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Pacific Community
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FAME
Fisheries, Aquaculture and Marine Ecosystems Division

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Cover picture: Fish pen, Tikehau, French Polynesia. ©Philippe Bacchet

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New biodegradable FADs developed for the Pacific Islands region: A step towards more sustainable tuna fisheries

By Lauriane Escalle, Gala Moreno and Tracey Holley

Tuna fisheries in the western and central Pacific Ocean (WCPO) are the largest and most productive in the world, accounting for over half of the global tuna catch (Hare et al. 2022). The same work concludes that the four key tuna stocks in this region – bigeye, yellowfin, skipjack and South Pacific albacore – are considered to be sustainably exploited. The use of drifting fish aggregating devices (dFADs) within the purse-seine fishery, however, has raised concerns about the entanglement of non-target marine species, marine pollution and damages to sensitive coastal habitats. With the deployment of 23,000–40,000 dFADs in the region's waters each year (Escalle et al. 2021), the need to reduce the number of environmental impacts is critical.

Why are FADs crucial for fishers?

FADs are important devices for both industrial and artisanal fishers. Fish are naturally attracted to floating objects, which provide shade and shelter. Human-made FADs are typically constructed from a variety of materials, and strategically placed in the sea to aggregate fish. Increasingly, especially since the 1990s, dFADs have had marker buoys with satellite tracking devices and echosounders attached to them so that purse-seine fishers can relocate their dFADs and obtain information on biomass of tuna gathering beneath them. These technologies have no doubt improved the efficiency of purse-seine fishing on dFADs.

Although the use of tracking devices has allowed the purse-seine industry to track and set on their dFADs, abandoned or lost dFADs that drift out of key fishing areas can negatively impact wildlife through entanglement and habitat damage. The floating rafts of dFADs use a variety of materials – basically whatever floats. Nets, ropes and lines are used to hold dFADs together and provide a dangling "tail" in the water column to attract tuna, but this subsurface mesh netting can entangle other species such as sharks and turtles. With the high number of dFAD deployments in the WCPO, there is an urgent need to transition to biodegradable and non-entangling dFADs (Escalle et al. 2023). Fortunately, trials of a biodegradable FAD constructed without netting in the WCPO marks the beginning of a new era towards the use of more environmentally friendly dFADs for tuna fishing.

Jelly-FADs: A sustainable solution

Jelly-FADs (Moreno et al. 2023) have been developed by the International Seafood Sustainability Foundation (ISSF) and oceanographers from the Insitute de Ciències del Mar in Barcelona, Spain, and are currently being tested by the Pacific Community (SPC) and ISSF as part of the Western and Central Pacific Fisheries Commission's Project 110 (non-entangling and biodegradable FAD trial), complemented by the National Oceanic and Atmospheric Administration's BREP project. SPC, ISSF and partner fishing companies, recently deployed the first batch of biodegradable dFADs in the WCPO. The newly-developed "jelly-FADs" – so called because they drift neutrally in the water column like jellyfish – are made with natural materials such as bamboo canes, cotton canvas and ropes, which become saturated with seawater after 20–25 days. Sand or clay blocks are used as bal-

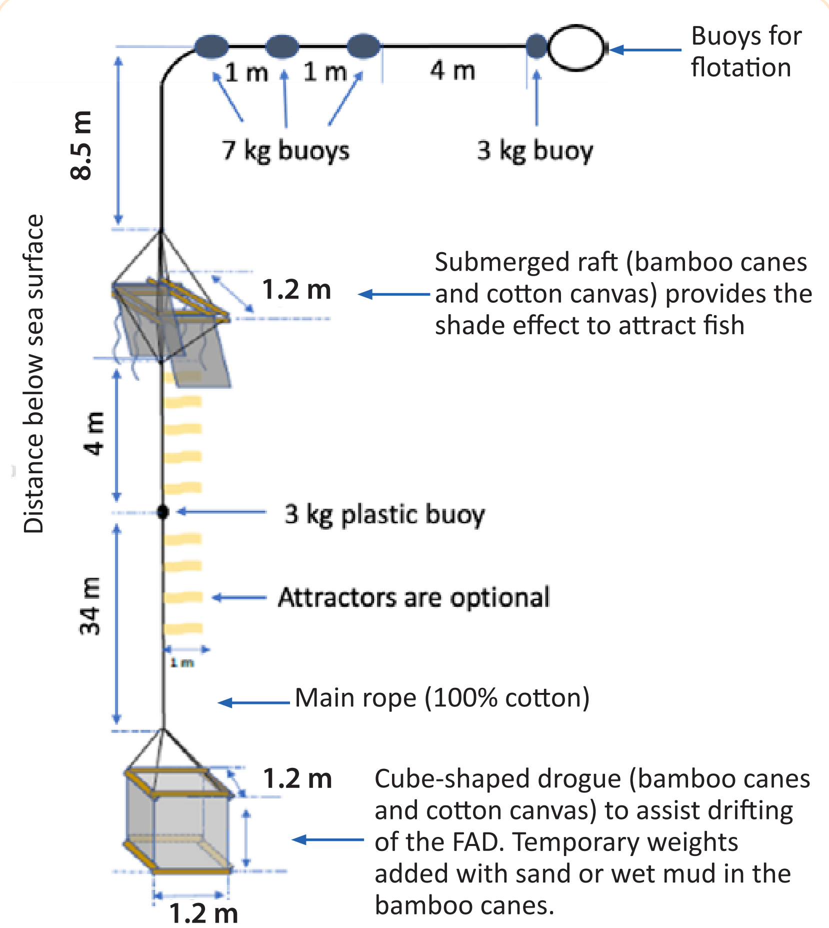

Figure 1. Diagram of a jelly-FAD. Source: ISSF

last, and will dissolve slowly once the bamboo canes become neutrally buoyant. The design has a very limited surface-level floating structure, just four plastic buoys – that are the only non-biodegradable materials present – and a satellite beacon. This neutrally buoyant design reduces structural stress from wind, waves and currents, thus giving the jelly-dFAD a longer lifespan. This is a key design feature because biodegradable materials are not as robust as synthetic materials. The materials will, ideally, degrade slowly after 9–12 months of use, and leave little in the way of an environmental footprint.

These jelly-FADs are the future for environmentally friendly FAD fishing at the industrial level, and will reduce the number of entanglements of non-target species such as turtles and sharks, as well as the impacts caused by lost and abandoned dFADs and their parts.

Trial and evaluation

How well do these new jelly-FADs perform in comparison to conventional FADs? A jelly-FAD can drift for many months (we hope around one year) and be used the same way as traditional dFADs are used. Over the coming months, we will be evaluating how effective jelly-FADs are at aggregating tuna, how well they drift in the open ocean, and how long they last. The satellite buoys with echosounders attached to the jelly-FADs will provide crucial scientific information for the trial. The data for the jelly-FADs will be compared with similar data collected at the same time for traditional synthetic dFADs.

In total, 426 jelly-FADs will be tested in the Pacific over a two-year period (late 2022 to late 2024). Last year, 100 jelly-dFADs were constructed in Ecuador, and deployed in late 2022 and early 2023 by the US purse-seine fleet (American Tunaboat Association and Cape Fisheries). Recently, 100 jelly-dFADs were constructed in the Federated States of Micronesia (FSM), and eight have been successfully deployed by Caroline Fisheries Corporation (FSM), FCF Co., Ltd (Taiwan) and Silla (Korea), and are now drifting in the ocean. The rest of the jelly-dFADs will be constructed over the coming months in FSM, American Samoa and Ecuador. SPC and ISSF scientists will analyse the data collected by skippers, fisheries observers, and through the satellite and echosounder buoys, with the first results expected by the end of 2023.

The future of sustainable dFAD fishing

A report on the scientific analyses will be provided to industry partners, national fisheries agencies, and WCPFC. When the trials are completed, the next steps will involve workshops with industry and national fisheries managers to develop implementation plans at the scale of the WCPO. The use of biodegradable dFADs has the potential to reduce the environmental impacts of dFAD fishing practices and contribute to improving the sustainability of tuna fisheries in the WCPO.

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The constructed jelly-FAD. ©James Wichman, SPC

Attaching the cotton ropes to the drogue. ©William Sokimi, SPC

Building the submerged raft with bamboo and cotton canvas. ©William Sokimi, SPC

Tick tock tuna stock: The advent of the epigenetic clock as an aging tool for fisheries stock assessments

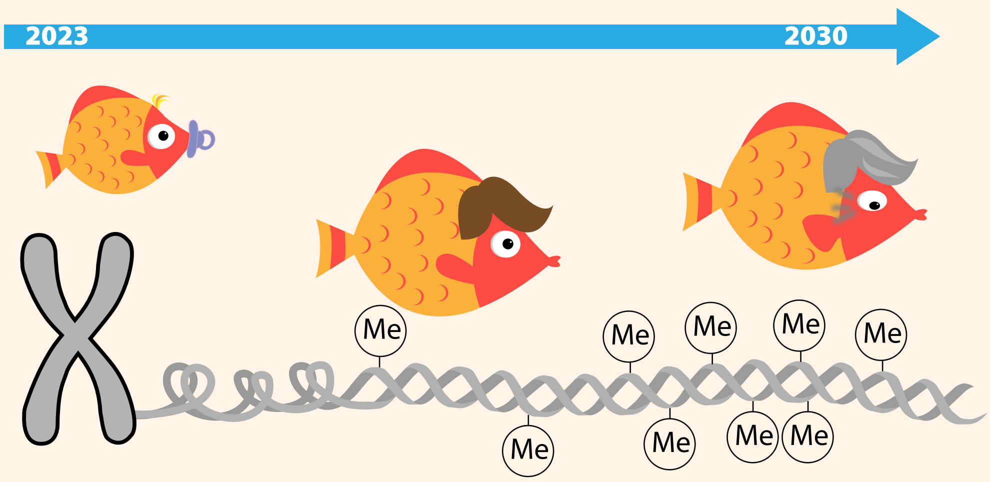
The genomics field is pushing its way into all sorts of research topics. It's possible that you've heard of the use of mitochondrial DNA barcoding to confirm the species of a sample when it isn't visibly evident, such as when using processed fish products (Pollack et al. 2018). Or perhaps you've seen studies predicting the impacts of climate change based on the standing amount of genetic variation in a population of concern (e.g. Capblancq et al. 2020). Or, here's a cool one: did you know that (epi)genomics is now increasingly being used to estimate the age of specimens? The concept is called an epigenetic clock, and it can improve everything, from flagging risk of age-related diseases in humans to growth estimates in tuna stock assessments.

The theory of the epigenetic clock is quite elegant. As individuals age, their DNA ages with them. By quantifying changes in the structure of DNA that occur at a predictable rate over time, it only takes some simple algebra to calculate how long those changes have been accruing and, therefore, how long the individual has been alive.

In slightly more detail, genetic aging occurs in various ways, including epigenetically. Epigenetic aging is distinct from the more commonly known way that DNA changes over time, in which the genome sequence itself is damaged or otherwise mutates in ways that can lead to protein malfunction and eventually to an individual's decline. In contrast, epigenetic processes are those involving the structure of the molecule, and do not affect the actual DNA sequence. The epigenetic mechanism of aging occurs when additional methyl groups bind to the phosphate backbone of a DNA molecule at key areas called CpG sites, where a cytosine precedes a guanine in the genetic code. The presence of the extra methyl groups makes it harder for enzymes to attach to the DNA and start the process of making proteins. Less protein synthesis begets less cell productivity begets less overall vivacity in the organism and more chances to develop dysregulation diseases like cancer. In fact, part of what makes epigenetic methylation such a powerful tool for estimating the age of an organism is that it directly quantifies one of the major mechanisms of aging, rather than providing a proxy.

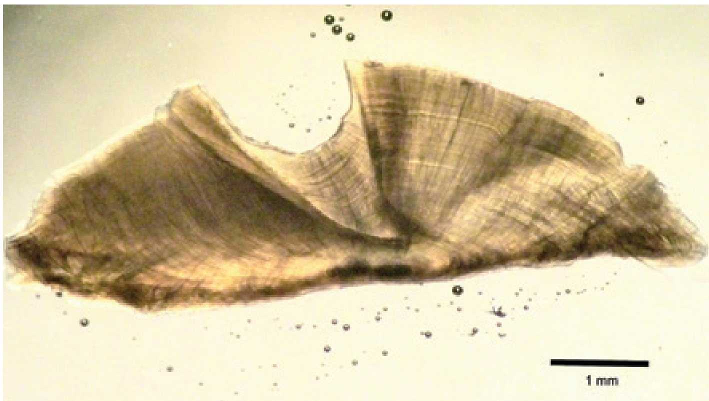
Another powerful benefit of observing epigenetic methylation (and of the epigenetic clock that measures it) is its efficiency of data collection. Given some up-front lab work to select the most informative subset of the genome to observe, and some statistical work to quantify the relationship between known age and the amount of methylation at those selected key points along the genome (which is similar to the amount of effort that goes into any age-versus-predictor curve), it becomes possible to estimate an organism's age from a highly targeted bisulphate sequencing genomic assay – the genomics equivalent of claiming something is "plug and play". Once the methodology is in place for a species, the only limit on the number of specimens that can be aged in parallel is the sequencing capacities of the laboratory.

In contrast, the current gold standard for estimating the age of a fish is via otolith aging. The process requires cutting little ear stones out of each specimen (which requires opening



A simplified diagram of epigenetic aging. Additional methyl groups (Me) bind to the phosphate backbone of a DNA molecule, affecting the structure of the DNA molecule.

Extracting otoliths from a tuna is not a simple process and requires killing the fish. ©Malo Hosken, SPC



Section of an otolith (from a ruby snapper) under the microscope.
©SPC 2012

the fish's brain cavity), setting the delicate calcium structure in epoxy, slicing off a one millimetre thick cross-section, putting it under a microscope, and (hopefully) counting out the number of growth rings that can be used as a proxy for years lived. The process is labour intensive and impractical to automate, and the step of counting rings can be surprisingly subjective. Additionally, and very pertinent to many species of fishery interest in the Pacific, strictly tropical species do not lay down clear, seasonal growth bands on their otoliths because they do not experience strong seasonality or other regime shifts. Therefore, even the gold standard of fish aging is uninformative in species like skipjack tuna.

Granted, epigenetic clocks have their weaknesses as well. An epigenetic clock can only be as accurate as the data it is calibrated against. For almost all bony fish species, that is otolith data. Therefore, the uncertainty in otolith aging estimates is introduced into an epigenetic clock's confidence intervals. In addition, epigenetic clocks introduce their own uncertainty into calculations. In particular, methylation is linked to the biological age of an organism, rather than its chronological age. This limitation circles back to the fact that the clocks observe an actual mechanism of aging, which varies between individuals in response to genetic and environmental factors. For example, in humans, we might blame an earlier decline in quality of life on an individual's family history, poor diet, smoking habits, a sedentary lifestyle, or living in proximity to a pollution-emitting industry. Equivalent factors influence variations in fish. An epigenetic clock's direct observation of biological age is highly useful in some contexts (e.g. predicting an individual's "all-mortality" risk) but the accuracy and precision of absolute age estimates may be impacted if the training dataset is unrepresentative of the population in some way, such as through spatial or temporal bias, or if only some age classes are represented.

Regardless of these potential drawbacks, the popularity of epigenetic aging continues to increase. Epigenetic clocks have been designed across species, with a single clock now developed that is conserved across all tested mammals (Wang et al. 2020), and with human clocks so sensitive they can account for using different types of tissue (Voisin et al. 2020). There are also efforts to understand the conservation of methylation patterns between taxa, which will expedite the development of assays for genomically uncharted species and those that cannot be independently calibrated (e.g. skipjack). The Pacific Community is currently working to develop epigenetic clocks for deep-water snappers, such as the flame snapper (*Etelis coruscans*) and albacore tuna (*Thunnus alalunga*). The tools will aid future fishery stock assessments by filling knowledge gaps about the age structure of snapper stocks, and by providing essential age information for an inaugural close-kin mark-recapture (CKMR) assessment of albacore tuna, which will estimate the absolute adult population size of the South Pacific stock.

The albacore study is a seminal example of how epigenetic clocks facilitate other types of research to circumvent logistical barriers. In order to give a confident result, CKMR will require age data and genomic sequences from 25,000–30,000 albacore specimens in just a few years. It is impractical, if not impossible, to age that many otoliths in the lifespan of the project. Furthermore, the study will sample commercially caught fish, meaning the cooperating fishermen may not appreciate the mutilation of their valuable catch in pursuit of an otolith. The only other option for aging is the length-at-age growth curve that will introduce a suboptimal amount of uncertainty into age data. In contrast, CKMR already requires the collection of a small amount of tissue for genetic purposes, which can be shared for epigenetic purposes. Without the option for aging by epigenetic clock, it would be difficult to apply CKMR to albacore tuna.

The benefits of epigenetic aging outweigh the shortcomings. Access to an epigenetic clock lifts a major logistical limitation on fisheries research by enabling the aging of hundreds of individuals in parallel using only a few cubic millimetres of muscle tissue that can be collected non-invasively and non-lethally. In the immediate future, it will become possible to apply CKMR to species with higher biomass, and to validate growth curves or age-at-maturity assumptions that significantly impact stock assessments. And the applications will only expand and diversify.

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Best practice standards for inserting body cavity tags in tropical tunas

Over the past 30 years, technological progress has enhanced biologging science, providing access to biological and environmental data in otherwise difficult to access habitats. The miniaturisation of electronic boards and sensors, and improvements in memory storage capacities and battery life has facilitated the use of animal-attached tags, such as those deployed in tropical tunas. The literature on best practices is limited for marine species, and near absent for tunas despite their regular application. In late 2022, the Fisheries and Ecosystem Monitoring and Analysis Section of the Pacific Community (SPC) collaborated with several tuna scientists to produce a manual listing *Recommendations towards the establishment of best practice standards for handling and intracoelomic implantation of data-storage and telemetry tags in tropical tuna* (Leroy et al. 2023). The present article summarises some of these recommendations.

The collection of data on animal movements and behaviour linked to their environment is now playing an important role in the conservation of some highly mobile marine species (e.g. turtles, birds, cetaceans). In recording some of the habitat parameters these species rely on, biologging also serves to augment oceanographic data collections.

The archival and telemetry tags, also called body cavity tags (BCTs), that SPC deploys on tropical tunas (see Fig. 1) have revealed fascinating information on the behaviour of these fish (see article in SPC Fisheries Newsletter 141) and their interaction with the fishing gear used to harvest their population all around the world.

The behaviour and physiology of those very active predators determines the internal implantation (Fig. 1) of the tags in their body cavity for the achievement of long-term deployments and appropriate data-series records. To maximise fish survival chances and minimise the potential for fish stress to induce post-release abnormal behaviour records, fish handling and surgical process require adoption of carefully established practices that are summarised in Figure 2 and described in detail in our recently published article (Leroy et al. 2023).

Figure 1: Two types of BCTs (on the left), and a tag implantation in a yellowfin tuna (right) demonstrating:
1 an insertion point for a sea-water hose to irrigate fish gills; 2 the positioning the fish ventral side up, taking care not to damage any fins;
3 positioning the tail to avoid possible contact with hard parts of the cradle frame when the fish's length is larger than the cradle length;
4 securing of the cradle on the vessel working deck; and 5 the cradle design with stable legs that ensures it is at a comfortable height for BCT implantation.

Some important tips (illustrated in Fig. 3)

- Bright lights increase the stress on a fish as soon as it is removed from the water. To minimise this, the tuna's eyes should be covered as soon as possible by a seawater-soaked chamois that will be stay in place until the fish is returned to the ocean.
- Positioning the fish belly-up induces a "tonic immobilisation", a kind of natural paralysis that allows quick tag implantation. The V-shaped cradle facilitates the process by safely maintaining the fish ventral side up.
- The slime that covers fish skin and scales plays a vital role in a fish's bodily functions, and forms a protective barrier against bacteria, fungi and viruses. Slime preservation is, therefore, highly important and requires minimal and careful fish handling, with all contact surfaces smooth and wet.

The described recommended practices have been established with experience gained from 3195 surgeries performed during tagging experiments implemented in the western and central Pacific Ocean. Over 87% of those BCTs were deployed by the Pacific Tuna Tagging Programme since this project first started in 2006. The data downloaded from recovered BCTs was used to investigate the possible impacts from the surgery on tuna behaviour and survival. Although this data analysis revealed the existence of some effects on individual behaviour, some direct observation of short-term recoveries (3–90 days) gave evidence of rapid incision healing (healed and closed in less than a week) and a rapid return to common behaviour after release.

We believe that the recommended practices could be used as a reference guide to help minimise the negative impacts of BCT implantation, prioritise animal wellbeing, and lead to minimal long-term impacts on tagged individuals.

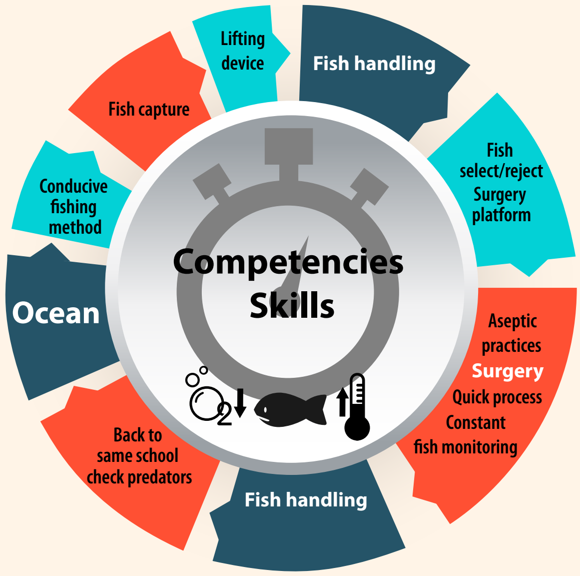

Figure 2: From the capture of a fish to its release back in the ocean, all processing steps need to be sensibly and quickly performed by trained and competent persons to minimise fish distress (enhanced by the raising of animal internal temperature and oxygen deficit) and maximise the fish's chance of survival.

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Figure 3: This bigeye tuna's eyes are covered by a seawater-soaked chamois cloth, while it is brought belly-up to the V-shaped surgery cradle. Note the smooth and wet examination gloves and the soft vinyl covered cradle berth (made of plywood and closed-cell EVA foam). ©SPC

Gourmet vs long-life food for mariculture larvae – Exploring preserved microalgae products as a feed for shellfish larvae

In order for mariculture to develop in the Pacific Islands region, the supply of mariculture seed or juveniles at a suitable economy and sustainable level is a problem that still requires research and development. While pathways exist to supply mariculture activities via the fishing of wild seed such as juvenile marine fish (milkfish) or the collecting of wild bivalve spat (giant clams and pearl oysters), these activities can negatively impact wild fisheries and cause plastic pollution and water quality degradation if they are not well managed. A Pacific Community project has been investigating the use of preserved microalgae products as part of developing technological improvements that may improve the supply of mariculture seed in the Pacific.

The production of mariculture seed from hatcheries offers advantages for sustainability, including a regular and consistent supply of seed and the ability to incorporate genetic improvements, particularly for the resistance of aquaculture stocks to risks associated with disease and climate change. The technology and management required to produce seed, even for animals with short larval cycles, is still difficult to implement in the Pacific Islands. However, there are now many examples in the region of established giant clam production, a group of organisms with easily managed larval and on-land juvenile rearing cycles.

Extending this productivity to other mariculture candidates of nutritional and economic value, such as sea cucumbers and rock oysters (*Crassostrea* and *Saccrostrea*), requires the simplification and application of hatchery methodologies. This can be established by private sector and community efforts, but sometimes there is no access to funds to develop mariculture seed supply operations based around current industry standard procedures.

The costs and impacts of live feed production

The production of live feed – microalgae, rotifers, copepods and artemia – is necessary for mariculture. Live feed is susceptible to contamination and supply continuity. For most mariculture species of interest in the Pacific Islands, the production of marine microalgae is essential. The production of live marine microalgae may account for around 40% of hatchery costs for rearing bivalve seed for example (Coutteau and Sorgeloos 1992; Helm 2004).

While extensive methods (culture in ponds) of live food production are used to produce mariculture seed in Asia in particular, they require significant capital expenditure for the construction of ponds and for water supplies, both of which may impact on coastal environments. Marine hatcheries with small footprints, both physically and financially, will benefit from new technologies such as solar power, mobile communications, and preservation of live food. This will enable their adoption and operation in areas of the Pacific Islands that have opportunities – with respect to water quality, broodstock availability and community need (economic or nutritionally) – to establish mariculture production.

Preserved feeds: Pastes and powders

Replacing cultured live microalgae with preserved microalgae is one strategy being pursued in marine hatcheries in the Pacific to simplify and reduce operational costs. There have been several trials that have produced the seed of sea cucumbers and pearl oysters using preserved (concentrated and refrigerated) microalgae pastes (Duy et al. 2016; Militz 2018; Southgate 2015). In addition to the available pastes, marine microalgae are now available as freeze-dried powders. These could be advantageous because it is not necessary to establish cold supply chains, which are difficult to manage in more isolated regions of the Pacific.

Comparison trial

The Pacific Community, in partnership with the Cawthron Institute of New Zealand, has had the opportunity to use the New Zealand's Ministry of Foreign Affairs and Trade and Pacific Community's Funding with Intent mechanism to contribute to this development of live microalgae replacement technology. The project has employed two experienced Pacific Island hatchery technicians to investigate the potential of more newly available freeze-dried microalgae in comparison with pastes and live microalgae (Vignier 2023). Both Tuaine Turua from the Cook Islands' Ministry of Marine Resources, and Rennie Reymond from Kiribati's Ministry of Natural Resource Development, worked at the Cawthron Aquaculture Park for four weeks in November 2022 to complete a trial using Greenshell™ mussels (*Perna canaliculus*) as an analogue animal for the invertebrates commonly under culture in the Pacific (oysters and sea cucumbers).

While microalgae pastes have been trialled in the Pacific, there has been no comparison with live microalgae because the facilities and staff for its culture are often not available in Pacific Island marine hatcheries. The trial at Cawthron enabled a comparison with live microalgae and the performance of the Greenshell™ mussel larvae was considerably better with standard live feed methods when compared with microalgae pastes and the newer freeze-dried versions.

Figure 1. Preparation of the freeze-dried algal treatment (from top left, clockwise): A) weighing and adding the algal powder to filtered seawater; B) blending to make up stock solution; C & D) feeding diluted preparations of freeze-dried algae to each larval rearing tank.

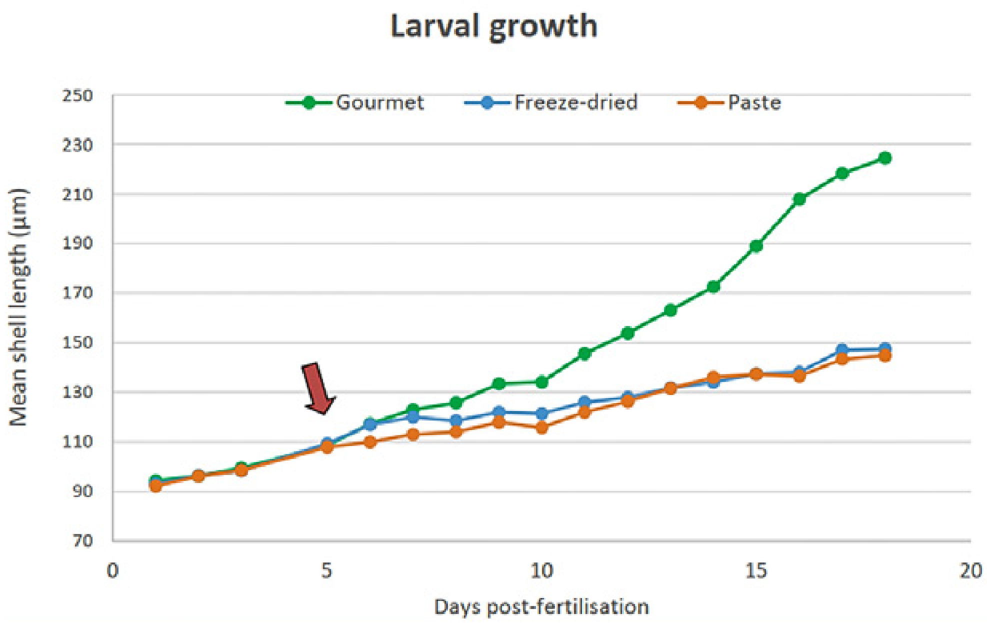

Figure 2. Greenshell™ mussel larval growth, expressed as mean shell lengths (in µm), assessed from day 1 post fertilisation until day 18 post fertilisation. Different feeding regimes consisting of gourmet algae (green), freeze-dried (blue) and paste (orange).

Despite the ease of preparation and storage of both freeze-dried and microalgae pastes, currently there is a large drop in both survival and growth of Greenshell™ mussel larvae fed on these (Fig. 1). Some growth was recorded for both freeze-dried and paste diets and a partial substitution of live microalgae may prove practicable (Fig. 2). The results of the trial suggest that feeding the preserved microalgae might be better in the latter part of the larval cycle, when larvae are larger and food particle size is less critical to ingestion.

Greenshell™ mussels show a preference for gourmet food, and this lends support to the idea that ingestion is very particular for different invertebrate species and selection for particle size and palatability for the species under culture in the Pacific (pearl oysters, rock oysters and sea cucumbers) may give different results (Fig. 3).

A way forward for Pacific mariculture?

Currently the use of preserved diets leads to a significant impact on marine invertebrate larvae performance, which may be offset in the Pacific Islands by a good amount of gametes and high-quality water. However, the implication that live food culture will still form the basis of operations for mariculture in the Pacific Islands leads to questions of scale and location for marine hatcheries. If marine hatchery operations, for species with live food requirements, still require a high level of capital and operational investment to produce live feed, then they are liable to be beyond the financial capacity of communities that have no significant government support.

Centralising marine hatchery production, coupled with regulatory and funding standardisation, in respect to both biosecurity for seed translocation and capital and operating costs, may provide a pathway forward. Further technological advancements in feed and cultured species' performance may, in the future, enable a) marine hatchery technology to be utilised by communities with moderate financial inputs, and b) ecosystem regeneration and nutritional improvements for these communities.

In the meantime, the efforts of Pacific Island aquaculture technicians like Tuaine and Rennie remain critical to fulfilling the aspirations of their governments and communities in developing mariculture in the Pacific. The potential of mariculture can then be realised in the blue economies of Pacific Island countries.

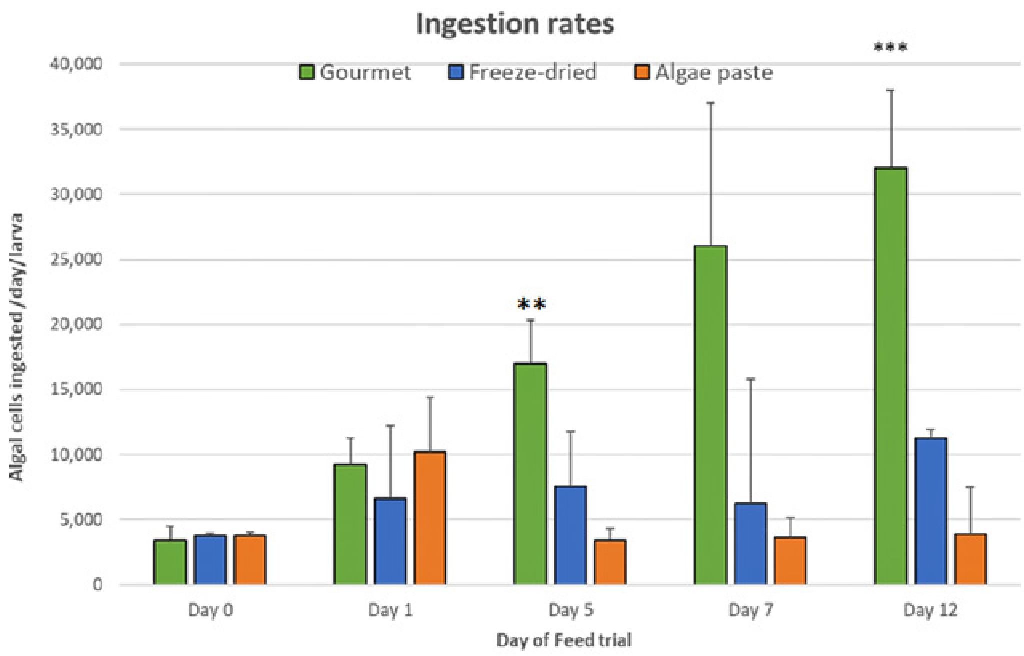

Figure 3. Mean ingestion rate of Greenshell™ mussel larvae fed for 123 days with different algal diets: live microalgae (green), freeze-dried (blue) and pastes (orange). Ingestion rates expressed as number of algae cells ingested per larva per day. ** *** significant difference

Acknowledgements

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Invitation to the 1st Pacific Islands Conference on Ocean Science and Ocean Management

Kiribati coastline. ©Karianako James

The Pacific Community Centre for Ocean Science (PCCOS)[1] is pleased to invite Pacific stakeholders to the first Pacific Islands Conference on Ocean Science and Ocean Management (PICOSOM)[2] in Nadi, Fiji, from 11 to 15 September 2023. This regional conference on ocean science and ocean management is part of the Ocean Decade[3] implementation in the region.

The conference aims to:

- identify, discuss and prioritise ocean science and management priorities in the Pacific with all relevant country stakeholders and partners;
- provide a platform for Pacific scientists to showcase their work and prioritise key scientific focuses and scientific questions;
- take stock of the current situation of integrated ocean management in Pacific Island countries and territories, and develop a shared understanding and way forward;
- share practical implications and examples of integrating traditional knowledge into scientific projects and ocean management; and
- discuss the implementation of the Ocean Decade in the Pacific and what it should look like.

The agenda will be based on responses to the registration form and a call for abstracts: https://forms.office.com/r/zWnpwi0fiD

The Conference will focus on the following themes:

Ocean science

- Advances in ocean observing, monitoring, forecasting systems and remote sensing
- Early warning systems and hazards
- Fisheries science and research to support sustainable resources management
- Marine plastic pollution
- Aquaculture and mariculture
- Migratory species ecology and conservation
- Ocean health, marine ecosystem services and human well-being
- Ocean acidification, rising temperatures, marine heatwaves and deoxygenation
- Traditional ecological knowledge and conservation practices
- Coral reef ecology, resilience and restoration
- Coastal communities, conservation and marine ecosystem management
- Data and information management

1 https://pccos.spc.int/
2 https://pccos.spc.int/work-areas/projects/pacific-islands-conference-ocean-science-and-ocean-management
3 https://oceandecade.org/

Ocean governance and policy for integrated ocean management

- Integrated ocean management and marine spatial planning
- Ocean governance and policy frameworks
- Best practices in strategic environmental assessment and environmental impact assessment for ocean management
- Ecosystem-based management – practical examples
- Conservation and management of threatened migratory species

Integrating traditional knowledge and science in ocean management

- Case studies of successful integration of traditional knowledge and science to inform marine management
- Community-based management of marine resources
- Traditional ecological knowledge, fishing practices and marine conservation
- Marine cultural heritage and archaeology
- Cultural values, indigenous rights and ocean conservation
- Collaborative management between indigenous communities and scientific experts

Cross cutting themes

- The United Nations Decade of Ocean Science in the Pacific
- Early Career Ocean Professional: Ocean leadership and capacity building
- People-centred approach to ocean science and management
- Ocean literacy and communications
- Indigenous knowledge
- Sustainable financing and resource mobilisation for the Ocean Decade and beyond

Inclusive participation

Financial support is available for the attendance of young Pacific Island professionals.

To ensure success, the Pacific Community has also invited governments to nominate participants who are members of their national ministries or authorities related to ocean science, ocean policy, maritime affairs, meteorology, and/or fisheries. This ensures that participants can engage effectively for the session period.

The Pacific Community is committed to common principles and goals such as social inclusion and gender equality. We also acknowledge various Pacific Leaders' commitments towards gender equality. In this regard, the promotion of more Pacific Island women accessing capacity building opportunities and participating in decision-making processes remain important priorities, nationally and regionally. Thus, we would like to support and encourage our country partners in pursuing a fair, inclusive and gender balanced selection of participants.

Registration

- **All potential participants must complete the online registration form no later than 3 July 2023: (https://forms.office.com/r/nZMzxE7AnW)**
- **Please send queries to Ms Virginia Rokoua (virginiar@spc.int) and Mr Pierre-Yves Charpentier (pierreyvesc@spc.int)**

Hope in the face of adversity: Pacific Island countries unite to address challenges in fisheries

By Toky Rasoloarimanana, Sonia Schutz-Russell and Neville Smith

In the past few years, the Pacific Islands region has experienced an unprecedented combination of events: a series of natural disasters, including cyclones, tsunamis and floods, have hit communities hard, caused severe damage, and impacted livelihoods. On top of that, the COVID-19 pandemic has further devastated the vulnerable economies of the region, leading many into significant uncertainty and hardship. Considering these challenges, the need for sustainable fisheries and aquaculture practices has become more critical than ever before. For the Pacific, fish are more than just a source of protein – they are the lifeline that sustains the region's people and economies.

The Pacific Community Heads of Fisheries meeting is an event organised by SPC since the late 1990s and brings together SPC's members to discuss key issues facing the fisheries and aquaculture sector. During the 15th SPC Heads of Fisheries meeting, held at SPC's headquarters in Noumea, New Caledonia, delegates from 25 member territories and countries came together to discuss the resilience and adaptability of the region's fisheries and aquaculture sector. The meeting was a testament to the Pacific's unwavering spirit of unity and collaboration in the face of seemingly insurmountable challenges.

Neville Smith, Director of the Pacific Community's Fisheries, Aquaculture and Marine Ecosystems Division, summed up the meeting by saying, "This *hui* [meeting/gathering] is our once-a-year opportunity for blue Pacific *kaitiaki* [guardians] to *korero* [talk/discuss], and brings the best of history, knowledge and science to bear on solutions for our contemporary challenges. It is a privilege to share the journey of *kaitiakitanga* [stewardship] with our members."

The meeting was a diverse collection of success stories and best practices from members, with each one generously sharing an example of what can be achieved through community and cooperation. In Tonga, local fishers are diversifying their catches by targeting the giant diamondback squid beyond the reef, thereby alleviating pressure on reef fish populations and creating new economic opportunities for local fishers. The Federated States of Micronesia uses anchored fish aggregating devices to attract pelagic fish, which provides local fishers with better chances of successful catches. In Solomon Islands, fisheries officers have received training on regulations and enforcement, leading to more sustainable lagoon fishing practices. French Polynesia has made considerable progress in improving the monitoring of its offshore tuna fisheries using e-reporting apps, which ensure more accurate and timely data collection.

A delegate from Tuvalu summed up the collective sentiment of the meeting, saying, "We have made significant progress in improving our role as stewards of our Blue Pacific, but there is always more work to be done. We are grateful for this opportunity to collaborate with our Pacific family to address the challenges facing our fisheries and aquaculture sector."

The Pacific Community Heads of Fisheries meeting was a truly special event, especially considering that it was the first

in-person meeting after three years of virtual gatherings due to the COVID-19 pandemic. Delegates appreciated meeting each other face-to-face again. The meeting highlighted the region's dedication to sustainable fisheries and aquaculture, and highlighted the deep connections that exist among Pacific Island countries and territories. The warmth and camaraderie that were present during the discussions demonstrated the power of unity and the strong Pacific spirit that drives the region forward.

As the delegates bade farewell to one another, they carried with them a shared sense of responsibility to build a better future for their fisheries and aquaculture. In the wake of unprecedented challenges, the meeting served as a powerful reminder of the unwavering spirit of unity that has come to define Pacific nations. With this spirit as their guide, these countries are willing to face the challenges ahead with the knowledge that they have the support of a strong community in their pursuit of a better future.

Plenary session at HoF. ©SPC

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Participants of the 15th Heads of Fisheries, held in Noumea, New Caledonia in March 2023. ©SPC

Tonga's Special Management Area programme: Insights from communities, and considerations for upscaling community-based fisheries management in the region

Introduction

In Tonga, coastal fisheries are mostly small-scale and serve multiple purposes, such as food, social commitments and, to a lesser extent, economic gain (Kronen 2004). Access to fisheries resources was, for a long time, open but the steady decline of stocks convinced the Tongan government to try a community-based approach to managing them (Gillett 2010). The Special Management Area (SMA) Programme started in 2002, providing exclusive access to fisheries for specific communities, and embedding core conservation of biodiversity elements. The programme has been successful in coastal communities and has resulted in positive conservation results (Smallhorn-West et al. 2020).

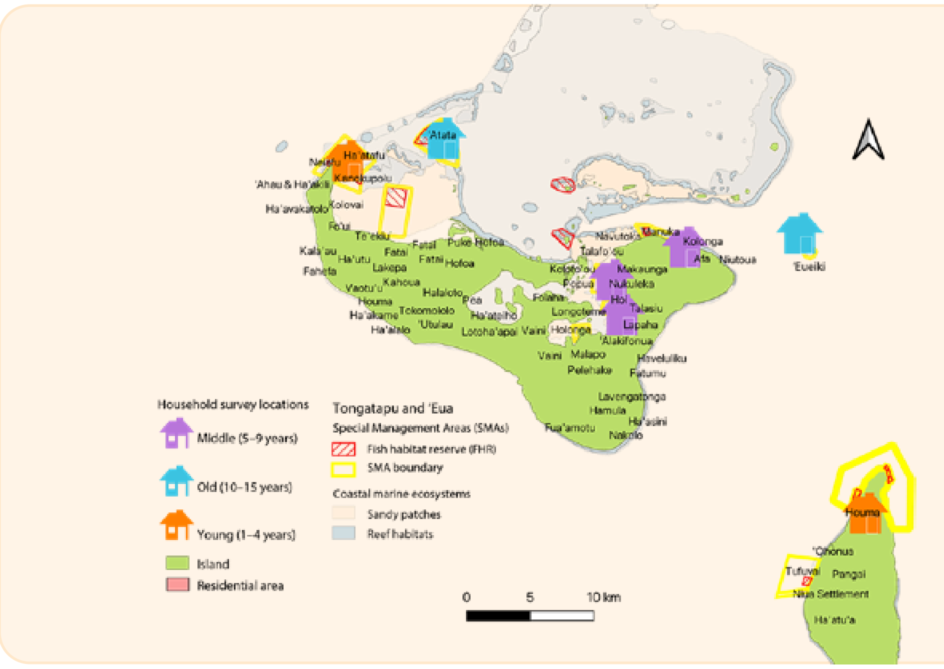
The potential benefit of devolving management powers to local communities has been identified by several countries in the region, leading to the development and approval of the community-based fisheries management (CBFM) framework (Pacific Community 2021). So, along with other countries in the region, Tonga is considering ways of reaching most coastal communities with its SMA programme. This idea requires careful consideration of advantages and disadvantages, available and required resources, and different strategies to optimise limited resources.

The socioeconomic assessment of the SMA programme, conducted in 2021, provided key insights from SMA communities to guide the upscaling of the programme and support most communities in the country to manage their own marine resources (MoF and VEPA 2022).

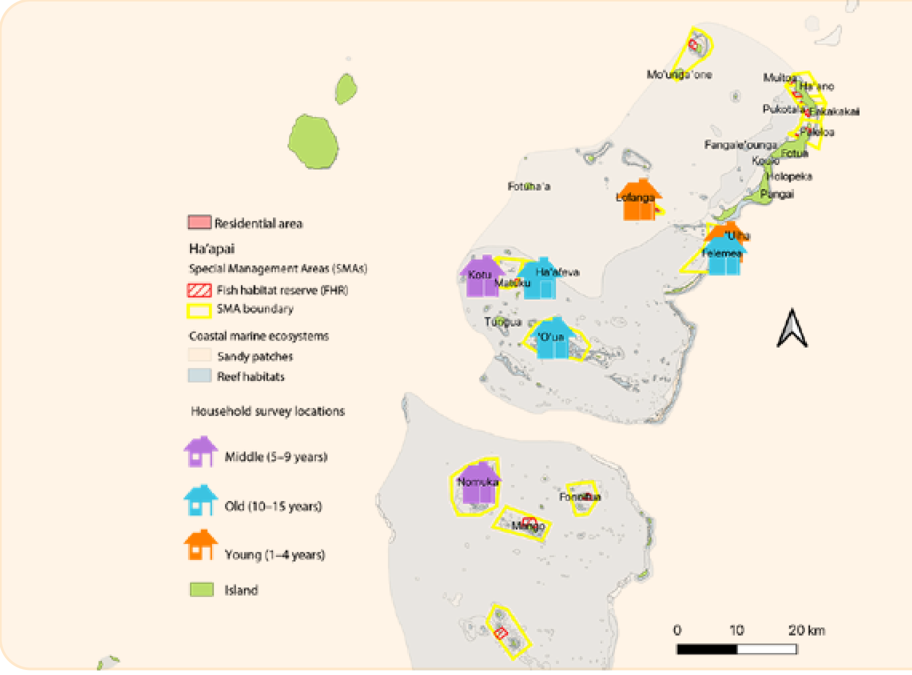
It is evident that community-based fisheries management is as diverse as the communities themselves and their ecosystems. A predetermined approach to establish a management system is often not appropriate. However, basic principles or recommendations can be learned from local experiences. We believe that the Tonga experience can contribute to the regional upscaling of CBFM, and so in this article we briefly present the most relevant results of the latest socioeconomic assessment, and the recommendations for scaling-up CBFM in Tonga and the rest of region.

Methods

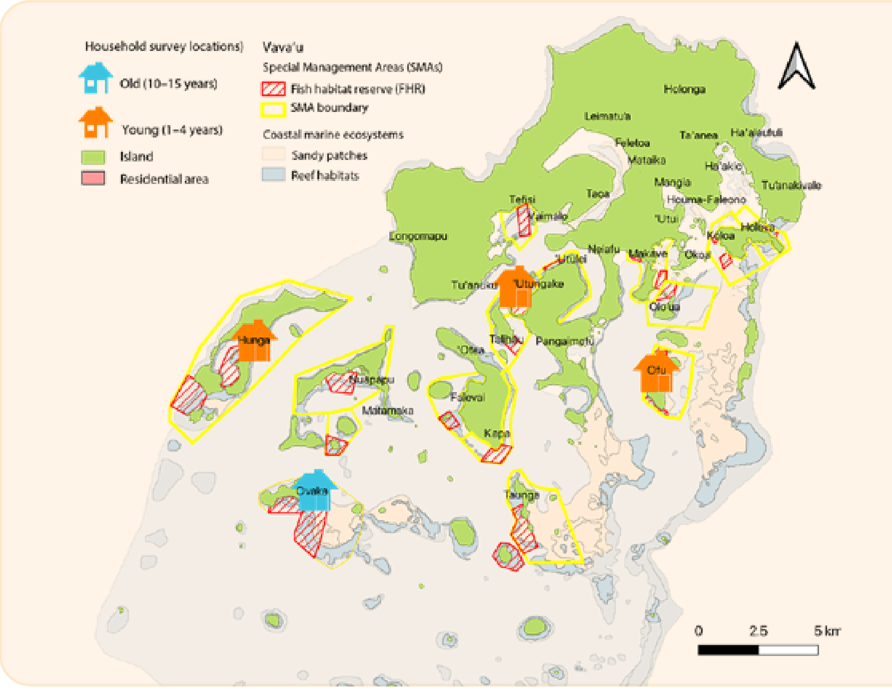
A full description of methods and results can be found in the full report (MoF and VEPA 2022). In total, 275 households were surveyed, covering proportionally equal numbers of SMAs according to their age: young SMAs (1–4 years), middle-aged SMAs (5–9 years) and old SMAs (10–



Map 1. Tongatapu (larger island) and 'Eua, showing household survey locations and the age of SMAs. The boundaries of all current SMAs are shown.



Map 2 . Ha'apai island group, showing household survey locations and the age of SMAs. The boundaries of all current SMAs are shown.



Map 3. Vava'u island group showing household survey locations and the age of SMAs. The boundaries of all current SMAs are shown.

14 years). The sample was also distributed across four groups of islands: Tongatapu, Ha'apai, Vava'u and 'Eua. Respondents included 140 men (of these, 21 were male youth) and 135 women (25 of which were female youth). The survey covered several aspects, including SMAs' impact on food security and household well-being, management effectiveness, and vulnerability to climate change.

Recommendations from the survey were complemented with insights from MoF staff and the results of the 2021 national SMA workshop. Impacts from, and coping strategies for, COVID-19 were analysed in a separate publication (Marre and Garcia 2021). This article focuses on the most relevant findings in relation to the upscaling of the SMA programme, and the recommendations that can support upscaling CBFM in the rest of the region.

Main findings and considerations

The number of people per surveyed households ranged from 1 to 20 members, with an average of 6 people. Most respondents had finished high school and worked informally. The most important income sources were remittances (more so for women), wage employment, reef fishing (mostly done by men), handicraft making (mostly done by women) and farming (more often done by men).

There were 120 active fishers in the sample (73 men and 47 women), with the highest proportions in Ha'apai and Vava'u. The most important fishing activities were reef fishing (done by 64 men and 22 women) and gleaning (46 men and 36 women). It is interesting to note that more men were involved in gleaning activities, an activity often dominated by women. Because the survey was conducted during COVID-19 restrictions, it would be interesting to find out if this change was temporary.

Fishing and marine resources were very important for most households. Reef fishing and gleaning were conducted mostly for household use, but income generation was important for certain households. Almost all households, however, consumed fish between three and four times per week, second in importance only to crops.

Regarding perceived effects of SMAs, it is important to highlight that most respondents had very positive views of SMAs, including their contribution to ecosystem health, and securing resources for future generations, as well as for economic, social and personal wellbeing.

However, for a select number of factors related to governance (e.g. ability to fish anywhere, ownership and access to resources, inclusion of women in decision-making and SMA support), some groups, including respondents living in middle-aged SMAs and women, were slightly less positive (see Annex 2 in MoF and VEPA 2022).

The proportion of dissatisfied women is low, but it is worth understanding their source of discontent and, if feasible, address any issues. Within the SMA programme are coastal community management committees, which must include women and youth. While all SMAs have such committees, it is likely that in older SMAs, women have had more time to become empowered, resulting in increased engagement and support of women in older SMAs compared to women living in middle-aged SMAs.

More generally, communities in middle-aged SMAs, most of them in Tongatapu, were also somewhat less positive about SMAs. Tongatapu is the most populated island group in Tonga, which is related to more pressure on natural resources, less dependence on productive activities as more people become employed, and the growing importance of a cash economy. All these factors can drive a reduced engagement in governing their SMAs and a related apathy towards, or ignorance of, marine resource management (note in the report the higher proportion of respondents answering "I don't know").

Relevant lessons from Tonga for scaling-up CBFM in the region include the following.

- A diversity of livelihoods and food sources increases community resilience to climate change and other shocks. When supporting some of these livelihoods, it is important to consider how an increased income can drive cultural changes, which in turn can affect governance structures that depend on social capital.
- A multi-sectoral approach is required to support communities, so that all key wellbeing aspects are considered (e.g. food security, health, education). Such an approach is also fundamental, as marine health depends not only on the management of fisheries, but on external impacts, such as natural disasters, development policies and sectoral growth.
- It is important to find out which sections of a community do or do not support CBFM programmes. Even if discontented sections are small, it is important to understand what lies behind their dissatisfaction, and work with communities to address any gaps. Unchecked disagreements can evolve into factions and potentially impracticable governance. Gender, socioeconomic status, religion, ethnicity and immigration status can be key sources of unfairness, perceived or real.
- Finding ways of using limited resources more efficiently to support CBFM communities is fundamental to increasing CBFM coverage and support. With this purpose, MoF is considering establishing district-level SMAs, as opposed to community-level ones. Respondents, however, mostly disagreed with this option. It is likely that they fear losing current privileges. It is, therefore, important to consider different options, like establishing district networks where experienced communities support new communities, thus reducing the need of government to drive all support activities. In addition, transparent two-way communications systems should be in place to allow communities to report to the government on key issues and advantages of different governance approaches.

Conclusions

CBFM approaches have created immense value in the Pacific, not only for the conservation and better management of natural resources (Smallhorn-West et al. 2020), but for communities' wellbeing, including improving food security and livelihood options (Cohen et al. 2014; Islam et al. 2014). It is also a more efficient and cost-effective way of managing resources, rather than having a centralised government policing whole countries, particularly those with very remote islands. It is, therefore, fundamental to nurture this win–win management approach by:

- Ensuring that communities continue to be satisfied with their governance and management arrangements in time; to this end, all decisions need to be taken by communities, and for communities.
- Embracing the strong social capital in the region. Pacific-style social networks of support and joint action, already culturally embedded, are key assets in the management of common resources. Thus, supporting the creation of CBFM networks should be a priority.

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A new tool available online: Coastal fisheries legal profiles of all Pacific Islands

Introduction

A new tool – called Legal Profiles – is now available on the REEFLEX database[1], which provides a quick overview of the legal and policy framework of coastal fisheries and aquaculture for 22 Pacific Island countries and territories (PICTs) and Timor-Leste. The profiles are intended for anyone (fisheries manager, legal officer, expert or practitioner) who wants to become acquainted with Pacific coastal fisheries and aquaculture governance. This article provides a brief comparative review of the key elements in each legal profile.

What are the objectives of this tool?

Legal Profiles is an overview tool that provides baseline information on existing legislation regarding coastal fisheries and aquaculture management in PICTs. Each country or territory profile attempts to give a snapshot of the institutional, legislative and policy frameworks that underpin coastal fisheries and aquaculture governance at the national and subnational level.

The profiles are designed as an introductory guide to PICTs' legislation and are not meant to be exhaustive. This section of REEFLEX offers an overview tool that aims to provide a synthesis of the information you can find in the other two sections Find laws & policies (search tool) and Compare Regulations (analysis tool).

Please browse the Legal Profiles to better understand the legal backbone of coastal fisheries governance in the Pacific Islands region.

What can you expect to find in each profile?

- The **Overview** section provides a general description for each country or territory with maritime zones and jurisdictions.
- The **Institutional framework** section identifies the main government authorities in charge of fisheries management, regulation and enforcement at national and local level and the legal basis for community-based fisheries management.
- The **Legislative framework** section identifies the main fisheries laws and describes the regulations that apply to coastal fisheries and aquaculture, including any licensing requirements for fishing, farming, processing and export.
- The **Policy framework** section highlights the main sector policies and plans promoting coastal fisheries and aquaculture, as well as some of the management plans in place for specific fisheries.

What do we know about the legal framework of coastal fisheries and aquaculture in PICTs?

Overview

Among the 22 members of the Pacific Community, **65%** are Pacific Island countries and **35%** are Pacific Island territories of France, New Zealand, the United Kingdom, and the United States. Timor-Leste is a Southeast Asian country that is within the territorial scope of SPC, in accordance with the 2013 amendment to the Canberra Agreement of 1947. Maritime jurisdiction within PICTs is often shared between national or central authorities and subnational authorities (states or provinces, or local authorities (island councils and villages). The majority of countries and territories have subnational or local governments with some degree of autonomy in managing coastal fisheries (e.g. fisheries of local interest or fisheries occurring within a certain distance from shore).

[1] The first REEFLEX tools were launched in 2019. The three integrated tools of REEFLEX are now operational for users to search laws and policies, compare regulations, and learn more about governance. The database and apps were developed, and are being maintained, through New Zealand and Australian funding (SCoFA project).

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Who regulates and enforces coastal fisheries and aquaculture?

Central fisheries administration

Coastal fisheries and aquaculture are generally managed and regulated by the ministry or department in charge of fisheries, which in about half of PICTs is a separate entity from other government divisions and/or ministries. In other cases, the fisheries division is part of another agency, such as the ministry of agriculture (e.g. Guam, Niue, Palau and Timor-Leste) or the ministry of environment (e.g. New Caledonia, Northern Mariana Islands, and Palau). Other ministries may be involved in coastal fisheries and aquaculture management, including ministries of land, tourism, maritime affairs, internal affairs (in charge of island councils and local government) and justice.

In fisheries enforcement, the authorised officers play a substantial role in ensuring compliance by fishers and communities through education and awareness. In the countries and territories reviewed, fisheries legislation provides enforcement powers to ensure the effectiveness of management measures. In the most recent fisheries legislation, authorised officers have broad powers, such as boarding any fishing boat, checking fishing licences, inspecting premises, taking samples, and seizing material.

Authorised officers are generally appointed by the minister or secretary for fisheries or justice. In some PICTs, a separate department is in charge of enforcing fish and wildlife legislation (e.g. Palau, Pohnpei). In addition, community officers may also be granted powers to locally enforce coastal fisheries regulations, bylaws or plans (e.g. Cook Islands, Fiji, Kiribati, Tonga and Vanuatu).

State/Provincial fisheries administrations

For federal countries such as the Federated States of Micronesia and Palau, coastal fisheries and aquaculture management heavily involve state governments and legislations that may regulate activities up to 12 nautical miles from shore. National legislation may apply within state jurisdictions to different degrees, depending on the country (e.g. only if local legislation is missing or less stringent on the regulated matter).

For countries and territories with provinces, such as New Caledonia, Papua New Guinea (PNG) and Solomon Islands, provincial governments may have exclusive or concurrent competence to regulate marine resources management within the limits of the territorial sea.

Solomon Islands. ©Tom Vierus and SPC

Local government and communities

Local governments include island councils, towns and municipalities that work closely with fishing communities, both directly and through governmental and non-governmental projects. Traditional authorities also play an important role in local fisheries management, particularly when they are recognised by law as local government, such as the Falekaupule in Tuvalu or the Fono in Samoa.

In some PICTs, community-based fisheries management is formally established under statutory law while in others, customary practice prevails over the written rule. Overall, at least **80%** of PICTs have some legislation in place supporting community-based fisheries management, although some could be strengthened (e.g. by improving fishers' representation in traditional bodies). On the other hand, almost **half** of PICTs recognise customary marine tenure and traditional fishing rights in statutory legislation. (More information on these aspects can be found in O'Connor et al. 2023).

What regulations apply to coastal fisheries and aquaculture?

Coastal fisheries legislation

Most countries have fisheries legislation in place, although some may be outdated or fragmented, particularly when it comes to coastal fisheries and aquaculture. Most existing fisheries acts and regulations deal with offshore industrial fisheries carried out by distant-water fishing nations in the exclusive economic zones of PICTs. In some cases, coastal fisheries and aquaculture legislation must be carved out from minimalistic provisions of the main fisheries act and developed into regulations. Most PICTs have regulations to implement the fisheries act, although there may be gaps that need to be filled or updates to be made. Depending on the country or territory, the available laws and regulations relating to coastal fisheries are more or less comprehensive and may sometimes create a substantive body of written rules (Fig. 1). Note that certain PICTs have an additional layer of government regulation at the state or provincial level, such as New Caledonia, PNG, Solomon Islands.[2]

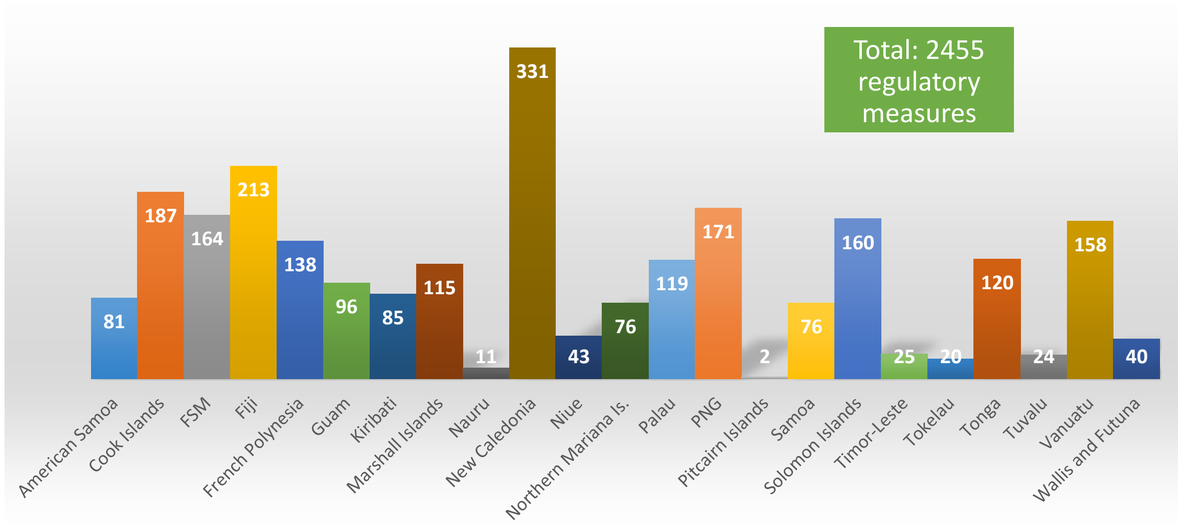


Figure 1. Number of coastal fisheries regulatory measures in 22 PICTs and Timor-Leste. Data source: REEFLEX

[2] Figure 1 covers national or territory-level legislation for all 22 PICTs and Timor-Leste and subnational legislation (state or province) for certain PICTs (e.g. FSM, New Caledonia, Palau, PNG, Solomon Islands), where available. Local-level legislation (such as island council bylaws and municipal ordinances) is not accounted for in Figure 1.

Common types of regulations

Based on the regulatory measures recorded in the REEFLEX Compare Regulations (Fig. 2), the most common types of coastal fisheries management measures adopted by PICTs through laws and regulations are:

- access restrictions through licensing and registration (e.g. commercial fishing, specific fisheries, aquaculture);
- restrictions on gear and fishing methods (including nets, hooks, traps, spearguns, scuba and destructive methods, such as poison, explosives or crowbars);
- size limits for vulnerable species (e.g. clams, lobsters, crabs, sea cucumbers, certain fish); and
- total fishing bans and trade bans for certain marine species (e.g. sea cucumbers, clams, berried/gravid crustaceans).

Also popular in PICTs are spatial measures, such as the establishment of marine protected areas (including sanctuaries but also community-managed areas) and temporal measures such as closed seasons (e.g. for groupers and snappers) or the prohibition of night fishing.

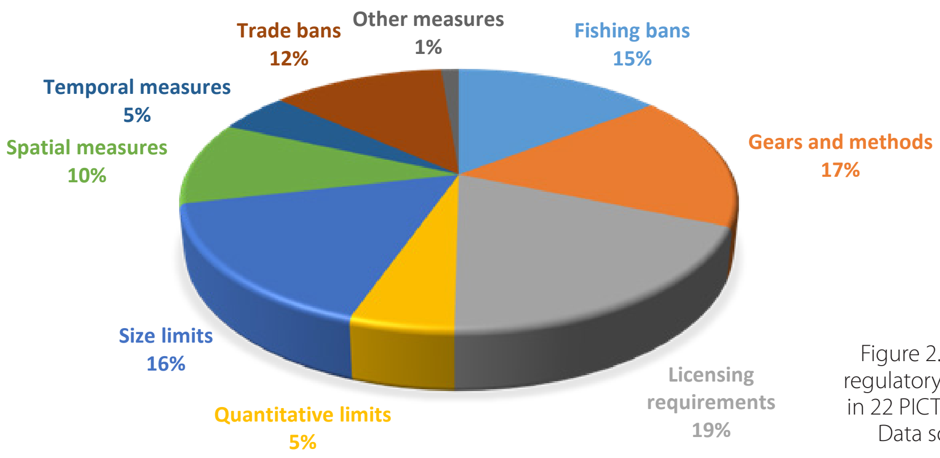


Figure 2. Coastal fisheries regulatory measures by type in 22 PICTs and Timor-Leste. Data source: REEFLEX

Species regulations

Regulation by species, often based on fisheries management plans that detail why certain measures are needed for a designated fishery, is also common. Of all regulatory measures recorded in the database, 71% are specific to a given marine species or group of species, the remainder being general provisions applicable to all fishing activities (e.g. fishing gear restrictions, commercial licensing requirements). As shown in Figure 3, invertebrate species account for more than 38% of all measures. These species, such as sea cucumbers, lobsters, crabs, clams or shells, are extremely vulnerable to overfishing. Regulated species also include

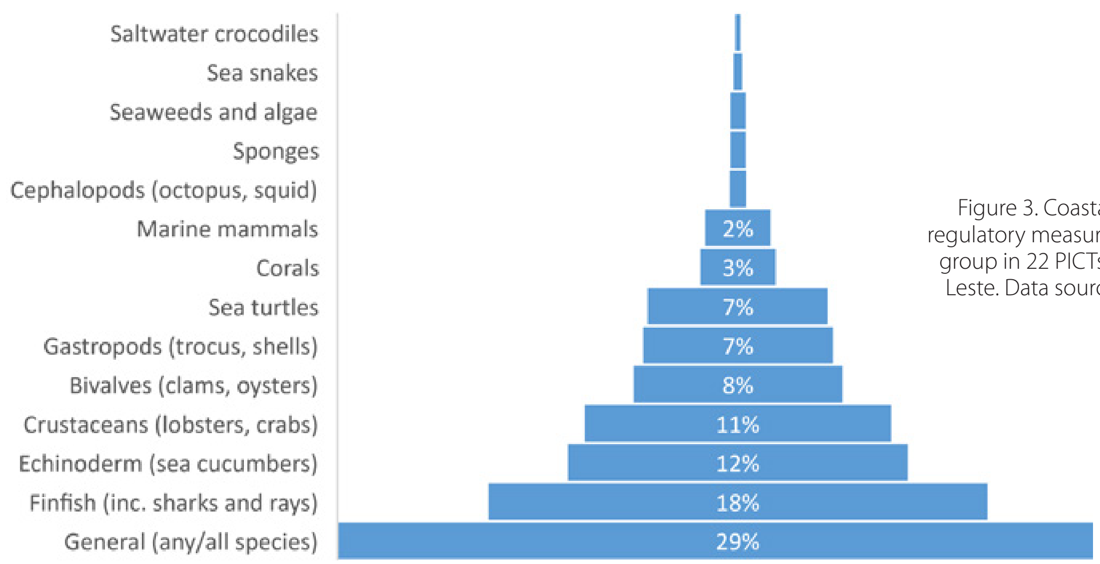


Figure 3. Coastal fisheries regulatory measures by species group in 22 PICTs and Timor-Leste. Data source: REEFLEX

finfish, covering both bony fish and cartilaginous fish, such as sharks and rays. Many species regulations are applicable to all fishing activities regardless of their purpose, be it commercial, subsistence or recreational (e.g. protected species). However, specific limitations may apply to certain types of fishing that are not subject to a licence (e.g. New Caledonia's bag limits for recreational fishing of reef fish and pelagic species).

Licensing requirements

In PICTs, coastal fisheries are generally the realm of local small-scale fishers, while foreign and industrial fishing vessels operate beyond the territorial waters of each country. Worldwide, small-scale or artisanal fisheries are regarded as a continuum of activities that resist strict categorisation (Smith and Basurto 2019). Due to the cultural and dietary importance of fish in Pacific islands, subsistence fishing often includes fishing for the purpose of local sale or barter as a side activity, although this is often not stated in legislation which makes it a grey area.

About 80% of PICTs require a licence for commercial fishing activities in their waters, whereas subsistence and traditional fishing are typically exempt from licensing or permitting requirements for food security purposes. This commercial licence may be conditioned by the size of the boat, such as in Nauru and Cook Islands where any boat of 10 metres or more in length must have a licence for fishing. When managing fisheries, a licensing system is an efficient tool to regulate access to certain designated fisheries and reduce the pressure on overexploited marine species. In addition to commercial fishing licences, special licences are generally required for certain species, fishing areas or gear. In some PICTs the deployment and use of anchored fish aggregating devices is also regulated (e.g. Samoa). In most PICTs, a permit is required for export of fish and fish products. About a third of PICTs also require a permit or registration for fish processing activities.

Aquaculture activities are subject to either licensing or registration in 40% of PICTs.

Traditional practices

Some of the PICTs recognise traditional practices though their constitution (e.g. Chuuk, Yap, and Vanuatu) or through statutory laws (e.g. Cook Islands, Fiji, Samoa, Solomon Islands, Tuvalu and PNG). Traditional fishing methods and practices can also be recognised and taken into consideration when developing a management plan (e.g. Kiribati, Marshall Islands, Nauru, Timor-Leste and Tonga) or a policy (e.g. Northern Mariana Islands). For others, such as American Samoa, Guam or Niue, some traditional fishing methods can be recognised under the fisheries act and regulations. Finally, traditional fisheries (e.g. for cultural or ceremonial purposes) can be exempted from certain prohibitions, as in New Caledonia or Solomon Islands.

How can policies be implemented to achieve sustainable development? This is the policy framework.

Policies and management plans are adopted at national level to direct government action and resources to the development of coastal fisheries and aquaculture, in accordance with the legal framework.

Currently, 70% of PICTs have adopted a national sustainable fisheries policy focusing on coastal fisheries. Half of these PICTs have also adopted specific policies and plans for the management of designated fisheries targeting vulnerable or high-valued species.

In some countries such as Cook Islands, Fiji and Solomon Islands, fisheries management plans are enforceable as regulations. Alternatively, management plans can be transposed into regulations and bylaws or become part of the terms and conditions attached to a fishing licence.

Solomon Islands. ©Zahiyd Namo

Kiribati. ©Patrick Rose, SPC

A coastal fisheries policy supporting CBFM is in place in 60% of PICTs, which indicates governments' willingness to scale-up CBFM in line with recent regional policy directions, namely the Pacific Framework for Action on Scaling-up CBFM 2021.

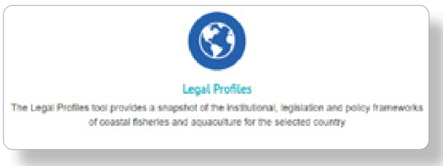
Finally, at least 50% of PICTs have adopted aquaculture sector policies, and aquaculture management and development plans, including on aquatic biosecurity.

You can find all this information and more on REEFLEX Legal Profiles to help change words into action.

Where can I find the legal profiles?

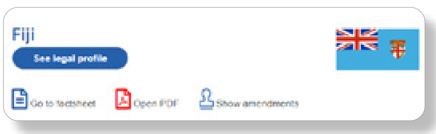
You can access the 23 Legal Profiles on coastal fisheries and aquaculture from the REEFLEX homepage by clicking on the icon that points to the overview tool:

- "Legal Profiles"



Alternatively, you can access each legal profile from the respective PICT page in the search tool:

- "Find Laws & Policies"



Do not hesitate to contact us if you want to provide us with updates, know more about REEFLEX or get advice on how to use the different tools in your fisheries management and research activities.

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Mini-FADs for *vaka* fishers: A creative solution to improve catch consistency in Niue

Launoa Gataua and Andrew Hunt

Niue has a unique fishery that provides regular catches of large and small pelagic fish such as yellowfin tuna, wahoo and scad. The culture of traditional *vaka* canoe fishing in Niue is as popular today as it was in the past, with fishers utilising both wooden craft and more modern canoes, and catching fish using a mix of traditional fishing methods as well as modern high-end rods and reels.

This *vaka* fishery is an important contributor to food security. While many catches are eaten by families of fishers, some of the catch is also sold to small restaurants catering to tourists on the island, or sold in the market for local consumption or for bait. One drawback of the *vaka* fishery has always been the inconsistency of catches. Catches can be very good when the season, tides and weather are in alignment, but other times quite disappointing, especially when conditions are less than ideal. Finding ways to develop the *vaka* fishery to ensure more consistent catches has been an ongoing challenge for staff of the Niue Fisheries.

A solution was to deploy near-shore mini fish aggregating devices (mini-FADs), exclusively reserved for use by the *vaka* fishery, and deployed in shallow water close to the island to provide locations for consistent catches, especially for scad. This idea came to former Niue Fisheries staff member James Tafatu, and acting Principal Fisheries Officer Launoa Gataua, seven or eight years ago. At the time, the Niue FAD programme had only just started; FAD materials were scarce and reserved for conventional offshore FAD deployment. In recent years, however, the fisheries office has had access to more FAD materials, as well as to a large search and rescue vessel donated by the New Zealand Aid Programme. Together, these enabled the deployment and testing of mini-FADs.

In 2019, six mini-FADs were deployed at depths of around 15–35 m and close to shore on the leeward side of the island. One mini-FAD was deployed near a small village, while two or three were deployed near larger settlements. Due to the shallow depth of deployment, Niue Fisheries staff were able to deploy the FAD anchors first, and later attach the rope and buoys using dive equipment.

Local fishers and village councils were consulted before and after deployment of the mini-FADs, which were found to be very popular and well used by most communities. The mini-FADs have provided an accessible and reliable fishing ground for small pelagic species such as scad, as well as occasional catches of large pelagic fish such as dogtooth tuna and yellowfin tuna. Data collection work through the SPC Tails app has been undertaken to assess the frequency of use and catch composition from these mini-FADs in order to better inform the deployment of subsequent FADs. Since the initial deployment, community demand for additional FADs has been strong and a new mini-FAD was deployed in early 2022 off the north end of the island, with more planned as equipment becomes available.

This creative approach to supporting a traditional canoe fishery is a great success story for Niue Fisheries. Working in close consultation with communities and fishers, the Niue Fisheries team hopes to continually improve the programme with new ideas and innovations.

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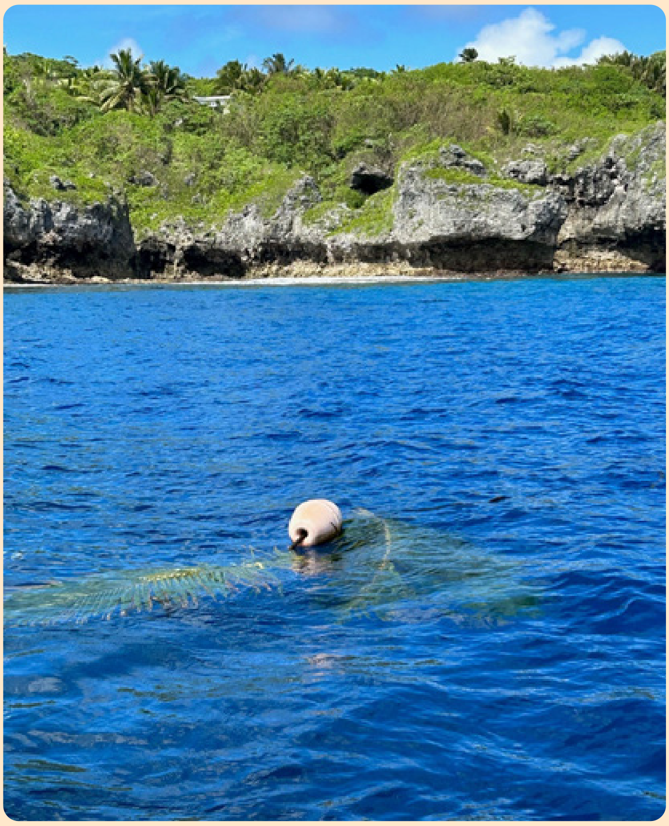

A close-up view of one of the mini-FADs. The coconut fronds attract and provide habitat for small pelagic fish. ©Launoa Gataua

Niue fisheries team performing maintenance on one of the mini-FADs. ©Launoa Gataua

My experience as a junior consultant working on the Benefish study

In late 2022, as a new graduate from the University of the South Pacific, I was asked if I would be interested in working with a well-known fisheries specialist on co-authoring a book on fisheries and economics. The Pacific Community (SPC) was interested in having a junior Pacific Islander work with the main consultant, Robert Gillett, with the idea that the junior recruit would learn how the study is carried out and, hopefully, be able to do similar work in the future. After a lot of thinking about my career path, and discussions and encouragement from my mentors, and despite some hesitation, I finally submitted my CV and was interviewed by Mr Gillett, the man who was to soon be my boss and mentor.

Before getting started with the job, I had to familiarise myself with the work I would be immersed in for the next few months and did a bit of studying of my own. The project – called the "Benefish Study" – was first carried out in 2001, then revised in 2008 and 2016, and brought together various types of fisheries information on the benefits of fisheries to Pacific Island countries and territories.[1] The study was written into a series of three books, all authored by Mr Gillett, and each book includes a chapter for each Pacific Island country and territory covering: 1) recent annual fishery harvests: values and volumes covering six fishery production categories; 2) fishing contribution to gross domestic product; 3) fishery exports; 4) government revenue from the fisheries sector; 5) fisheries employment; and 6) fisheries' contribution to nutrition.

Some of the work that this study entails was completely new to me but has been a good learning experience for me. Throughout the eight or so months that I have been a junior consultant, I have had the privilege of travelling with Mr Gillett to several Pacific Island countries for the purpose of learning how in-country visits work, the protocols for entering each country and organising meetings, as well as having the pleasure of making connections with some of the fisheries officials across the Pacific. Prior to the travelling, I assisted Mr Gillett with conducting internet searches relevant to fisheries in the Pacific, and learned how to analyse the information procured from fisheries agencies. At the early stages of the study, due to the COVID-19 pandemic, contingency plans for visiting countries had to be carefully devised and much time was spent with finding out the entry requirements for each Pacific Island country. Subsequently, I made trips to Nauru, New Caledonia, Samoa and Tonga, all of which provided me with new challenges and memorable experiences.

In October 2022, I made my first work trip to Samoa and Tonga, and learned much about the way the study is implemented. Because it was my first trip, I was optimistic about the way in which we were received by the Ministry of Fisheries. The room was full of fisheries officials who were all evidently happy to gather as much information for us as they could. It was from this trip that I tried to observe and learn the processes by which things were conducted, as well as mentally taking in tips from Mr Gillett about getting the information we need. First, I learned that even though it might look positive conducting a meeting with a room full of people from various sectors, some fishery officials shied away from speaking. Second, Mr Gillett stressed the importance of getting the requested fishery reports and documents while in the country because promises to send them by email often do not happen, and I had to learn this the hard way.

By the end of the Samoa and Tonga trip, Mr Gillett had enough confidence in me to send me off to Nauru by myself to carry out the same work. Preparations for my first solo trip were difficult but most of all, I was nervous; not because I was a woman travelling alone or that I would not have anyone to rely on if I needed help, but because I was doubtful that my young, inexperienced self would not be able to do as good a job as Mr Gillett. Although I felt like I was "thrown into the deep end of the pool", as Mr Gillett would say, I thought that maybe there is no better way to learn something. So, I took on the task and left for Nauru with a positive mindset. Because Nauru received its first COVID-positive case that year, restrictions were tight and self-isolation was necessary for a few days. Thereafter, I went back and forth between the Bureau of Statistics and the Nauru Fisheries and Marine Resources Authority and managed to speak to a few locals about their views and struggles, and I learned just how challenging collecting information can be. Nonetheless, I was able to appreciate the work experience and enjoyed the trip, regardless of the work pressure. I was also able to take up a colleague's offer on giving me a tour of the country as it only took an hour to see the whole of Nauru.

Shortly after returning to Fiji, I dove straight into writing Nauru's country chapter after reviewing a few other country chapters written by Mr Gillett. Subsequently, I was also given the task of writing Niue's chapter as well. Throughout the process of writing, editing and reviewing all country chapters, there were a lot of interesting features that emerged from the study, and a few stood out to me and are worth mentioning here. Evidently, a lot of the fisheries information was produced by national statistics offices and there sometimes seemed to be a lack of cooperation between national statisticians and fisheries officials on fisheries matters. Another interesting finding was the degree of reluctance of some of these countries with sharing their national fisheries information, especially financial data. Additionally, another

[1] The 2016 edition of *Fisheries in the economies of Pacific Island countries and territories,* the "Benefish study", is available from: https://purl.org/spc/digilib/doc/pvyuo

finding that stood out was the lack of knowledge or record-keeping of aquaculture production in most Pacific Islands countries. Considering the amount of money spent on developing aquaculture, it was astounding to find that very little was known about current production; so, this was an area in which Mr Gillett had to spend a lot of time. On a more positive note, although most fisheries agencies are usually dominated by men, Mr Gillett and I held a meeting with all female fishery officers in Samoa, which was very encouraging to see.


The author, Merelesita Fong

For a newly graduated young person, working on a project as big as this one presented a lot of challenges that I had to overcome. The first one was struggling to understand the economics part of the study, which I had no experience or background in. Mr Gillett helped me out a lot in this area, from conducting classroom sessions in his little office in Suva or even at airports during our travel, to pushing me out of my comfort zone and encouraging me to ask questions in meetings with statisticians. Another challenge during this study was, interestingly, planning each in-country visit and making sure every national entry requirement was met. I only realised later when I had to prepare for my trip to Nauru, just how much time is spent on carefully planning and considering dates and time schedules, especially having them correspond to when fisheries officials would be present in the country. Prior to travelling, a lot of time was also spent on trying to satisfy COVID-related entry requirements, but by the end of the study, almost all COVID restrictions had been removed. Lastly, a personal challenge I faced was going through a lot of self-doubt. Having to conduct meetings with highly experienced and senior fishery officials can be a little intimidating, especially when they are expecting a fisheries consultant but find a very young and timid woman instead. It was demotivating at first, but I am slowly learning to overcome this challenge as I gain more experience in this line of work.

Having joined Mr Gillett on his fourth series of the Benefish study has been a rewarding experience. Some of my successes from this study, I would say, include accomplishing a solo work trip to Nauru. This was something I never thought I was capable of doing. Nevertheless, I was pushed out of my comfort zone, and with Mr Gillett, I was driven to gain a better understanding of the processes of conducting this study and the many challenges that come with in-country visits. Another one of my successes is having the privilege of travelling to other Pacific Island countries and territories and expanding my network of people within other national fisheries agencies. This was further expanded after my last country visit to New Caledonia (SPC Headquarters) with Mr Gillett in early 2023. Visiting the headquarters in Noumea proved to be eye-opening; to see how things worked at SPC, as well as familiarising myself with various people from different fisheries sectors and positions, turned out to be a memorable experience. Having built connections with a variety of people in the fisheries sector will surely be useful for future collaborations as well as with sharing information. Finally, I have come to understand self-reflection and feel I have made a conscious effort to improve myself. After spending a lot of time with Mr Gillett for the duration of this study, I have come to realise that it takes more than just knowledge and experience to successfully carry out a project such as this. Anyone who knows Robert Gillett would agree with me when I say he is a man of determination, and whatever he sets his mind to, he gets. This study, through Mr Gillett, has taught me the importance of extreme discipline and hard work. Although I have a lot to work on, I have progressed from the woman I was before taking on this study.

All in all, the Benefish study has provided me with the opportunity to expand my career in more ways than one. It has allowed me to grasp the careful preparations that are carried out before undertaking country visits, and to consider how best to conduct a meeting correctly for the purpose of effectively and efficiently procuring fisheries information. During my travels, along with building my network, I was able to connect with officials and locals and learn about the various fisheries systems in place. This study has enlightened me with interesting insights into fisheries in the Pacific, and throughout the process has brought me many successes along with tough challenges. With these lessons and experiences, I only hope to improve and develop my career in the fisheries sector.

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Assessing resource status using length-based spawning potential ratio – A first step towards sustainable resource management on Wallis Island

Baptiste Jaugeon,[1] Gabrielle Cotonéa,[1] Benjamin Flais,[1] Savelina Taiava[1] and Jeremy Prince[2]*

Abstract

Starting in 2019, the Fisheries Unit of the Wallis and Futuna Department of Agriculture, Forestry and Fisheries has been carrying out activities with its partners aimed at sustainable coastal resource management. The unit started collecting data as part of the Pacific Territories Regional Project for Sustainable Ecosystem Management on landed fish catches to assess the status of fisheries resources. The length-based spawning potential ratio (LBSPR) methodology was applied to assess the spawning potential ratio (SPR) of fisheries populations off of Wallis Island. The results suggest that the species assemblage is less overfished than other Pacific Islands. Species catch compositions, however, showed that fishing occurred at lower trophic levels. Some 23 of the 45 species assessed are considered to be sustainably fished (SPR >0.3), and 11 species had an SPR below the replacement threshold of SPR>0.2 (i.e. below the threshold at which species are able to renew their population). These species may be vulnerable because of selective fishing pressure, such as night spearfishing or fishing during spawning periods, which prevents stocks from recovering. This fresh information on Wallis Island's resource status sheds new light for discussions on fishing practices and management measures.

Introduction

Small-scale coastal fisheries are essential to the food security and subsistence of over 200 million people globally, and over half the world's catches are made by small-scale fisheries (Garcia and Newton 1995). Unlike large-scale commercial fisheries, which are regularly monitored for their economic impact, small-scale fisheries lack the means required for well-informed resource management (Prince et al. 2019). This is the case in most Pacific Island countries and territories, where there are large numbers of reef fish species but data on catch trends and biology are insufficient for applying standard methods for assessing trends in biomass (Prince et al. 2019). The lack of biological information on reef fish catches has been a long-term challenge for their assessment and management (Andrew et al. 2007; SPC 2015).

A new methodology based on assessing reproductive potential in terms of length (LBSPR) has recently been developed for determining the status of data-poor fisheries (Hordyk et al. 2015). It combines the catch-length composition and local estimate of length at maturity to provide the spawning potential ratio (SPR) of a given population (Prince et al. 2019). A stock's SPR indicates its reproductive potential at a

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More than 14 youth gained valuable skills in data collection and analysis during the spawning potential survey in Wallis. They were not afraid to dive into their mission. @Gabrielle Cotonéa.

given fishing rate as compared with its maximum reproductive potential (Mace and Sissenwine 1993). It can be used as a population status indicator (Hordyk et al. 2015), providing an indication of whether the population is likely to decline, increase or remain stable (Prince et al. 2020).

Unfished or lightly fished stocks complete their full life cycle and reach 100% natural reproductive potential (SPR = 1). Conversely, fishing shortens specimens' average lifespans, thus reducing their potential for spawning to below 100% of the natural unfished level (Prince et al. 2021).

At around 0.5, SPR is considered ideal and results in the best catch rate for fishers (Prince et al. 2019). An SPR between 0.3 and 0.5 may be considered a fishing rate that could provide maximum sustainable yields (MSY) leading to maximum production long term (Prince et al. 2020). An SPR of 0.2 is regarded as the replacement threshold (Mace and Sissenwine 1993). This is the internationally established benchmark above which stocks must be maintained to reduce the risk of long-term decline (Prince et al. 2019). Below this point, the recruitment of young fish is expected to diminish.

Fishing has declined considerably in Wallis and Futuna. In 2020, only 9% of Wallisian households fished and ate fresh fish compared to 35% in 2006 (Bouard et al. 2021). Although these figures are related to a declining (human) population (the territory lost 22% of its population from 2003 to 2018), they also reflect profound societal change and possible dwindling resources (Jaugeon et al. 2022). Despite this, there are very few management measures addressing fishing methods, and the available data on Wallis and Futuna are insufficient for providing an objective picture of resource status. The perception surveys carried out by the Fisheries Unit in 2018, 2019 and 2020, revealed varying perceptions of resource status by stakeholders. Some fishers reported dwindling lengths of fish and catches, but this observation was, however, only infrequently seen as a problem and often came with a degree of fatalism and no expectation of any action to be taken. As far as most respondents were concerned, there was no causal relationship between fishing methods and diminishing resources. External factors, such as global warming and foreign ships were often cited instead. In 2021, Jaugeon and Juncker recommended developing resource monitoring and community-wide communication on the link between the various pressures and changes in resources as the first step towards setting up sustainable, participatory coastal resource management in Wallis and Futuna.

The European Union-funded Pacific Territories Regional Project for Sustainable Ecosystem Management (PROTEGE) enabled the Fisheries Unit of the Wallis and Futuna Department of Agriculture, Forestry and Fisheries to set up its own coastal fisheries observatory. The unit was able to apply the LBSPR method to regularly collected landing data. The method was specifically selected to conduct participatory work with communities and provide objective data for discussions about resource status in order to work towards sustainable marine resources management.

The assessment of resources fished off Wallis and Futuna using the LBSPR methodology is a first. This report presents the results, advantages and limitations of the method and the various implications for introducing participatory sustainable marine resource management on Wallis and Futuna.

Material and methods

Landing surveys

This study was carried out on Wallis Island in the French overseas territory of Wallis and Futuna. Data collection occurred from January 2020 to March 2023. A Responsible Fishers contest was held in 2021 and throughout 2022 to encourage fishers to take part in data collection. Several prizes were offered to fishers to encourage them to complete daily surveys. The database covered most fishing methods and all fishing grounds off Wallis Island were sampled. Each data collection exercise on catch lengths from a single fishing trip was called a "survey".

From January 2020 to March 2023 21,519 fish were measured. In all, 32 surveys were conducted, and 32 fishers took part in them. Surveys were carried out at the fishers' landing locations, points of sale or at fishers' homes. Samples were taken from some 20 landing sites, and surveys were conducted when fishers returned from their trips.

Data was gathered using the IKASAVEA app developed by the Pacific Community (SPC) in Noumea, New Caledonia.

Table 1: Data collected on fishing trips and effort through landing surveys.

Trip data	Effort data
• Landing site • Departure and return date and time • Targeted fisheries • Reason for fishing • Vessel information (name, vessel type, engine type) • Value (in French Pacific francs) of fuel used for each trip	• Fishing method • Area (high seas, coastal waters, lagoon) • Habitat (coral, seagrass, mangrove) • Time spent fishing • Fishing ground (defined by the Fisheries Unit)

Collecting data and enjoying pleasant conversations with local fishers. ©Chloé Faure

Several data points were requested from the fishers and entered into the app.

For each fishing trip, all of the caught fish were photographed on a special 100 cm x 70 cm tarpaulin developed by SPC. A ruler and scales were also used. Specimens' fork lengths were measured to the nearest millimetre by image analysis. Older length data had been measured manually to the nearest half centimetre. All data collected were transferred to, and analysed using, a landing survey database and coastal fisheries web application set up by SPC.[3]

LBSPR assessment method

The LBSPR assessment method is based on the fact that a fished population is dependent on the F/M ratio, known as relative fishing pressure, where *F* denotes fishing mortality and *M* natural mortality, and both life history ratios – M/k and L_m/L_∞, where k is the von Bertalanffy growth coefficient. L_m, which is also known as L_{50}, is length at maturity (i.e. the length class in which 50% of individuals reach maturity, and L_∞ is asymptotic length (i.e. the length an individual would reach if left to grow indefinitely (Hordyk et al. 2015). The model's algorithms calculate SPR by comparing catch lengths to length at maturity (Prince et al. 2020)

The data inputs required for the LBSPR model are:

i. catch size data, indicating fish lengths within a population;
ii. estimated length at maturity, defined by L_{50} (or L_m) and L_{95}, the lengths at which 50% and 95% of the population become mature (Prince et al. 2020);
iii. the L_m/L_∞ ratio, which is the relative length value obtained by dividing initial sexual maturity (L_{50}) by the length a specimen would reach if left to grow indefinitely (L_∞);
iv. the M/k ratio, which is a measure of the speed at which each species grows to asymptotic length (L_∞) (Prince et al. 2021).

Based on the assumed M/k and L_∞ parameters and a given targeted stock's length composition, the LBSPR model estimates the species' selectivity curve. This logistic curve is defined by the selectivity parameters at lengths SL_{50} and SL_{95} and by relative fishing mortality, which are then used to calculate SPR (Hordyk et al. 2015).

[3] https://www.spc.int/CoastalFisheries/FieldSurveys/LdsSurvey

Like many length-based methods, the LBSPR model relies on a number of assumptions that need to be made arbitrarily in data-poor fisheries. Such underlying assumptions include asymptotic selectivity, growth as described by the von Bertalanffy equation, equal catchability between sexes, normal length distribution, constant natural mortality among adult age groups, and a constant growth rate among a stock's cohorts (Prince et al. 2015a).

The M/k and L_m/L_∞ model input parameters used in the study were estimated values taken from a meta-analysis conducted by Jeremy Prince using available studies on age, growth and maturity of Indo-Pacific reef species (Prince et al. 2023)

SPR assessments were carried out on RStudio software using the LBSPR package.

Determining length at maturity

Two methods were used to determine L_{50} and L_{95} lengths at maturity. The first method, based on length frequency was used for all species analysed. The method consists of converting the left-hand side of the catch length-frequency histogram into a cumulative frequency curve, as the 50^{th} percentile of that curve approximates histological estimates of size at maturity. For this method, it is important to have specimens from each length class. This may lead to problems when immature specimens are not targeted or included in catches. When only mature specimens are caught in every length range, this can partially or totally distort the definition of the length-at-maturity curve (Prince et al. 2020). When this occurs, L_{95} is calculated as 15% above L_{50}.

A second method, based on macroscopic gonad observation, was used. Because this method requires more time and resources, it was used for the most heavily targeted and eaten species. Macroscopically determined sizes at maturity were used for LBSPR analysis for the following species: *Caranx melampygus, Chlorurus microrhinos, Epinephelus polyphekadion, Etelis coruscans* and *Lutjanus gibbus*.

Results

More than 271 finfish species were recorded during the study, showing the diversity of catches from Wallis Island. Such diversity also revealed how unselective fishers were and that the environment was ciguatera-free. Because the species were so diverse and so many fishing methods were used, the species recorded were very mixed. Samples of more than 1000 specimens were reached for only three species, namely *Acanthurus xanthopterus* (2908), *Lutjanus gibbus* (2595) and *Crenimugil* spp. (1866). Some 14 species had 300 to 1000 specimens, 18 species had 100 to 300 and 10 other species had 50 to 100 specimens.

Fourteen fishing methods were recorded. Some 7460 fish (38% of catches) were obtained by daytime spearfishing, 5197 (22%) by gillnetting and 4965 fish (21%) by handlining. The remaining fish were caught using manual or electric droplines, cast nets, night spearfishing or line casting.

To ensure the results were viable, a minimum threshold of 50 length measurements was set for each species. Species for which distributions were not representative, or for which SPR values were too variable (confidence interval or

A ruler and scale device was used to measure and weigh fish like this *Monotaxis grandoculis*, the humpnose big eye bream. ©Baptiste Jaugeon

Table 2: LBSPR assessment input parameters. Ideal fishing in green (SPR >0.5); fished at maximum sustainable yields (MSY) in orange (0.3 <SPR <0.5), and overfished in red (SPR <0.3). Values with confidence intervals (95% CI 95%. Average SPR = 0.42 (95% CI 0.33–0.52).

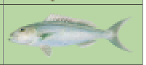
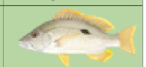
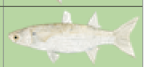
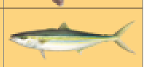
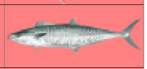
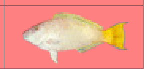
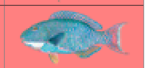
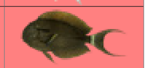
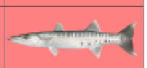
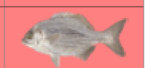
Species	No. of specimens	SPR	SL_{50} (cm)	SL_{95} (cm)	F/M	M/K	Linf (cm)	L_{50} (cm)	L_{95} (cm)	Fishing technique	Harvest status	
Caranx melampygus	570	1 (1–1)	29.62 (28.15–31.09)	36.88 (33.83–39.93)	0 (0–0)	1.15	52.93	32.29	41.24	Line, net, spearfishing	Optimal	
Lutjanus bohar	346	1 (1–1)	32.13 (29.03–35.23)	45.49 (39.79–51.19)	0 (0–0)	0.75	44.59	33.00	37.95	Line, net, spearfishing	Optimal	
Aprion virescens	203	1 (1–1)	40.37 (38.94–41.8)	43.88 (40.88–46.88)	0 (0–0)	0.75	59.82	44.27	50.91	Line and spearfishing	Optimal	
Epinephelus howlandi	78	1 (1–1)	26.34 (24.65–28.03)	29.08 (25.78–32.38)	0 (0–0)	0.96	43.15	28.48	32.75	Line and spearfishing	Optimal	
Variola louti	68	1 (1–1)	31.15 (23.83–38.47)	43.51 (30.33–56.69)	0 (0–0)	0.96	45.53	30.05	34.56	Line and spearfishing	Optimal	
Etelis boweni	103	0.99 (0.85–1)	23.29 (20.88–25.7)	29.33 (24.81–33.85)	0.01 (0–0.12)	0.75	36.27	26.84	30.87	Line	Optimal	
Acanthurus olivaceus	180	0.97 (0.53–1)	19.13 (17.64–20.62)	22.02 (19.4–24.64)	0.03 (0–0.45)	0.47	24.78	20.07	23.08	Line and spearfishing	Optimal	
Lutjanus monostigma	191	0.91 (0.61–1)	25.19 (23.41–26.97)	30.05 (27.08–33.02)	0.07 (0–0.33)	0.75	38.23	28.29	32.53	Line and spearfishing	Optimal	
Etelis coruscans	298	0.9 (0.65–1)	49.97 (46.22–53.72)	62.96 (56.62–69.3)	0.08 (0–0.32)	0.75	74.41	55.06	63.32	Line	Optimal	
Caranx ignobilis	159	0.79 (0.52–1)	55.78 (50.45–61.11)	71.93 (63.03–80.83)	0.2 (0–0.51)	1.13	91.44	56.69	65.19	Line and spearfishing	Optimal	
Lutjanus gibbus	2595	0.6 (0.56–0.65)	24.21 (23.98–24.44)	26.86 (26.43–27.29)	0.5 (0.41–0.59)	0.75	34.34	25.41	34.20	Line and spearfishing	Optimal	
Lethrinus xanthochilus	311	0.59 (0.44–0.74)	34.23 (31.47–36.99)	42.99 (38.53–47.45)	0.69 (0.22–1.16)	0.82	47.79	33.45	38.47	Line and spearfishing	Optimal	
Crenimugil spp.	1866	0.52 (0.48–0.55)	38.04 (37.45–38.63)	43.64 (42.69–44.59)	0.97 (0.79–1.15)	1.66	54.88	36.77	42.29	Net	Optimal	
Ellochelon vaigiensis	693	0.48 (0.43–0.54)	31.27 (30.93–31.61)	33.44 (32.85–34.03)	0.77 (0.59–0.95)	1.66	47.78	32.01	36.81	Net	MSY	
Lethrinus harak	137	0.46 (0.32–0.6)	22.54 (21.75–23.33)	24.86 (23.47–26.25)	0.81 (0.38–1.24)	0.82	34.09	23.86	27.44	Line and spearfishing	MSY	
Naso hexacanthus	476	0.45 (0.36–0.54)	45.17 (43.38–46.96)	51.95 (49.19–54.71)	2.1 (1.14–3.06)	0.47	51.14	41.42	47.63	Spearfishing	MSY	
Cephalopholis argus	97	0.38 (0.24–0.52)	25.29 (23.92–26.66)	28.91 (26.45–31.37)	1.05 (0.46–1.64)	0.96	39.85	26.30	30.25	Line and spearfishing	MSY	
Epinephelus fuscoguttatus	166	0.37 (0.15–0.59)	66.54 (54.54–78.54)	87.99 (71.36–104.62)	1.89 (0.05–3.73)	0.96	89.55	59.10	67.97	Line and spearfishing	MSY	
Acanthurus xanthopterus	2908	0.33 (0.29–0.37)	39.15 (38.23–40.07)	49.02 (47.69–50.35)	2.6 (2.15–3.05)	0.47	44.80	36.29	41.66	Spearfishing	MSY	
Epinephelus maculatus	145	0.33 (0.22–0.44)	30.46 (28.8–32.12)	35.74 (32.86–38.62)	1.25 (0.67–1.83)	0.96	48.24	31.84	36.62	Line and spearfishing	MSY	
Elagatis bipinnulata	82	0.33 (0.17–0.49)	53.1 (47.46–58.74)	64.68 (55.35–74.01)	1.33 (0.4–2.26)	1.13	87.44	54.21	62.34	Line and spearfishing	MSY	
Acanthurus blochii	296	0.32 (0.25–0.4)	31.24 (29.94–32.54)	37.52 (35.45–39.59)	2.38 (1.45–3.31)	0.47	38.23	30.97	35.62	Spearfishing	MSY	
Sphyraena qenie	260	0.32 (0.21–0.43)	74.87 (65.81–83.93)	99.14 (84.65–113.63)	1.68 (0.81–2.55)	1.01	127.17	67.4	77.5	Line and spearfishing	MSY	

Table 2 con't

Species	No. of specimens	SPR	SL_{50} (cm)	SL_{95} (cm)	F/M	M/K	Linf (cm)	L_{50} (cm)	L_{95} (cm)	Fishing technique	Harvest status	
Chlorurus microrhinos	*763*	0.3 (0.27–0.34)	34.74 (34.08–35.4)	39.25 (38.04–40.46)	1.8 (1.48–2.12)	0.78	51.74	34.15	42.16	Spearfishing	Overfished	
Lethrinus olivaceus	*498*	0.29 (0.17–0.41)	59.58 (56.29–62.87)	77.17 (73.26–81.08)	>5	0.82	64.36	45.05	51.81	Spearfishing, line and net	Overfished	
Scomberomorus commerson	*58*	0.27 (0.1–0.44)	72.51 (63.09–81.93)	90.62 (74.8–106.44)	1.44 (0.36–2.52)	0.79	118.51	80.59	92.68	Spearfishing and line	Overfished	
Monotaxis grandoculis	*255*	0.26 (0.07–0.45)	44.71 (40.72–48.7)	57 (52.39–61.61)	>5	0.82	48.94	34.26	39.40	Spearfishing and line	Overfished	
Lethrinus atkinsoni	*112*	0.24 (0.16–0.33)	27.5 (26.09–28.91)	31.22 (28.85–33.59)	2.44 (1.23–3.65)	0.82	38.97	27.28	31.37	Line	Overfished	
Caranx sexfasciatus	*116*	0.24 (0.03–0.45)	53.62 (43.9–63.34)	68.03 (54.92–81.14)	3.51 (0–7.26)	1.13	74.63	46.27	53.21	Spearfishing and line	Overfished	
Scarus rubroviolaceus	*319*	0.23 (0.16–0.3)	37.54 (35.11–39.97)	45.58 (41.69–49.47)	3.08 (1.84–4.32)	0.78	55.09	36.36	41.81	Spearfishing and net	Overfished	
Hipposcarus longiceps	*334*	0.23 (0.14–0.32)	36.66 (33.73–39.59)	44.67 (40.28–49.06)	4.01 (1.9–6.12)	0.78	50.64	33.42	38.43	Net and spearfishing	Overfished	
Ctenochaetus striatus	*64*	0.23 (0.09–0.37)	18.81 (17.39–20.23)	21.38 (19.19–23.57)	>5	0.47	22.49	18.22	20.96	Spearfishing and net	Overfished	
Cetoscarus ocellatus	*183*	0.22 (0.07–0.37)	45.41 (40.19–50.63)	56.75 (49.75–63.75)	>5)	0.78	58.41	38.55	44.33	Spearfishing	Overfished	
Paracaesio kusakarii	*63*	0.22 (0.04–0.4)	50 (42.02–57.98)	64.68 (53.23–76.13)	2.95 (0.18–5.72)	0.75	65.41	48.40	55.66	Line	Overfished	
Naso unicornis	*299*	0.19 (0.06–0.33)	48.08 (44.87–51.29)	59.67 (55.8–63.54)	>5	0.47	51.22	41.49	47.72	Spearfishing and net	Overfished	
Caranx papuensis	*366*	0.19 (0.04–0.34)	55.65 (48.57–62.73)	78.07 (69.52–86.62)	>5	1.13	71.06	44.06	50.67	Net and spearfishing	Overfished	
Pristipomoides flavipinnis	*134*	0.17 (0.06–0.28)	40.33 (37.29–43.37)	49.02 (44.97–53.07)	>5	0.75	48.62	35.98	41.37	Line	Overfished	
Sphyraena forsteri	*360*	0.14 (0.11–0.16)	43.1 (41.98–44.22)	48.33 (46.2–50.46)	3.64 (2.9–4.38)	1.01	79.13	41.94	48.23	Line	Overfished	
Carangoides orthogrammus	*70*	0.14 (0.08–0.19)	36.59 (34.81–38.37)	41.35 (38.32–44.38)	>5	1.13	56.94	35.30	40.60	Net and spearfishing	Overfished	
Acanthurus nigricauda	*709*	0.13 (0.08–0.17)	23.27 (22.71–23.83)	25.74 (25.02–26.46)	>5	0.47	26.91	21.80	25.07	Nett	Overfished	
Scomberoides lysan	*331*	0.12 (0.08–0.16)	43.39 (41.79–44.99)	49.32 (46.92–51.72)	>5	0.79	61.25	41.65	47.89	Net	Overfished	
Sphyraena barracuda	*185*	0.11 (0.08–0.14)	65.86 (63.46–68.26)	75.8 (71.62–79.98)	3.86 (2.82–4.9)	1.01	125.28	66.40	76.36	Spearfishing and line	Overfished	
Kyphosus vaigiensis	*91*	0.09 (0.03–0.15)	35.04 (31.43–38.65)	42.16 (36.46–47.86)	>5	0.50	50.60	34.41	39.57	Spearfishing and net	Overfished	
Scarus ghobban	*81*	0.09 (0–0.19)	39.51 (35.45–43.57)	46.36 (41.07–51.65)	>5	0.78	53.41	35.25	40.54	Spearfishing and net	Overfished	
Epinephelus polyphekadion	*422*	0.07 (0.05–0.09)	39.95 (38.08–41.82)	48.92 (46.07–51.77)	>5	0.96	67.97	44.86	58.59	Line and spearfishing	Overfished	

CI>0.5), were excluded. In total, 45 species were selected for this assessment.

The model results showed varied SPR values for the 45 species assessed. The quality of the model estimates mainly depends on the number of individuals measured. Values were distributed around and above the average SPR value, which was 0.42 (95% CI 0.33–0.52).

However, 11 species fell below the replacement threshold set at 0.2, meaning that the species had a reproductive potential that did not enable it to renew its population and so an "overfished" status was assigned to these species, which was the case for *Caranx papuensis*, *Naso unicornis*, *Epinephelus polyphekadion* and *Scarus ghobban*.

Another 11 species had an SPR of 0.2 to 0.3. Although this was above the international replacement threshold, some authors consider that a stock cannot be sustainably fished below a threshold of 0.3 (Ault et al. 2008). Species such as *Hipposcarus longiceps*, *Scarus rubroviolaceus*, *Scomberomorus commerson* and *Chlorurus microrhinos* were, therefore, also classified as overfished.

A further 10 species, including *Acanthurus xanthopterus* and *Epinephelus fuscoguttatus*, had an SPR of between 0.3 and 0.5, which may be considered a fishing level that is conducive to maximum sustainable yields (MSY) (Prince et al. 2020).

Thirteen species, including *Lutjanus gibbus, Caranx ignobilis* and *Crenimugil* spp., could be considered as fished to ideal levels, with an SPR over 0.5 and were, therefore, classified as well managed and/or moderately fished species, based on the same international benchmarks (Prince et al. 2019).

Discussion

The LBPSR assessment method was used for the first time on Wallis Island.

With the collaboration of some 30 local fishers, data gathering was carried out over a period of three years and the data collected was used to assess the stock status of the 45 most heavily fished reef and lagoon species, 23 of which could be considered as sustainably targeted (SPR > 0.3).

A tarpaulin, designed by SPC, was used to easily collect data at landing sites. ©Gabrielle Cotonéa

Data collection efforts in Futuna increased in 2023. Findings should be available by the end of the year. ©Gabrielle Cotonéa

Fishing pressure and methods that prevent fish stocks from replenishing

The results nevertheless call for caution because, of the 45 species considered, 22 may be considered overfished (SPR <0.3). This means that current fishing pressure is preventing fish stocks from replenishing themselves. The results also agree with fishers' testimonies of a fall in fish lengths and numbers as well as fish being harder to catch.

Off of Wallis Island, catch compositions indicated that fishing was tending towards lower trophic levels (Pauly et al.1998). Larger species, such as *Bolbometopon muricatum*, *Cheilinus undulatus* and *Plectropomus laevis* appeared less often in catches, while other species such as *Epinephelus polyphekadion, Scomberomorus commerson* and *Sphyraena barracuda* had SPRs below 0.2. The fact that smaller species such as *Lutjanus gibbus, Lethrinus xanthochilus* and *Lethrinus harak* appeared in catches also showed that fishing effort was focusing on ever smaller species.

Some species caught mainly by spearfishing and netting in the parrotfish family (e.g. *Scarus ghobban, Scarus rubroviolaceus, Cetoscarus ocellatus, Chlorurus microrhinos* and *Hipposcarus longiceps*) and the Acanthuridae family (e.g. *Naso unicornis, Acanthurus nigricauda* and *Ctenochaetus striatus*) had SPRs below 0.3.

One of the most widespread and harmful fishing methods in Wallis and Futuna is undoubtedly night spearfishing. Although prohibited by regulation, it is still deeply rooted in the customs and practices of many fishers. The method brings a selective fishing pressure to bear on certain species, often the most prolific breeders, which prevents populations from rebuilding their numbers. It has also been demonstrated that it could have a major impact on parrotfish and on grouper spawning aggregations (Gillett and Moy 2006). Despite the lack of data on this method, there is no doubt that it has harmful effects on resources. Even during the day, spearfishing cannot be discounted from the methods contributing to overfishing in coastal waters, as it can have fast-acting, deleterious effects on populations due to its effectiveness and selection of species that are unable to withstand the pressure (Gillett and Moy 2006). Stringent management, therefore, needs to be introduced, especially as the method targets herbivorous fish, such as surgeonfish (Arcanthuridae) and parrotfish (Scaridae), both of which provide essential ecosystem services for maintaining coral reefs.

Satisfactory outcomes for the region

The 0.42 average SPR value obtained (CI 95% 0.33–0.52) fell within the international standard interval (0.3-0.4) used as a proxy for fishing levels that may be conducive to MSYs (Prince et al. 2020). The results were more satisfactory than for other Pacific Island countries such as Palau, where the average SPR was only 0.12 for 12 species considered in 2015 (Prince et al. 2015b), or Fiji where the average SPR was 0.19 for 29 species assessed in 2019 (Prince et al. 2019). The SPR for *Lutjanus gibbus* species, for example, was 0.6 at Wallis Island but only 0.09 in Fiji and 0.10 in Palau. Results were closer to those observed in Solomon Islands in 2020, where average SPR was approximately 0.35 (Prince et al. 2020).

Gonad analysis at the DSA veterinary clinic. ©Baptiste Jaugeon

The camouflage grouper *Epinephelus polyphekadion* had the lowest SPR at 0.07. At that stage, the stock can be considered collapsed, and *E. polyphekadion* is under heavy fishing pressure (F/M >5) and can be caught either by spearfishing, netting or handlining. Like other Serranidae family species, *E. polyphekadion* populations appear to be sensitive to fishing pressure, as seen in Fiji, where stock assessment results highlighted the species' fragility at SPR 0.03 (Prince et al. 2019). These low estimates may be due to the species' breeding method. During the breeding season, they form brief spawning aggregations in which hundreds or even thousands of fish gather and breed in the various inlets (Rhodes and Sadovy 2002). Around Wallis, fishers regularly, even systematically, fish in the inlets, which are passageways for a multitude of species and large specimens that are less commonly found in the lagoon. Some fishers, however, increase their fishing effort during spawning aggregations to catch as many specimens as possible, which may affect breeding in some species.

Prospects for sustainable participatory coastal resource management on Wallis Island

One of the study objectives was to raise awareness among local communities regarding the threats to their marine resources. Such participatory work with fishers is a means of informing them about the causal link between fishing and dwindling resources. Marine ecosystems face many pressures such as climate change, eutrophication of coastal waters, habitat damage and pollution, all of which have increasingly harmful effects on fisheries. Overfishing, however, remains the main human-induced factor (Prince et al. 2021). Before the Wallis and Futuna fisheries observatory was set up, the local community did not seem to be particularly concerned when faced with a decline in some species, and did not see coastal resource management as a priority. Several measures have now been taken under the Wallis and Futuna coastal resource management strategy, enabling various stakeholders (fishers, traditional leaders and managers) to rally around a shared interest. The preliminary study results have recently stimulated discussion over introducing resource restoration management measures and provide a glimmer of fresh hope for reef and lagoon resource management on Wallis Island.

Although some species are not directly in danger of collapse, applying management measures, such as banning night spearfishing, temporarily banning fishing on spawning grounds and imposing minimum catch sizes on Wallis Island would help increase SPR levels to above 0.3, thus ensuring that fishers gain better yields and stocks remain more resilient to global environmental changes. Awareness and communication campaigns in this area must continue in order to ensure management measures are effectively applied.

Despite the limitations encountered, the LBSPR method proved to be the best option for assessing small-scale fisheries on Wallis Island. A more accurate estimate of species size at maturity and SPR can be achieved by collecting larger samples. Data collection has begun on Futuna, and the data gathered will ultimately provide the information required to manage reef and lagoon resources for both islands.

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An effective tool for shared management of marine resources: The Coastal Fisheries Observatory

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Coastal fisheries observatories (CFOs) were developed and implemented in New Caledonia and Wallis and Futuna to provide managers information on the status of the resource stocks. The observatories' primary missions are to collect, manage and analyse coastal fisheries data in order to communicate them to everyone involved in this sector.

Thanks to the relationships of trust and cooperation established with fishers, these tools have proven to be relevant and effective: the status of the stocks of commonly consumed or high-value commercial species is now known, just as are certain key biological parameters for managing the resource.

After describing the context in which the CFOs were developed, this paper will address the following questions: What is a Coastal Fisheries Observatory? Who does it serve and what is its purpose? How does it operate? What resources does it need? What data does it collect and what relevant information can be drawn from them? What is the future for a CFO?

History and context

Fisheries play a critical role in the lives of Pacific Islanders, who depend, in large part, on coastal marine resources for their food security. Fishing practices there are very diverse and subsistence fishing represents 67% of the total volume of seafood taken from lagoon areas in 2014 (Gillett 2016). Coastal fisheries must be managed sustainably to ensure that island ways of life and economies can be sustained.

Sustainable management of these resources requires detailed knowledge of all fishing activities (including gear, efforts and areas) and catches (species targeted, volume by species and size of individuals caught). While information may exist regarding some Pacific Islands, only partial knowledge is available for the overall activity due to its diversity, the irregular provision of data, and the unreliability of data on fishing effort and catches.

To improve the collection system, a structure that centralises and analyses data on coastal fisheries would provide regular, objective and reliable information to better understand the sector and its development.

Under the auspices of the PROTEGE project, financed by the 11th European Development Fund and implemented by SPC, both New Caledonia and Wallis and Futuna - two Pacific territories with very different environmental, socio-economic and cultural contexts – sought to establish coastal fisheries observatories to manage their resources (Figure 1). The overall objective of PROTEGE is to build sustainable and climate-resilient economies in the Overseas Countries and Territories to address climate change by emphasising biodiversity and renewable natural resources.

In New Caledonia, where lagoons and reefs cover an area totalling 23,400 km^2, all three provinces and the New Caledonia Government have jurisdiction over coastal marine resource management. These four authorities have expressed the desire to develop a tool to collect, centralise and standardise all fisheries data to achieve overall management of the resources, harmonised across the territory. Their shared need to acquire additional knowledge about marine resources contributed to this shared desire to create a single platform.

In Wallis and Futuna, a much smaller territory, where lagoons and reefs cover 932 km^2,[6] coastal fisheries operate under the Fisheries Service, within the territory's Agriculture, Forestry and Fisheries Department (Jaugeon and Juncker 2021). The lack of information on catch trends and the state of the resource prompted the desire to create a structure that could meet the expectations of fisheries stakeholders – fishers, managers, elected officials and traditional leaders – in terms of marine resources management.

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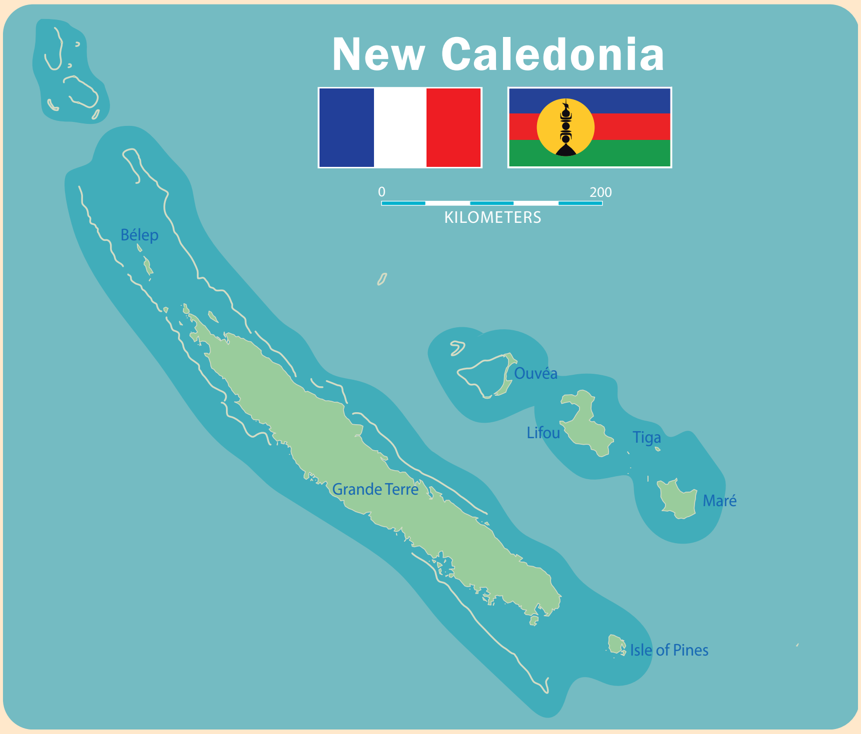
6 Reef and lagoon area, excluding shoals.



	New Caledonia	Wallis and Futuna
Population	270,000 inhabitants	13,500 inhabitants
Lagoon and reef area	23,400 km^2	932 km^2
Coastal fisheries annual catch	8700 tonnes	around 200 tonnes
Percentage of commercial catch	15%	16%
Number of species caught		227

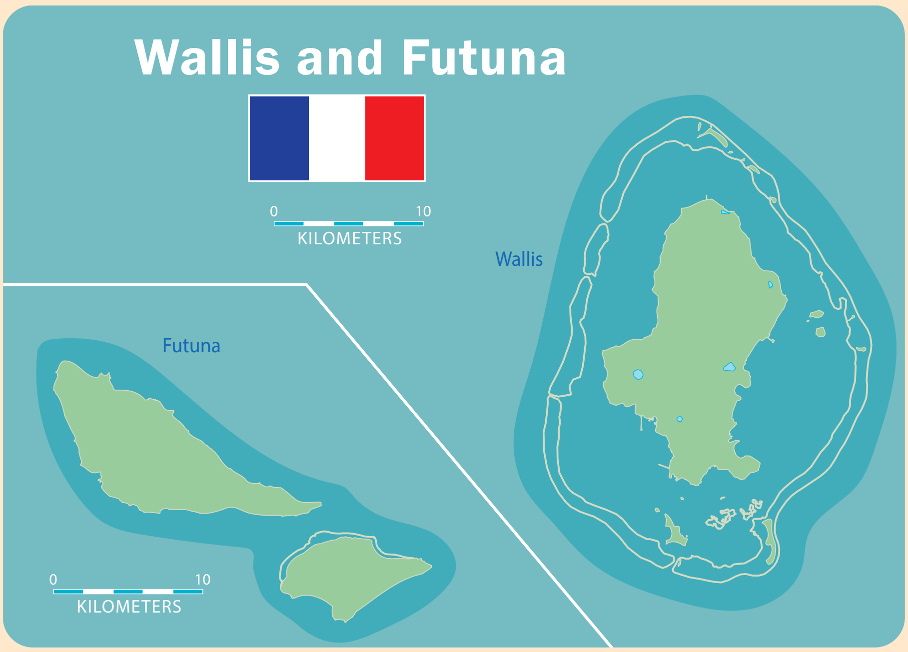


Figure 1. New Caledonia and Wallis and Futuna island groups, showing coastal fishery areas (dark blue).

So, because the institutions responsible for marine resources management in New Caledonia and Wallis and Futuna lacked all the data needed to prevent risks of overfishing of various coastal marine species, they wanted to set up a CFO.

Thanks to the earlier feasibility study on implementation of the New Caledonia CFO, conducted in the territory's South Province (Guillemot and Leopold 2017), as well as the organisational efforts of ADECAL-Technopole,[7] concerned stakeholders' specific questions and expectations were identified. In Wallis and Futuna, the CFO implementation feasibility study incorporated the needs of all the fishery actors, as well as the population's perceptions in terms of the acceptability of an observatory (Preuss and Sabinot, 2021). Identification and consideration of all the needs proved to be critical for ensuring that stakeholders were properly represented.

In very different contexts but with a common interest: "to improve knowledge for more effective management", the CFOs in New Caledonia and Wallis and Futuna were established in February 2020 and September 2021, respectively These CFOs were set up to validate their operational feasibility, based on the PROTEGE 2020-2030 action plan. This phase constituted a real opportunity to shape and design each CFO to ensure their long-term existence.

An observatory for whom and for what purpose?

Definition and genesis of an observatory

An observatory is a mechanism by which to observe, analyse and communicate, launched by one or more organisations to monitor developments in an area over time and space (Lemoisson et al. 2008). In general, it seeks to address sustainable resource management and biodiversity issues and involves multiple stakeholders. For example, in the context of developing a major mining project in southern New Caledonia, an area of remarkable natural wealth, the community's questions and concerns and the need for institutional stakeholders to obtain information on the conservation measures to be taken strongly shaped the emergence of the New Caledonia Environmental Observatory (OEIL) (Juncker 2015).

One feature common to all of these observatories is the existence of an information system. This system involves IT infrastructures, through which the data collected are stored, analysed, and then reported on in summary form as tables, maps or indicators. The information produced is based on science and is objective, neutral and impartial.

Given the specific characteristics of coastal fisheries in the Pacific – diverse practices, diverse species, a very significant and little-known subsidence sector – a CFO offers the advantage of banking a host of very varied data. The data collected or produced include information on fisheries, biological and socio-economic conditions drawn from a geographic area reaching from the coast to the outer reef slopes.

Lastly, a CFO is defined as a tool for collective action that networks a range of stakeholders (fishers, public authorities, elected officials, traditional leaders, research organizations and NGOs) to set up exchanges, participate in discussions, conduct studies on the coastal resources' status, acquire biological knowledge, and, ultimately, contribute to decisions regarding sustainable fisheries management. Facilitation of a CFO is critical to enabling collaborative work among partners, as well as the sharing and dissemination of information.

CFO's objectives and mission

A CFO has three key objectives:

- **Facilitate understanding** of the coastal fisheries sector by producing fishery statistics and indicators on the status of resources and fisheries;
- **Inform decision-making and issue alerts** based on the analysis and monitoring of the indicators characterizing the fisheries and resources; and,
- **Inform and support fishers** and managers through knowledge-sharing.

To achieve these objectives, a CFO has the following key missions (Figure 2):

- **Acquire knowledge** about coastal fisheries and the status of the resource;
- **Produce, collect, centralise, organise and standardise** biological, fisheries and socio-economic data;
- **Analyse and interpret** those data, **produce indicators and identify alert thresholds**;
- **Promote and communicate the information** produced on various media and to a wide audience; and,
- **Facilitate a network of stakeholders** involved in coastal fisheries through this single authoritative platform, which also provides a forum for exchange and consultation on fisheries issues.

[7] Semi-public, non-profit organisation (under the Association Law of 1901), created to promote innovative projects, particularly with regard to the development of marine and land biological resources in New Caledonia. The General Assembly brings together representatives of public authorities and organisations representing the private sector and the research communities. Its members by right, which primarily finance the CFO, are the French Government, New Caledonia, and the Northern, Southern and Loyalty Islands provinces.

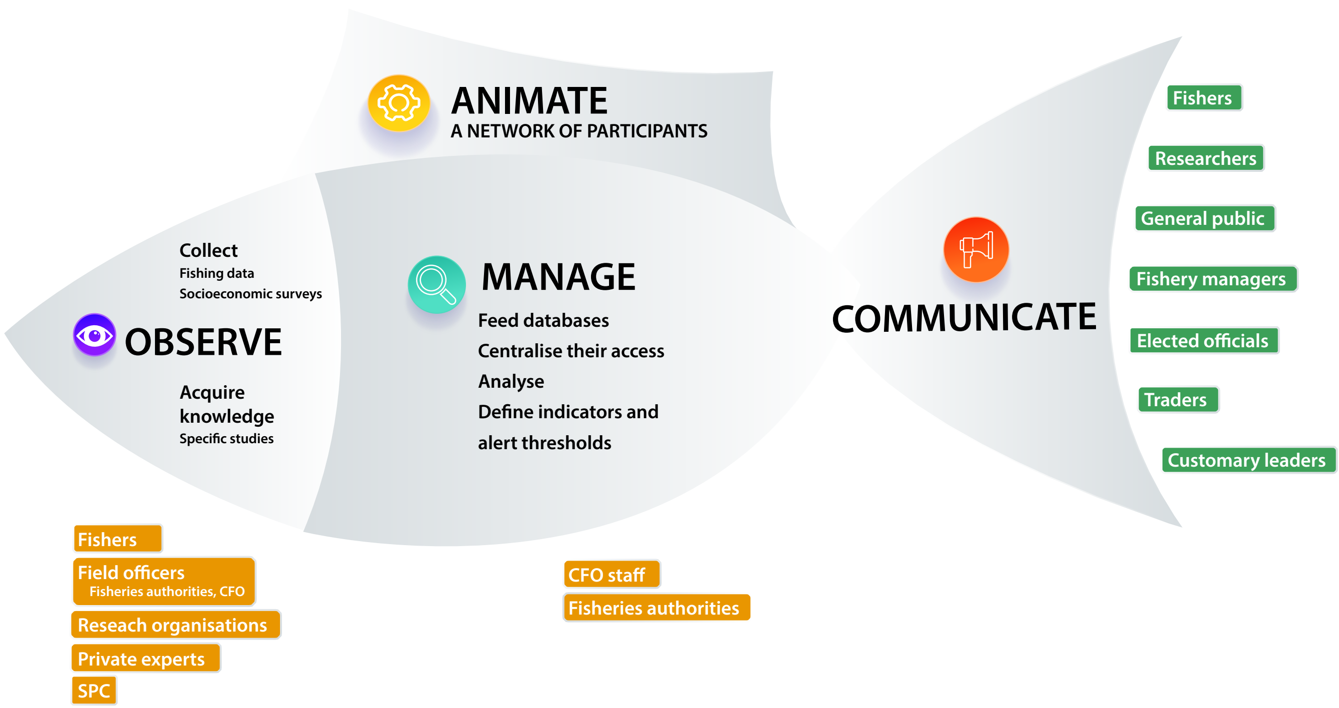


Figure 2. The Coastal Fisheries Observatory's missions, stakeholders and targets.

Thanks to the New Caledonia and Wallis and Futuna CFOs' experience, the main factors essential to the proper operation and success of an observatory can be identified:

- **Clear, consensus-based identification of the objectives** and the issues that the tool should address;
- **Definition of a technical and scientific framework** for collecting and processing the data;
- **Active, ongoing facilitation**;
- **Development of a relationship of trust** among the stakeholders;[8]
- **Regular communication** targeted to different audiences; and,
- **Ensuring the continued use of the tool** and **regular updating** of the data.[9]

All stakeholders recognise that an observatory's **mediation** function is central and essential to its success. An observatory can play a meaningful role only if it serves as an intermediary, providing a forum for stakeholders to engage with one another, discuss, and define an issue or, even, a controversial topic (Piveteau, 2011).

Who are the CFO's target audiences?

The CFO is, above all, a tool to serve public authorities and fishers. Its role also includes informing the community about fisheries and the status of the resource.

Information feedback for fishers is essential to maintain, long-term relationships of trust among the CFO, the public authorities in charge of the fisheries, and fishers, the main suppliers of data. Because coastal fishers are composed of multiple categories (subsistence, recreational and commercial fishers, professional associations and chambers of commerce), the levels of information communicated are adapted to the audience.

Sharing information with the community at large helps increase environmental awareness and the marine resources they depend on.

Identification of the target audiences guides the choice of communication materials (Table 1 and Figures 3 and 4). They fall into two categories:

- **Publishing and digital communications:** annual reports, statistical reviews, PowerPoint presentations, SPC fisheries newsletters, leaflets, videos/films, radio, website, Facebook page; and,
- **Events:** topical festivals, awareness-raising campaigns, meetings with associations and villagers.

[8] Provide reassurance specifically that the CFO is not a monitoring tool used to impose sanctions.

[9] Resource monitoring is only meaningful over the long term.

Table 1. Range of communication materials and their audiences.

Communication materials	Audience
Annual reports and statistical reviews	• Internal • Technical committees and working groups • SPC and other research entities • Chambers of commerce and professional associations • Commercial fishers • Elected officials and decision-makers
Verbal feedback and individual annual files	Commercial fishers
PowerPoint presentations	• Elected officials and decision-makers • Commercial fishers • Chambers of commerce and professional associations
SPC fisheries newsletters	SPC member countries and territories
Leaflets, video/film, radio, website, Facebook page	• Elected officials and decision-makers • Commercial and non-commercial fishers • Traditional leaders • Technical services • Businesspeople • Public at large
Events (for example, Fishing symposia in New Caledonia and Fisheries Fridays in Wallis and Futuna	• Commercial and non-commercial fishers • Traditional leaders • Managers and technical services

Figure 3. Sustainable fishing day in Wallis and Futuna.

How does a CFO operate?

Governance

The CFO is the product of a shared commitment among several partners who may represent public authorities, the private sector or the research community. All of the stakeholders involved in fisheries agree to the objectives set by the observatory, following completion of the feasibility study. Thus, governance of a CFO is generally assigned to a group of stakeholders who come together as a steering committee, whose role is to define broad guidelines for the Observatory's work.

In New Caledonia, a steering committee was created, composed of public authorities, professional associations, the Chamber of Agriculture and Fisheries, and ADECAL Technopole.

It meets two times/year to define the strategic plan, approve the actions and studies to be conducted, and plan the budget.

In Wallis and Futuna, a fisheries consultative committee composed of all relevant fisheries stakeholders meets regularly to present the Observatory's data and results.[10]

Organisation and human resources

An observatory may adopt one of these three organizational forms as its legal structure (ADEME 2011):

- Tool managed and led by an existing entity;
- Network of several founders, coordinated by an existing entity; or,
- Its own legal structure.

In both New Caledonia and Wallis and Futuna, an existing structure sponsors and houses the CFO. In Wallis and Futuna, that structure is the Fisheries Service of the Agriculture, Forestry and Fisheries Department, which manages the observatory and reports to the Territorial Assembly. In New Caledonia, ADECAL Technopole was the consensus choice, as it already deals with issues of the sustainable management of marine resources at the territorial level.

The human resources needed for the proper functioning of a CFO vary based on the objectives and the human resources available within the existing structure.

The professions required for the proper functioning of an observatory involve the following responsibilities and activities:

Figure 4. Examples of communication materials (cover of the New Caledonia CFO's annual report and internet site, cover of the Wallis and Futuna CFO's annual report and Facebook page).

[10] The committee includes the Customary Minister of the Environment, the Customary Minister for the Primary Sector, the Chair of the Agriculture and Fisheries Committee, the head of the Economic Affairs and Development Department, the head of the statistics office, the DSA director, the Territorial PROTEGE Coordinator, the PROTEGE fishing and aquaculture facilitator within the DSA, the Wallis and Futuna CFO agent within the DSA, several village chiefs, members of fishers' associations and federations, commercial fishers, young fishers, recreational fishers and store managers.

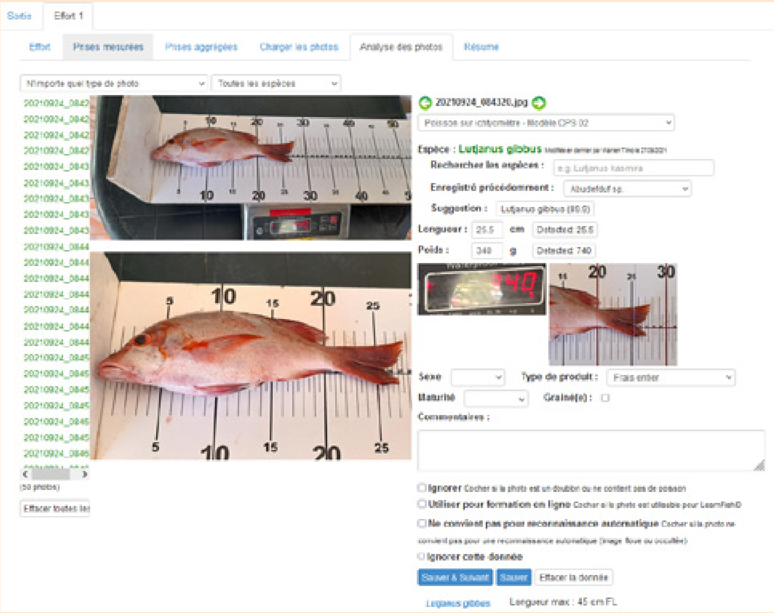


Figure 5. Measuring board and scale analysis module: the device automatically recognises the species, length and weight of each individual.

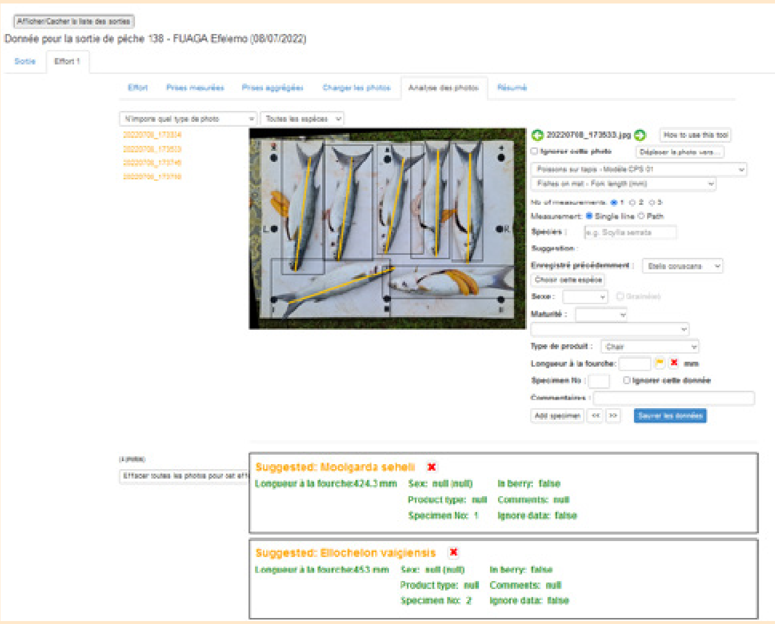


Figure 6. Analysis module of landing mat photos: the device recognises the fish species laid out on the tarp designed for that purpose. Each species must then be selected and measured using the measurement tool.

- Coordination and management, which are essential to the group dynamics of the stakeholder network and to ensure that relationships of trust are maintained between fishers and the CFO;
- Data collection by field agents: their proximity to fishers helps to maintain a relationship of trust and improve the quality of data collected. The number of field agents varies based on the geographic scope to consider (currently, three in New Caledonia (one/province) and two in Wallis and Futuna (one/island); and,

Communication, which is the culmination of the observatory's work. This may be carried out by one or two in-house agents or be outsourced.[11]

In addition to the agents dedicated to these CFOs, other human resources provided by the host organizations and their partners can contribute significantly to accomplishing the observatories' mission, including by providing data, participating in data collection and analysis, and relaying the CFOs' communications. This cooperation – between a dedicated coordination unit and a network of involved stakeholders – is what makes the CFO tool effective.

Technical and financial resources

Developing a CFO requires anticipating a budget for a feasibility study, which is essential to determine the observatory's scale and design, based on its objectives.

An initial investment budget provides funding to hire the CFO team and acquire the necessary equipment, IT infrastructure and digital applications.[12]

A basic operating budget allows the CFO to launch operations. In addition to funding for staff, the budget should include funds to conduct routine biological, fisheries and socio-economic monitoring and analyses, as well as for monitoring and analyses dedicated to CFO communications, facilitation and management (administrative, accounting, logistical and IT). Human resources are the largest budget category, accounting for more than half of the operating budget.

An additional budget should be anticipated to finance specific activities (for example, to address a specific resource or for a given activity) and to hire additional staff as needed.

These two CFOs were financed with European Union funds through the PROTEGE programme for 2019-2023. They also receive ongoing scientific and technical support from SPC's Coastal Fisheries Programme.

[11] For both CFOs, PROTEGE provided funding for the communication strategy, which each observatory then took ownership of and adapted to its own context.

[12] The investment level varies by the country's need to develop its own IT platform, which is more expensive than using the existing applications developed by SPC.

Regarding digital applications, Wallis and Futuna received support from SPC's FAME Division to develop data collection and entry protocols. The data collected are entered using the IKASAVEA application and hosted on the SPC's coastal fisheries portal. This portal features several modules, including LANDING SURVEYS, used for landing surveys; FISHER LOGBOOKS, for fishing logs; and DATA DEPOSITORY, for hosting databases created outside of the CFP portal. Devices such as "fish on measuring board" and "fish on landing mat" are used to facilitate data collection and minimise the time spent in the field (Figures 5 and 6).

New Caledonia also uses entry and analysis modules developed by SPC. However, given the need to compile data from different institutional bases, it purchased its own IT and statistical tool: the Meta-Info Centre (MIC).[13] This tool can link all of the existing databases if they are completed using compatible formats.

The interface allows for intuitive, dynamic interaction between data and graphics. It is thus possible, at any time, to extract raw data and summary graphics and complete some 40 indicators related to fisheries and the resources used (Figure 7). This tool also helps to improve the collection of source data, providing feedback on their use.

From data collection to indicator-based management

Source data and indicator examples

The data collected deal, first, with commercial fisheries. Those data are easier to access and are drawn from different sources: fishing logs, fishers' surveys, and biological sampling during landing, at markets or at other sales locations. Surveys of fishers' perceptions of the status of the resource and how it is changing help to enrich the quality of the database.

Data on non-commercial catch are often unavailable on a country/territory-wide level. They are estimated indirectly based on household consumption data collected during population surveys or censuses or from specific surveys of non-commercial fisheries. The 2019 household consumption survey conducted in Wallis and Futuna is an example (Bouard 2021).

A study of catch estimates from rural non-commercial fisheries has just been completed in New Caledonia. Based initially on three pilot sites, it was used to develop and implement a reproducible method that relies on distinguishing between two types of fisheries: daily and event based. It was also used to extrapolate catch at the municipal area level (Faure et al. 2022). The ultimate purpose of the CFOs is to integrate monitoring of subsistence and recreational coastal fishers and to step up monitoring efforts.

The information gathered is grouped into four large categories of indicators, outlined in Table 2.

Certain indicators are calculated using measured parameters. For example, a species' size measurements are used to develop the size structure by species, providing information on the status of the fished population. The spawning potential of the proportion of juveniles in catches is another example of an indicator built based on data collected in the field, such as size at sexual maturity.

Conclusive and meaningful results

Over the last three years, the two CFOs have built their structure and implemented systems to collect, process and disseminate data specific to each, adapted to their socio-economic and cultural contexts, and that evolve in line with their needs.

The New Caledonia CFO carried out 25 activities during its first three years. Some of its accomplishments involved analysing fisheries and biological data collected during landings or based on fishing logs, while others focused on improving the knowledge of certain species where stock status is still unknown. The mangrove crab (*Scylla serrata*), snappers (*Etelis* spp., *Pristipomoides* spp.) and the humphead parrotfish (*Bolbometopon muricatum*) have received special attention in New Caledonia.

In Wallis and Futuna, an equally large number of activities have focused primarily on the status of marine resources, based on landing measurements, and on improving fisheries data collection and processing.

The two examples below were chosen to illustrate some of the CFO activities.

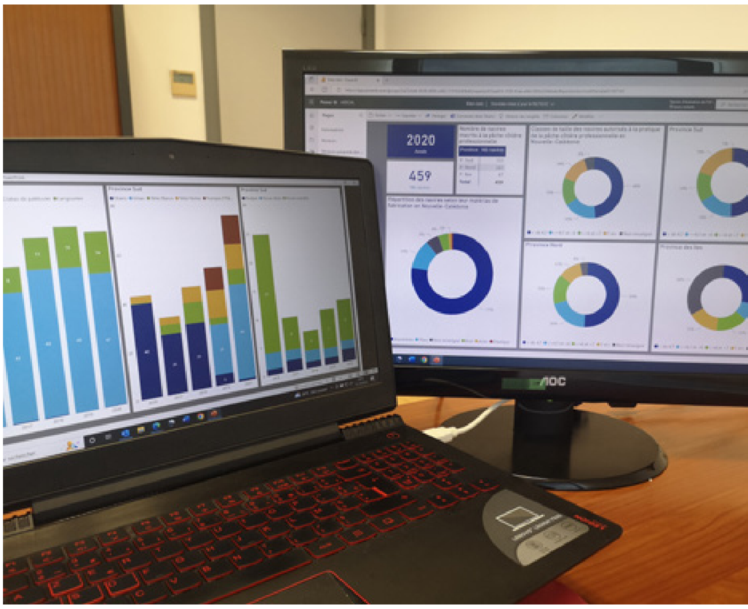


Figure 7. New Caledonia's Meta-Info Centre IT interface.

[13] The technical solution chosen, which uses a very ergonomic interface, relies on Microsoft® tools (Cloud Azure and the Power BI decision-making tool).

Table 2. Classification of information gathered in catch surveys and key indicators chosen.

Nature of the indicator	Key indicators
Fishery	• Fishing effort measured, at the very least, by number of fishing trips and days • Catch by species or group of species, by fishing technique (and by fishing area explored during a trip) • CPUE (catch per unit effort) • Stock status indicators (by species)
Biological	• Length, weight, gonad maturity stage • Size structure • Proportion of juveniles in catches and spawning potential ratio (SPR)
Economic	• Catch value (turnover) • Average sale price by species (first sale and market price) • Fishing trip expenses (including fuel consumption) • Amount of fuel subsidy/kg of catch • Yield: quantity caught/litre of fuel
Socio-professional and administrative, by profession	• Number of seafarers and skippers, on foot or onboard, age and gender • Number of fishing permits/licenses Number of special permits • Number of boats and technical features (size, engine, age, materials) • Fishing log reporting rate • Fuel subsidy access rate

1- **Implementation of an analytic method based on measuring size at sexual maturity of fish sampled in 2022 in Wallis and Futuna. This is a relevant example of assessing stock status for different species caught**.

Information on a species' size at sexual maturity makes it possible to distinguish a juvenile from an adult capable of reproducing. Because a species' size at maturity varies by geographic area, it is important to collect biological data at the local level, reflecting the actual status of the resource at a given location.

The assessments conducted by the CFO and the Wallis and Futuna Fisheries Service helped to determine the stock status of the 45 most-fished coastal fish species, using an indicator calculated based on data recorded during landing surveys. This indicator – the spawning potential ration or SPR[14] – uses an assessment method that compares the size of fish caught to their size at maturity.

From January 2020 to December 2022, more than 20,000 individuals were weighed and measured. Of those, 3200 were analysed to assess the maturity of their gonads, which was used to calculate the percentage of catch of immature specimens for each species (Figs 8 and 9). Of the 45 species assessed, 23 can be considered as having been fished sustainably, with an SPR above 0.3. Eleven species had an SPR below the threshold at which individuals can renew their population, with an SPR below 0.2 (Jaugeon 2023). Figure 10 displays the results for 14 fish species (Wallis and Futuna CFO 2021b).

The results obtained were used to alert managers about the stocks of certain species and guide them toward measures to preserve the impacted resources, particularly regulatory measures. Improving the reproduction potential for these species would increase the number of individuals and, ultimately, improve fishers' yields. The CFO estimated the minimal catch sizes corresponding to the size at which the fish can be caught, having reached a size enabling them to reproduce at least once.

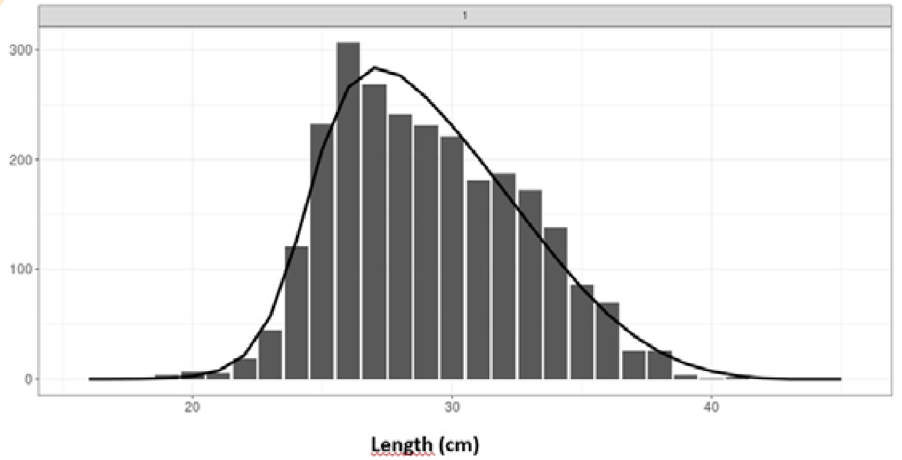
These results were presented at a September 2022 Fisheries Committee meeting. They were also used to catalyse a marine protected area project, at the fishers' own initiative, in Hihifo district. In addition to the benefits expected, the project aims to create public awareness of sustainable fishing.

2- **The New Caledonia CFO coordinated a study assessing the stocks of commercial sea cucumber species in New Caledonia's waters**.

New Caledonia is particularly focused on management of these species, especially because two of the high-valued species – the black teatfish (*Holothuria whitmaei*) and the white teatfish (*Holothuria fuscogilva*) - were listed in Annex II of the Convention on International Trade of Endangered Species (CITES) in 2020. Recent data show a decline in New Caledonian production since 2017, probably linked to unsustainable harvest levels (Gilbert et al. 2022).

This goal of this study, conducted between December 2020 and June 2022, was to assess the stocks of 18 commercial species in nine areas identified as priorities by each of New

[14] The indicator is based on the Length-Based Spawning Potential Ratio (Hordyk et. al. 2015). The LBSPR assessment is a method used in fisheries that have little data to determine the size at maturity of the fish and their spawning potential by species.



SPR	SL50	SL95	F/M	MK	Linf	L50	L95
0.65 (0.6-0.7)	24.41 (24.18-24.64)	27.12 (26.68-27.56)	0.41 (0.33-0.49)	0.977	35.29167	25.41	34.2

Figure 8. Length class frequency histograms for *Lutjanus gibbus* and SPR value (Wallis and Futuna).

Species	% immature individuals in catches
Caranx melampygus	18.65
Acanthurus xanthopterus	6.6
Chlororus microrhinos	8.52
Lutjanus gibbus	18.2
Epinephelus polyphekadion	74.05
Moolgarda sp.	3.07
Hipposcarus longiceps	9.91
Scarus rubrioviolaceus	9.76
Epinephelus fuscoguttatus	18.09
Caranx pauensis	8.54
Etelis coruscans	3.54
Scarus ocellatus	12.9
Lutjanus monostigma	8.27

Optimal exploitation

Maximum sustainable yield

Overexploitation

Figure 9. Percentage of immature individuals caught among 13 species fished (Wallis and Futuna).

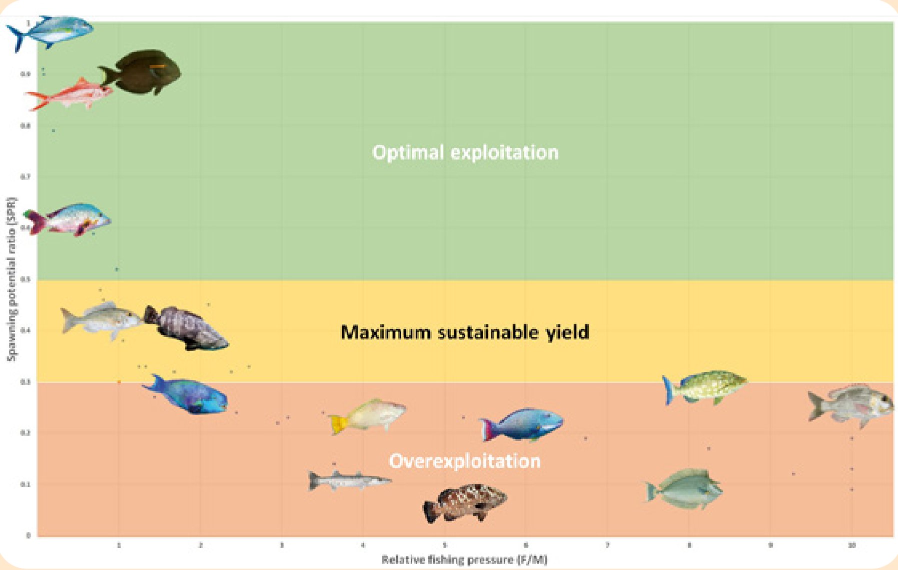


Figure 10. Reproductive potential based on fishing pressure for 14 species fished (Wallis and Futuna).

Figure 11. Teatfish (*Thelenota ananas*) measurement during an underwater sampling in Lifou (Loyalty Islands). ©Matthieu Juncker

Caledonia's provinces. It was used to establish an optimised sampling method for teatfish stocks and to train all provincial and private partners, from theory (during an SPC training workshop) to operational implementation in the field. Underwater censuses of all teatfish species were conducted using the transect method. Densities by species were noted, taking account of habitat types encountered (Fig. 11). The biomass indicators were calculated based on the densities, average weight, and useful area of the habitats for each species.

Approximately 94 hectares (ha) of habitat were sampled over more than 3800 transects, for a useful area mapped of 81,613 ha where the stocks were estimated.

Thirty-one teatfish species were recorded across all nine areas. The total cumulative biomass of 10,136 tonnes, compared to a reference biomass[15] of 2913 tonnes (total wet weight), was estimated with average and low commercial value species clearly dominating (Figure 12).

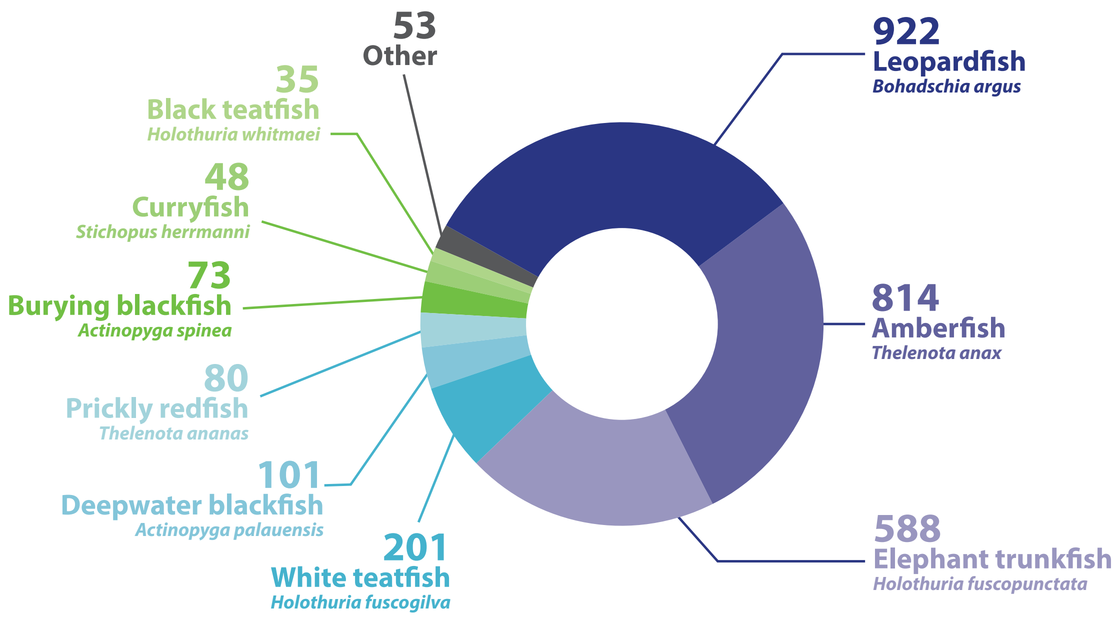


Figure 12. Cumulative distribution of baseline biomass by species for all nine studies in tonnes of total wet weight.

[15] The reference biomass corresponds to the confidence interval lower than the allowable biomass. This involves the stock on whose basis a quota may be defined by area.

The two CITES-listed species were observed at most of the areas where their favourable habitats were sampled. With the exception of two species, the size of the individuals fished was generally larger than the size at sexual maturity, which means that the spawning stock are being exploited.

Managers now have stock estimation logs with detailed information on habitat, species and area. This inventory provides baselines that will be useful if quotas are established for areas identified by the provinces.

Outlook and conclusion

Observation is only meaningful over the long term. Today, after three years of set-up and operation financed by European funds, the CFOs of New Caledonia and Wallis and Futuna are working to ensure their continuity. A strong political commitment could secure the resources to achieve that goal. Another option would be to diversify their funding sources, either through regional or international tenders or partnerships with private operators, such as representatives of the fisheries sectors.

The CFOs still seek to develop and optimise their collection, analysis and communication functions. Today, for example, the data collected provide rough geographic information. They could be refined with a finer-grained analysis of information on catch locations; that would make it possible to assess the state of the resource and appropriate management. The New Caledonia CFO also has plans to link the sea cucumber resource databases developed (including processing ratios, sizes at sexual maturity, exporters' purchase register, traceability from fisher to export, and stock assessment). This will make it possible for the management of this resource to be standardised from fisher to export across the entire territory.

In Wallis and Futuna, the CFO has focused on continuing to perform landing measurements and extending them to Futuna. Spatial resource management is not a current priority as the geographic accuracy obtained is adequate, for now, to understand the overall resource management issues. The Wallis and Futuna CFO continues to focus primarily on minimal catch sizes and fishing practices to be regulated.

Creating the marine protected area (MPA) in the northwest area of the Wallis lagoon is one of the short-term projects supported. To obtain maximum buy-in, the Observatory wants to strengthen and expand its communication efforts, particularly in villages and with youth and student associations, and to set up a private fundraising effort to support the MPA.

In conclusion, these CFOs appear to have become operational structures in less than three years. The support they provide for the sustainable management of coastal fisheries, made possible by relationships of trust and strengthened cooperation among the stakeholders, could inspire other countries and territories in the region.

In the final quarter of 2023, a PROTEGE "lessons learned" workshop on coastal fisheries will be organised with the OCTs and regional experts. This event will provide an opportunity to promote these observatories, which have demonstrated their value, and to share experiences and know-how with the goal of a stronger partnership among the territories.

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Genetic population structure and connectivity of four key coastal fisheries species across the Gilbert Islands of Kiribati

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Introduction

Artisanal coastal fisheries play a major role in providing food security and socioeconomic resilience throughout the Pacific (Gillett 2016). Coastal finfish fisheries are particularly important, accounting for up to 60% of catches from nearshore fisheries landings (Dalzell and Adams 1996). Nearly 80% of these landings are primarily for subsistence (Bell et al. 2009), making fish the main protein source in most Pacific Islands (Charlton et al. 2016). Surplus reef fish are traded at local and regional markets, and sometimes internationally. This supports local economies and provides income for communities (Kronen et al. 2010; Gillet 2016).

Rapidly increasing Pacific Island populations with access to better fishing technology and refrigeration options are responding to the increased demand from local and international markets for fresh seafood. This has increased coastal fishing pressure to unsustainable levels in many locations, and highlights the need to effectively manage coastal resources to avoid a continued decline in coastal fisheries catches. Successful management of coastal fisheries requires appropriate data and information from which to make decisions. Unfortunately, in many Pacific Island nations, such data are limited thus constraining countries' ability to make effective management choices. While national coastal fisheries agencies are tasked with collecting the necessary data, there nevertheless remains a severe shortage of information on the life history and demographics of targeted species across the Pacific Islands.

The Republic of Kiribati, in the central Pacific Ocean, is unique in having three separate archipelagoes: Phoenix, Line and Gilbert islands (Alsied 2006; Kiareti et al. 2015). Kiribati's population relies heavily on marine resources and has the highest fish consumption per capita in the Pacific (Charlton et al. 2016). A recently completed (2019–2020) national household income and expenditure survey (Ministry of Finance and Economic Development Government of Kiribati 2021) indicates a total population of ~ 120,000 people across all three archipelagoes, with about 90% or approximately 108,000 people located in the Gilbert Islands chain. Within the Gilbert Islands, the population distribution is also heavily skewed, with about 58% of the population living in South Tarawa, Kiribati's capital.

Unsurprisingly, the fishing pressure around Tarawa (population 63,000) is degrees of magnitude higher than in other atolls where the next most populated atoll (Abaiang) has a population of only 5500 (National Statistics Office 2016). Such a concentration of fishing effort raises an important question: How resilient to fishing pressure are targeted species around Tarawa? One aspect of this question, which is the focus of this study, is understanding the degree of connectivity that exists between resident fish populations of the same species and those from other atolls. Highly connected populations function as meta-populations and have a much higher degree of overall resilience than do isolated and poorly connected populations (Kritzer and Sale 2004).

This study was part of a broader programme looking at the effects of fishing across a human population gradient in the Gilbert Islands. Three atolls – Tarawa, Abemama and Onotoa – were chosen, each with human populations of 70,000, 3200 and 1400, respectively (National Statistics Office 2016). Surveys identified four coastal fish species as being predominant in catches across all three atolls, so our objectives were to determine how genetically isolated the populations around these atolls were from each other, and to gain insights into the level of meta-population resilience that may be intrinsic to the Gilbert Islands.

The four species of interest were: bonefish, *Albula glossodonta*, an inhabitant of sandy lagoons; sweetlip emperors, *Lethrinus nebulosus* and *L. obsoletus*, which inhabit areas with sandy and rubbly bottoms inside and outside of lagoons; and the paddletail snapper, Lutjanus gibbus, which inhabits areas dominated by coral reef. The genetic structure and connectivity of *A. glossodonta*, *L. nebulosus*, *L. obsoletus* and *Lutjanus gibbus* is either unknown or poorly documented in the Gilbert Islands (Colborn et al. 2001; Friedlander et al. 2007; Wallace 2015). Our principal aim was to determine the degree of population genetic structure and inferred connectivity across three atolls using the highly polymorphic mitochondrial DNA (mtDNA) markers cytochrome b and the control region (Ekerette et al. 2017; Lalitha and Chandavar 2018).

Methodology

Study location

This study focused on the Gilbert Islands with biological samples collected from the three atolls separated by 100 km to 400 km (Fig. 1). Tarawa is the most populated atoll and has the largest lagoon area of 534 km^2, which is three and seven times larger than Abemama (152 km^2) and Onotoa (75 km^2), respectively (Ministry of Internal and Social Affairs 2012a, 2012b, 2008).

Sampling design

Fin clips were sampled opportunistically from fishers' catches at local boat landing sites during creel surveys conducted between May and December 2019 (Gislard 2020). Samples of *Albula glossodonta* and *Lethrinus obsoletus* were obtained for all three atolls, while samples of *L. nebulosus* were obtained from Tarawa and Abemama atolls, and *Lutjanus gibbus* from Abemama and Onotoa. In total, 241 fin clips were collected and preserved in 95% ethanol: *Albula glossodonta* (n=85), *L. nebulosus* (n=47), *L. obsoletus* (n=52) and *Lutjanus gibbus* (n=57) (Table 1).

Because *A. glossodonta* is morphologically almost indistinguishable from Indo-Pacific sympatric species of the same genus (Wallace 2015) – *A. vulpes*, *A. oligolepis*, *A. argentea*, *A. virgata*, *A. escuncula* and *A. gilberti* – genetic analyses for this species were first concentrated on confirming species identity before connectivity analyses were done.

DNA extraction, mitochondrial DNA (mtDNA) amplification and sequencing

Total genomic DNA was extracted from a 1 cm^2 piece of fin tissue using a DNA extraction kit. Depending on the species, cyt b or CR markers were used. Such markers (mtDNA) are known to be sensitive to differentiation at the population level (Askari et al. 2013; Grunwald et al. 2002; Imtiaz et al. 2017).

Amplifications by polymerase chain reaction (PCR) and Sanger sequencing were then performed by Macrogen. More details on PCR and sequencing conditions are summarised in Table 1.

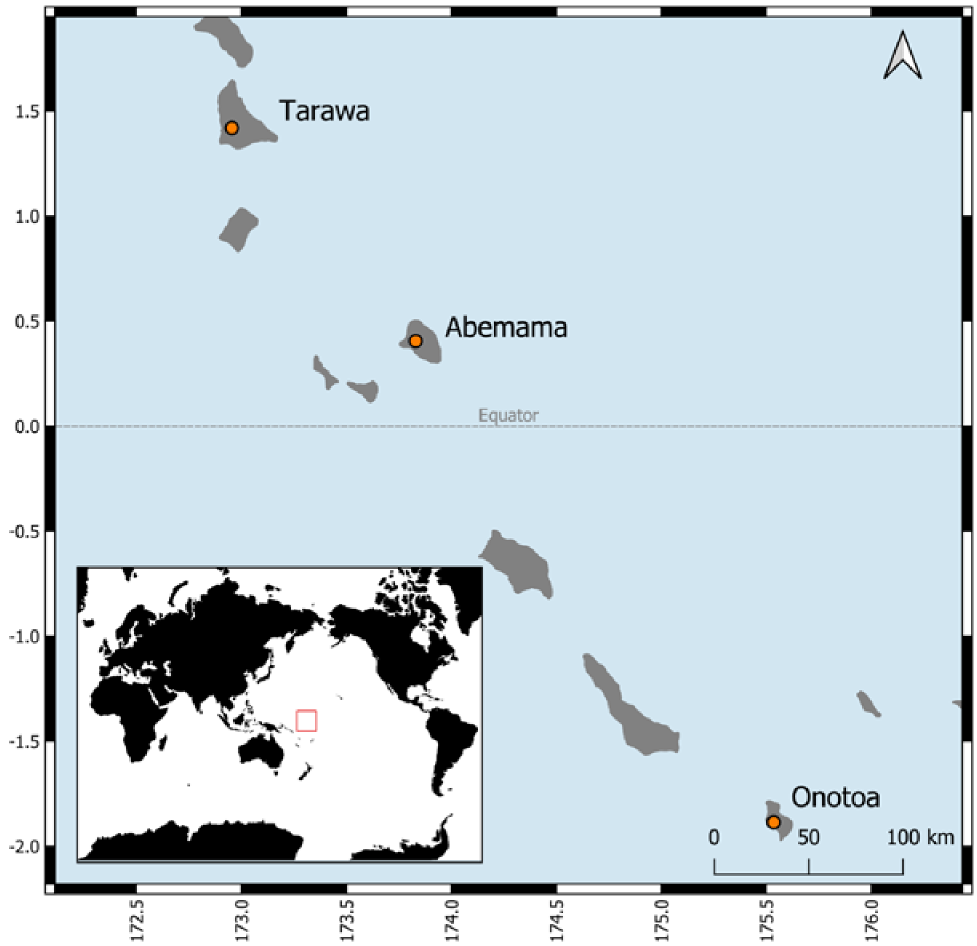

Figure 1. Biological sampling locations in the Gilbert Islands (orange dots). Grey represents land and reef area.

Table 1. Parameters of mitochondrial DNA amplification for four reef fish in the Pacific Ocean. The accession number gives access to the sequence on the National Center for Biotechnology Information open data.

Species	Markers	Sense	Primers sequences	Accession number
Albula glossodonta	Cyt b	Forward	5'-GTCTCCAAGAAGGTTAGGCGA-3'	OL542768 OL542781
		Reverse	5'-TGCTAGGGTTGTGTTTAATTA-3'	
Lethrinus nebulosus	CR	Forward	5'-CGGTCTTGTAAACCGGATGT-3'	OL580786 OL580794
		Reverse	5'-GTCATGGCCCTGAAATAGGA-3'	
Lethrinus obsoletus	CR	Forward	5'-CGGTCTTGTAAACCGGATGT-3'	OL580795 OL580810
		Reverse	5' GTCATGGCCCTGAAATAGGA-3'	
Lutjanus gibbus	Cyt b	Forward	5'-TGGCAAGCCTACGCAAAAC-3'	OL580811 OL580827
		Reverse	5'-TATTCCGCCGATTCAGGTAA-3'	

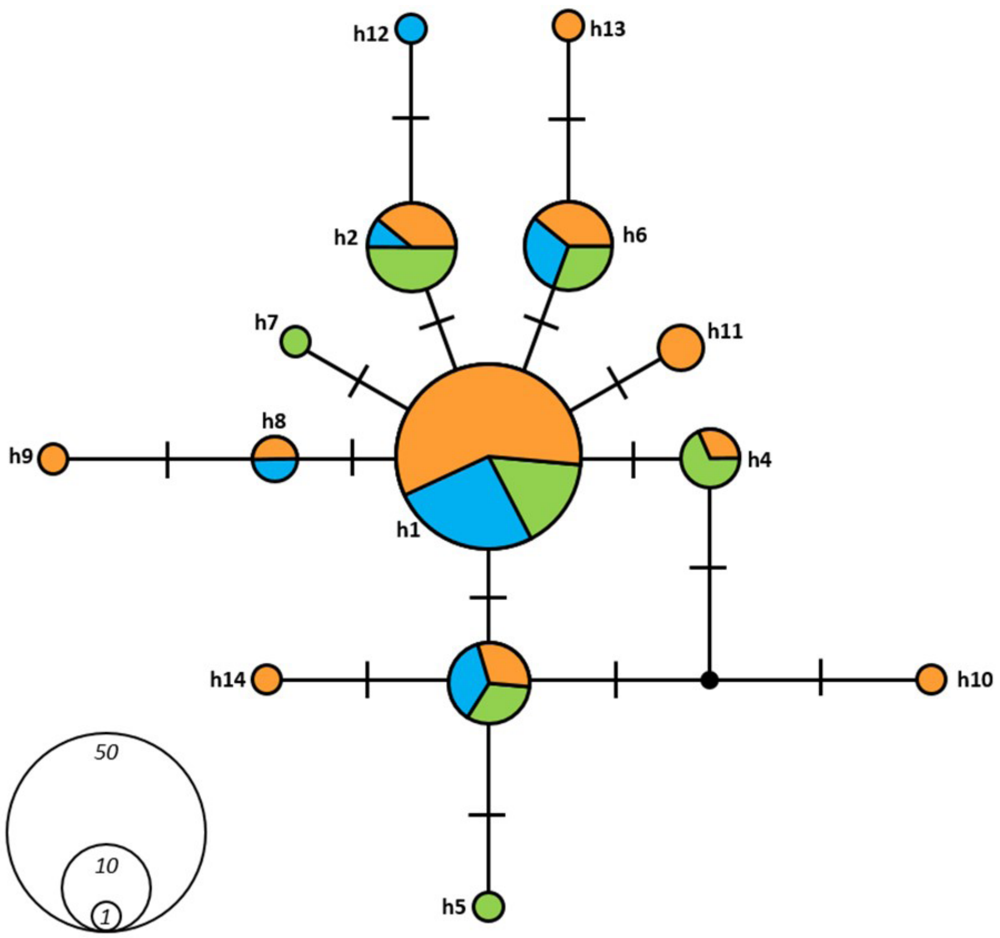

Figure 2. Median-joining haplotypic network among *A. glossodonta* individuals. Circles represent haplotypes with their size proportional to individual frequencies. Colours represent regions of origin (blue: Onotoa; orange: Abemama; green: Tarawa). Length of black lines represent the number of base changes. Black dots represent unsampled median haplotypes.

Genetics analysis

Sequences were aligned and manually edited using Mega software (Kumar et al. 2018). To confirm Albula samples were actually *A. glossondonta*, all sequences were compared to the nucleotide collection from the National Center for Biotechnology Information (NCBI), an international genetics database hosted by the United States National Library of Medicine.

To investigate genetic diversity among atolls, the genetic structures were estimated at both the haplotype (h: haplotype diversity) and nucleotide (π: nucleotide diversity) levels (Nei 1987) using the software Arlequin v 3.5. (Excoffier et al. 2007). To investigate the evolutionary history of the populations, potential bottlenecks were tested using neutrality tests (Tajima's D test and Fu's FS test). Genetic differentiation between atolls was assessed with a pairwise fixation index for haplotype frequency differentiation (FST).

A haplotypic network of relationships among the Gilbert Islands' mtDNA haplotypes was constructed with Network V10.0 (Fluxus Technology) to visualise connectivity between locations.

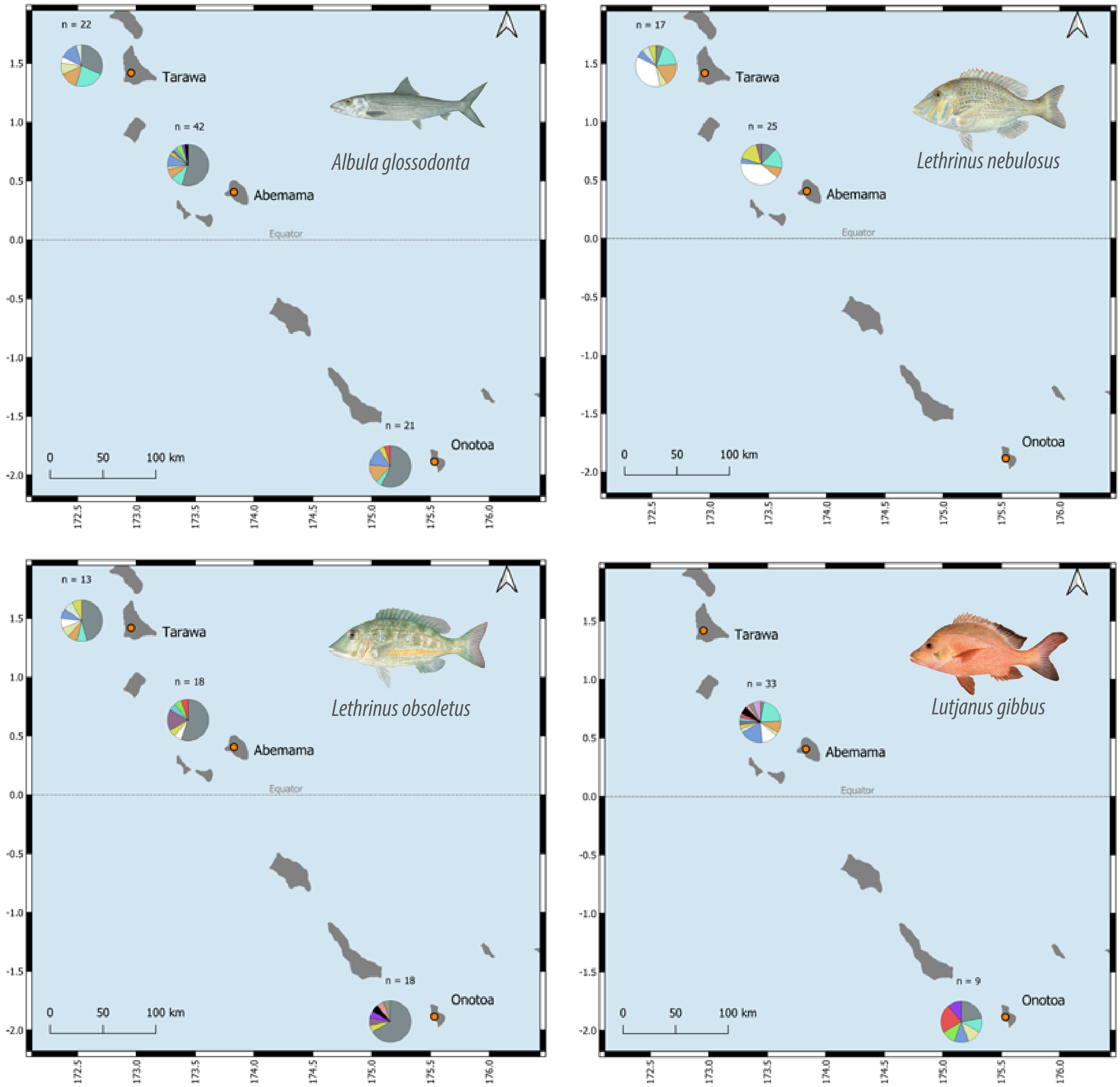

Figure 3. Haplotype map of four reef fish species across the Gilbert Islands. Each haplotype is represented by colour, and n represents the number of specimens sampled.

Table 2. Genetic diversity of the four key fish species at the atoll-scale, based on mtDNA.

Species	Atolls	n	Haplotypic diversity (h)	Number of hap-lotypes	Number of unique haplotypes	Polymorphic sites (s)	Nucleotide diversity (π)	Tajima's D test (p-value)	Fu's FS test (p-value)	FST (p-value)		
										Tarawa	Abemama	Onotoa
Albula glossodonta	Tarawa	22	0.835 ± 0.047	8	2	7	0.002 ± 0.001	-0.653 (0.289)	-1.856 (0.105)	x	0.025 (0.107)	0.028 (0.153)
	Abemama	42	0.688 ± 0.075	11	4	11	0.002 ± 0.001	-1.534 (0.043 *)	-5.884 (0.001 *)	0.025 (0.107)	x	0 (0.941)
	Onotoa	21	0.657 ± 0.103	6	1	6	0.002 ± 0.001	-0.988 (0.190)	-1.777 (0.088)	0.028 (0.153)	0 (0.941)	x
	Overall	85	0.722 ± 0.045	14	7	14	0.002 ± 0.001	-1.511 (0.039 *)	-7.490 (0.003 *)			
Lethrinus nebulosus	Tarawa	17	0.846 ± 0.066	8	2	47	0.041 ± 0.021	0.444 (0.719)	5.640 (0.980)	0 (0.855)		
	Abemama	25	0.797 ± 0.060	7	1	45	0.039 ± 0.020	0.263 (0.656)	11.386 (0.999)			
	Overall	42	0.805 ± 0.044	9	3	48	0.039 ± 0.020	0.375 (0.701)	13.819 (0.998)			
Lethrinus obsoletus	Tarawa	13	0.808 ± 0.113	8	5	33	0.020 ± 0.011	-1.054 (0.145)	0.947 (0.674)	x	0 (0.598)	0.004 (0.385)
	Abemama	18	0.686 ± 0.112	7	3	55	0.025 ± 0.013	0.212 (0.631)	5.071 (0.969)	0 (0.598)	x	0 (0.713)
	Onotoa	18	0.569 ± 0.138	7	4	33	0.015 ± 0.008	-1.552 (0.047 *)	2.496 (0.862)	0.004 (0.385)	0 (0.713)	x
	Overall	49	0.670 ± 0.076	16	12	68	0.019 ± 0.010	-0.832 (0.217)	1.000 (0.149)			
Lutjanus gibbus	Abemama	33	0.911 ± 0.028	15	6	37	0.010 ± 0.005	-0.940 (0.183)	-0.058 (0.537)	0.014 (0.266)		
	Onotoa	9	0.944 ± 0.070	7	2	18	0.007 ± 0.004	-0.313 (0.395)	-0.653 (0.304)			
	Overall	42	0.922 ± 0.022	17	8	39	0.009 ± 0.005	-1.004 (0.162)	-0.460 (0.472)			

Results

Genetic identification of Albula glossodonta

The 85 sequences obtained from the Albula samples were compared to sequences stored in the NCBI database. Among the 100 higher scores of target sequences, the first 27 sequences corresponded to partial sequences of *A. glossodonta* cyt b gene with an identity percentage from 99.4% to 100%. This identity percentage decreased below 95% for *A. esuncula* and below 90% for other species of the same genus (*A. gilberti, A. koreana*). Consequently, the 85 *Albula* samples were assigned to *A. glossodonta*.

Sequence descriptive analysis

The 608 base pairs (bp) consensus cyt b sequences of *A. glossodonta* revealed 14 polymorphic sites that defined 14 different haplotypes, with a mean number of pairwise nucleotide differences of 1.282 ± 0.813 (Table 2). The 469 bp and 475 bp consensus CR sequence of *Lethrinus nebulosus* and *L. obsoletus* revealed 48 and 68 polymorphic sites that defined 9 and 16 different haplotypes, with a mean number of pairwise nucleotide differences of 18.167 ± 8.223 and 9.190 ± 4.299, respectively (Table 2). The 962 bp consensus cyt b sequence of *Lutjanus gibbus* revealed 39 polymorphic sites that defined 17 different haplotypes, with a mean number of pairwise nucleotide differences of 8.667 ± 4.083 (Table 2).

Historical demography

Neutrality tests were statistically significant for *A. glossodonta* pooled at the archipelagic level, Tajima's test (D= - 1.511*, p< 0.05) and Fu's FS (Fs= -7.490*, p< 0.05). However, this result is driven by *A. glossodonta* samples from Abemama, the only atoll where neutrality tests were significant (D= -1.534*, p< 0.05; Fs= -5.884*, p< 0.05).

The median-joining network is star-shaped (Fig. 2), with a central main haplotype (h1: n= 42) from which other haplotypes derive with one or two mutations.

Tajima's test on *Lethrinus obsoletus* from Onotoa was also significant (D= -1.552; p< 0.05) but Fu's FS was not. Both neutrality tests were insignificant for *L. obsoletus* pooled across atolls. This was also the case for *Lethrinus nebulosus* and *Lutjanus gibbus* when pooled across atolls. Because the haplotypic networks of *L. nebulosus, L. obsoletus* and *Lutjanus gibbus* did not show a genetic trend, the results are not presented in this publication, although they are available on request to the authors.

Genetic diversity and connectivity among atolls

For each species, the main haplotype observed in most specimens was common to all atolls: 83.5% of *A. glossodonta* specimens, 93% of *Lethrinus nebulosus*, 63% of *L. obsoletus* and more than 55% of *Lutjanus gibbus*. Among the 14 haplotypes recorded for *A. glossodonta* and the 16 for *L. obsoletus,* four and two haplotypes were shared among the three atolls, respectively. Similarly, among the nine haplotypes recorded for *L. nebulosus* and the 17 for *Lutjanus gibbus*, six and five were shared, respectively, across Tarawa-Abemama and Abemama-Onotoa (Fig. 3).

Haplotypic diversity (*h*) increased from the southernmost atoll (Onotoa) to the northernmost (Tarawa) except for *Lutjanus gibbus*, while nucleotide diversity tended to be constant across atolls. For instance, the haplotypic diversity of *A. glossodonta*, *Lethrinus obsoletus* and *L. nebulosus* in Tarawa was, respectively, *h*= 0.835 ± 0.047, *h*= 0.808 ± 0.113 and *h*= 0.846 ± 0.066. This was followed by Abemama, with intermediate to high values ranging from *h*= 0.686 ± 0.112 to *h*= 0.797 ± 0.060 and the lowest values in Onotoa with haplotypic diversity ranging from *h*= 0.569 ± 0.138 to *h*= 0.657 ± 0.103.

As an indicator of differences in genetic structure across atolls, pairwise comparisons based on haplotype frequencies were investigated for each species between all sampled areas, (Table 2). For each species, pairwise FST were relatively low, ranging from 0 to 0.028, and were not significantly different across atolls.

Discussion

Our investigation of genetic structure and connectivity of populations of *Albula glossodonta*, *Lethrinus nebulosus*, *Lethrinus obsoletus* and *Lutjanus gibbus* across three atolls within the Gilbert Islands did not uncover the presence of genetically distinct subpopulations. This indicates regular genetic connectivity between Tarawa, Abemama and Onotoa, of these species. Haplotypic diversity, which reflects genetic diversity across the atolls increased from south to north, with samples collected in Tarawa having a higher genetic diversity than samples collected in Abemama and Onotoa. Our analyses also confirmed that our samples of *Albula* belong to a single species, *Albula glossodonta*, and the population of *A. glossodonta* has experienced a historically drastic decline in population size.

Genetic structure and connectivity across atolls

The permutation tests on pairwise FST for all species showed that genetic structure was not significantly different across atolls, indicating regular gene flow between stocks from Tarawa, Abemama and Onotoa.

All four species are pelagic spawners with long pelagic larval durations of between 25 and 58 days on average (Friedlander et al. 2007; Soeparno et al. 2012). Considering the relatively small distances separating the atolls (100 km to 400 km), larvae from one atoll drift long enough to reach other nearby atolls, hence providing sufficient gene flow to maintain the observed genetic similarity between atolls. Similar findings have been reported in the Line Islands, Kiribati where larvae from *A. glossodonta* population in Palmyra Atoll, separated by a distance of 700 km, were recruited from Kiritimati (Friedlander et al. 2007).

In terms of fisheries management, this result suggests that fish stocks from one atoll might be replenished by recruitment of larvae coming from other atolls. However, as only a few individuals are needed to maintain genetic similarity, a genetic analysis such as conducted here is insufficient to distinguish whether larval connectivity is frequent enough and large enough to be demographically relevant. Combining genetics studies with other approaches such as biophysical modelling will provide a much more powerful test of connectivity relevant to fisheries management (Leis et al. 2011). For example, by providing insights into the proportion of larvae that might survive to settle between atolls.

Therefore, under current levels of knowledge, the species we have investigated should be managed at the atoll level.

Genetic diversity gradient across atolls

For all species except *Lutjanus gibbus*, haplotypic diversity analysis revealed a descending genetic diversity gradient from Tarawa to Onotoa. One hypothesis to explain this gradient is that the proximity of an atoll to more adjacent reefs would favour more diverse larval recruitment. Within a 155 km radius, Tarawa, Abemama and Onotoa are, respectively, surrounded by six, five and four neighbouring atolls with a mean distance of 75 km to 80 km. According to the biophysical model by (Treml et al. 2012), the greater the distance, the lower the probability of connection, 95% of larval settlement is projected to occur within 155 km of the source population.

Abemama Island (Kiribati) © Pauline Bosserelle (SPC)

Another recognised influence on genetic diversity is habitat size and fragmentation (e.g. Rauch and Bar-Yam 2005; Manel et al. 2020). Total lagoon area is two to four times larger in Tarawa than Abemama and Onotoa, which correlates positively to the genetic diversity gradient.

Irrespective of the drivers underlying the observed patterns, genetic diversity has been used in fisheries as an indicator of population declines (Smith 1994). The observed genetic diversity of these four species should be considered a reference point that can be periodically monitored to assess the longer term stability of stocks (Bruford et al. 2017).

Confirmation of bonefish species

All bonefish specimens collected for this study were confirmed to be *Albula glossodonta*. This aligns with previous work on bonefish species diversity in the region, which has found only *A. glossodonta* across numerous locations in Kiribati (Friedlander et al. 2007; Wallace 2015).

Historical population reduction hypothesis

Owing to the significant non-neutrality tests and the diagnostic star-shaped Median-Joining haplotypic network, we suggest that *A. glossodonta* has undergone a significant population reduction, known as a bottleneck effect, at some stage in its evolutionary history (Bouzat 2010; Nei et al. 1975). This trend has been observed on a larger geographic scale in the Indo-Pacific Ocean (Friedlander et al. 2007; Williams et al. 2020).

While the cause of bottleneck effect has been mainly attributed to anthropogenic and ecological factors such as environmental variations, introduction of non-native species, habitat destruction and overexploitation, the consequences and its management implications remain unclear (Atarhouch et al. 2006; Bouzat 2010; Parra et al. 2018).

According to the paradigm of inbreeding depression, a reduction in the genetic diversity of a population caused by a bottleneck effect can have a deleterious impact on its fitness and affect the viability of the population in the long term, and increasing its risk of extinction (Bouzat 2010; Charpentier et al. 2005; Da Silva et al. 2006).

While the paradigm of inbreeding depression suggests that the loss of genetic diversity resulting from a bottleneck effect can directly lead to extinction, this relationship may be oversimplified. Some researchers argue that other factors, such as phenotypic adaptation, could play a critical role in a population's survival (Bouzat 2010). Therefore, a more complex approach may be necessary to fully understand the dynamics between genetic diversity and extinction risk.

Limitations of the study

Sampling

Sampling was opportunistic from fishers at the time, hence there are low numbers or missing samples from some combinations of atoll and fish species (e.g. the lack of *Lutjanus gibbus* samples from Tarawa, and the relatively low sample size from Onotoa). Missing or small sample sizes limits the inferences that can be made from analyses of the genetic material. Further sampling will be undertaken in the near future to fill in these gaps and to add additional species to the investigations.

Genetic method

It is known that the cyt b gene is more conserved than the mtDNA CR (Ardura et al. 2013), and may fail to detect different subpopulations at small geographic scales. It nevertheless remains a widely referenced universal gene that is technically straightforward to investigate without the need for developing prior sequencing and proven trials, which makes it a practical choice for many genetic studies (Cantatore et al. 1994). Further investigations using microsatellite approaches and/or developing mtDNA CR primers for *Albula glossodonta* and *Lutjanus gibbus* would, therefore, be necessary to confirm the presence or absence of genetically different populations.

Conclusions

As coastal fisheries species continue to be heavily fished and as (human) Pacific Island populations continue to grow, the need for effective management remains as urgent as ever. In order for management to be effective, it needs to be driven by decisions that are informed by scientifically rigorous data. This study provides foundational evidence of linkages between fish populations across the atolls making up the Gilbert Islands, and confirms the existence of a single species of bonefish in the region. These results should be thought of as a starting point from which further targeted work can be done to obtain the necessary data on which to implement sustainable coastal fishing approaches for Kiribati.

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