the FADs: Kadavu Talaulia, which was deployed in 2018 several months after monitoring started. However, 67 of the 68 of the fishing events recorded at this FAD are from the same landing site where most of the other FAD fishing events have been recorded (including prior to the Talaulia FAD deployment). This makes a before and after analysis much more challenging.

Tuna stomachs: Is the glass half full, or half empty?

Pauline Machful,[1] Annie Portal,[1] Jed Macdonald,[1] Valérie Allain,[1] Joe Scutt Phillips[1] and Simon Nicol[1]

For some of us, fishing is a bit like playing bingo: you need to be lucky, but unlike bingo, with experience and scientific knowledge you can increase your chances of winning the fishing competition or putting the catch of the day on the menu. The ongoing analysis of more than 16,000 tuna stomachs tells us more about their feeding behaviour. Looking at their fullness state under various fishing methods, we observed they had empty stomachs when caught at drifting fish aggregating devices, and fuller stomachs in free schools.

Tropical tuna ecology

Over the past 20 years, the Pacific Marine Specimen Bank has been gathering biological samples of muscles, stomachs, liver, blood, and other parts of fish caught in the Pacific Islands region and collected by fisheries observer programmes (Portal et al. 2020). Coordinated by the Fisheries, Aquaculture and Marine Ecosystems Division of the Pacific Community, we have sampled 16,396 stomachs of skipjack (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), and bigeye tuna (*T. obesus*) – three of the main tuna species targeted and caught in the western and central Pacific Ocean. Among these stomachs, which continue to rise in number, 8089 have been examined at the Pacific Community's fisheries laboratory in New Caledonia (Fig. 1).

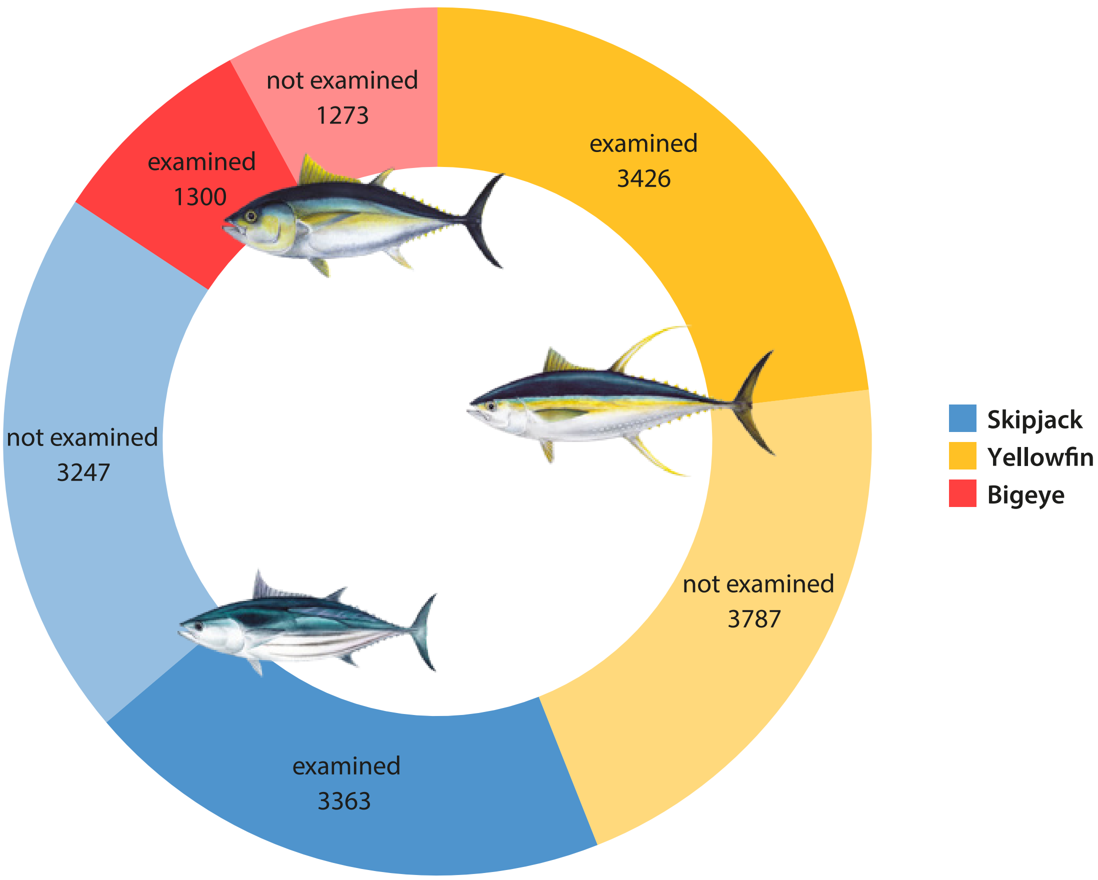

Figure 1. Summary of tuna stomachs sampled and examined.

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The foraging behaviours of top-level marine predators such as tunas provide considerable knowledge about the dynamics of the pelagic ecosystem, including food web structure, based on predator-prey distributions and how fishing or climate change is impacting this system.

The diet of tunas is linked to each individual's behaviour, habitat use, energy supply and interactions between other tunas and other species. The more we understand why the diet of large pelagic predators varies, the better we can monitor the ecosystems they are part of and manage the fisheries.

The examination of tuna stomach contents allows us to characterise their diet directly. It is a good way to look at what they have eaten at a given time, and to study the trophic interactions between species and changes that may occur over time and space (Machful and Allain 2018). For this study, SPC's FEMA team (Fisheries Ecosystem Monitoring and Analysis) wanted to quantify ingested food.

Analysis of tuna stomachs

In the laboratory, stomach samples are weighed before being opened. If baitfish were used during fishing operations, and recorded in the fishing logbook for proper identification, they are removed from the stomach content samples studied. A qualitative estimation method that visually classifies fullness into one of five categories is used to determine how much is in the fish's stomach (0 = empty, 1 = less than half full, 2 = half full, 3 = more than half full, 4 = full). This "fullness coefficient" represents the quantity (volume) of prey in the tuna's stomach. Prey species are then identified, measured and weighed. The final step of the examination is to weigh the stomach wall without prey, which allows the total weight of the stomach contents to be deduced.

Many of the stomachs examined were empty or near empty at the time the fish was captured. This is most apparent in skipjack tunas, for which 46% of all stomachs analysed were empty, while empty stomachs represented only 16% and 33% for yellowfin and bigeye tunas, respectively (Fig. 2). But why are they empty? What factors influence the success of tuna feeding? What makes some tuna feed less than others?

Choosing the most appropriate fullness index

Several approaches are used to describe the diet of fish, and are divided into qualitative and quantitative methods, all with varying degrees of bias. Here, we aim to focus on "stomach fullness" because it is a useful index to quantify ingested food, and is often used by scientists in trophic studies (Hyslop 1980; Chipps and Garvey 2006).

An accurate index of stomach fullness provides information that complements other data we collect on which prey species are on the menu and how abundant they are. It can also help answer ecological questions on the foraging efficiency of tunas, and gives information on individuals' dietary choices by telling us whether stomach fullness varies, for example, according to size and species (do they eat the same way?). Such an index also allows an understanding of the many ecological processes at the community-scale, such as how fish behave during a fishing operation (are they hungry when caught?), or to study the cohesion of fish according to the association of schools (why and how do they group together?).

As a first step to study the stomach fullness of a fish, it is possible to use the fullness coefficient qualitative estimation method, determined during stomach examination, which is simple, easy and quick to apply. However, this has been criticised by scientists because of its potential subjectivity (Hynes 1950) because it depends on the experience and judgment of the person performing the examination. Because the stomach is a muscle that can expand, some examined stomachs presented a very thin wall while others were very thick with clearly visible pleats, which means they were not expanded. Therefore, the perception of fullness can often be biased (Fig. 3). It can be considered a useful index but has some limitations. For example, it is a practical tool for fisheries observers because it allows them to assess stomach fullness at sea.

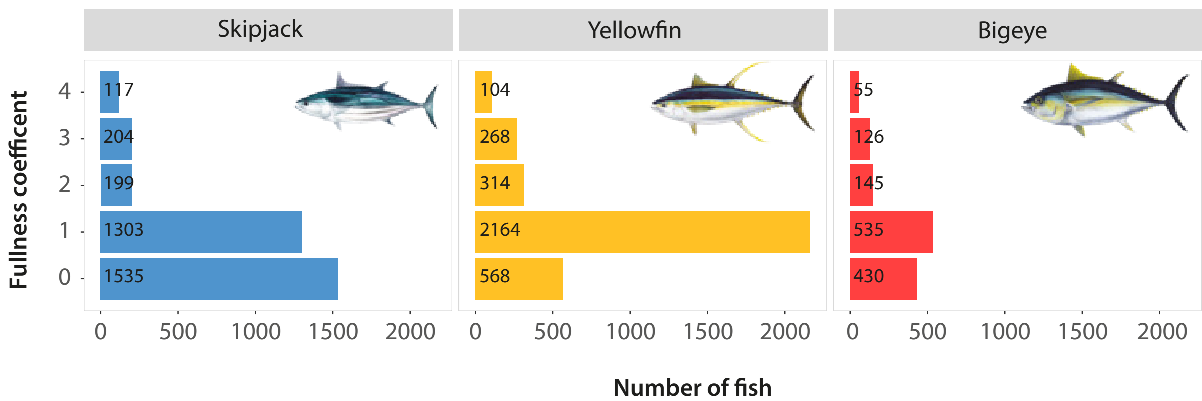

Figure 2. Distribution of the fullness coefficient by species.

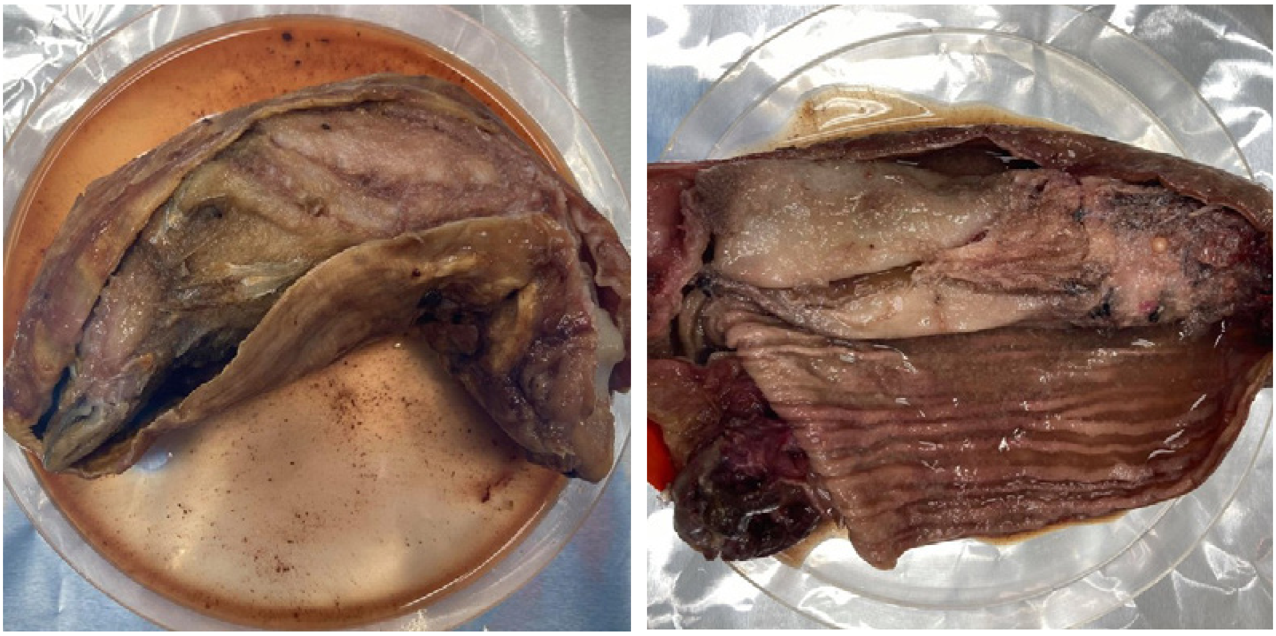

Figure 3. Two stomachs with different wall thicknesses: thin and stretched on the left, and thick with pleats on the right).

To minimise subjectivity, we use the gastrosomatic relationship (GSR) (Herbold 1986) by calculating the ratio between the observed weight of the food or prey in the stomach (prey weight) and the fish's body mass (weight):

GSR = prey weight / fish weight

However, fish weight can vary, for example, with the reproduction period, creating a bias in the GSR, thus making it impossible to compare values through time. Moreover, it is impossible to compare GSR values between tuna species. To avoid these problems, we have begun using a new, standardised fullness metric, which is more robust and comparable between time and species, but above all, that can directly capture the fullness itself. The fullness metric we propose takes into account the length of the fish, and the maximum capacity of the stomach (when full). We have, therefore, applied the following formula first proposed by Herbold in 1986:

FM = prey weight / predicted max. prey weight

Where again: prey weight is the observed weight of prey in the stomach and predicted max. prey weight is the predicted maximum weight of prey for a fish of a given length. The predicted maximum weight of prey at length was calculated using a log-log regression between the maximum stomach content weight observed (using only the 277 full stomachs, with a fullness coefficient of 4, Fig. 2) and fish length from our database.

We have chosen to use the new fullness metric for further inference in our analyses because it provides a more quantitative measure of stomach fullness than the fullness coefficient, and can be compared for fish of all sizes. The fullness metric values range from 0 to 5, with zero representing an empty stomach, and maximum values representing the fullest stomachs (Fig. 4).

Effects of covariates of interest

This alternative fullness metric is being used to understand what could potentially drive stomach fullness in tunas. Through this work, we are exploring the effects of ecological, fishery-related and environmental factors for each of the three tuna species.

We fitted a series of generalised linear models to the fullness metric of tuna to better visualise the effect of each factor before combining them all into one model. We describe these results in detail for skipjack below, with a summary for yellowfin and bigeye tuna.

Results for skipjack

Effects of fishing gear

For the model, fishing gear is a significant factor contributing to the variations in stomach fullness of the tunas. Skipjack were caught mostly by pole-and-line and purse-seine methods. These tunas have fuller stomachs when caught by pole-and-line, and emptier stomachs when caught by purse-seine gear, with a significant difference between these two gear types (Fig. 5). If we look at longline gear, the mean is similar to pole-and-line, but with a greater variability. The wide confidence intervals for handline gear may be due to the small amount of data for this gear type. Each fishing gear has different sampling methods, which would explain the differences in values. It may also be related to a number of other factors, including the type of fish schools targeted by the fisheries.

Effects of fish school association

Tropical tunas tend to aggregate around floating objects, and this is why fisheries target fish aggregating devices (FADs) and other structures associated with fish schools (e.g. logs, seamounts). The model predicts a significant relationship between the stomach fullness and this parameter.

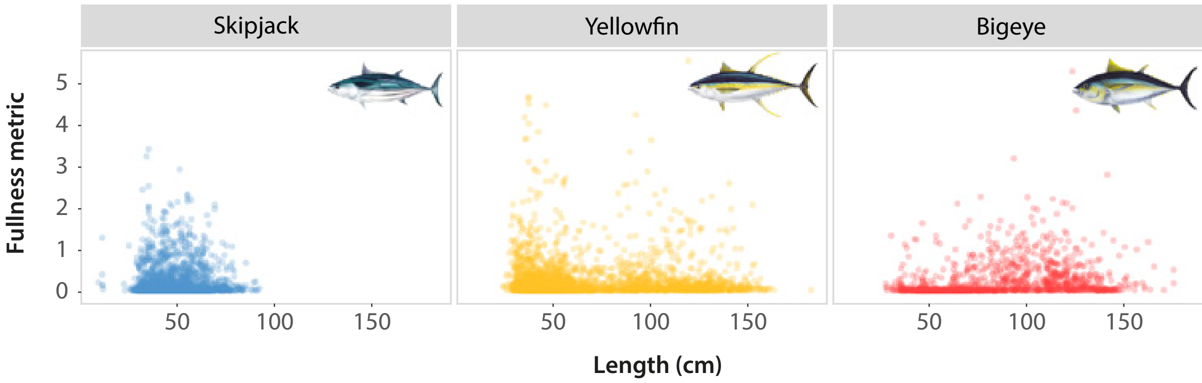

Figure 4. Distribution of the fullness metric by species and size.

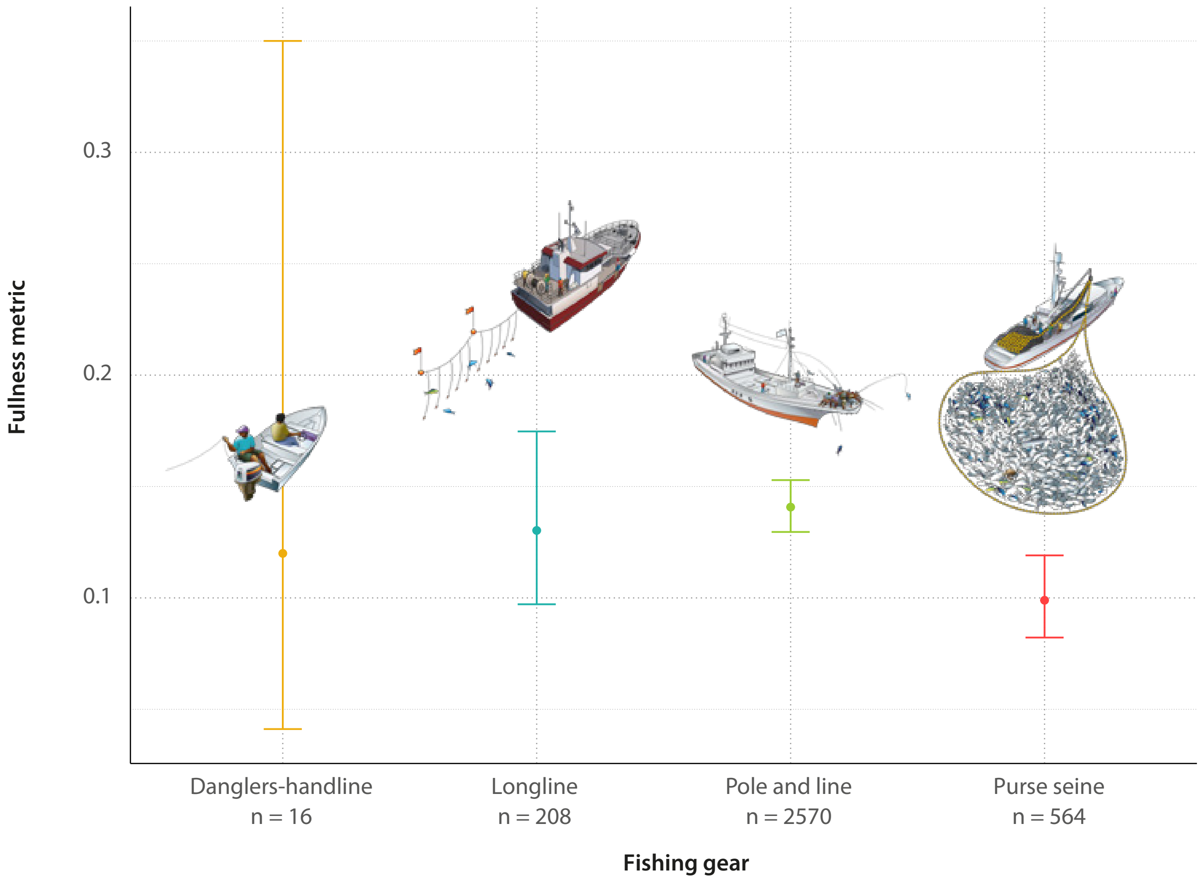

Figure 5. Predicted average of fullness metric and 95% confidence intervals for each fishing gear type (n = number of observations).

Skipjack were caught mostly around anchored FADs and in free schools (Fig. 6). Stomachs are fuller when these tunas are in free schools and around seamounts. But seamounts show greater variability, perhaps due to the paucity of data. These two school types were mostly targeted by pole-and-line gear. Stomachs are clearly fuller in free schools than when associated with anchored FADs, drifting FADs and logs. The FAD effect on stomach fullness has already been demonstrated by other authors and it may be due to a depletion of locally available prey at the FADs by the aggregated predators (Buckley and Miller 1994; Menard et al. 2000). Stomachs are emptier at drifting FADs – the school association that purse-seine vessels target the most. In addition to fishing methods and prey availability, differences in results between fish school associations may be due to location (e.g. close to or far away a coastline).

Effects of time of the day

The time of the day at which an individual tuna was caught was also examined for its effect on the stomach fullness metric. Fish caught early in the morning, as is often the case with associated schools, were very likely to have empty or near empty stomachs, while stomachs were more likely to be full later in the day (Fig. 7).

Effect of sea surface temperature

We also tested a model with the sea surface temperature anomaly. The model indicates that sea surface temperature influences stomach fullness, and stomachs are predicted to be fuller when the sea surface temperature is warmer than usual (Fig. 8). This may be related to seasonal movements of water masses, such as when the warm pool expands during El Niño events and allows skipjack to access different areas and, therefore, new prey species.

Results for yellowfin and bigeye tunas

The same analysis was undertaken for yellowfin and bigeye tunas. The results show similar trends but with some differences for each species. Some averages of the fullness metric are higher for these two species and there is more variability. Tunas always seem to feed better when they are in free schools and caught by longline, possibly because they may be actively hunting when they are targeted by this fishing

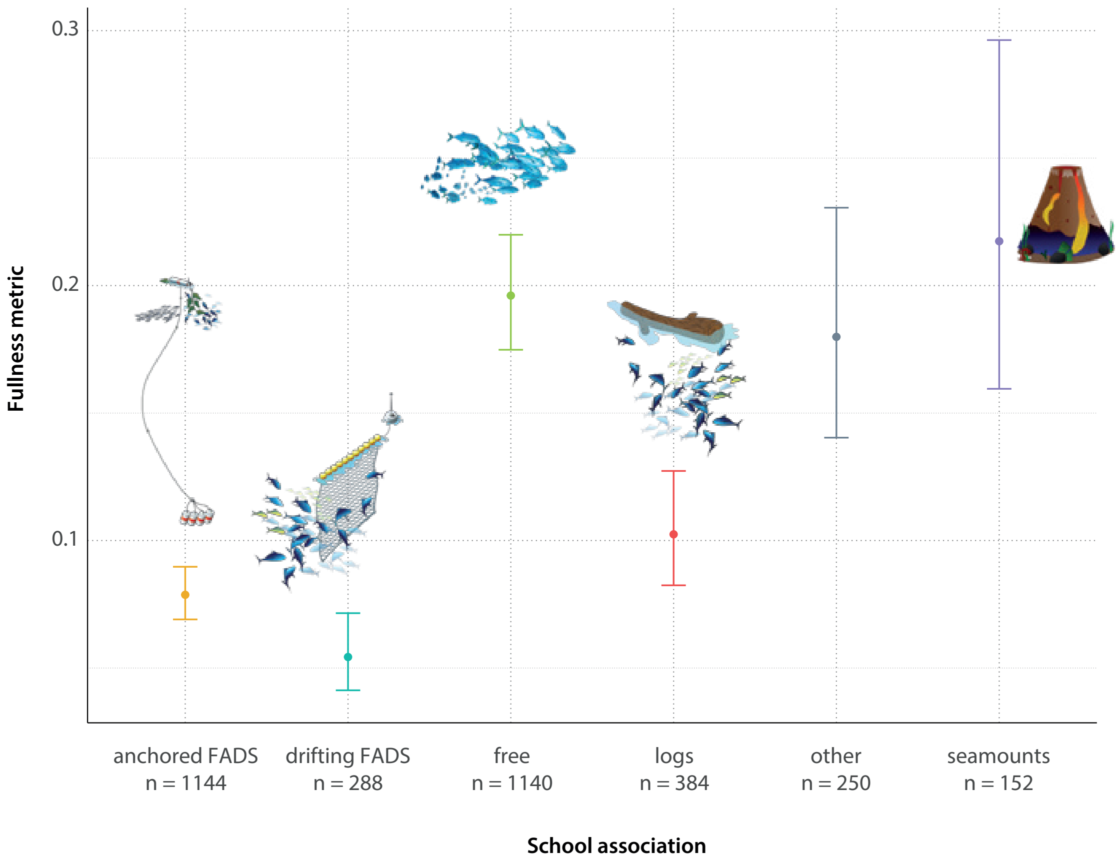

Figure 6. Predicted averages of fullness metric and 95% confidence intervals for each fish school association (n = number of observations).

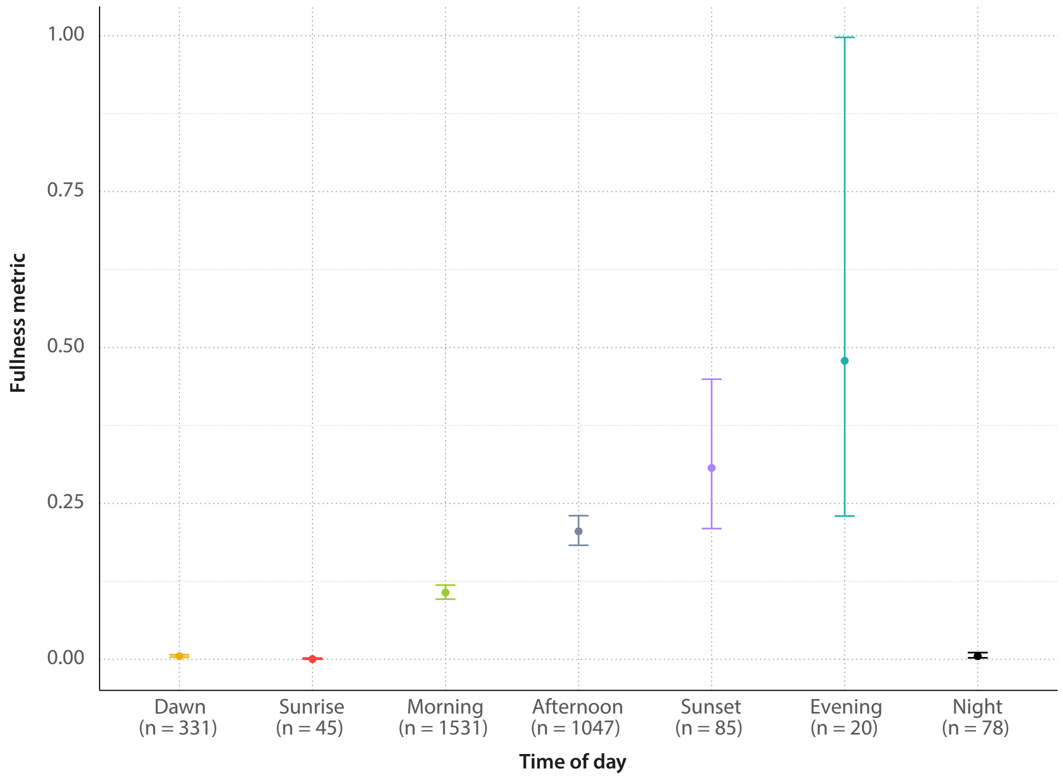

Figure 7. Predicted averages of fullness metric and 95% confidence intervals for different periods of the day (n = number of observations).

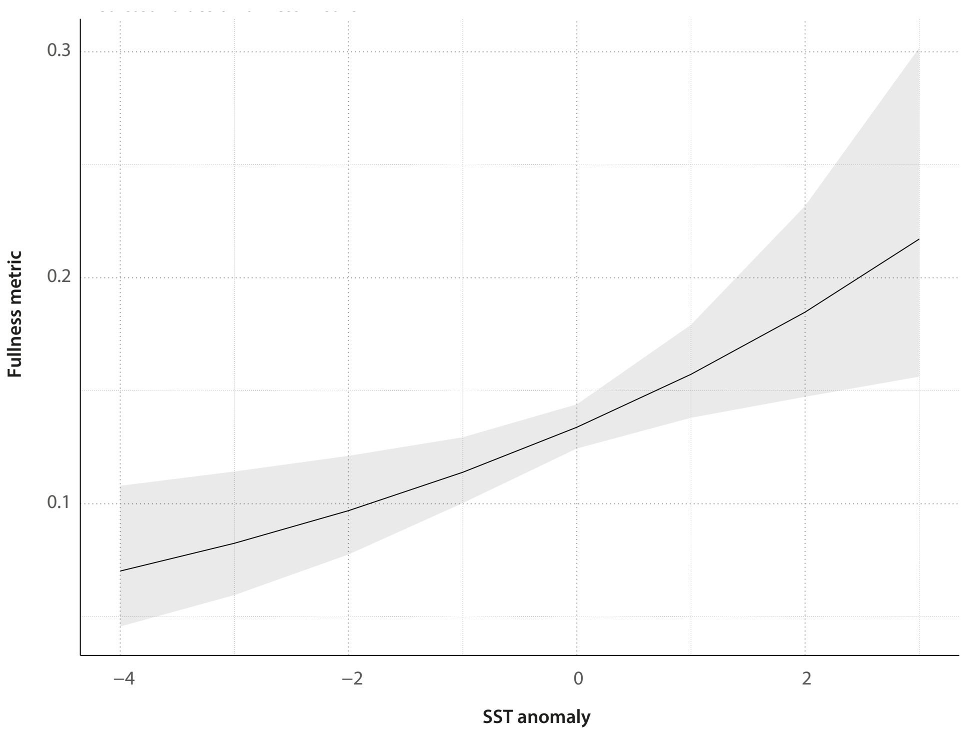

Figure 8. Predicted averages of fullness metric and 95% confidence intervals for the sea surface temperature anomaly (in degrees Celsius).

gear type. As with skipjack, these two species also have a fuller stomach when the sea surface temperature is higher than usual.

Further work

The fullness metric is useful to study the diet of tunas, and these preliminary results allow us to conclude that feeding success varies with differing degrees, depending on the species and other factors. Analyses continue as we still need to test additional ecological parameters and generalised models to further investigate the results and understand if strong changes in, or impacts on, tuna feeding success may have occurred in the western and central Pacific Ocean.

References

Buckley T.W. and Miller B.S. 1994. Feeding habits of yellowfin tuna associated with fish aggregation devices in American Samoa. Bulletin of Marine Science 55:445–459.

Chipps S.R. and Garvey J.E. 2006. Assessment of food habits and feeding patterns. American Fisheries Society 43: 473-514.

Herbold B. 1986. An alternative to the fullness index. P. 315–320. In: Simenstad C.A. and Cailliet G.M. (eds). Contemporary studies on fish feeding: Proceedings of GUTSHOP '84. Springer, Netherlands, Dordrecht.

Hynes H.B.N. 1950. The food of fresh-water sticklebacks (*Gasterosteus aculeatus* and *Pygosteus pungitius*), with a review of methods used in studies of the food of fishes. Journal of Animal Ecology 19:36. https://doi.org/10.2307/1570

Hyslop E.J. 1980. Stomach contents analysis-a review of methods and their application. Journal of Fish Biology 17:411–429. https://doi.org/10.1111/j.1095-8649.1980.tb02775.x

Machful P. and Allain V. 2018. A la carte menu for tuna: Kid's dishes, regional and seasonal specialities, or how tuna diet vary in the Pacific. SPC Fisheries Newsletter 157:2–7. https://purl.org/spc/digilib/doc/d2zjh

Menard F., Fonteneau A., Gaertner D. et al. 2000. Exploitation of small tunas by a purse-seine fishery with fish aggregating devices and their feeding ecology in an eastern tropical Atlantic ecosystem. ICES Journal of Marine Science: Journal du Conseil 57:525–530.

Portal A., Roupsard F., Vourey É. and Allain V. 2020. A carefully protected treasure: the Pacific Marine Specimen Bank. SPC Fisheries Newsletter 161:40–44. https://purl.org/spc/digilib/doc/dcnek

What is CPUE standardisation and why is it important for stock assessments?

Nicholas D. Ducharme-Barth[1*]

One of the key elements of any stock assessment model is the abundance index. This provides information on how the population has changed over time. Combining the abundance index with the historical fishery removals (sometimes referred to as catch or landings) can allow scientists to estimate the reproductive potential of the stock (also referred to as the spawning potential or spawning biomass). Together these form the basis for sustainable fisheries management. Here we evaluate a new approach for catch per unit effort (CPUE) standardisation using western and central Pacific Ocean skipjack tuna (*Katsuwonus pelamis*) as an example.

How do we derive abundance indices?

Ideally, abundance indices would be derived from fisheries-independent surveys, such as those carried out on research vessels at sea. These are surveys that are scientifically designed to representatively sample across the geographical range of the fish population (typically referred to as *random* sampling), and are carried out in a way that consistently samples from year to year using a standardised procedure. This means that annual changes in the survey index (i.e. abundance index) can be interpreted as being directly proportional to changes in the underlying population. A good example of a fisheries-independent survey is the *Eastern Bering Sea Continental Shelf Bottom Trawl Survey of Groundfish and Invertebrate Resources* conducted by the National Oceanic and Atmospheric Administration Fisheries (Conner and Lauth 2017). This survey has consistently sampled 356 sampling stations spread evenly across the continental shelf in the eastern Bering Sea off the coast of Alaska since 1982 (except for a gap in 2020 caused by COVID-19). In addition to providing abundance data for a number of important commercial groundfish and crustaceans across a large extent of their range, this survey also serves as a vital platform for collecting length, age, stomach content, and other biological samples for these species.

Although fisheries-independent data provide the highest quality data for use in stock assessments, they are expensive and difficult to implement over large spatial scales. Within the Pacific Islands region, there are no large-scale, fisheries-independent surveys for highly migratory species such as tunas and billfishes, although such surveys exist for more sedentary species such as deepwater snappers in Hawai`i (Ault et al. 2018) and hoki, hake and ling in New Zealand (Marsh et al. 2018).

In many cases, due to cost or other logistical issues, fisheries-independent surveys are just not feasible and so fisheries-dependent, catch-rate data (CPUE) must be used to create an abundance index for stock assessments. CPUE data are typically already collected as a part of normal fishing operations and recorded as a part of the logbook or observer reports, making these data an inexpensive and convenient alternative to fisheries-independent survey data. Averaging the fisheries-dependent CPUE within years can produce an annual abundance index, and this is usually called the "nominal" index.

Effort creep and hyperstability

Unlike the abundance index from a fisheries-independent survey, the nominal index from fisheries-dependent CPUE cannot be assumed to change in a way that is directly proportional to abundance. There are a number of reasons for this, and two cases are described in further detail. In the first case, fishers may change their gear from year to year in an effort to catch fish more efficiently. For example, upgrading sonar can target fish schools more effectively and result in less wasted effort to produce the same amount of catch as in previous years, even if abundance does not change. This greater efficiency or "effort creep" may show up in the index as an increase in the nominal CPUE. This does not necessarily mean that the underlying population abundance has increased because the fishers became better at catching fish with less effort. In some fisheries, effort creep is estimated to increase the efficiency of fishing effort by at least 1–6% per year, depending on the length of the time period considered (Palomares and Pauly 2019). This may not seem like a lot but over time it can add up! Effort creep is generally defined as the gradual change in fishing effort efficiency (of the fleet or individual vessels) over time due to changes in

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gear, technological advancements, and/or knowledge acquisition by fishers. Effort creep can result in nominal CPUE remaining stable over time even as the underlying fish stock declines, referred to as "hyperstability".

The second case has to deal with where fishers choose to fish related to the distribution of their target stock. Fish are not distributed evenly in the ocean, and there are areas of high and low population densities. Fishers are naturally drawn to fish in areas where they have good catch rates, which are usually areas of higher fish population density. So compared to a scientific survey with *random* sampling, fishery-dependent data often involve targeted fishing referred to as *preferential* sampling. If a fisher fishes in a high-density area one year, and then moves to fish in a lower density area the next year, their catch rates could be expected to fall. This may show up in the index as a decrease in the nominal CPUE but this does not necessarily mean that the overall level of population abundance has changed.

Using nominal CPUE directly in a stock assessment as an abundance index can lead to biased estimates of stock status. If the nominal CPUE is stable or changes (declines) at a rate that is slower than the true rate of change of the population (hyperstability) then stock assessments will be overly optimistic and may result in managers not making the necessary decisions to prevent overfishing and the stock becoming overfished. If the nominal CPUE changes (declines) at a rate that is faster than the true rate of change of the population (hyperdepletion) then stock assessments will be overly pessimistic, and may result in managers unnecessarily restricting fishing effort or catch. Hyperdepletion could occur if gear becomes less efficient at catching fish over time, potentially due to fish learning to avoid the gear or other collective behavioural changes in the targeted population.

Standardising CPUE indices

Given that fisheries-dependent nominal CPUE indices may not accurately reflect changes in the underlying population abundance, and that fisheries-independent surveys are often unfeasible to implement, it is important to "standardise" fisheries-dependent CPUE indices before they are used in stock assessments. The process of standardising CPUE recognises that fishers may fish differently over time and among each other, and that these differences can affect catch rates independent of variation in fish abundance. CPUE standardisation aims to account for these differences by including identified variables that can influence catch rates, unrelated to fish abundance, as covariates in a statistical model. Using this statistical model, the goal is to remove the effects of these variables on CPUE, so that the *standardised* fisheries-dependent CPUE index is more closely related to the underlying fish abundance.

Considerable research has been devoted to the topic of CPUE standardisation over the years, with a large research focus on how to deal with spatial differences in catch rates and how to model areas that are not fished in all years (Campbell 2015; Walters 2003). If fishers do not fish in a given area, then we do not know how the abundance of that portion of the population may have changed. Ignoring these "unfished" areas in the CPUE standardisation makes the implicit assumption that unfished areas have the same abundance as the average of the fished areas. This assumption might be acceptable to make if fishers fish randomly with respect to fish density. However, as discussed before, fishers are more likely to follow the fish, so making this assumption in the analysis of fisheries-dependent data could lead to hyperstability in the abundance index.

Evaluating spatiotemporal modelling approaches using Pacific skipjack tuna as a case study

Recently, spatiotemporal approaches to traditional statistical models for standardising CPUE have become more popular. Spatiotemporal models explicitly account for the spatial and temporal relationships in data by taking advantage of the idea that "near things are more related than distant things" in space and time (Tobler 1970). These spatiotemporal models have been shown to outperform traditional statistical models (Grüss et al. 2019), and are well equipped to handle spatial variation in catch rates. Additionally, by explicitly modelling the spatiotemporal relationships in the data, scientists can make a more appropriate inference on what the catch rate would be in unfished areas when creating a standardised CPUE index. However, spatiotemporal models assume that data are collected from a *random* sampling process, which is not usually the case in fisheries-dependent data.

In our recently published study (Ducharme-Barth et al. 2022), we sought to evaluate the performance of spatiotemporal modelling approaches in situations where the underlying model assumptions are violated, such as when standardising fisheries-dependent CPUE. We also wanted to identify how well spatiotemporal modelling approaches handled changes in fishing location over time and their ability to account for effort creep. These investigations were done using a simulation framework so that we could compare our estimated standardised abundance indices with the simulated "true" population. Our simulation was constructed to be representative of the Japanese pole-and-line fishery for skipjack tuna[2] (*Katsuwonus pelamis*) in the western and central Pacific Ocean. We used output from the SEAPODYM spatial ecosystem and population dynamics model developed for skipjack tuna (Lehodey et al. 2008; Senina et al. 2020) as a realistic, simulated "true" population (Fig. 1). We then "fished" this population under

[2] See: https://www.youtube.com/watch?v=i5mMI8t7vV0

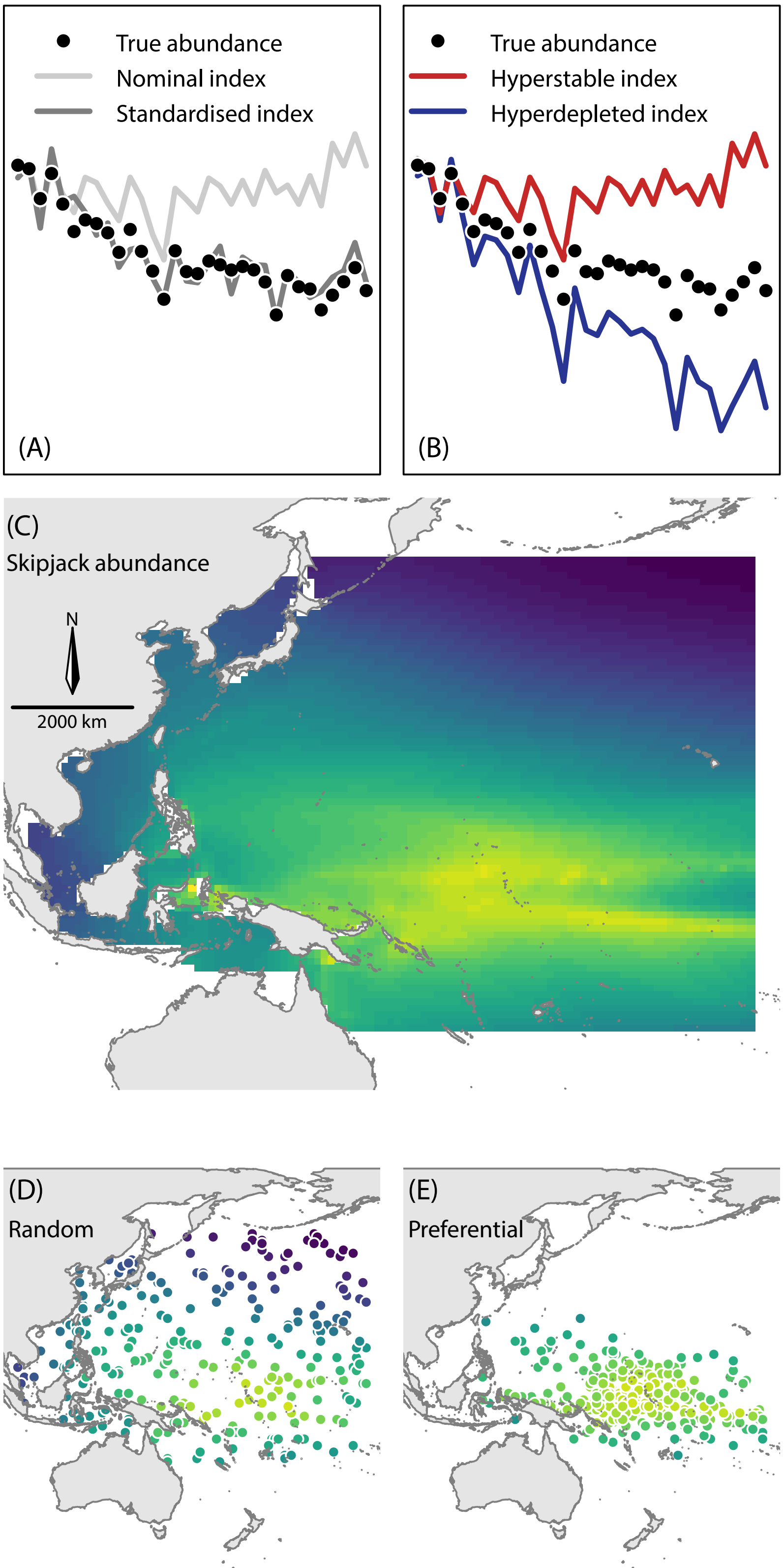

Figure 1. Panel A) A simulated time series of abundance (black points) with the nominal CPUE index (light grey) and the standardised CPUE index (dark grey). Panel B) A simulated time series of abundance with an example of a hyperstable nominal CPUE index (red) and a hyperdepleted nominal CPUE index (blue). Panel C) Simulated skipjack abundance distribution in the western and central Pacific Ocean from the SEAPODYM model. Darker colours indicate areas of lower abundance, and lighter colours indicate areas of higher abundance. Panel D) Example of random spatial sampling. All locations have an equal probability of being sampled, including areas of low abundance (darker colours). Panel E) Example of preferential spatial sampling. Areas of higher abundance (lighter colours) have a higher chance of being sampled resulting in few samples located outside of the core of the population distribution.

different fishing location scenarios, including *random* and *preferential* sampling types. Lastly, we fit spatiotemporal CPUE standardisation models to our simulated fisheries data to estimate abundance indices and obtain an understanding of the level of error and bias in our estimated indices across the different scenarios.

Skipjack tuna was selected as a relevant case study because of its cultural and economic importance to the Pacific Islands region – total western and central Pacific skipjack tuna catches in 2020 were valued at ~USD 2 billion (Williams and Ruaia 2021) – but also because of the unique challenges associated with assessing this species. Skipjack are caught across a huge area in the western and central Pacific, from as far south as the Tasman Sea to the Kuroshio Extension current off Japan, and extending within the tropics across the eastern Pacific. This enormous spatial extent makes developing a fisheries-independent survey of the population difficult from both financial and logistical standpoints. As a result, the stock assessment relies exclusively on fisheries-dependent data for its abundance index. Unfortunately, the two predominant sources of fisheries-dependent data, pole-and-line and the tropical purse-seine fisheries, have issues that may result in indices that do not change in proportion to skipjack population abundance. Historically, skipjack were primarily caught from pole-and-line vessels, and the Japanese pole-and-line fleet fished across a large portion of the assessment region. These data were used as the basis for the abundance index applied in the stock assessment. However, this fishery has greatly reduced its spatial extent such that it no longer samples the entire skipjack population distribution. More recently, skipjack catches have been dominated by the industrial purse-seine fishery, which primarily operates in tropical waters around the equator. The purse-seine fishery also has a limited geographical scope, although the bigger concern for this fishery is the ability to appropriately account for effort creep, which has been recently estimated at levels between 3% and 6% per year (Vidal et al. 2021). While data from the Japanese pole-and-line fishery may also contain the effects of effort creep, there exists a more robust record of gear and technological changes within this fishery that allow for some accounting of effort creep within the standardisation models.

Conclusions and considerations

Our research shows that spatiotemporal approaches are able to account for changes in the spatial location of fishing, provided that the shift in fishing was not too extreme of a departure from the underlying population distribution. Additionally, models were able to simultaneously account for minor changes in spatial location of fishing and effort creep, provided that all factors contributing to effort creep were included in the model. However, our results also confirmed that *random* sampling, as conducted in a fisheries-independent survey, performed as well or better than the different fishery-dependent scenarios in almost every situation.

So, what does this all mean, and in particular, what does this mean for upcoming assessments of western and central Pacific Ocean skipjack tuna? It is always important to consider how the data were collected in order to evaluate if there are potential issues with using them to develop an abundance index for a stock assessment. If you are able to account for all the factors leading to effort creep or other changes of capture efficiency in your standardisation model, then you may be able to create a viable abundance index. However, it is difficult to account for shifts in spatial sampling in a standardisation model, particularly if large shifts have occurred. More advanced modelling techniques applied to fisheries-dependent data are not a substitute for devising an index from data that are collected as a part of a well-designed fisheries-independent sampling study. With regards to western and central Pacific Ocean skipjack there is a real need to start thinking outside of the box, given that the Japanese pole-and-line fishery no longer sufficiently samples the total spatial extent of the skipjack population, and that effort creep remains challenging to model for the purse-seine fishery This means continuing to work with the industry to identify factors leading to effort creep (Wichman and Vidal 2021), and collecting the required data to effectively model these changes within the standardisation process. However, it also means exploring and investing in emerging technologies and techniques such as genetic analysis, including close kin mark recapture (Bravington et al. 2016), and/or acoustic data collected from autonomous platforms (De Robertis et al., 2021) in order to collect fisheries-independent data that can be used to reliably track abundance. Nevertheless, cost and logistics may continue to remain a challenge at the scales required.

The full study (Ducharme-Barth et al. 2022) is freely available at: https://doi.org/10.1016/j.fishres.2021.106169. The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author and do not necessarily reflect those of National Oceanic and Atmospheric Administration, the US Department of Commerce, or the Pacific Community.

References

Ault J.S., Smith S.G., Richards B.L., Yau A.J., Langseth B.J., O'Malle, J.M., Boggs C.H., Seki M.P. and DiNardo G.T. 2018. Towards fishery-independent biomass estimation for Hawaiian Islands deepwater snappers. Fisheries Research 208:321–328. https://doi.org/10.1016/j.fishres.2018.08.012

Bravington M.V., Grewe P.M. and Davies C.R. 2016. Absolute abundance of southern bluefin tuna estimated by close-kin mark-recapture. Nature Communications 7(1). https://doi.org/10.1038/ncomms13162

Campbell R.A. 2015. Constructing stock abundance indices from catch and effort data: Some nuts and bolts. Fisheries Research161:109–130. https://doi.org/10.1016/j.fishres.2014.07.004

Conner J. and Lauth R.R. 2017. Results of the 2016 eastern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate resources. Washington, DC: US Department of Commerce. https://repository.library.noaa.gov/view/noaa/14324

De Robertis A., Levine M., Lauffenburger N., Honkalehto T., Ianelli J., Monnahan C.C., Towler R., Jones D., Stienessen S., McKelvey D. and Godø O.R. 2021. Uncrewed surface vehicle (USV) survey of walleye pollock, *Gadus chalcogrammus*, in response to the cancellation of ship-based surveys. ICES Journal of Marine Science 78(8): 2797–2808. https://doi.org/10.1093/icesjms/fsab155

Ducharme-Barth N.D., Grüss A., Vincent M.T., Kiyofuji H., Aoki Y., Pilling G., Hampton J. and Thorson J.T. 2022. Impacts of fisheries-dependent spatial sampling patterns on catch-per-unit-effort standardisation: A simulation study and fishery application. Fisheries Research 246. https://doi.org/10.1016/j.fishres.2021.106169

Grüss A., Walter J.F., Babcock E.A., Forresta, F.C., Thorson J.T., Lauretta M.V. and Schirrip M.J. 2019. Evaluation of the impacts of different treatments of spatio-temporal variation in catch-per-unit-effort standardisation models. Fisheries Research 213:75–93. https://doi.org/10.1016/j.fishres.2019.01.008

Lehodey P., Senina I. and Murtugudde R. 2008. A spatial ecosystem and populations dynamics model (SEAPODYM) – Modeling of tuna and tuna-like populations. Progress in Oceanography 78(4): 304–318. https://doi.org/10.1016/j.pocean.2008.06.004

Marsh C., McKenzie A., Francis R.I.C.C. and Doonan I. 2018. Evaluating the effects of changes in the frequency of research trawl surveys and age sampling on the hoki, hake, and ling stock assessments. New Zealand Fisheries Assessment Report 2018/43. Wellington, New Zeland: Ministry for Primary Industries. https://fs.fish.govt.nz/Doc/24641/FAR-2018-43-Frequency-of-trawl-surveys.pdf.ashx

Palomares M.L.D. and Pauly D. 2019. On the creeping increase of vessels' fishing power. Ecology and Society 24(3). https://doi.org/10.5751/es-11136-240331

Senina I., Lehodey P., Sibert J. and Hampton J. 2020. Integrating tagging and fisheries data into a spatial population dynamics model to improve its predictive skills. Canadian Journal of Fisheries and Aquatic Sciences 77(3):576–593. https://doi.org/10.1139/cjfas-2018-0470

Tobler W.R. 1970. A computer movie simulating urban growth in the Detroit region. Economic Geography 46:234–240. https://doi.org/10.2307/143141

Vidal T., Wichman M., Hamer P., Pilling G. and PNAO. 2021. Effort creep within the WCPO purse-seine fishery. Information paper for the Scientific Committee Seventeenth Regular Session (online meeting), 11–19 August 2021. https://meetings.wcpfc.int/node/12591

Walters C. 2003. Folly and fantasy in the analysis of spatial catch rate data. Canadian Journal of Fisheries and Aquatic Sciences 60(12):1433–1436. https://doi.org/10.1139/f03-152

Wichman M. and Vidal T. 2021. Incorporating industry knowledge to understand purse seine effort creep andevolution of fishing strategies in the WCPO. https://meetings.wcpfc.int/node/12592

Williams P. and Ruaia T. 2021. Overview of tuna fisheries in the western and central Pacific Ocean, including economic conditions – 2020. Information paper for the Scientific Committee Seventeenth Regular Session (online meeting), 11–19 August 2021. (WCPFC-SC17-2021/GN-IP-1). https://meetings.wcpfc.int/index.php/node/12527

Tuna help to map mercury pollution in the ocean

Anaïs Médieu,[1] David Point,[2] Valérie Allain[3] and Anne Lorrain[4]*

Whether as sushi, steak or tinned, tuna is one of the world's most widely eaten saltwater fish, and yet it is known to contain toxic methylmercury, the most toxic form of mercury, which affects the nervous system, with foetuses and young children being at high risk (Box 1). The new environmental policies under the Minamata Convention[5] for reducing mercury emissions, and their unhealthy effects on humans, are based on scant knowledge of how such emissions affect fish mercury levels. This document provides the first detailed mercury concentration map for skipjack tuna in the Pacific Ocean, and highlights the link between anthropogenic (human-made) mercury emissions and concentrations in this species in the northwest Pacific for the first time (Médieu et al. 2022). Our study also shows that natural ocean processes heavily influence tuna mercury concentrations, especially in terms of the depth at which methylmercury bioavailability is at its highest in the water column.

In a previous study on three tuna species (yellowfin, *Thunnus albacares*; bigeye, *T. obesus*; and albacore, *T. alalunga*) in the western and central Pacific, we demonstrated that mercury concentrations were higher in the largest and deepest-diving fish, but that they also depended on species and geographical origin (Houssard et al. 2019; Lorrain et al. 2019). In this latest multidisciplinary study, funded by the French National Research Agency in the framework of the MERTOX[6] project, the French National Research Institute for Sustainable Development (IRD) and the Pacific Community (SPC) – assisted by a large number of partners and through access to several specimen banks[7] – looked into where the mercury in Pacific tuna was coming from (Fig. 1A) by focusing on skipjack (*Katsuwonus pelamis*), which is the most commonly eaten tuna species globally.

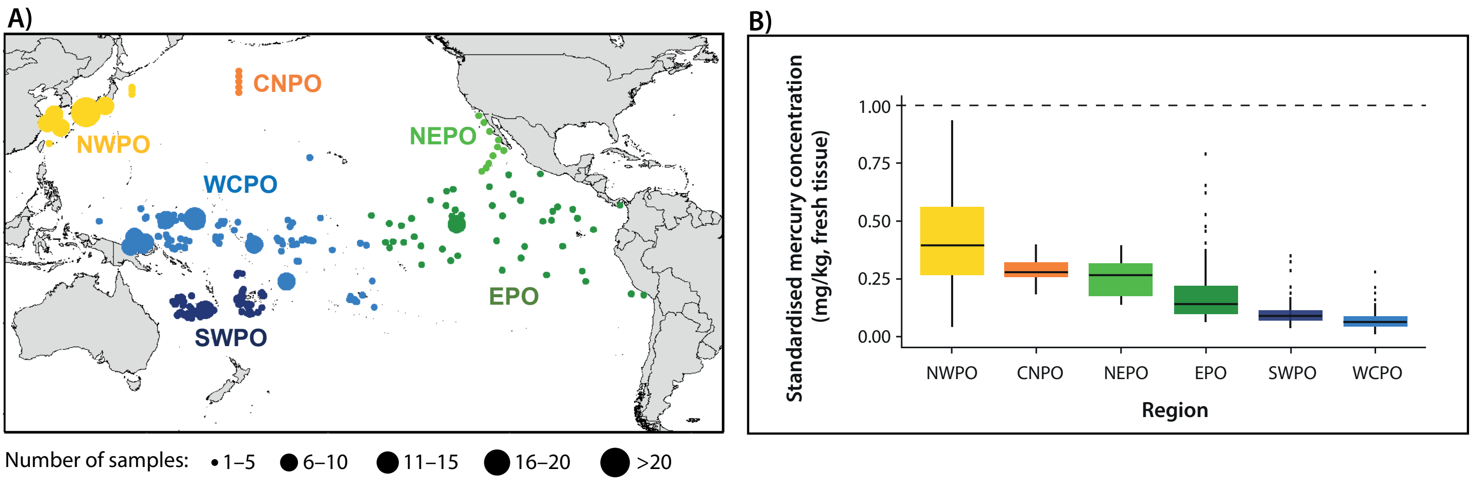

Figure 1. A) Spatial distribution of mercury-tested skipjack in six Pacific Ocean regions (NWPO = northwest Pacific Ocean, CNPO = central north Pacific Ocean, NEPO = northeast Pacific Ocean, EPO = eastern Pacific Ocean, SWPO = southwest Pacific Ocean, and WCPO = western and central Pacific Ocean). B) Standardised mercury concentrations (mg/kg, fresh tissue) in skipjack based on the six Pacific regions for a standard length of 60 cm. The dotted horizontal line indicates the maximum authorised mercury concentration (1 mg/kg, fresh tissue) for large predators such as tuna.

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[6] ANR MERTOX https://www.get.omp.eu/recherche/projets-scientifiques/mertox/
[7] Western and Central Pacific Fisheries Commission Tuna Tissue Bank, Pacific Marine Specimen Bank managed by SPC, Tokyo University Environmental Specimen Bank, Japan, Inter-American Tropical Tuna Commission (IATTC) specimen bank and Daniel Madigan's sample collection (University of Windsor, USA).
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Value of skipjack in studying mercury bioavailability in the oceans

Out of a total of 650 tested skipjack tuna specimens, none had mercury concentrations exceeding recommended health thresholds (1 mg/kg of fresh tissue; WHO and UNEP Chemicals 2008) (Fig. 1B). Although skipjack has some of the lowest mercury concentrations among the tuna species, it is still valuable for understanding and mapping ocean mercury pollution. In terms of health, it is the most heavily fished (mainly in the Pacific) and eaten tuna species, much of it in tinned form, making it a major source of animal protein worldwide. In biological and ecological terms, the species is noted for its fast growth rate and shallow vertical distribution; it migrates within the upper 100 metres of the water column, while other tuna species – such as albacore and bigeye – dive daily to depths of over 500 metres to forage. By choosing to work on this surface species, we hypothesised it could reflect mercury levels in surface waters, which are estimated to have tripled in response to anthropogenic atmospheric emissions (Box 1). The species has also been studied by a variety of research programmes and contributed to specimen banks through the efforts of onboard fishing vessel observers throughout the Pacific. As a result, we have been able to study skipjack mercury in highly contrasting areas of the Pacific (Fig. 1A), and explore various mechanisms that may affect mercury bioaccumulation in food webs. More specifically, we had access to skipjack specimens obtained off the Asian coast, where high levels of anthropogenic mercury emissions are released into the atmosphere (Box 1).

Variable concentrations in different Pacific regions

Mercury naturally bioaccumulates during the lifetime of organisms, with older, larger fish having higher mercury concentrations. We, therefore, first standardised mercury concentrations to a given size (i.e. 60 cm), the average size of the tested skipjack. Strong standardised concentration gradients were revealed between the Pacific regions (Figs. 1B and 2); with concentrations 1.5 to 2.0 times higher in the northwest Pacific than in the north-central and eastern regions, and 4.0 to 5.0 times higher than in the intertropical regions of the western and central Pacific and southwest Pacific.

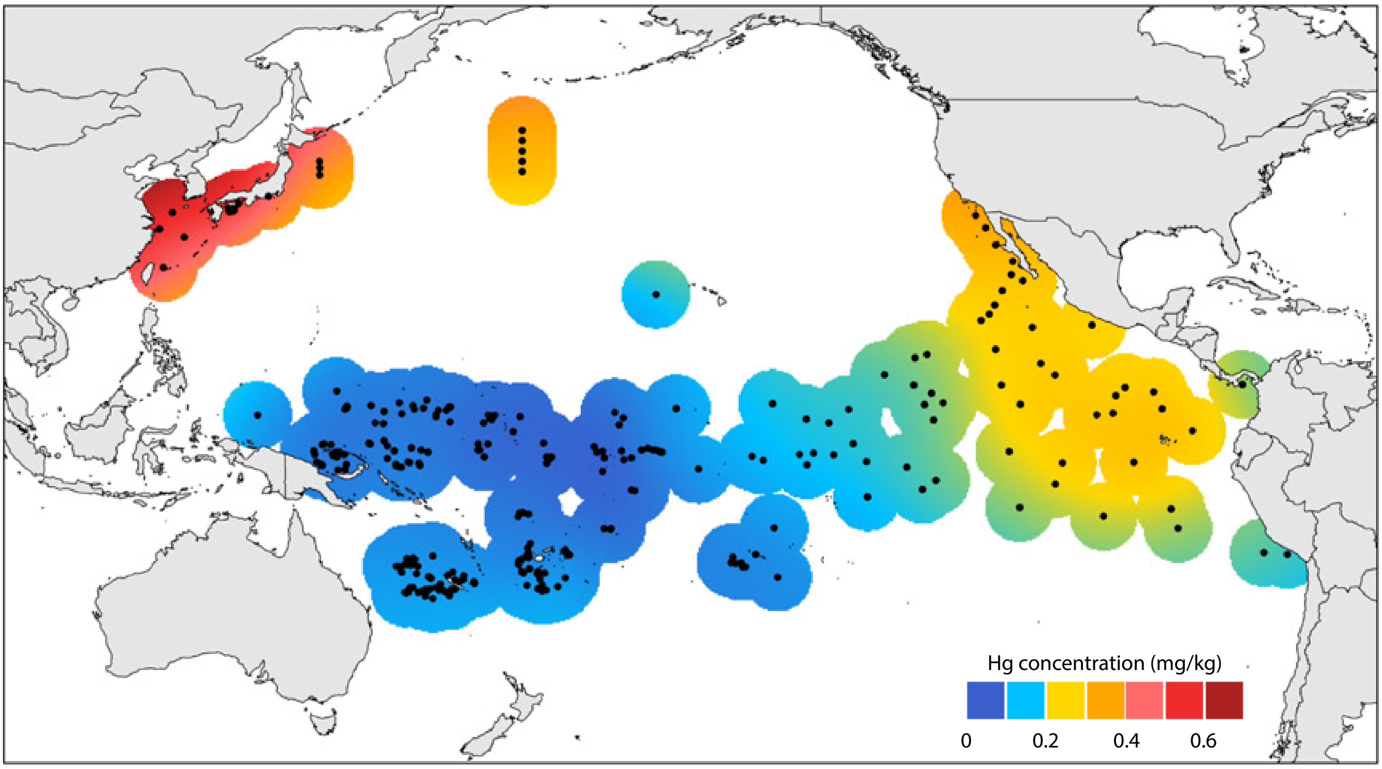

Figure 2. Spatial distribution of mercury concentrations (mg/kg, fresh tissue) in skipjack for a standard size of 60 cm. Black dots show the catch locations of the tested fish.

Mercury gradients in tuna induced by natural ocean biogeochemical processes

In order to attempt an explanation for such high spatial variability, we used a set of tracers to establish whether the underlying accumulation mechanisms were related to tuna dietary differences, methylmercury bioavailability at the base of the food webs, or anthropogenic mercury emissions. Using this approach, we were able to show that biogeochemical processes related to the Pacific Ocean's physical mechanisms naturally generated strong spatial methylmercury gradients in tuna. The relatively high mercury concentrations in the eastern Pacific and northwest Pacific (Fig. 2) appeared to be due to low oxygen levels in the ocean, especially in the eastern region, owing to bacteria breaking down surface organic matter. We hypothesised that such specific conditions in these areas caused methylmercury concentrations to peak in water closest to the surface (< 100 metres) as compared with the western Pacific, where the methylmercury peak occurred in deeper water, between 400 and 800 metres. The fact that the methylmercury peak was closer to the surface and in closer contact with the food chain suggests that bioavailability was higher there. In regions where this occurs, organisms in surface food chains, including skipjack, can ingest and accumulate more methylmercury there than in the rest of the Pacific.

High levels of anthropogenic mercury emissions in the northwest Pacific

The very high mercury concentrations in the northwest Pacific (Fig. 2), however, may also be due to major sources of anthropogenic emissions located nearby (Box 1). They may be caused by recent atmospheric emissions linked to intensive fossil fuel use by Asian power plants. Such human-related sources (Fig. 3) add to natural biogeochemical processes that are conducive to surface methylmercury bioavailability in food webs.

What are the implications for understanding the mercury cycle and the Minamata Convention?

For the first time ever, this study highlights the relationship between anthropogenic mercury emissions and mercury concentrations in tuna in the northwest Pacific. In general terms, even though mercury concentrations in skipjack are still below maximum authorised levels, it is vital to monitor and reduce the release of anthropogenic mercury into the environment to maintain human and ecosystem health, as required by the Minamata Convention that came into force in 2017.

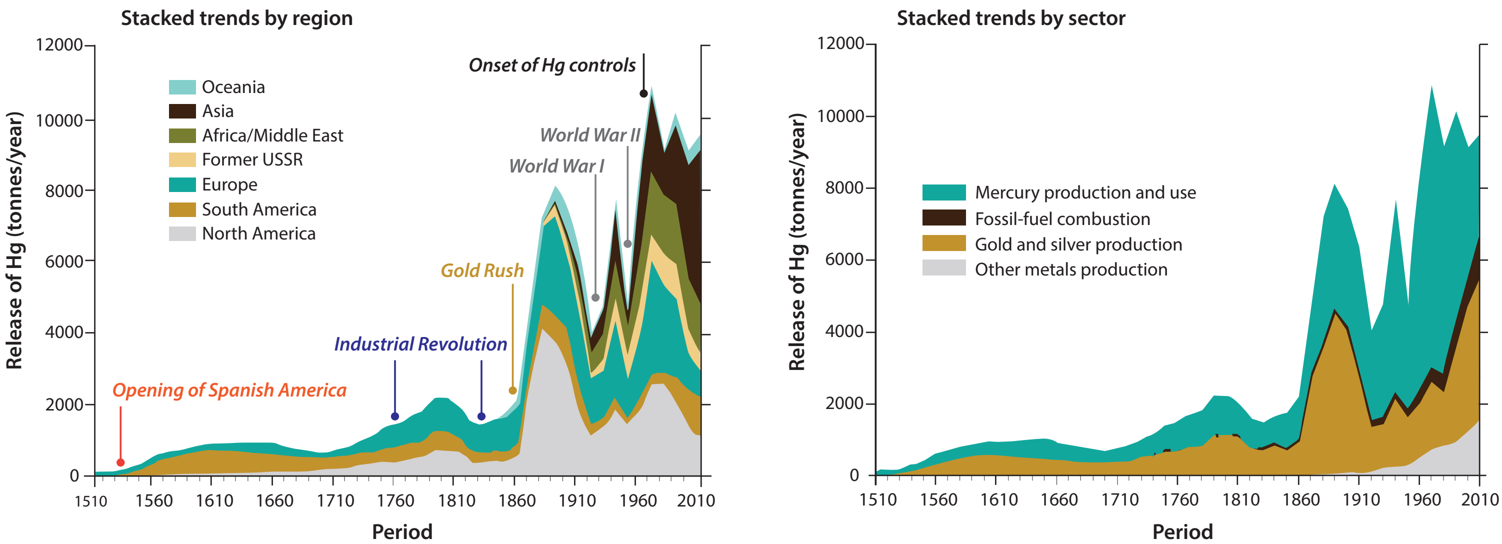

Figure 3. Temporal anthropogenic mercury release profiles from 1510 to 2010 by world regions (left) and emission source types (right) adapted from Streets et al. (2019). The "mercury production and use" category includes mercury production for use in gold and silver extraction (amalgamation techniques) and various commercial applications, such as chlorine and caustic soda production and waste processing.

By revealing the important role that biogeochemical processes play in mercury accumulation, our study also supports the assumption that climate change may affect methylmercury concentrations in marine food webs. The already-observed expansion of the oxygen-minimum zone in the eastern Pacific is forecast to continue over the next few decades and may be conducive to forming methylmercury and increasing its bioavailability at the base of food webs. On the other hand, changes to primary productivity and organic matter export may also counter this trend. Current ocean circulation models cannot accurately predict such biogeochemical changes, specifically in tropical areas such as the eastern Pacific, and so the effect of climate change on the mercury cycle is, as yet, unknown.

Our study suggests that skipjack is an effective bioindicator species for ocean mercury pollution, as it appears to reflect a given ecosystem's mercury exposure (in this case, Pacific surface waters) while also including several mercury sources on various spatial scales. Combined with mercury measurements in the air and ocean, skipjack could provide vital information for designing and implementing future large-scale mercury biomonitoring, as required for assessing the Minamata Convention's effectiveness. A comparable study on a global scale that includes the Indian and Atlantic oceans, and combines other mainstream tuna species (e.g. yellowfin and bigeye tunas), is currently underway to confirm or refute our findings.

References

Horowitz H.M., Jacob D.J., Zhang Y., Dibble T.S., Slemr F., Amos H.M., Schmidt J.A., Corbitt E.S., Marais E.A. and Sunderland E.M. 2017. A new mechanism for atmospheric mercury redox chemistry: implications for the global mercury budget. Atmospheric Chemistry and Physics 17. https://doi.org/10.5194/acp-17-6353-2017

Houssard P., Point D., Tremblay-Boyer L., Allain V., Pethybridge H., Masbou J., Ferriss B.E., Baya P.A., Lagane C., Menkes C.E., Letourneur Y. and Lorrain A. 2019. A model of mercury distribution in tuna from the western and central Pacific Ocean: Influence of physiology, ecology and environmental factors. Environmental Science and Technology 53:1422–1431. https://doi.org/10.1021/acs.est.8b06058

Lamborg C.H., Hammerschmidt C.R., Bowman K.L., Swarr G.J., Munson K.M., Ohnemus D.C., Lam P.J., Heimbürger L.-E., Rijkenberg M.J.A. and Saito M.A. 2014. A global ocean inventory of anthropogenic mercury based on water column measurements. Nature 512: 65–68. https://doi.org/10.1038/nature13563

Li C., Sonke J.E., Le Roux G., Piotrowska N., Van der Putten N., Roberts S.J., Daley T., Rice E., Gehrels R., Enrico M., Mauquoy D., Roland T.P. and De Vleeschouwer F. 2020. Unequal anthropogenic enrichment of mercury in Earth's Northern and Southern Hemispheres. ACS Earth Space Chemistry 4: 2073–2081. https://doi.org/10.1021/acsearthspacechem.0c00220

Lorrain A., Point D. and Allain V. 2019. Size, species, capture location: What makes tuna get high on mercury? SPC Fisheries Newsletter 158:37–41. https://purl.org/spc/digilib/doc/okbus

Médieu A., Point D., Itai T., Angot H., Buchanan P.J., Allain V., Fuller L., Griffiths S., Gillikin D.P., Sonke J.E., Heimbürger-Boavida L.-E., Desgranges M.-M., Menkes C.E., Madigan D.J., Brosset P., Gauthier O., Tagliabue A., Bopp L., Verheyden A. and Lorrain A. 2022. Evidence that Pacific tuna mercury levels are driven by marine methylmercury production and anthropogenic inputs. PNAS 119. https://doi.org/10.1073/pnas.2113032119

Outridge P.M., Mason R.P., Wang F., Guerrero S. and Heimbürger-Boavida L.E. 2018. Updated global and oceanic mercury budgets for the United Nations Global Mercury Assessment 2018. Environmental Science and Technology 52:11466–11477. https://doi.org/10.1021/acs.est.8b01246

Streets D.G., Horowitz H.M., Lu Z., Levin L., Thackray C.P. and Sunderland E.M. 2019. Global and regional trends in mercury emissions and concentrations, 2010–2015. Atmospheric Environment 201: 417–427. https://doi.org/10.1016/j.atmosenv.2018.12.031

United Nations Environment Programme. 2019. Global mercury assessment 2018. Geneva: UNEP.

World Health Organization and the United Nations Environment Programme. 2008. Guidance for identifying populations at risk from mercury exposure. Geneva: WHO and UNEP.

Box 1. The (methyl)mercury cycle in oceans: major uncertainties regarding human activity and climate change

Mercury is released into the atmosphere as a gas by natural sources, such as volcanic eruptions, but more so by human activities (anthropogenic emissions) such as coal combustion or artisanal gold mining (Fig. A). The inorganic mercury is deposited in the oceans, where it is partly converted to methylmercury, a neurotoxin that naturally accumulates in organisms during their lives (bioaccumulation) and across the food web (biomagnification). This is why marine predators such as tunas have high methylmercury concentrations, with methylmercury representing the dominant form (> 91%) of the total mercury in tuna. Humans are then exposed to methylmercury by eating marine fish.

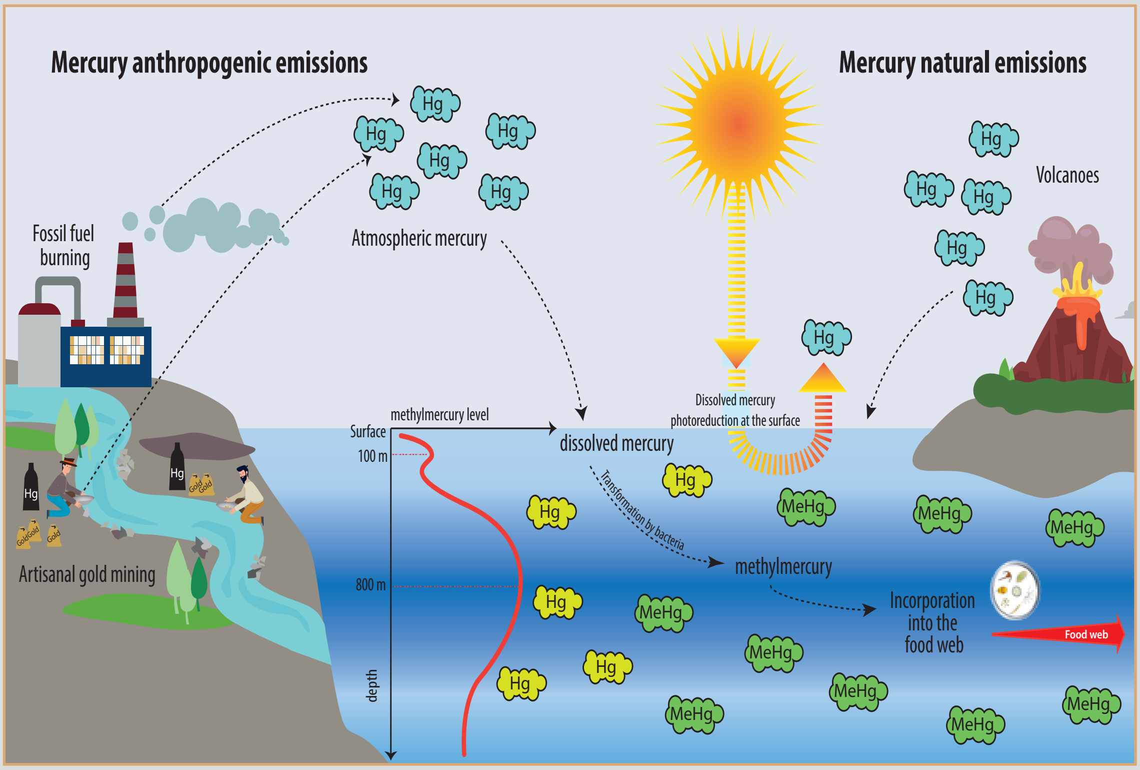

Figure A. Where does the methylmercury (MeHg) in the ocean come from? (Source: Lorrain et al. 2019; illustration Constance Odiardo)

Anthropogenic emissions began some 500 years ago in Europe and North America, but today come mainly from Asia, particularly China, where they have greatly increased over the past two decades with fossil fuel use in energy production (UN Environment 2019) (cf. Fig. 3 on page 52). Taken together, anthropogenic emissions have profoundly altered the mercury cycle and are estimated to have increased mercury concentrations by 450% over the past 20 years (Outridge et al. 2018), with rates of increase being higher in the Northern Hemisphere than in the Southern Hemisphere (Li et al. 2020)(Fig. B). In the ocean, anthropogenic emissions are said to have tripled the total mercury pool (inorganic mercury + methylmercury) (Lamborg et al. 2014), although the impacts on methylmercury concentrations in water and marine organisms, especially large predators, is undocumented.

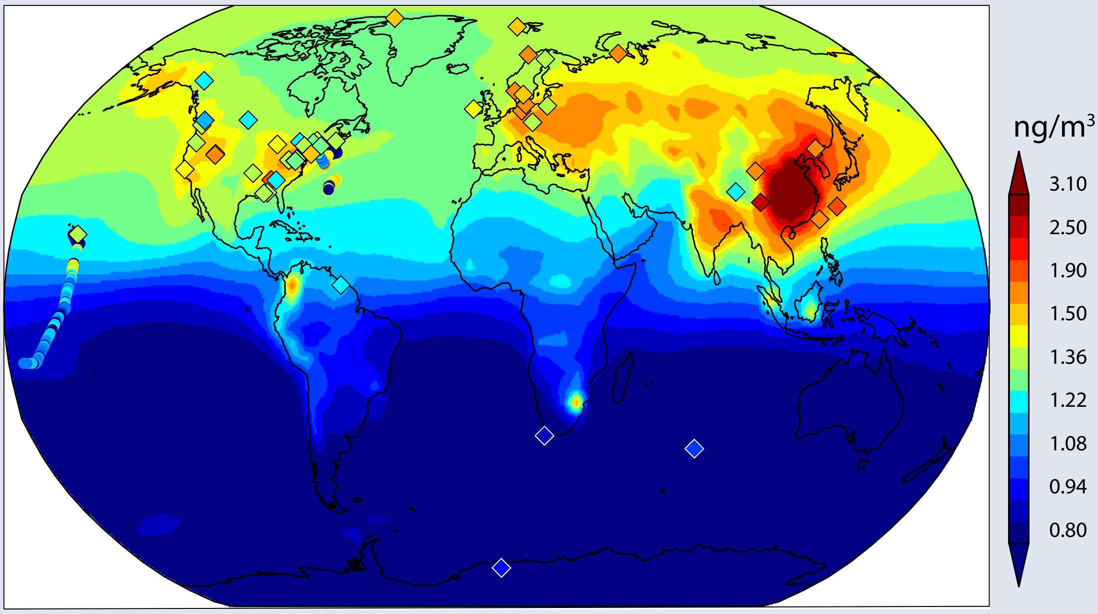

Figure B. Modelled global distribution of gaseous mercury concentrations in the atmosphere (total gaseous mercury, TGM, ng/m3), by Horowitz et al. (2017). The "diamonds" indicate gaseous mercury concentration measurements in the atmosphere and are used to confirm the modelled concentrations.

Another major uncertainty regarding the mercury cycle involves the impact of climate change, particularly on methylmercury formation and bioavailability at the base of marine food webs. It is commonly accepted that gaseous mercury dissolved in water turns to methylmercury (methylation) when broken down by bacteria in deeper, less-well-oxygenated areas of ocean (at depths of 400–800 metres). This methylmercury may be further converted into gaseous mercury in the surface layers, where it could then potentially be re-released into the atmosphere. The methylation and demethylation processes are still poorly understood, but we do know that it is the balance between the two that determines the amount of bioavailable methylmercury at the base of marine food webs. Because climate change may modify ocean circulation and productivity, and expand oxygen-minimum zones, it may also profoundly alter the mercury cycle.

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