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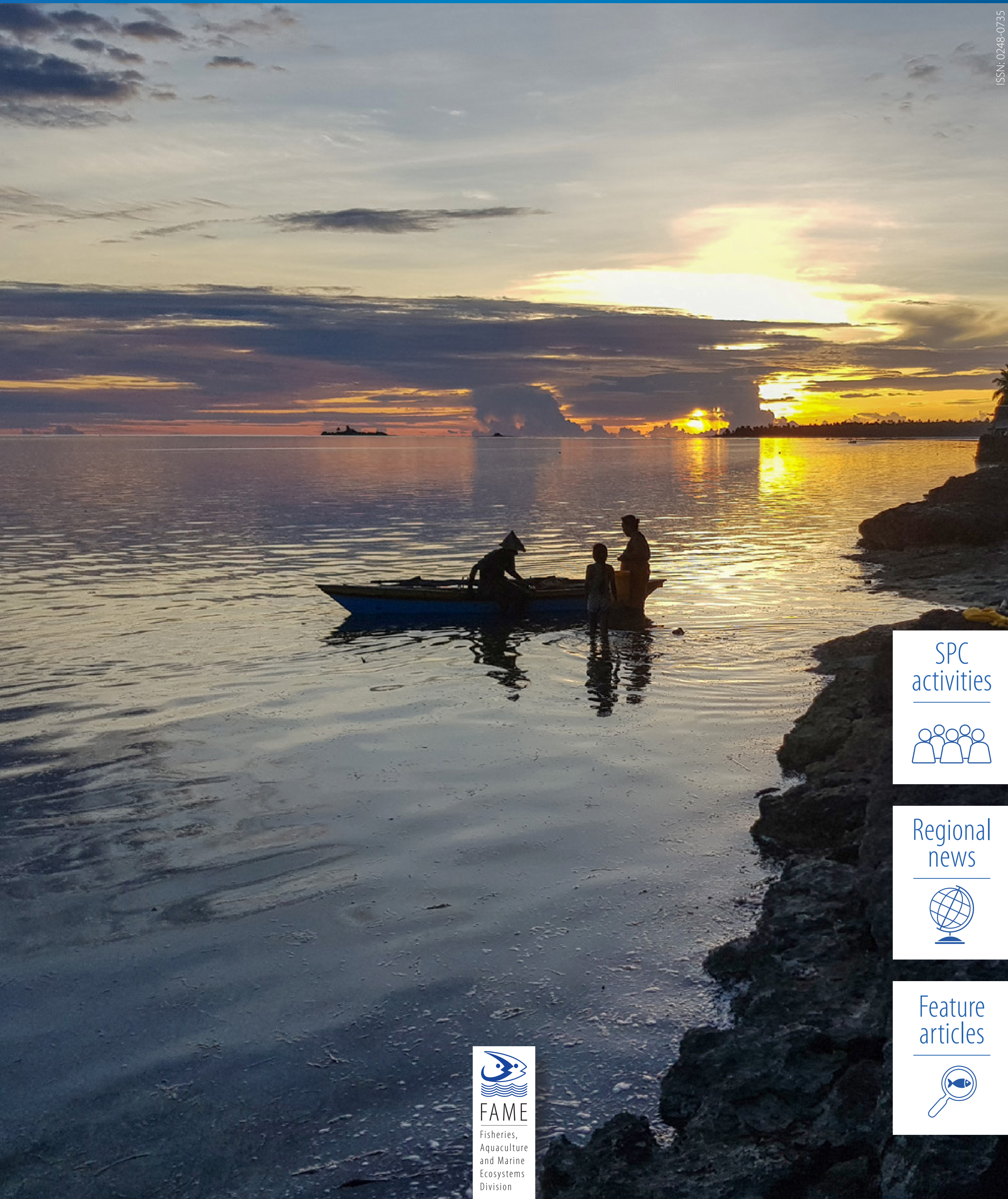

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Fisheries, Aquaculture and Marine Ecosystems Division

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Regional Aquaculture Project successfully completed

A regional project on aquaculture, the Sustainable Pacific Aquaculture Development Activity, was successfully implemented across the Pacific Community's 22 Pacific Island country and territory (PICT) members over five years from 30 June 2016 to 30 June 2021. Funded by New Zealand Aid under the Ministry of Foreign Affairs and Trade (MFAT), the project provided support in aquatic biosecurity risk management, enhanced aquaculture business acumen and increased uptake of improved aquaculture practices.

The Activity strengthened aquatic biosecurity capacity at the regional level through the development and implementation of a Regional Framework on Aquatic Biosecurity. As a result, national level aquatic biosecurity plans and standards have been developed, adopted, and applied in aquaculture to strengthen national capacity in risk assessments, national aquatic animal health capacity, and improved national aquatic diseases reporting systems.

The Activity has contributed to enhancing business acumen among private sector aquaculture operators through business mentoring and training to strengthen capacity in fundamental business skills. Selection of enterprises was based on calls for proposals, and the delivery of mentoring services was run by external international and national consultants sourced through the project. Technology transfer to the selected enterprises was provided through a co-funding arrangement with 60% of the financial support provided by the activity and 40% by the selected enterprise. In addition, the Activity increased uptake of improved aquaculture practices by strengthening government and farmer capacity for seed, feed and brood stock management.

Key project achievements

- The project has significantly improved SPC members' capacity to improve on their national aquatic disease status reporting the International des Epizooties (OIE). From an initial baseline of two PICTs (French Polynesia and New Caledonia) reporting regularly to the OIE in 2016, there has been an increase to 12 PICTs (three OIE members plus nine non-OIE members) reporting annually to OIE by 2021. Significant effort was made by this Activity to encourage non-OIE PICTs to voluntarily report annually to OIE as a matter of good aquaculture practice.

Feeding time at a tilapia fish pond in Samoa. (image: ©Tim Pickering, SPC)

Members of Muanaira Womens Group carrying out mangrove oyster farm maintenance tasks at Vutia in Rewa Province of Fiji. (image: ©Tim Pickering, SPC)

- The number of PICTs conducting regular disease and threats surveillance has also increased, from an initial baseline of two PICTs (French Polynesia and New Caledonia) conducting targeted surveillance for identified biological risks of national importance, to five PICTs (French Polynesia, New Caledonia, Fiji, PNG and Vanuatu) by Year 5 of the project.
- In terms of policy, the number of PICTs with aquatic biosecurity plans surpassed the target of six, to seven PICTs having aquatic biosecurity plans by Year 5, from a baseline of no PICTs with national aquatic biosecurity plans at the start of the project.
- There was an increased uptake and adoption of improved aquaculture practices. The formation of farm clusters in Fiji and Papua New Guinea strengthened on-farm support and exchange of knowledge and information between farmers. This was mentioned in the independent Project Mid-Term Review to be working well.
- A five-year *Regional Framework on Aquatic Biosecurity*[1] was developed for the region and endorsed by the First Regional Fisheries Ministers Meeting in 2020.
- In terms of technical support to the private sector, with an initial target of 25 private sector enterprises, three calls for proposals were made, resulting in 17 private sector enterprises, one farmers' association and one aquaculture training institution being approved and receiving assistance under the grant agreement arrangement of 60% activity funding and 40% enterprise co-funding for capacity building, business mentoring and technology transfer. Recipients were spread across 11 PICTs (Federated States of Micronesia, Fiji, French Polynesia, Kiribati, New Caledonia, Palau, Papua New Guinea, Republic of Marshall Islands, Solomon Islands, Tonga and Vanuatu), covering all three of the Pacific sub-regions of Melanesia, Micronesia and Polynesia.

Key issues and challenges

- There have been some significant challenges in working with enterprises. It is worth highlighting that priorities for the private sector can shift very rapidly in a short time frame and, with SPC's procurement rules, it is challenging to adjust and obtain approvals quickly enough to to meet private sector needs in a timely manner.

[1] https://purl.org/spc/digilib/doc/23nkb

[2] Under this grant scheme, the Activity provides 60% of the cost, and the enterprise provides the remaining 40%.

- There are challenges in encouraging more women-owned and/or -led enterprises to submit proposals for assistance under the 60/40 grant scheme[2] for private enterprises. The Activity team "re-pitched" the advertisement in a third call for proposals under this Activity using a story-telling approach to attract more women entrepreneurs. This is an approach that should continue, but it is also important to recognise the dual role of the wife/husband "family-farm" setting and to continue to support this area.
- Undertaking aquatic disease testing by collecting and sending biological specimens to reference laboratories for tests has been an important task under the Activity. An issue to highlight is what happens when there is a positive test result, and the member country or territory refuses to report on the result to OIE. There are no mechanisms in place which SPC, being the commissioned agency for the Activity and funder of the testing, could demand that the country concerned report the positive test result to the OIE. There is a need to put in place a mechanism to address this.
- The uncertainty around PICTs re-opening from the COVID-19 restrictions remains as a key challenge going into 2022 for the next Activity phase under the NZ MFAT Sustainable Coastal Fisheries and Aquaculture for Pacific Livelihoods, Food and Economic Security (SCoFA) project.
- Support to farm clusters and enterprises by project staff in on-farm aquatic biosecurity support remained a significant challenge and could not be rolled out effectively under the Activity during the COVID-19 restrictions.
- Use of national consultants has had mixed results, only working well in PICTs where there is a good pool of experts to select from. However, depending on the field of expertise, it can be difficult, and some consultants had to be "head hunted" for the work. In some PICTs, there is good local capacity on the ground that can also receive support from the national fisheries agencies (or from SPC staff when there are appropriate staff available). For instance, that was the case with seaweed value-adding work in Solomon Islands where the SPC office in Honiara and national fisheries staff provided technical assistance.

Key lessons learned to improve future delivery

- Staff recruitment and replacement is critical for the effective and timely delivery of the Activity. The two professional and national staff recruited joined six months after the start of the Activity. The national position (Aquaculture Production Technician) was difficult to replace when the first incumbent resigned. This position has now been upgraded from a local position to a professional/international position (Aquaculture Technical Officer) in the new Activity, which should attract a wider pool of applicants for the role, rather than limiting the role to the host member country, as required with local positions.
- Some of the training and workshops where participants are funded to travel overseas need to be better targeted at those who will benefit the most and use the training. The dramatic increase over the last two years in the use of virtual platforms to run trainings and workshops, as a result of the global pandemic travel restrictions, has had the benefit of allowing a wider audience to attend workshops, including a significant increase in female participation. The use of virtual platforms will continue for future trainings and workshops where appropriate.
- The 60/40% grant scheme has had some challenges, particularly for small-scale farm holders who stand to benefit the most. They often struggle to come up with their 40% contribution. The scheme needs to be streamlined so the process is more appropriate and easier for small-scale farmers to apply for and meet the selection criteria. The larger scale enterprises require less support, so in future a greater focus should be on the small-to-medium-scale enterprises.
- The exclusion of the territories in the project design stage and during the first year of the Activity, caused confusion and inconsistency in Activity execution between this Activity and the parallel Effective Coastal Fisheries Management Activity, where territories were included. The territories raised their concerns at the Tenth Heads of Fisheries (HoF10), requesting to be included in this Activity. This was discussed and endorsed at the subsequent Activity Project Steering Committee.
- Absence of reliable baseline data in the results frameworks made it difficult to assess the impact and contribution of the Activity to its medium- and long-term goals. For a new Activity such as SCoFA, efforts should be made to establish concrete baseline data through commissioning a detailed regional assessment of the coastal fisheries and aquaculture sectors at Year 1 and a follow-on assessment by at least Year 5.
- Considerable effort has been made in strengthening the role of women in aquaculture, particularly in supporting women-led enterprises. From a total of 19 enterprises supported, two were women-led, one of which was the successful establishment of a private tilapia commercial hatchery. Attention will continue to be needed in making women's roles more visible and to ensure greater participation of women in aquaculture.

Relationships

Relationships and partnerships were built both internally, across SPC's Division of Fisheries, Aquaculture and Marine Ecosystems, and with other SPC Divisions. There was a close collaboration between the Activity and SPC's

Land Resources Division around terrestrial and aquatic biosecurity, with the organisation of a joint regional workshop on biosecurity risks management. A close collaboration was also maintained with SPC's Human Rights and Social Development Division, particularly on gender and social inclusion in aquaculture. External relationships and partnerships with the United Nations Food and Agriculture Organization (FAO) and the World Organisation for Animal Health (OIE) were maintained through conducting joint regional meetings such as the SPC/FAO/OIE Sub-Regional Meeting on Emergency Preparedness and Response for PICTs in 2019, commissioning a review on the impact of aquatic exotic species in the Pacific in 2018[3] and on the development of Federated States of Micronesia National Aquatic Animal Health and Biosecurity Strategy.[4] Internally within the Coastal Fisheries and Aquaculture Programme, the Activity team has been working well with the Coastal Science Management and Livelihoods Section team in strengthening areas around governance, such as development of national aquaculture strategic plans, legislative reviews and more recently on monitoring, control and surveillance (MCS).

The Activity team has established a healthy working relationship with the aquaculture private sector, particularly by working with 19 enterprises addressing capacity building through business literacy trainings, mentoring as well as in technology transfer across 11 PICTs. Partnerships have also been established with non-government organisations, for example, with the Wildlife Conservation Society (WCS)[5] in Fiji to assist community pearl oyster farmers.

Conclusion

A significant contribution has been made on building the capacity, knowledge and establishing standards for aquatic biosecurity at both the national and regional levels. The adoption of the Regional Framework on Aquatic Biosecurity provided the roadmap for member countries and territories to establish national aquatic biosecurity plans, undertake aquatic disease surveillance and manage aquatic biosecurity risks. In addition, the Activity has made significant contributions to supporting private-sector enterprises through capacity development, business mentoring and

3 Garcia-Gomez R., Bermudes, M. & Pickering, T. 2018. Case studies on the impacts of aquatic exotic species in the Pacific, SPC.

4 MacKinnon, B., Lavilla-Pitogo, C.R., Arthur, J.R., Vitug, A.A., Garcia Gómez, R., Wichep, J., Martin, V. and Bondad-Reantaso, M.G. 2020. National Aquatic Animal Health and Biosecurity Strategy – FAO project TCP/MIC/3603/C2 for The Federated States of Micronesia. FAO Fisheries and Aquaculture Circular No. 1209. Rome, FAO. (https://doi.org/10.4060/ca9814en)

5 Vitukawalu B., Mangubhai S., Ma F., Dulunaqio S., Pickering T., Whitford J. 2020. Establishing a community pearl oyster farm in Vatulele Village, Fiji. SPC Fisheries Newsletter 160. Noumea, New Caledonia: Pacific Community. (https://purl.org/spc/digilib/doc/yi8pz)

Tilapia for distribution (image: ©Avinash Singh, SPC)

technology transfer, which resulted in enhanced business acumen and improved aquaculture practices, for instance, through diversification in primary product to new product development for new markets and being able to withstand shocks from the COVID-19 impacts, small scale enterprises establishing their own hatchery and producing seeds commercially to avoid being reliant on seeds supplied by government run hatcheries or imported seeds from commercial hatcheries. Small-scale individual farmers have increased economies of scale by being organised into farm clusters or groups where they were able to provide peer-to-peer on-farm extension support to each other, enhanced information exchange and support between farmers, and sharing of resources and support to a larger number of farmers, which is logistically easier. While farm clusters have been limited to tilapia aquaculture in Fiji and PNG, there were lessons to be drawn to help expand the cluster work to other PICTs in future.

Sincere thanks to New Zealand Government's Ministry of Foreign Affairs and Trade for providing funding support, for their leadership and for being a great partner to this Activity.

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Sea cucumber *Holothuria scabra* (sandfish), spawned and reared at the Mariculture Centre of Fiji Ministry of Fisheries at Galoa on Viti Levu, destined for sea ranching in conjunction with community-managed marine protected areas. (image: ©Avinash Singh, SPC)

Nature is increasingly claiming legal rights for itself, but what about fish?

Introduction

Over the past 15 years, a new type of rights, known collectively as the rights of nature, has emerged in a growing number of countries to find a new approach enabling a better protection of the environment and stop the increasing degradation of nature, including fisheries resources. In 2021, the Pacific Community (SPC) has commissioned a study to review national and local initiatives in the world and produce a comparative legal analysis to identify trends and lessons learned for Pacific Island countries and territories (PICTs).

Main findings

Yes, nature has rights just like humans

In certain countries, nature has been granted rights of its own, either as a whole or through specific ecosystems such as a river, a mountain, a forest, or a land area. While Ecuador and Bolivia have recognised rights to nature as a whole – the former in its constitution and the latter in its national legislation – Canada and New Zealand have granted the rights to a particular ecosystem, a river. If a large variety of ecosystems have been granted rights of their own, countries have chosen different pathways to do so that are often linked to the country's history and to local circumstances.

What rights does nature have?

The rights of nature approach rejects the notion that nature is human property, meaning an object to be owned and used at will by human beings. It rather advocates for the recognition of the rights of the natural world to exist, thrive, regenerate and naturally evolve – nature as a subject with legal rights. These fundamental rights often include the right to restoration, which is not limited to financial remedies but may also include concrete measures to restore ecosystems to their original state.

To these inherent rights of nature and natural beings, some countries such as New Zealand have added procedural rights that are associated with legal persons, for instance the rights to sue and be sued, enter into contracts and own property.

> *"How can rights of nature become an asset for effective coastal fisheries management, underpinned by an ecosystem approach and implemented by local communities?*

In the Pacific, nature can be granted legal personality…

"The unitary principle of life – according to which humans belong to the natural environment that surrounds them and identify themselves in the elements of that natural environment – is the founding principle of the Kanak society. To reflect this worldview and the Kanak social system, **certain elements of Nature may be recognised as legal persons with rights of their own**, subject to applicable laws and regulations."

(Unofficial translation of Article 110-3 of the Environment Code of the Loyalty Islands Province, New Caledonia)

« Le principe unitaire de vie qui signifie que l'homme appartient à l'environnement naturel qui l'entoure et conçoit son identité dans les éléments de cet environnement naturel constitue le principe fondateur de la société kanak. Afin de tenir compte de cette conception de la vie et de l'organisation sociale kanak, ***certains éléments de la Nature pourront se voir reconnaitre une personnalité juridique dotée de droits qui leur sont propres,*** *sous réserve des dispositions législatives et réglementaires en vigueur. »*

(Article 110-3, Code de l'environnement de la province des îles Loyautés, Nouvelle Calédonie)

Who stands in court on behalf of nature?

When nature or a particular ecosystem has been recognised as a legal person, the protection of its rights is generally entrusted to a legal guardian (individual or group) specifically appointed for that purpose. By contrast, when nature or a given ecosystem has been granted rights without being recognised as a legal person, the protection of these rights is generally the responsibility of the public at large, either collectively or individually, meaning that nature appears as a plaintiff in court through the representation of the legal guardian or the public at large.

Can marine ecosystems have rights?

To date, no rights have been accorded to marine areas or oceans. However, Australia attempted to recognise rights of the Great Barrier Reef in 2018. The purpose of the bill is to protect the health and well-being of the Great Barrier Reef by recognising the inherent rights of the Barrier to naturally exist, flourish, regenerate and evolve, and its right to restoration.

There has been growing enthusiasm around this approach and a great diversity of ecosystems have been granted rights, as have plant species (such as the Manoomin rice in the US). One may wonder how long before legal rights are recognised for marine ecosystems (e.g. tabu or sacred areas) or even to marine species (e.g. endangered seaweed species or totem animals, such as sharks in certain cultures).

Next steps

The SPC study, which is currently under review, attempts to explain the emergence of the rights of nature, their mode of recognition and the types of rights recognised. It also raises the question of how the rights of nature can strengthen or improve coastal fisheries management in the Loyalty Islands Province and perhaps in the Pacific region.

In view of the special relationship between the natural environment and the Pacific people and the high level of reliance of the Pacific Islands' economies and livelihoods on marine resources, the variety of examples contained in this study could inspire the region in the preservation of coastal areas.

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The Bay of Prony "needle", in New Caledonia, and one of its many inhabitants, New Caledonia. (image: ©Matthieu Juncker)

Selected countries or territories where rights of nature have been recognised

Bolivia	Law on the Rights of Mother Earth 2010
Colombia	Constitutional Court Decision 2016 (Atrato River)
Ecuador	Constitution of 2008
Canada	Quebec Ekuanitshit Innu Council Resolution 2021 (Magpie River) Quebec Minganie Regional County Municipality Resolution 2021
New Caledonia	Environment Code of the Loyalty Islands Province 2016
New Zealand	Te Urewera Act of 2014 (land area and indigenous communities) Te Awa Tupua (Whanganui River Claims Settlement) Act 2017
USA	Nottingham Water Rights and Self-Government Ordinance 2008 Minnesota Rights of Manoomin Ordinance of 2018

Drafting coastal fisheries legislation: A new training course available online!

The Coastal Fisheries and Aquaculture Programme of the Pacific Community (SPC) has recently published an online capacity building course on legislative drafting for coastal fisheries, targeting fisheries policy and legal officers from Pacific Island countries and territories (PICTs). The course was developed with expertise from the University of California, Hastings College of the Law (UC Hastings). Funding for the development of the course was provided under the Effective Coastal Fisheries Management Project, through the New Zealand Ministry of Foreign Affairs and Trade.

Why this course?

PICTs have highlighted the need for legal support in preparing and reviewing coastal fisheries legislation in regional forums, such as the SPC Heads of Fisheries Meeting and the Regional Technical Meeting on Coastal Fisheries and Aquaculture, at least since 2003.[1] SPC has been providing support through mentoring as well as face-to face training on legal matters,[2] until the COVID-19 pandemic put a halt on travel within the Pacific region. Although restrictions are now slowly being lifted, the shift to online – or at least to hybrid mode – for workshops seems inevitable. Against this backdrop, SPC is pleased to announce the launch of a new online training course on legal drafting to help build capacity for effective coastal fisheries management.

Content overview

The course covers legislative drafting and analysis techniques, including how to draft clearly and unambiguously, organise concepts logically, and turn policy into law. This online course merges different learning modes, including video lectures, presentation slides, reading material and quizzes, exercises, or assignments, in order to be as engaging as possible for participants. The course requires an internet connection and is organised in two phases of five modules each: Phase I explores the basics of legal drafting for coastal fisheries and can be taken online without the need for personalised feedback from SPC; Phase II aims to guide participants through the drafting process and will require SPC staff to provide personalised feedback on the assignments.

Learning outcomes and assessment

After successful completion of the course, participants will be able to understand the importance of clear drafting, identify key features of legislation, and formulate clear legislative language to achieve identified policy goals. Most importantly, they will learn how to critically analyse and review the form and substance of legislation and explanatory documents, and understand how to improve them. A competency-based assessment workshop will then be organised to allow those who have taken the full online course to present their work and share their drafting experience with others.

Course access and duration

If you want to learn how to draft laws and regulations on coastal fisheries or you know someone who would, please get in touch with us. We will be circulating information through SPC's official channels on how to apply for the course. No prior knowledge of coastal fisheries or legislation is required. The estimated total duration of the course is around 25 to 30 hours, but participants can take each of the 10 online modules at their own pace. Those who have successfully completed the course will be able to participate in the assessment workshop, which will be supervised and facilitated by SPC to ensure a fruitful exchange within the region.

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[1] Recommendation 4 of the Strategic plan for fisheries management and sustainable coastal fisheries in Pacific Islands, endorsed by the Third SPC Head of Fisheries Meeting reads as follows: "It is recommended that SPC establish a legal service to respond to requests from island countries for assistance in legislation related to coastal fisheries." (HOF3/WP7 p. 13; see HOF3 Recommendations, n. 13).

[2] How to draft effective coastal fisheries and aquaculture legislation by Alex Sauerwein, Ariella D'Andrea and Jessica Vapnek. SPC Fisheries Newsletter, Number 164 (January–April 2021).

FADs for family: Capitalising on Pacific Islands motivators to promote codes of conduct around FADs

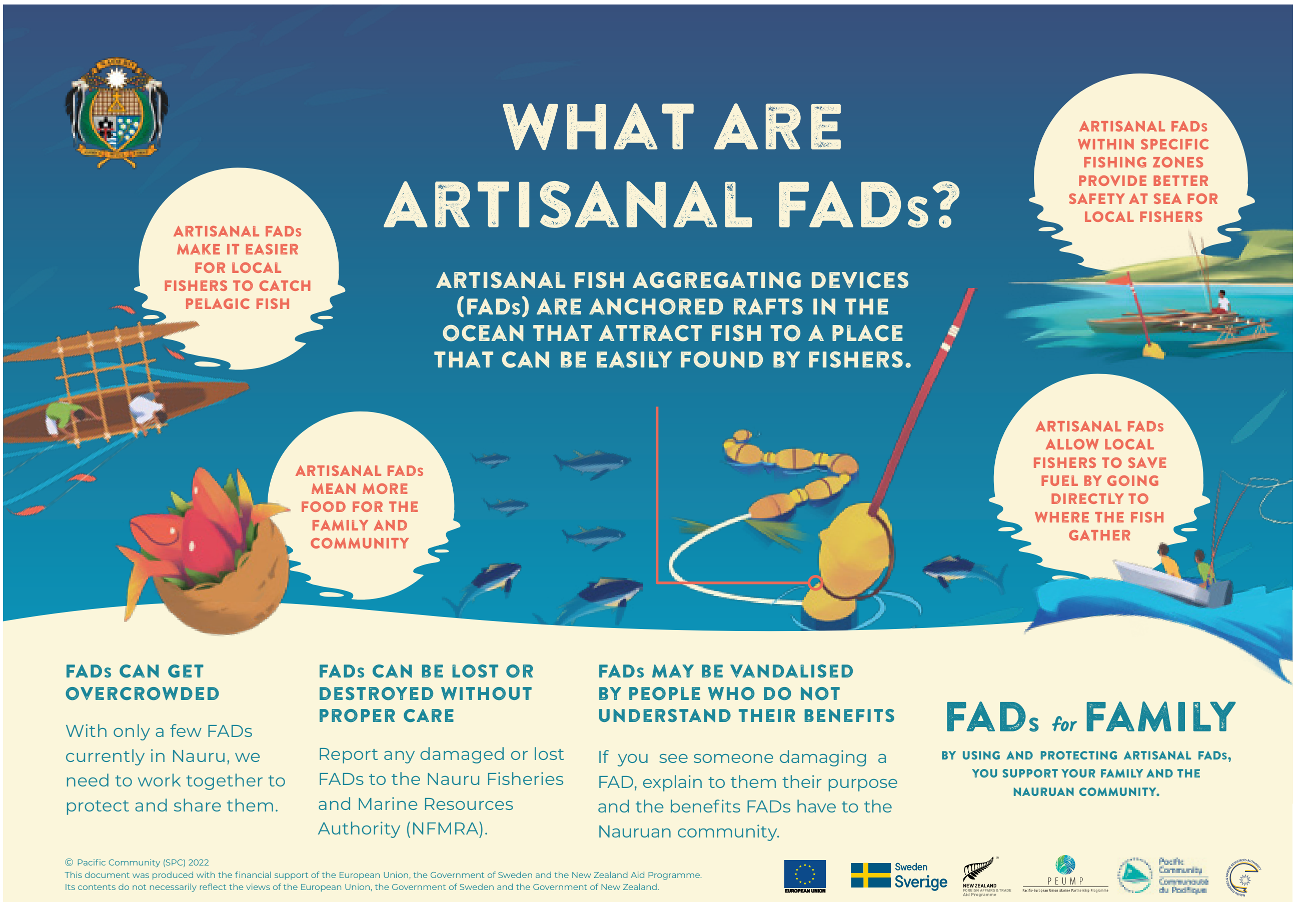
As part of an ongoing fish aggregating device (FAD) strategic development plan in Nauru, a community toolkit has been developed to address issues such as FAD misuse, vandalism and maintenance.

The FAD programme in Nauru

Like many other Pacific Island nations, Nauru has taken advantage of FADs to support local food security, fishing safety and efficiency, and provide an alternative to reef fishing. While artisanal FADs are proving to be an effective tool for Nauru's fisheries, a few issues have been identified during stakeholder meetings as restricting the success of the programme.

- General awareness: There is a need to raise awareness of the general Nauruan community not only about what FADs are, but also about their benefits and how they work.
- Intentional tampering: There have been reports of intentional vandalism, often in the form of fishers cutting marker flags to ensure others will be unable to find FADs.
- Unintentional damage: There are cases where FADs are also being damaged unintentionally, for example when uninformed fishers tie their boats to FADs to save fuel.
- Fisher conflict: While conflict among FAD fishers in Nauru appears to be rare, there are some issues among younger fishers not fishing appropriately around FADs.

In collaboration with the Nauru Fisheries and Marine Resources Authority (NFMRA) and the Pacific Community (SPC), the company Story 1st, Technology 2nd (S1T2) was engaged to help develop an awareness campaign to address this need, under the governance of the Effective Coastal Fisheries Management Project[1] and the Pacific-European Union Marine Partnership (PEUMP) programme.[2]



[1] The Effective Coastal Fisheries Management Project is funded by the New Zealand Aid programme.
[2] The PEUMP programme is funded by the European Union and the Government of Sweden.

Image from the "FADs for family" video: a father teaches his son how to fish around FADs.

Interests and motivators in Nauru

As a first step, a research phase was conducted with the goal of working with target audiences to establish an information strategy and identify effective and efficient ways to build an awareness campaign about artisanal FADs in Nauru. A total of three remote focus groups were conducted with target audience groups: fishers, coastal communities and women's/youth associations.

While the use and value of FADs is a concept that may be unfamiliar to most Nauruans, the idea of family is one that is recognised across Nauru – in Nauru, family is everything. Thus, when we present the idea of FAD use to Nauruans we want to share our story in a way that demonstrates something greater than the individual.

- FADs ensure loved ones get home safe.
- FADs give fishers the means to provide for their families.
- FADs have long-lasting benefits to the community.
- FADs protect local culture and enable learning across future generations of fishers.

In this way, the fishers of Nauru can appreciate that a FAD is not just a piece of technology designed to catch more fish, but rather, it is a means to preserve culture, well-being and community.

As such, there appears to be an opportunity to craft an effective awareness campaign with simple messaging and shifting the focus to tell a compelling story of their benefits, which can then be supported by more detailed information as required. This approach has the benefit of appealing to audiences on a more personal level, drawing on the foundational values of family and community security.

Key delivery mechanisms

- Social media. In 2011, over 90% of households in Nauru had access to a mobile phone. This was confirmed by focus group participants who commented that everyone in Nauru had a smartphone. Focus group participants consistently recommended social media – particularly Facebook – as an appropriate platform for raising awareness, regardless of the target audience age.
- Community outreach sessions. Community consultation sessions were identified as a key platform for raising awareness. Participants suggested that finding ways to integrate these sessions into existing activities – such as school and football practices/games – would ensure better reach and engagement.
- Interactive engagement. The campaign should be strengthened by including interactive activities that promote local ownership and encourage individual and collective engagement.

A step-by-step campaign

Using the tagline "FADs for family", the English and Nauruan version of the awareness toolkit is now available. It includes a video raising fishers' voices, a poster and illustrations for social media highlighting the benefits of FADs as well as a detailed brochure with a code of conduct for fishers fishing around FADs. The campaign video will be distributed later this year on TV and across social media. It will be followed by community visits, trainings with fishers, and a competition on social media and with local schools to further integrate FADs into the social and community context of Nauru.

Access to the toolkit

This toolkit is available to be adapted for other countries of the region upon request. It is available from SPC's Digital Library: https://www.spc.int/DigitalLibrary/FAME/Collection/Toolkit_NAU_FADs

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The Code of conduct relays five important messages to ensure that fishers know exactly what is required of them when fishing around FADs. It is part of a brochure produced in English and Nauruan.

How the "BBNJ" agreement could help Pacific Islands tuna fisheries managers achieve some of their joint policy aims

Tim Adams[1]

"BBNJ" is shorthand for the intergovernmental process to draw up a new agreement under the United Nations Convention on the Law of the Sea (UNCLOS) to address some of the gaps in the governance of marine Biodiversity in areas Beyond National Jurisdiction.[2] This process has been under discussion for 18 years now, but the final meeting of the BBNJ Conference to agree a treaty-level text for consideration by the UN General Assembly should take place in August 2022.[3]

The gaps in the current UNCLOS legal regime include:

- the management of bioprospecting, particularly the assignation of intellectual property rights over genetic material ("marine genetic resources" or MGR) derived from organisms found in international waters;
- the ability to protect certain marine areas beyond national jurisdiction from all forms of new exploitation (through marine protected areas or MPAs), and to provide the legal basis for setting up mechanisms to manage and allocate opportunities to pursue responsible exploitation (through area-based management tools or ABMTs);
- the ability to require an environmental impact assessment before any new potentially impactful activity on the high seas or international seabed is started.

The management of fisheries on the high seas and mining of the international seabed are already covered under the two existing UNCLOS Implementing Agreements – the UN Fish Stocks Agreement (UNFSA, which came into force in 2001, and upon which the Western and Central Pacific Fisheries Convention is based), and the UNCLOS Part XI Agreement (which came into force in 1994 and is implemented by the International Seabed Authority) – while transboundary marine transport is managed by the International Maritime Organisation. However, as technology advances and economic pressures increase, new uses are being found for the high seas all the time, from carbon sequestration experiments to open-water mariculture. And many of these new uses are not yet subject to any controls or limits, nor do they have mechanisms to promote equity in sharing of any opportunities that may arise.

Some high seas fisheries figures

- Only 4.2% of world's total marine capture fisheries landings are taken on the high seas, and the high seas provide only 2.4% of the global aquatic food supply, if aquaculture and freshwater fisheries are taken into account;
- 9% of the tuna catch in the Western and Central Pacific Ocean (WCPO) is taken on the WCPO high seas;
- 68% of the tuna catch in the Atlantic, Indian and Eastern Pacific Oceans comes from the high seas in those regions.

The BBNJ Agreement will address the allocation of rights over intellectual property resulting from Marine Genetic Resources prospected from Areas Beyond National Jurisdiction (ABNJ), and will provide mechanisms for assessing the potential benefit or harm that might result from new ways of using the high seas, and of restricting or allowing their application in certain areas under agreed conditions. The non-fishery, non-mining uses of the high seas will no longer be a free-for-all, nor will their potential impact on Pacific Island fisheries be uncontrollable.

There has been a great deal of concern expressed by some major distant water fishing nations and those to whom the "freedoms of the high seas" are sacrosanct that the BBNJ Agreement will undermine the existing powers of Regional Fisheries Management Organisations to control fishing or allocate fishing opportunities on the high seas. This is despite the fact that the UN General Assembly decision that set up the BBNJ Convention Conference specifically enjoins it to avoid undermining existing mechanisms and agreements, and the BBNJ negotiators are careful to uphold this. The continuation of relatively unfettered high seas freedoms is valuable to distant water fishing nations – something that has long been evident to Pacific Island fisheries negotiators

[1] Gonedau Consultants. Email: tim.adams@gonedau.com
[2] "Marine Areas Beyond National Jurisdiction" are the high seas (the water outside EEZs) and, when it concerns the seabed, the seabed area outside extended continental shelves.
[3] See https://www.un.org/bbnj/ for more details.

at the Western and Central Pacific Fisheries Commission (WCPFC) when trying to set up rules to prevent high seas fishing from undermining exclusive economic zone (EEZ) fisheries of small island developing states (SIDS) – and guarantees that there will be continued opposition to both BBNJ and to further tightening of minimum standards for high seas fishing through WCPFC.

Will BBNJ be good or bad for Pacific Island tuna fisheries aspirations?

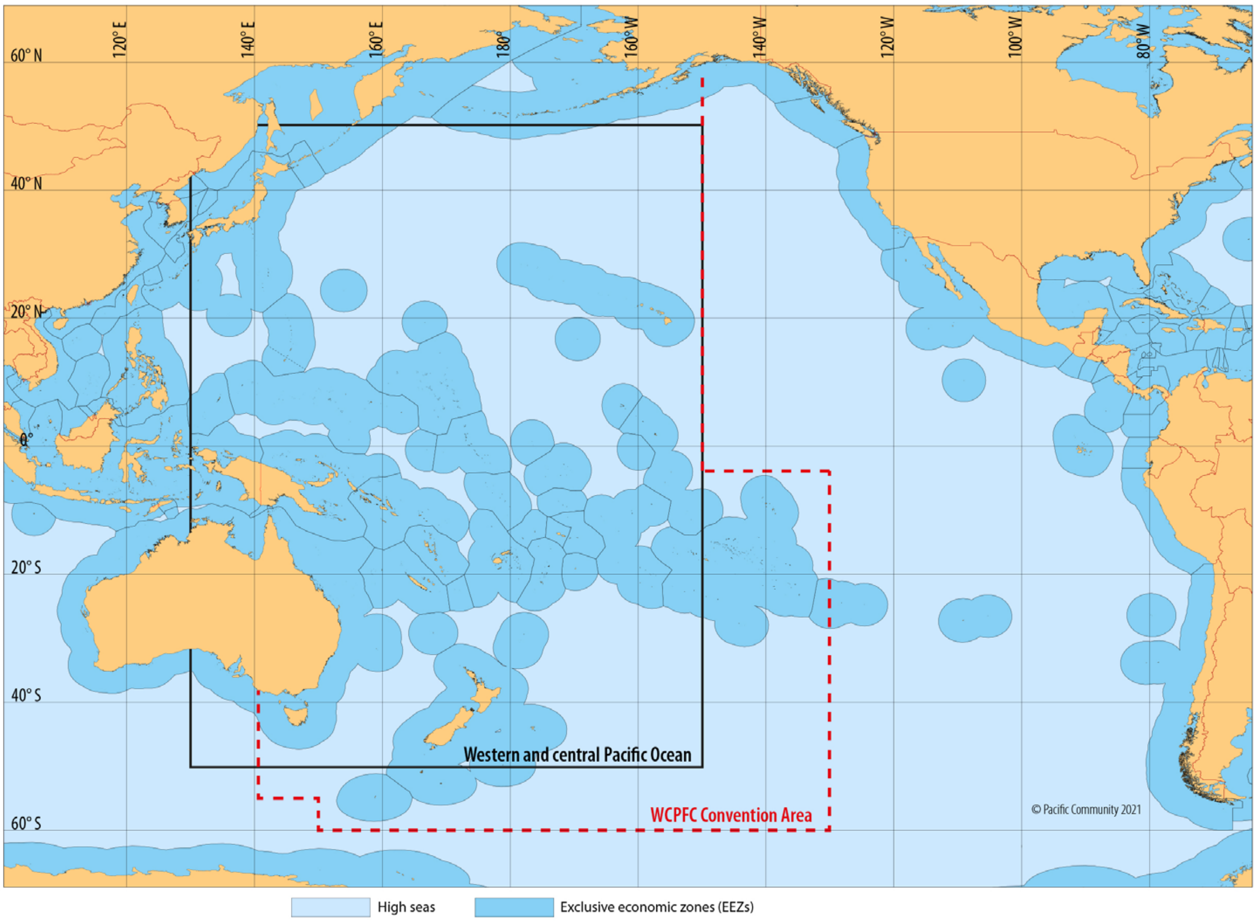
A look at the history of Pacific Island policy positions on high seas fisheries[4] makes it clear that Pacific Island states and territories have long sought to control and limit distant water tuna fishing on the Western and Central Pacific high seas – indeed, this was one of the main motivations for inviting distant water fishing nations (DWFNs) to the multilateral high-level consultation that eventually led to the creation of the WCPFC itself. Despite a few early wins such as the high seas boarding and inspection scheme, the high seas vessel monitoring system (VMS), and WCPFC's temporary agreement to close the two western high seas pockets to purse-seining in compatibility with the Parties to the Nauru Agreement (PNA) 3rd Implementing Arrangement, WCPFC (not the organisation itself, but the consensus decisions of its entire membership) has generally not been able to apply minimum standards to high seas fishing that are compatible with those applied collectively by SIDS to the fisheries within their own EEZs.

This has had economic impacts on some SIDS. Examples are included below.

- Lower standards for high seas fishing have allowed some longline fleets to move their operations out of certain EEZs when those SIDS have tried to tighten up their access provisions. This particularly affected Kiribati and Solomon Islands.
- The availability of free purse-seine fishing opportunities on the high seas reduces the value of purse-seine vessel days in SIDS EEZs.

Will high seas MPAs affect SIDS' own tuna fisheries?

The fisheries on the high seas of the western and central tropical Pacific are tuna fisheries. Tuna are defined under international law as highly migratory, and fishing for tuna is already limited on a Pacific-wide basis by agreement between WCPFC member countries, including both the high seas



[4] See: https://blog.gonedau.com/2022/03/how-new-bbnj-agreement-could-support.html

and EEZs. Whether the high seas of the WCPFC tropical region are closed to exploitation or completely open, the amount of tuna that can be taken from the entire region will remain, more or less, the same under the WCPFC Harvest Strategy Approach. This requires fishing to be controlled in such a way that its impact on a tuna stock keeps the regional biomass around an agreed regional Target Reference Point. And because tuna can migrate freely across boundaries, between EEZs and the high seas, it does not much matter where that fish is caught – whether within EEZs or on the high seas.[5] The actual catch of fish should remain the same, whether it is caught only within EEZs, or only on the high seas, or both in EEZs and on the high seas.

Currently, the great majority (90%) of the western tropical Pacific tuna catch comes from EEZs, where regulations are stricter, where monitoring is much stronger (particularly for longline fisheries) and where enforcement is generally more effective. Pushing that remaining 10% into EEZs would not put undue pressure on highly migratory tuna stocks, at least none that would not be counterbalanced by the reduction in illegal, unreported, and unregulated (IUU) fishing, including the under-reported catch of longline fisheries laundered through poorly verified high seas transhipments.

It might also be noted that the 30 × 30 initiative[6] endorsed by more than 70 nations in the Global Ocean Alliance[7] is only looking at protecting 30% of the ocean, and WCPFC will remain responsible for the allocation of tuna fishing opportunities outside any MPAs that are set up by the BBNJ high seas. WCPFC is already required to take into account the special requirements of SIDS in general (and of the particular circumstances of individual SIDS that have no high seas boundaries, or whose EEZ is composed of several non-contiguous areas). There are several Pacific Island nations with an interest in high seas tuna fishing themselves, but they will be able to continue to exercise that interest because BBNJ is not going to close all the high seas to fishing and because SIDS must have preferential access through the WCPFC Convention that will govern access to high seas areas that are not marine protected areas (MPAs).

Will BBNJ affect SIDS EEZ fisheries?

As mentioned earlier, the vast majority of tuna caught in the SPC region come from EEZ fisheries. The jurisdiction of the BBNJ Agreement is confined to areas beyond national jurisdiction, and there is no requirement for compatibility between EEZs and high seas in the draft text. If this remains the case, then BBNJ will not affect coastal and EEZ fisheries. The nearest that any area beyond national jurisdiction comes to the coast of any nation is 200 nautical miles (366 km).

BBNJ may, however, have a positive effect in providing the means to reduce the disproportionate burden of conservation action that currently falls on those SIDS that have enacted massive MPAs within their EEZs, in the name of tuna conservation. Currently there are no MPAs on the high seas of the western and central Pacific, and consequently small island EEZs are bearing this entire burden which, if MPAs do indeed contribute towards the conservation of tuna stocks, is benefitting the entire region including the longliners that often congregate on the high seas just outside SIDS EEZ boundaries.

What next?

These outcomes will need to be negotiated to fruition. The BBNJ text is not yet agreed and there is still scope for major divergence from expectations, despite the number of areas of convergence. And there is little clarity about the mechanisms for implementation yet – whether through a global or several regional organisations, or a hybrid mechanism whereby a global body agrees minimum standards and regional bodies implement them in ways appropriate to each major ocean region.

The next (and hopefully final) BBNJ Conference meeting has been recommended for August 2022, subject to the approval of the UN General Assembly.

Pacific Island Forum Leaders in their 2021 Ocean Statement[8] recognised that BBNJ and fisheries development are not mutually exclusive. If negotiated carefully, BBNJ could be of considerable assistance in helping conserve the biomass of fish stocks that will be crucial to the continued development of several Pacific Island economies, and the continued livelihoods and nutrition of rural coastal Pacific Islanders, as well as helping limit the opportunities for IUU fishing. It may also help in ensuring that some climate justice can be done as the western Pacific warm pool gets warmer and shifts the centre of abundance of tuna stocks eastwards from EEZs towards the central Pacific high seas in coming decades.

This article is a summary of an online document that can be downloaded from https://drive.google.com/file/d/1-StyE6JS48ox-PKqQP5jwDanRgIjTe6cm/view

[5] This is a simplification, of course – there will be local effects caused by slower or faster migration, by variable oceanographic conditions, or by denser or more diffuse fishing effort, but these local effects already apply to WCPO tuna fisheries and we already make major decisions about fishing in EEZs and the high seas, despite these uncertainties.

[6] See: https://en.wikipedia.org/wiki/30_by_30

[7] Including the SPC members Australia, Federated States of Micronesia, Fiji, Kiribati, Niue, Palau, Samoa, Tonga, Vanuatu, United Kingdom and United States of America

[8] https://www.forumsec.org/2021/03/22/pacific-islands-forum-leaders-ocean-statement-2020-21/

How effective are artisanal fish aggregating devices?

Robert E. Gillett[1]

Preparing a FAD flotation system in Fiji. (Image: © Michael Savins)

Introduction

Fish aggregating devices (FADs) have been used in Pacific Island countries for more than four decades to assist small-scale fishers in catching pelagic fish. Presently most of the government fisheries agencies in the region have FAD activities in which funds from local and overseas sources are used to manufacture and deploy FADs. A general conclusion from many years of experience in fisheries development efforts throughout the Pacific Islands is that FADs are one of the few innovations that enable small-scale fishers to more economically take advantage of the region's large tuna resources. Although there is a consensus that FADs are effective, quantitative evidence of this effectiveness has been elusive.

This paper is a short summary of a longer report of a study carried out in late 2020. This work was a component of the Japan-funded FAO-implemented project "Enhancing livelihoods and food security through fisheries with nearshore fish aggregating devices in the Pacific Ocean", commonly referred to as the FishFAD Project.

Studying FAD effectiveness

What is FAD effectiveness? Because FADs are deployed for various reasons, there are several ways in which a FAD programme could be effective or ineffective. In other words, effectiveness depends on the objectives of a FAD programme. Some of the main objectives of FAD programmes in the Pacific Islands region are improving the catch per unit effort (CPUE) of small-scale pelagic fishing, increasing economic returns for fishers, relieving fishing pressure from coastal resources and recovering from natural disasters. Each FAD objective is associated with a different way in which effectiveness can be viewed. In this report, this is referred to as a dimension of effectiveness.

The purpose of the study is to identify and examine the various dimensions of FAD effectiveness, review the literature on FAD effectiveness studies, identify and explore factors influencing FAD effectiveness and make observations and suggestions on studies of FAD effectiveness – with the overall intent of improving FAD programmes.

Previous work relevant to the study of FAD effectiveness

The study obtained 160 research papers from around the world conceivably relevant to the study of FAD effectiveness. Those reports were closely examined to identify those that give the results of specific quantitative studies of FAD effectiveness. This resulted in a list of 17 reports. Each of those reports was examined for the dimension of FAD effectiveness studied. Many of the reports had slightly different names for the various dimensions, but for comparison purposes, the dimensions were placed into six general categories, the shortened names of which are: catch rates (i.e. CPUE), cost–benefit, profitability, coastal fishing pressure, tuna production, and sportfishing development. Those papers are shown in Table 1.

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Table 1. FAD effectiveness studies: the dimension(s) of effectiveness studied and the results.

Author	Year of report	Area	Dimension of effectiveness	Results
Buckley	1986	American Samoa	CPUE	The FAD CPUE was 3.6 times greater than the open-water CPUE, and the bank/seamount CPUE was 1.8 and 6.4 times greater than the FAD and open-water CPUEs, respectively.
Sims	1988	Cook Is.	Cost–benefit	Returns of 312% on FAD expenditure are realised.
Buckley et al.	1989	American Samoa	CPUE	The quantitative information in this study on differential catch rates between open-water areas, FADs, and offshore banks, conclusively shows that FADs are an effective method for enhancing the troll fishery catches of commonly caught pelagic fish in American Samoa.
Cillaurren	1990	Vanuatu	Profitability	The results indicated a troll fishery around the FADs was not viable due mainly to high running costs because of travel to and from the FADs.
Cayré et al.	1991	Comoros	CPUE	FADs significantly (+86%) enhanced the CPUE of both species of tuna for handline gear, but only the CPUE of yellowfin gear for trolling gear (+29%)
MRAG	1994	Fiji	Tuna production, CPUE; coastal fishing pressure	There has been a large increase in tuna landings due to FADs. CPUE on FADs is greater for yellowfin (not skipjack) tuna. FADs appear to have had little impact on effort on coastal fisheries except for spearfishing.
MMR	1999	Cook Is.	Cost–benefit	The cost for a single FAD is approximately NZD 7000 with estimated returns in 1989 of NZD 69,000 from trolling. This is 10 times the cost of deploying a FAD.
Chapman et al.	2005	Niue Cook Is.	Cost–benefit, coastal fishing pressure	In both Niue and Rarotonga, the value of the catch far exceeded the cost of the materials. The success of FADs as a management tool (i.e. changing coastal fishing effort) was harder to determine.
Templeton and Blanc	2008	Nauru	Cost–benefit	The total cost of one nearshore FAD was AUD 2100, which meant the value of catches at the nearshore FADs was equivalent to the cost of 10 of the FADs, so nearshore FADs tested were cost effective.
Sharp	2011a	Niue	CPUE, cost-benefit	Although offshore FADs have the greatest impact on CPUE (kg/hr), it is clear that inshore FADs also improve CPUE (kg/hr). Unlike some other studies, the "benefit" in this study is the net production gain plus the fuel cost saving (i.e. not just the gross value of the catch). The government investment of NZD 39,729 provided an economic return of NZD 95,813 over a two-year period.

Table 1. (continued)

Author	Year of report	Area	Dimension of effectiveness	Results
Beverly et al.	2012	Mauritius	Sportfishing development, cost–benefit	The number of sport fishery boats increased from 40 to 75, though only 45 of those were considered to be fishing regularly.
Guyader	2013	Guadeloupe	Profitability	Profitability was greater for FAD vessels than coastal vessels.
Sharp	2014	Yap	CPUE, coastal fishing pressure, cost-benefit	FADs improve fisher efficiency, in terms of increasing CPUE; FADs may divert fishing activity away from the coast; the financial cost incurred from procuring and installing FADs is significantly outweighed by the additional catch values generated.
Albert et al.	2014	Solomon Is.	Cost-benefit	A cost–benefit analysis indicated that the financial cost of the FADs (including materials, deployment costs and fisher training) can be recovered within 2–5 years, as long as the FADs are well utilised.
			(CPUE and tuna production in different papers from same study)	This study was also covered by two other papers: Masu and Albert (2014) and Albert et al. (2013), with the latter having (a) a CPUE analysis indicating that catch rates at the FADs areas were not significantly higher than at the non-FAD fishing areas, and (b) a tuna production analysis showing FADs increasing the supply of fish to four communities.
Albert et al.	2018	Vanuatu	CPUE	Contrary to expectations, catch rates for all fishing methods were not consistently higher at the FADs than at non-FAD fishing areas.
James	2018	Fiji	CPUE	The data suggest that FADs are twice as efficient as reef and lagoon fishing. FADs tended to provide a good return per dollar spent in fishing activity when compared to open ocean, but not compared to spearfishing.
Tilley	2019	Timor-Leste	CPUE, cost–benefit	There was a significant positive effect of FADs on productivity, with a mean CPUE value of 2.17 kg/(fisher-hour) for FAD-associated fishing compared with 1.21 kg/(fisher-hour) for reef fishing and 0.8 kg/(fisher-hour) for other habitats. Time to 100% return on investment was from 18 days in Vemasse to 3343 days in Biacou.

Several features emerge from Table 1. The most common dimensions of FAD effectiveness examined in those studies were CPUE (10 studies), cost–benefit (9), coastal fishing pressure (3), profitability (2), tuna production (2) and sportfishing development (1). Although a large number of objectives for FAD programmes have been cited, many objectives do not appear to have been studied for effectiveness (e.g. reducing sea safety incidents, producing food for post-cyclone recovery efforts). A careful reading of the reports listed in Table 1 suggests that studying FAD effectiveness is often associated with a number of difficulties, including the reliance on non-verified fisher-supplied data, distinguishing a FAD fish from a non-FAD fish, and the use of inappropriate methodology.

Summary of the results

Analysis of the studies in Table 1 reveals several features detailed below.

How conclusive have the past FAD effectiveness studies been?	The analysis shows: • The cost–benefit and CPUE studies appear to be reasonably conclusive; there have been a large number of such studies and almost all show that FADs have a favourable cost–benefit ratio and that FADs result in relatively high catch rates. • The issue of whether FADs relieve coastal fishing pressure is relatively difficult to study and the results from past studies have not come up with strong evidence that FADs can perform this function, and therefore the results of those studies should be considered inconclusive. • The other types of FAD effectiveness studies examined (profitability, tuna production increases, sportfishing development) cannot be considered conclusive due to the small number of these studies.
FAD monitoring	In this report "monitoring" is considered to be the periodic observing and recording of data relevant to FADs. It can include information about the condition of FADs, fish catches, fishing areas, fishing operations, fish sales and fish consumption.
Current FAD monitoring in the region	The results of two regional surveys that included FAD monitoring indicate that most countries in the region are having difficulty with monitoring. Many of the problems associated with FAD monitoring can be placed in three categories: lack of monitoring, difficulties with the monitoring methodology, and not using the data collected.
Conditions required for FAD monitoring	Certain conditions are necessary for a national FAD programme to be able to carry out effective FAD monitoring. These include that adequate money is available for the monitoring, the FAD monitoring budget is not subject to cuts, there is enthusiasm for FAD monitoring (among both Fisheries Department staff and fishers), the staff of national FAD programmes have the capacity to monitor/report, and the results are used. There appears to be the assumption in several of the reports and comments on FAD monitoring that these conditions occur – but the reality is that these prerequisites simply do not exist in most Pacific Island countries and territories.
Mitigation of FAD monitoring difficulties	If monitoring and reporting are not happening due to shortages of resources and capacity, one approach would be to aim, at least initially, for something cheap/simple. Very basic monitoring that produces useful information for various purposes is probably better than a very sophisticated system that is dysfunctional. Another approach is to establish a hierarchy of priorities for the various types of monitoring. FAD monitoring can range in complexity from recording the presence/absence of a deployed FAD to the collecting of information to determine whether a FAD is relieving coastal fishing pressure. A country could identify several possible types of monitoring of varying complexity and cost – with the appropriate level being chosen depending on the current national FAD objectives and resources available.
Specific factors influencing FAD effectiveness	FADs relieving coastal fishing pressure appears to be the most complex in terms of interplay of factors that affect success, contributing to the fact that no study has established how effective FADs are at reducing coastal fishing pressure. FAD fishing skills are important for almost all the dimensions of FAD effectiveness.
Relationship between FAD programme institutionalisation and FAD effectiveness	It is now generally accepted that national FAD activities are most effective where there is a national FAD programme as part of the government fisheries agency – rather than a project that comes/goes with the availability of funding, pressure from fishers, or the availability of external FAD services. An ongoing FAD programme within a fisheries agency allows for greater continuity of FAD work, in-house training, successful technology transfer to staff, and a mechanism for interaction with stakeholders. By being an established unit inside a fisheries department (rather than a project with no permanent staff), there is likely to be greater stability of funding. Without institutionalisation, the process of learning from past FAD-related mistakes is more difficult.
Stakeholder input	Several studies indicate that formal input of FAD users is important for FAD effectiveness, with the general situation being summed up thus: Involving local fishers in the site selection process is important. This local knowledge can also increase the effectiveness of the FAD by locating it at a known productive fishing ground. Through the community engagement process, mechanisms are also required to enable conflict and dispute resolution.

The impact of FAD effectiveness studies	Have FAD effectiveness studies (1) helped the flow of FAD funding, or (2) determined if FAD objectives have been met? • From the limited information available, it appears that there are several examples of #1 being successful. • The ability of FAD effectiveness studies to determine whether FAD objectives are being met (#2 above) depends on the conclusiveness of the studies. The analysis shows that effectiveness studies have been successful in determining the meeting of objectives related to cost–benefits and CPUE, but not for the other objectives. • Another finding is that effectiveness studies oriented to defined objectives (e.g. cost–benefits, CPUE) appear to have been most relevant at the early part of the FAD era (1980–2000).
The future of FAD effectiveness studies	The need for FAD effectiveness studies probably varies considerably between Pacific Island countries and territories. In places where there are only rudimentary FAD activities, such studies are probably much more useful than in countries where there is a well-functioning national FAD programme. Another concept related to the need for future FAD effectiveness studies concerns competing priorities. In the use of scarce funding for FADs and related work, what has the highest priority? Obviously, this would differ between countries, but for many countries the establishment and development of national FAD programmes is arguably the most important, or at least more important than additional effectiveness studies.
Improving future FAD effectiveness studies	It is important to have considerable economic expertise in designing such studies and in the subsequent analysis. Several other suggestions for improvement of future studies are given in the full report of the study.
Additional significant messages from this study	• FAD fishing skills are important for almost all the dimensions of FAD effectiveness. • Fisher inputs into FAD programmes are also important for many dimensions of FAD effectiveness. Fisher associations seem to be good at initiating and maintaining this input. • At least some monitoring of FADs needs to be carried out, with the simplest being a system for determining the presence/absence of a deployed FAD. Any less than this could be considered negligent.

The main recommendations from the study

Countries that do not have a national FAD programme institutionalised into the government fisheries agency should consider making steps in that direction. This suggestion is especially relevant for the countries and territories of the region that have sporadic FAD activities dependent on the availability of external funding and FAD expertise.

Prior to committing to new FAD effectiveness studies:

- countries should realistically appraise whether there are more beneficial alternative uses of FAD-related funding;
- in countries where national FAD activities are constrained by lack of knowledge of FAD effectiveness, the results of previous FAD effectiveness studies (including those in neighbouring countries) should be publicised;
- certain conditions are required for effective monitoring in support of FAD effectiveness studies (e.g. adequate budget that is not subject to reduction, and capacity/enthusiasm to monitor and report); deficiencies in those requirements should be addressed before committing to a FAD effectiveness study.

In the design of new FAD effectiveness studies:

- there should be considerable economic expertise input into the study formulation process (and in the subsequent analysis);
- countries should consider the advantages of a "learn-to-walk-before-running" approach; first attempting simple studies (e.g. daily cost of a FAD or CPUE) before embarking on types of effectiveness studies that are more complex or have rarely been conclusive in the past;
- to the extent possible, study methodology should be formulated to account for "messy data" that has plagued many past studies, and consideration should be given to the use of new technologies to mitigate these difficulties;
- the study design should take into account the large difference in studying FAD effectiveness at villages and close to urban areas;
- provisions should be made (budget, work activities) for publicising and using the results of the FAD effectiveness study.

For the study of the effectiveness of FADs for relieving fishing pressure from coastal fishery resources, countries should consider the cost, complexity, and inconclusiveness of past studies – and examine the option that SPC or an external research organisation lead the work, rather than the study being an activity undertaken exclusively by a national FAD programme.

Organisations and donors that are involved with FADs should consider:

- promoting approaches to encourage institutionalisation of FAD activities in national FAD programmes;
- sponsorship of studies to determine effectiveness of FADs studies for relieving coastal fishing pressure;
- including a component of FAD fishing skills into all packages of assistance involving FADs.

Concluding thoughts

FADs have been demonstrated to be one of the few mechanisms by which small-scale fishers in the Pacific Islands are able to economically access the large tuna resources of the region. If we assume that FADs are indispensable for coastal fisheries development in the region, steps should be taken to improve the functioning of FADs in the various countries. Following from this, the need for FAD effectiveness studies must be compared to the need for other work that would improve the benefits from FADs. Although there is no doubt that effectiveness studies have been beneficial in the past, the situation is evolving. Many FAD specialists in the region feel that in some countries other work, especially institutionalisation of FAD activities into a national FAD programme, should have higher priority than effectiveness studies. This contention is consistent with the impressions received in this study.

Another perspective is that the various countries have different FAD-related needs. Some are striving to prove the value of FADs to the government, public, and donors; for others, where their value is well recognised, FAD effectiveness studies are probably less needed. However, the region as a whole could benefit from more knowledge on whether FADs can relieve pressure on coastal fishery resources.

Despite being generally accepted that national FAD activities are most effective where there is a national FAD programme as part of the government fisheries agency, such programmes are not common in the region. SPC has undertaken work in this area (e.g. the checklist for sustainable national artisanal FAD programmes; SPC 2017), but other approaches should be considered, such as a requirement for countries to demonstrate progress in this area to be eligible for a visit from a FAD technician.

A detailed 79-page report of this study is available from the author on request at rgillett1@yahoo.com

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Setting a FAD, and getting ready to drop the anchor in Kiribati (Image: © Michael Savins)

Unlocking the potential of pelagic fisheries: How can anchored fish aggregating devices be used to address food insecurity in tropical small-scale fisheries?

Olivia Smailes[1]

The Fish and Fisheries Lab (www.fishandfisheries.com), based at James Cook University in Australia, teaches several undergraduate and masters level subjects about fisheries management. One of the most popular subjects is "Managing Tropical Fisheries", where students learn about the importance and complexity of tropical fisheries, and how they need very different management approaches compared to more traditional industrialised fisheries such as cod or swordfish. As part of the course, students are required to submit an essay on a complex area of tropical fisheries. Many students submit well written, well researched, and insightful essays that we felt are worth sharing. Following Rachel Mather's essay published in 2020,[2] we are pleased to share with you through the SPC Fisheries Newsletter the essay by Olivia Smailes, the pick of the essays submitted in 2021. Well done, Olivia.

Dr Andrew Chin – Course Coordinator

Introduction

While there is a lack of consensus on what exactly defines a small-scale fishery (SSF), their contribution to the socio-economic well-being of coastal communities is clear. Within these communities, fish are considered critical to food security and health through the provision of daily protein requirements and essential micronutrients (Gibson et al. 2020). Furthermore, the engagement in fisheries offers important livelihoods for some of society's most vulnerable people, particularly in the tropics where the greatest proportion of fish-dependent populations reside (Teh and Pauly 2018). By 2050, tropical fisheries are predicted to decline by as much as 30% due to climate change and shifts in primary production (Cheung et al. 2016). The vulnerability of SSF to such changes is further exacerbated by issues of equity and social justice (Andrew et al. 2007). Amidst such dire projections, there is an urgent need for management measures that better address food security concerns in SSF.

Nearshore anchored fish aggregating devices (aFADs) are presented as a practical and effective approach to improving local food security within SSF (Tilley et al. 2019b). The propensity for pelagic fish to aggregate around floating bodies has long been exploited by fishers to improve catch rates. Roman author Opian provided evidence for the exploitation of this behaviour to catch dolphinfish, *Coryphaena hippurus*, as early as 200 AD (Dagorn et al. 2012; Churchill 2021). The fishing practices associated with these structures extract a far greater biomass than those that target free-swimming schools (Griffiths et al. 2018). Since their conception, FADs have become an essential fishing tool around the world (Taquet et al. 2011). Of note is the successful application of nearshore aFADs in improving catch rates within SSF. These devices comprise one of two basic categories of FADs, the second being drifting FADs (dFADs) that are used by industrial purse-seine fisheries. It is important to distinguish between these two categories as the use of the dFADs is frequently criticised for its negative impacts on marine resources (Dagorn et al. 2013). The aFADs are simple structures anchored in coastal areas at a distance accessible to small artisanal fishing vessels (Beverly et al. 2012). Despite their simplicity, these devices offer an array of benefits including increased catch per unit effort (CPUE) and reduced pressure on reef ecosystems (Beverly et al. 2012). Of perhaps the greatest significance is the access provided to highly nutritious pelagic fish stocks. There is convincing evidence that indicates that aFADs directly address food security concerns by increasing both the supply and consumption of pelagic fishes (Albert et al. 2014; Bell et al. 2015a). As such, aFADs have been integrated into many national fisheries action plans and policies (Sharp 2011; Campbell et al. 2016; Tilley et al. 2019b).

Tackling food insecurity and micronutrient deficiencies with fish

Food insecurity persists as one of the most significant public health challenges across the developing world. Unreliable access to food contributes to child wasting, stunting and micronutrient deficiencies (FAO 2018). Across the world, an estimated 1.5 billion people are affected by one or more forms of micronutrient deficiency and 2 billion people lack key micronutrients such as iron and vitamin A (Global Nutrition Report 2017; FAO 2018). Due to the lack of even progress in tackling malnutrition, food and nutrition security have remained high on the global development agenda. Fish are presented as a practical solution to address these issues as they are rich sources of bioavailable micronutrients (Hicks et al. 2019). As such, they remain a key focus of food and nutrition policy, particularly within

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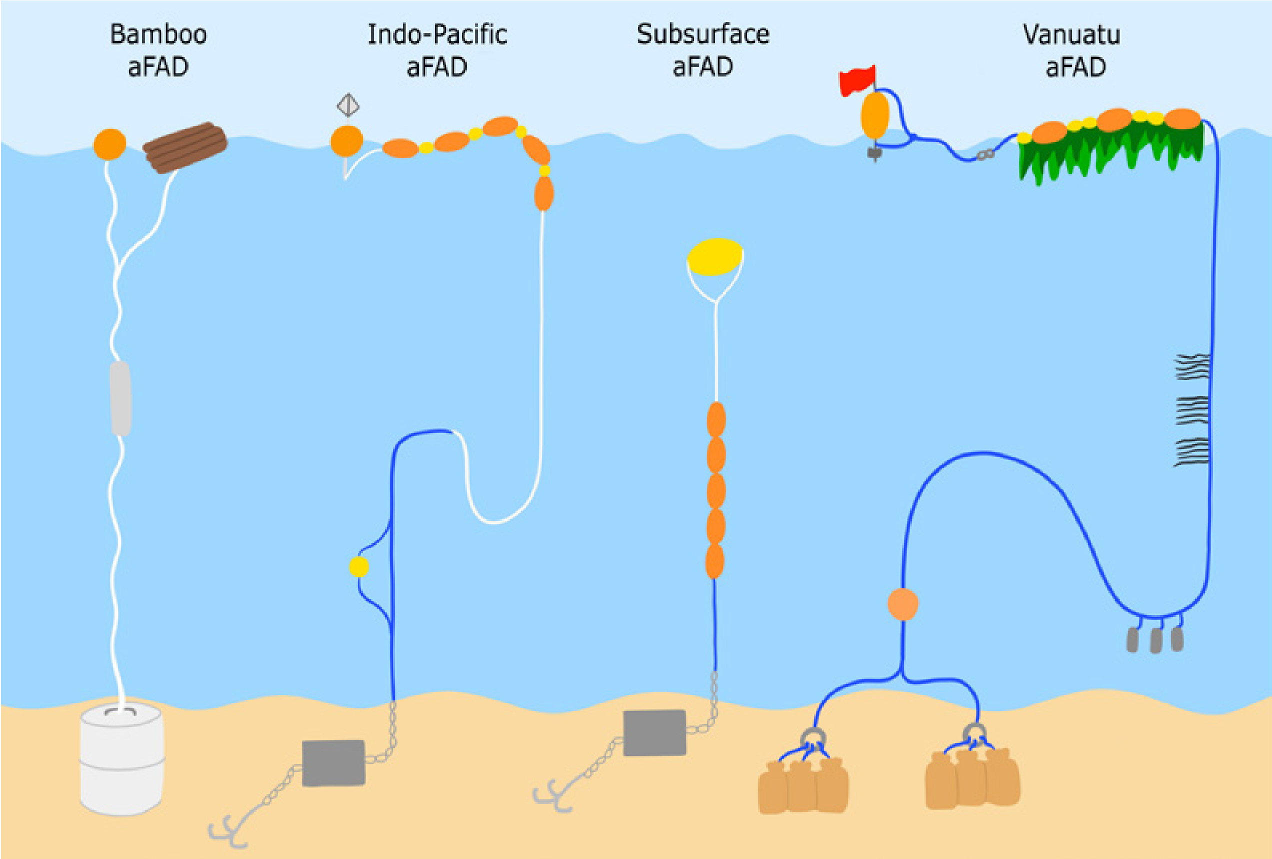

Figure 1. The diversity displayed in artisanal FADs. FAD design typically differs based on location and the given context – no one-size-fits-all. (Illustration: Olivia Smailes; adapted from Sokimi et al., 2020).

the tropics, where fish are widely harvested and traded due to the scarcity of arable land (Bell et al. 2015a). Throughout the tropics, small-scale fishing makes a vital contribution to the livelihoods of some of society's poorest and most marginalised people (Teh and Pauly 2018). The small-scale sector is responsible for 55% of the annual capture fisheries production. Of this amount, 62% is used directly for local consumption within developing countries. The proportion of fish consumed locally can be used as an indicator for the contribution of fish and fisheries to food and nutritional security (Mills et al. 2011).

The value of pelagic fisheries

Pelagic fisheries demonstrate a number of desirable characteristics that favour their use in SSF. They comprise robust migratory stocks that, due to direct feeding on planktonic systems, exhibit high concentrations of omega-3 fatty acids and protein (Hicks et al. 2019). Their nutritional value is much higher than the nutrient-poor imported foods that are pervasive within regions of the tropics such as the Pacific (Bell et al. 2015a). Because pelagic fishes grow rapidly and are short lived, they support very productive populations upon which fisheries heavily rely (Morais and Bellwood 2020). This productivity can potentially sustain heavy fishing for decades, thus highlighting its potential in addressing food security concerns. Due to their propensity to roam throughout a greater area of the ocean, pelagic fishes also possess the capacity to rapidly replace harvested stocks. Furthermore, they are less sensitive to harvest due to the fundamentally different ecosystem processes that take place in the open ocean (Birkeland 2017). In Hawaii, nearshore pelagics such as *Selar crumenophthalmus* and *Decapterus macarellus* displayed resistance to overexploitation despite three decades (1966–1997) of high catch rates (Birkeland 2017). The favourable characteristics displayed by pelagic fisheries demand a shift away from coral reef species, which currently dominate catches in SSF.

Using aFADs to unlock the benefits of pelagic fisheries

Despite increasing awareness about the value of pelagic fisheries, a gap is emerging between the amount of fish required for optimal nutrition and coastal fish catches. This gap is largely driven by exponential population growth and the deterioration of coastal fisheries production (based mainly on coral reefs) due to overexploitation (Bell et al. 2018). By increasing access to pelagic fish resources, aFADs present a practical solution to helping feed rapidly expanding coastal populations. In contrast to their industrial counterparts, aFADs are relatively rudimentary and highly diverse (Fig. 1) (Sokimi et al. 2020). These purpose-built structures are anchored offshore (at depths between 100 and 1500 m) to benefit from the tendency of pelagic species to aggregate (thigmotropism) (Fig. 2). While there is little known about the mechanism that underlies this phenomenon, it has been suggested that fish aggregate around artificial floating objects for reasons including refuge and feeding (Beverly et al. 2012).

Qualitative modelling indicates that despite their simplicity aFADs are among the innovations with greatest positive effect on food security (Bell et al. 2015b). The access provided by aFADs to underutilised pelagic resources can produce sizeable increases in fish yields (Beverly et al. 2012). While the assemblage of species caught around aFADs is less diverse than that associated with reef fishing, it comprises highly productive species that are relatively resistant to exploitation (Tilley et al. 2019b). Of the species caught, tuna is the most prevalent and can be caught year-round. An aFAD programme implemented in Mauritius revealed that tuna accounted for 78% of the artisanal catch weight (Beverly et al. 2012). The value of tuna caught around FADs typically exceeds the costs of materials and installation (Bell et al. 2015b). Given the substantial contribution of tuna to food security, providing better access to this resource is high on development agendas. The expansion of aFADs can help enhance both the catch and supply of tuna in SSF and should therefore be at the focus of national infrastructure for food security (Bell et al. 2015b).

Convincing evidence indicates that aFADs greatly increase the efficiency of fishing in SSF. Tilley et al. (2019b) identified a significant positive effect of aFADs on catch rates and CPUE in Timor-Leste. Increases in the quantity of fish landed contributed to improvements in rural access to fish and thus micronutrient availability. In Yap State, Federated States of Micronesia, deployment of aFADs led to an increase in CPUE from 10.91 to 24.94 kg/hr/boat (Sharp 2014). As observed in the Solomon Islands, improvements in fishing efficiency can increase household income and nutrition (Albert et al. 2014). According to accounts from a fisher focus group in Adara, Timor-Leste, the reduced time required to catch enough fish is considered the primary benefit of aFADs. The use of these devices allows fishers to allocate additional time to other livelihoods such as land and

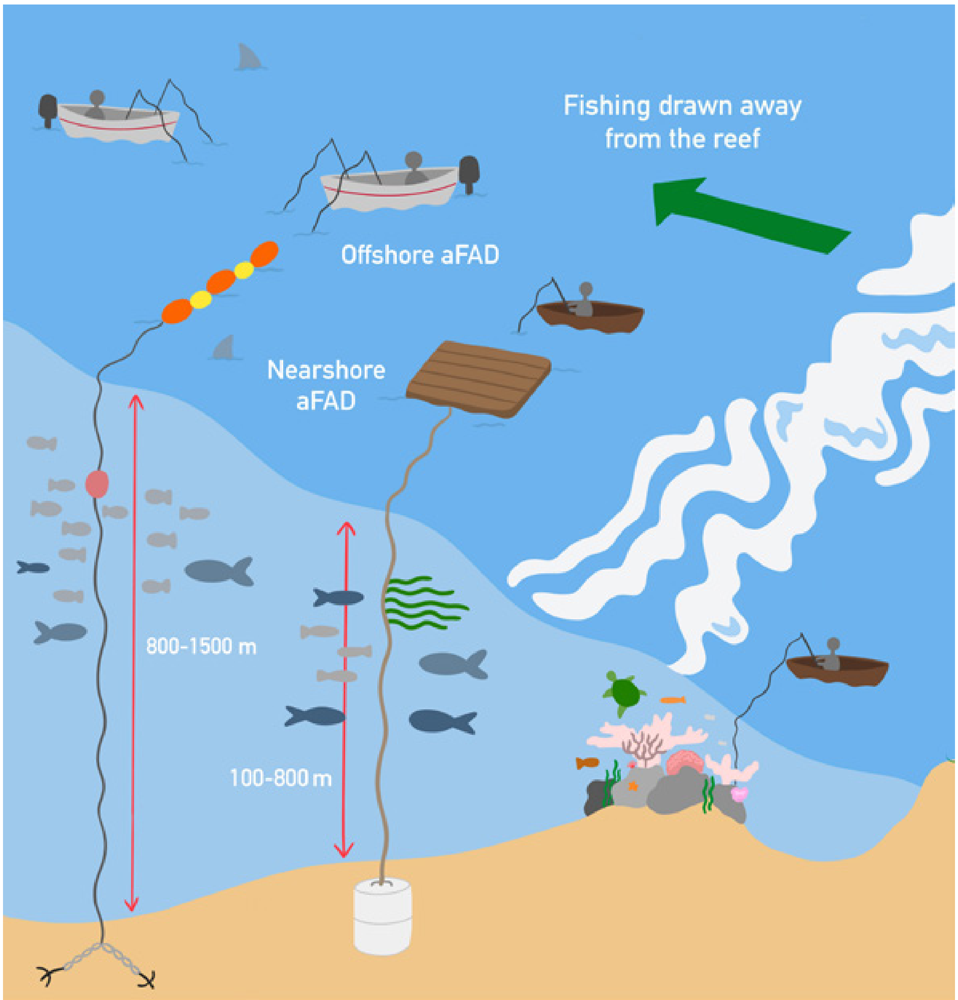

Figure 2. FADs are installed at depths of up to 1500 m. Fishing is drawn away from heavily exploited nearshore reefs and catch is instead focused on productive pelagic fish resources. (Illustration: Olivia Smailes)

livestock cultivation (Tilley et al. 2019b). Livelihood diversity is considered an important factor in increasing the adaptive capacity of a community. By providing households with the ability to spread their efforts across different livelihoods, it allows them to better cope with environmental and economic shocks. In doing so, it buffers against the impacts on food security (Mills et al. 2017). This is especially significant for SSF, which are inherently dynamic and subject to extreme uncertainty and change (Finkbeiner 2015).

In addition to increasing the supply and consumption of nutrient-rich pelagic fishes, aFADs also offer an alternative source of fish that can provide communities with the opportunity to transfer some of their fishing effort away from heavily exploited coral reefs (Bell et al. 2015a) (Fig. 2). Over 75% of coral reef fisheries are currently fished at levels deemed to be unsustainable (MacNeil et al. 2015). The overexploitation of these fisheries poses a significant threat to the millions of people who depend on them for livelihoods and food. SSF concentrate a large proportion of fishing effort on reefs that are dominated by slow-growing, late-maturing species (Sharp 2014; Birkeland 2017). In Yap State, Federated States of Micronesia, reef fish comprise 74% of total reported catch (Sharp 2014). These fisheries are not capable of yielding the recommended 35 kg of fish per person per year, nor are they able to fulfil demand (Bell et al. 2015a). In areas where productivity of reef fisheries is limited, fishers have reported declines in catch volume and fish sizes. Under such circumstances, there is a need to diversify fisheries to exploit more productive pelagic stocks (Tilley et al. 2019a). The use of aFADs presents an opportunity to shift fishing effort away from reefs, towards abundant pelagic resources. A community-based aFAD programme in Uripiv Island, Vanuatu, provides evidence for this shift in fishing effort. Following the implementation of this programme there was a 76% reduction in landings of reef fishes as effort was transferred to FADs and over deep slopes (Amos et al. 2014). When Marine Protected Areas (MPAs) are established, aFADs also offer an alternative source of fish. These spatial protections are an efficient way of relieving pressure on reef ecosystems, yet they are often contested for squeezing out small-scale fishers from their traditional fishing grounds (Cohen et al. 2019). Under such circumstances, aFADs provide fishers with the opportunity to shift their effort away from MPAs towards abundant pelagic fish stocks. While these examples illustrate the potential of aFADS to offset MPA impacts or shift fisheries to more resilient species, the changes in fishing behaviour following the installation of aFADS need to be better documented.

Optimising the use of aFADs in SSF: recommendations for fisheries managers

Harnessing the potential benefits of aFADs needs careful planning and consideration about the design, implementation and use of these structures.

Practical and financial considerations in FAD deployment and beyond

From a practical perspective, there are a number of technical aspects involved in the successful deployment of aFADs within an SSF. Bell et al. (2015a) highlight four important considerations (Fig. 3).

- Coastal communities should be closely consulted with to help identify sites where optimal catches of tuna and other pelagic fish species have been made
- Sufficient distance (~1 km) must exist between aFADs and coral reefs to prevent the translocation of reef-associated fish species such as Spanish mackerel and trevally.
- So as not to compromise the potential for each aFAD to aggregate pelagic fish such as tuna, aFADs should be positioned at least 20 km apart.
- To ensure that artisanal vessels can easily access aFADs, they should be located at a close enough distance to coastal villages. Exceptions can be made in certain situations, for example, where the shoreline bathymetry is not suitable.

So that they are best placed to meet food security commitments, aFADs should be deployed close to communities where dependence on fish is high and access to productive fishing areas is limited (Albert et al. 2015). In cases where resources are scarce, focus ought to be concentrated on maximising the benefits of existing aFADs to prevent a "quantity over quality" scenario. In doing so, it will optimise the use of aFAD programmes and maximise their potential to meet food security commitments (Campbell et al. 2016). There is convincing evidence to support the concept that the longer the life of an aFAD, the higher the return on investment. To realise the full financial potential of aFADs, management measures should therefore target longevity (Beverly et al. 2012). Sufficient budget needs to be allocated to the ongoing maintenance of an aFAD and clear guidelines must be in place that stipulate who is responsible for maintenance tasks (Sharp 2011). In Timor-Leste, a positive effect was identified between aFAD longevity and overall revenue. To maximise the benefits of this effect, fishers were encouraged to cooperatively engage in aFAD maintenance (Tilley et al. 2019b).

While deployment is a contributing factor to success, it alone cannot guarantee the delivery of aFAD benefits. Short funding timeframes often lead to the over-allocation of project resources to deployment activities. In consequence, long-term monitoring, evaluation, and adaptation processes are often neglected. Such processes are critical to helping ensure development objectives are being fulfilled and, in cases where they are not, identifying feasible alternatives (Campbell et al. 2016). This short-term, project-based approach might perhaps explain the frequent failure of aFADs to live up to expectations (Sharp 2011; Bell et al. 2015a). It is also a contributing factor to the scarcity of data

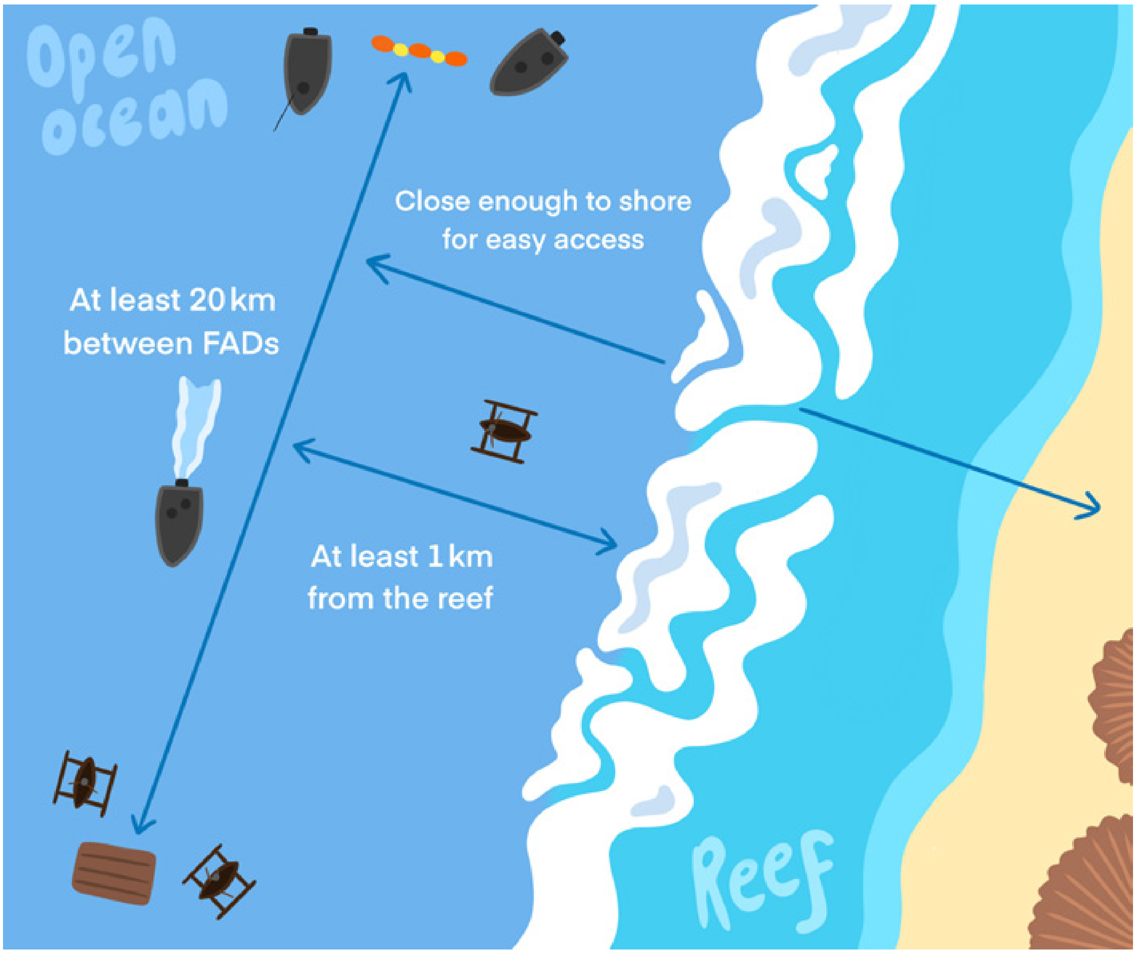

Figure 3. The practical considerations required for successful deployment of aFADs for small-scale fishing communities. (Illustration: Olivia Smailes)

pertaining to the delivery of aFAD benefits. For example, there is much uncertainty as to whether more fish are consistently caught around aFADs and whether these fish are being consumed by people most in need. This lack of key information presents several challenges including the following (Campbell et al. 2016):

- the inability to adapt aFAD programmes so that they are better positioned to meet food security commitments
- difficulty in conducting a cost-benefit analysis of aFADs in SSF
- the undermining of proposals to secure sustained, external funding support.

Considering these challenges, funding programmes and managers need to provide adequate support that enables fisheries managers to establish long-term aFAD programmes that reach far beyond deployment.

Addressing the ownership and right-based use of aFADs in SSF

Effective operationalisation of aFADs within SSF requires an understanding of the complex politics and institutional landscapes that can exist (Bell et al. 2015a), without which conflicts can arise. Often these conflicts take place over ownership and to a greater extent, the rights-based use pertaining to a particular aFAD (Beverly et al. 2012). Vandalism is a persistent problem and arises due to aFAD access inequities (Albert et al. 2014). To reduce the occurrence of such conflicts, fisheries managers need to understand the local mix of use rights, customary tenure, and ownership (Albert et al. 2014). Community consultation is therefore vital in facilitating this understanding. Consultations must equitably represent the diversity of views from different stakeholders, including women whose role in SSF is substantial. An estimated 47% of workers in the SSF sector are women. In the Pacific, this accounts for half of the annual coastal fisheries catch (Mangubhai and Lawless 2021). Given the integral involvement of women, their role in SSF aFAD programmes must not be overlooked (Beverly et al. 2012). Their inclusion in the planning and implementation of these programmes is vital to addressing gender issues in SSF. Beyond community engagement, aFAD governance must also be considered. Credence is given to efforts that promote co-managed aFADs in regions of the tropics such as the Eastern Caribbean (Pittman et al. 2020). Co-management embodies several principles reminiscent of "good" governance including democracy, transparency and sustainability (Andrew and Evans 2011). Such principles may be translated across to SSF management through the implementation of co-managed aFAD programmes. In doing so, co-management serves to reduce conflicts such as vandalism and helps optimise the contribution of aFADs to local food security (Bell et al. 2015a; Pittman et al. 2020).

Conclusion

Despite the critical role that SSF play in poverty alleviation and food security, there is a significant lack of effective assessment and management measures that ensure sustainability. The scarcity of such measures highlights a need for innovation that addresses both the diversity and vulnerability of SSF. The use of aFADs presents a feasible solution by increasing access to highly productive, nutrient-rich pelagic fishes. In doing so, aFADs can help better align fisheries management and development activities with key priorities such as food security. Furthermore, they can aid with the capacity building of small-scale fishing communities and thus enhance the community's ability to meet its own needs. So that aFADs are best placed to fulfil their potential, fisheries managers must approach aFAD programmes as long-term investments, with particular focus on the current scarcity of monitoring and evaluation information. Given the prevalence of issues pertaining to ownership and user rights, efforts should be focused on establishing clearly defined boundaries. Community consultation is critical to this process as it offers important insights into the social complexities of SSF.

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Journey into the world of age and maturity in Pacific lobster fisheries

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Introduction

The fishery research

The annual harvest of lobsters by Pacific Island nations is relatively small, estimated at about 7 per cent of the world's production, yet the lobster fishery has high economic and social importance for the Pacific communities, which stems from the ability of local fishers to catch these species without high financial costs. Given the fishery's economic and social importance, lobsters comprise only a very small proportion of the total catch of the fisheries in each country and little is known about their reproductive biology and how this is affected in a fisheries context. Estimates of the annual lobster catch are difficult to quantify, and mostly underestimated, because a significant proportion is consumed at home by fishers and their families (Pitcher 1993). Additionally, market systems for the lobster fishery are generally casual and sales are not usually recorded. Some exceptions do occur, for example, in Fiji, where commercial sales of lobster are well established, and locals earn a living from selling fresh lobsters to hotels, resorts, and restaurants.

Classification and distribution

Spiny lobsters are decapod crustaceans belonging to the family Panuliridae. There are five common species of lobsters from the genus *Panulirus* that are widely distributed in the tropical Pacific region (Prescott 1980). The abundance and distribution for each species, however, vary throughout the Pacific. The golden rock lobster, *Panulirus penicillatus* is the most abundant species and the most commonly fished species in the Pacific (Pitcher 1993; Poupin and Juncker 2010).

Morphology

Spiny lobsters exhibit considerable variation in colour and morphology. Each species has distinct characteristics such as the number of spines on the antennular plate, the colour and shape of the abdominal segments, and the colour and pattern of the shell and legs (Poupin and Juncker 2010) (Fig. 1).

Figure 1. Four species of *Panulirus*:
A *P. ornatus*, ornate rock lobster;
B *P. versicolor*, painted rock lobster;
C *P. penicillatus*, golden rock lobster; and
D *P. femoristriga*, stripe-leg spiny lobster.
(Images: A,B: ©George Shedrawi, SPC; C,D: ©Faasulu Fepuleai, Ministry of Agriculture and Fisheries, Samoa).

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Ecology

Panulirus species occupy a wide variety of benthic shallow water habitats in the tropical Pacific but are most commonly associated with coral reefs, which provide shelter and a diverse range of food (Pitcher 1993; Briones-Fourzan and Lozano-Álvarez 2013). Spiny lobsters are considered opportunistic omnivorous scavengers feeding on a range of food including molluscs (especially gastropods), crustaceans, echinoderms, seagrass and algae (Pitcher 1993). Each species responds differently to habitat gradients of depth, turbidity, temperature, salinity, coral cover and wave action (De Bruin 1969; Pitcher 1993). For example, *P. penicillatus* are restricted mainly to depths above 10 m on windward surf zones of oceanic reefs, where the water is clean and clear with minimal terrestrial influence and relatively constant water temperatures (George 1974). In contrast, *P. ornatus* (ornate rock lobster) inhabits a larger range of habitats from coral and rubble reefs to sandy seafloors with high organic content, up to a depth of 200 metres. *P. ornatus* is also relatively common in turbid conditions on continental shelves that are influenced by terrestrial run-off (George 1968; Poupin and Juncker 2010).

Reproduction

Spiny lobsters have similar life cycles and breeding behaviour regardless of species. Intermoult females with developing ovaries mate with male lobsters. Using paired penile projections at the base of the fifth walking legs (Fig. 2), a male lobster will deposit an acellular mass containing tubular spermatophores onto the fourth and fifth sternal plates of the female (Pitcher 1993) (Fig. 3). Before depositing eggs via paired gonopores at the base of the third walking legs (Fig. 4), the female scrapes the surface of the acellular mass ("tarspot") and releases the sperm using special chelae on the dactyl of the fifth walking legs (Kagwade 1988) (Fig. 5). Several hundred thousand unfertilised eggs expressed by the female are then fertilised as they pass over the spermatophoric mass inside a chamber formed by curving the abdomen over the sternum (Kagwade 1988). The female carries the eggs for about a month before they are released (Pitcher 1993). The duration of the larval stage varies with species from 4 to 22 months and passes through more than 10 morphological stages to grow into a colourless miniature adult of 50 mm total length (Phillips and Sastry 1980). At this stage, juveniles transition from oceanic to being a benthic animal (seafloor) and quickly moult into pigmented juveniles (Phillips and Sastry 1980).

Growth and size-at-maturity

Like other crustaceans, spiny lobsters grow between increments of moulting (Lyle and MacDonald 1983). Growth rates are affected by biotic and abiotic factors including water temperature, food availability, salinity and injury (Robertson and Butler 2003), which in turn can affect the size at which lobsters mature (Briones-Fourzan and Lozano-Álvarez 2013). This means a single species can exhibit a different size at first maturity depending on their environment, which has implications for local and regional management of these species (Briones-Fourzan and Lozano-Álvarez 2013). In general, growth rates slow as females become larger and more fecund because they divert energy into producing eggs and reproduction rather than growth (Hunt and Lyons 1986; Pitcher 1993).

The size-at-maturity (L_{50}) is defined as the size at which 50% of individuals are functionally or physiologically able to reproduce. Environmental factors and high fishing pressure can reduce size-at-maturity by removing large individuals that reach maturity at larger sizes (i.e. above legal size limits) (Atherley et al. 2021). This reduces their input into the genetic structure of the population; therefore, individuals in the population below the legal-size limits that reach maturity at earlier ages or smaller gradually become dominant (Atherley et al. 2021). Therefore, estimating L_{50} for a species has important implications for management because it can be used to determine a minimum legal catch length (MLL). In the case of the length-based spawning potential method used by Prince (2015), MLL is usually set around 1.2–1.4 times functional size-at-maturity. Size-at-maturity as they transition into the adult reproductive phase is also different for males and females (George and Morgan 1979). The stage of maturity of an individual can be estimated by visual assessment of the gonads, especially around spawning periods. However, outside reproductive periods histological examination of the gonads may be required.

There are two important methodologies used to assess maturity in lobsters. First, functional maturity is when all secondary attributes have developed sufficiently to enable successful mating and production of viable offspring in their natural habitat (Aiken and Waddy 1980). Second, gonadal or physiological maturity is when the gonads can produce mature gametes (Aiken and Waddy 1980). Functional size-at-maturity for female lobsters can be visually assessed by the presence of eggs under the abdomen (ovigerous or berried females) and the presence of "soft windows" or "tarspots" on various segment of the sterna (Comeau and Savoie 2002). The morphological features, however, are different between species; for example, some external features used to assess functional maturity such as "soft windows" on the sternum plate are absent for *P. longipes* (George 2005). It is difficult to determine the maturation stage of male lobsters by just considering the external morphological features alone, such as the penile process, because these can be difficult to stage (George and Morgan 1979). There are clear external changes observed, however, in some spiny lobsters; for example, in *P. versicolor* growth in the length of first leg is observed and penile processes on the sterna are pointed, serrated and have fine hairs (George and Morgan 1979; George 2005). For *P. penicillatus*, the shape of the carapace changes from sub-cylindrical to barrel-like as they mature (Pitcher 1993). The penile process used to determine functional maturity in males is just as critical as female maturity because testicular development may occur in males that are much smaller than the smallest mature females; therefore, these small males may be unable to mate with mature females due to their small size and may thus be unable to reproduce before being caught if minimum legal sizes are set by female maturity stages (George and Morgan 1979). It thus becomes important to consider smaller males in the population, when setting minimum legal length.

Previous studies on size-at-maturity in the region

There have been very few studies on the size-at-maturity of spiny lobsters in the region and those that were undertaken occurred decades ago and are location or country specific. For example, *P. penicillatus* has been studied in countries including Marshall Islands (Ebert and Ford 1986), Solomon Islands (Prescott 1988), Tonga (Zann 1984; Udagawa et al. 1995), Samoa (King and Bell 1989; Coutures 2003) and Palau (MacDonald 1988); *P. versicolor* in Palau (MacDonald 1988) and *P. ornatus* in Papua New Guinea (MacFarlane and Moore 1986) (Table 1).

Age

Age is also a vital component to know when trying to understand the life history of aquatic animals. Age is an important parameter for population modelling or fisheries stock assessment and it cannot always be inferred from size (Zhu et al. 2018). Knowing the age structure of populations improves our understanding of longevity, and size or reproductive maturity at a specific age (Becker et al. 2018). For fish, there are a range of structures that can be used for ageing including otoliths, statoliths, fins, teeth, scutes and skeletons (Sheridan et al. 2016). Direct ageing in crustaceans has proven elusive, however, because long-term calcified structures are lost as growth occurs, such as through consecutive moulting of the calcified exoskeleton (Gnanalingam et al. 2018). Nevertheless, for some species of crustacean, the age of an individual can be determined through analyses of sequentially deposited growth marks in some calcified structures including gastric mill ossicles and possibly eye-stalks (Leland et al. 2015).

Table 1. A comparison of the estimated size-at-maturity (SAM) of the spiny lobster among various studies in the region using different methods.

Species	Country	SAM – carapace length (mm)	Source	Method
Panulirus penicillatus	Enewetak Island, Marshall Islands	62	Ebert and Ford 1986	Ovigerous females ≥ 62 mm CL
Panulirus penicillatus	Solomon Island	50	Prescott 1988	Smallest ovigerous female
Panulirus penicillatus	Tonga	53	Udagawa et al. 1995	Smallest ovigerous female
Panulirus penicillatus	Tonga	65–69	Zann 1984	50% of the females ovigerous
Panulirus penicillatus	Western Samoa	75.3	King and Bell 1989	First maturity
Panulirus penicillatus	Palau	100	MacDonald 1979	Based on the average size of berried females
Panulirus penicillatus	Western Caroline Islands, Palau	69	MacDonald 1988	Smallest ovigerous female
Panulirus penicillatus	American Samoa	70	Coutures 2003	50% of the females ovigerous
Panulirus versicolor	Western Caroline Islands, Palau	82	MacDonald 1988	50% of the females ovigerous
Panulirus ornatus	Papua New Guinea	78.6	MacFarlane and Moore 1986	Smallest ovigerous female

Current and future work

Because life-history characteristics of single lobster species can differ across gradients of influence, regional differences in reproductive and population characteristics must be considered on a country-by-country basis where possible. Hence, the Pacific Community (SPC) has begun working with interested member countries and territories to collect relevant information on their lobster populations. With the support of SPC and using SPC's data collection tools (Web Applications and IKASAVEA App)[3] Samoa, New Caledonia and Fiji have already started fishery-dependent data collection on their lobster populations.

It is anticipated that SPC's ongoing and future training with data collection tools and sampling methodologies will provide a smooth path for more of the SPC member countries and territories to incorporate assessments of their lobster populations as part of sustainable fisheries management.

To ensure data collection is consistent across countries and territories, SPC is developing standardised protocols for documenting and recording size-based indicators on *Panulirus* species in the region. The areas of focus are:

A. external morphology, which will provide guidelines for identifying general differences between male and female spiny lobsters and enable macro-staging of functional maturity;
B. internal morphology, which will provide guidelines for identifying differences between male and female gonads and determine their physiological maturity; and
C. exploring the potential of using gastric mill ossicles and eye-stalks to determine age.

Protocols

A. Gross external morphology in spiny lobsters (functional maturity)

There are several features that can be used to identify the male and female spiny lobsters.

I. Penile process

Panulirus species exhibit well-developed prominent penile projections at the bases of the last pair of legs (George 2005) (Fig. 2). The penile processes are used to deposit a spermatophore at the ventroposterior end of the female lobster's thorax which is called the "tarspot" (George 2005). The tarspot develops when the spermatophore hardens in seawater (George 2005). The size and shape of the penile process varies over the life cycle of males and between species (George 2005).

Figure 2. The penile process of three *Panulirus* species.
A *P. versicolor,*
B *P. penicillatus,* and
C *P. ornatus*

(Images A–B: ©Prakriti P. Rachna, SPC; C: ©Prakriti P. Rachna)

[3] See: Shedrawi G., Bosserelle P., Vigga B., Magron F., Gislard S., Tiitii S., Tanielu E., Fepuleai F., Rachna P., Halford A.R. 2021. Using COVID-19 travel bans to precipitate a digital transition in coastal fisheries science. SPC Fisheries Newsletter 165:24–27. https://purl.org/spc/digilib/doc/qzcjs

II. Soft windows, tarspot and gonopores

The adult and mature females also have segments of soft tissue or sets of round or oval decalcified "windows" formed at the sternum on the thorax (Lindberg 1955; Berry 1970). These windows are named "soft windows" (George 2005) (Fig. 3A). This is where the spermatophore mass is deposited by the male lobster, which becomes the tarspot (Fig. 3B). Females have a pair of gonopores present at the base of the third walking legs, which release mature eggs during reproduction (Pitcher 1993) (Fig. 4).

III. Nipper claws

Female spiny lobsters have nipper claws and males do not (Fig. 5). The purpose of the nipper claw is to release the sperm by breaking the spermatophore deposited by the males (Pitcher 1993).

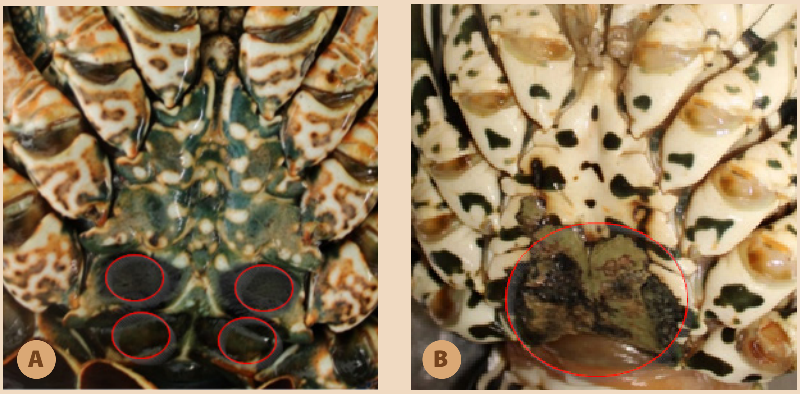

Figure 3. Sternum plates of female lobsters:
A soft windows on *P. penicillatus*, and
B tarspot on *P. versicolor*

(Images: ©Prakriti P. Rachna)

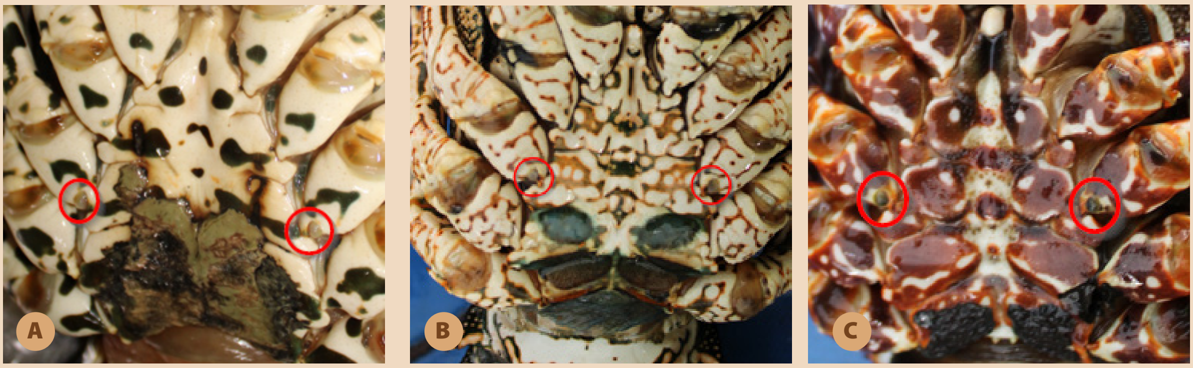

Figure 4. A pair of gonopores at the sternum of the thorax of *Panulirus* female lobsters. A *P. versicolor*; B *P. penicillatus* and C *P. fermoristriga*. (Images: ©Prakriti P. Rachna)

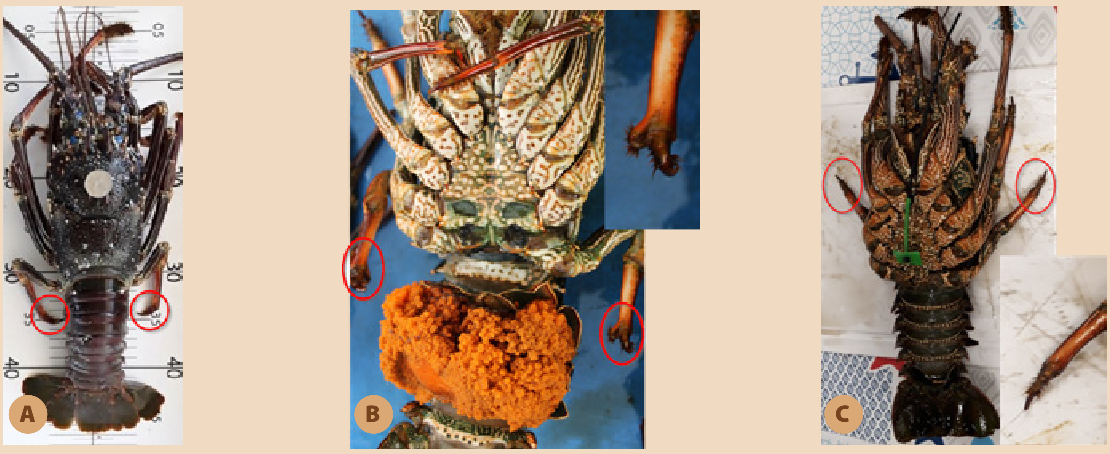

Figure 5. Image of A the claw on the fifth walking leg of a male *Panulirus penicillatus*; B the nipper claw of a berried female *P. penicillatus*; and C the claw on the fifth walking legs of a male *P. penicillatus*.

(Images A: ©Faasulu Fepuleai, Ministry of Agriculture and Fisheries, Samoa; B: ©Prakriti P. Rachna; C: ©Prakriti P. Rachna, SPC)

IV. Pleopods

The size and the number of pleopods or swimmerets differ between males and females. Males have one pair of smaller pleopods on each segment of the tail (Fig. 6), whereas female spiny lobsters have one pair of large pleopods (exopodite) and a second pair of pleopods with feathery appendages (setae) underneath the tail called endopodites (Kizhakudan and Patel 2010). The extra pair of pleopods on the first segment of the tail are about the same size as the exopodite. These extra appendages under the tail of a female allow attachment of eggs after fertilisation and development of larvae until they are released (Pitcher 1993) (Fig. 6).

B. Internal morphology in spiny lobsters

A pair of scissors was used to cut at the base of the carapace to remove it, which exposed the inner moult-layer, which holds the viscera in the cephalothorax (Fig. 7A). This was gently cut to expose the viscera where the gonads and gastric ossicles are located (Figs 7C and 7D). The gonads were gently removed, weighed, staged and placed in 10% formalin with an ID tag for later examination.

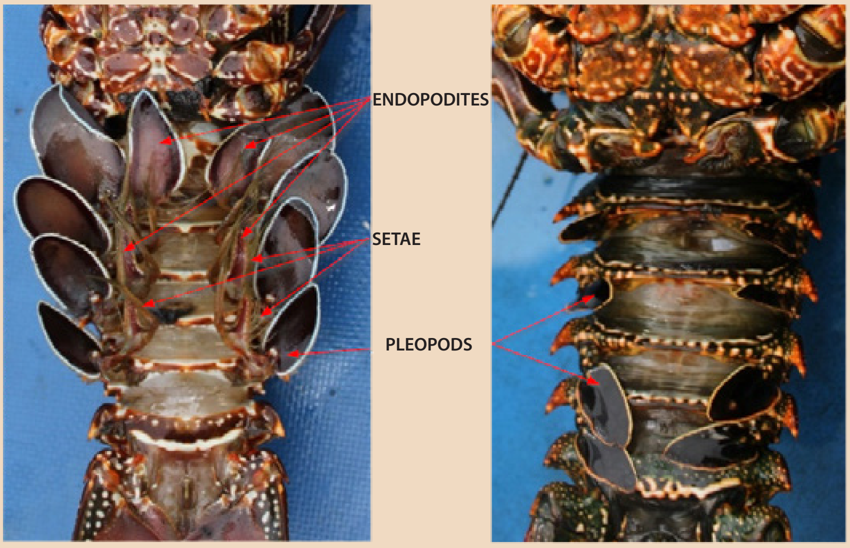

Figure 6. The tail of female *P. femoristriga* (left) and male *P. penicillatus* (right) lobsters showing the endopodites, setae and pleopods.
(Images: ©Prakriti P. Rachna)

Figure 7. Opening the carapace to see the inside the cephalothorax. (A) cutting the carapace of a *Panulirus penicillatus*; (B) removing the intermoult layers of a *P. longipes*; (C) the dorsal view of a *P. ornatus cephalothorax* after removing the carapace and inner moult layers exposing gastric ossicles; and (D) the location of the gonad (ovary) in the viscera of a *P. ornatus* cephalothorax after removing the gastric ossicles. (Images A–B: ©Prakriti P Rachna, SPC; C–D: ©George Shedrawi, SPC)

I. Macro staging of gonads to determine maturity in spiny lobsters (physiological maturity)

Physiological maturity can be assessed by observing the stage and condition of the ovary and the presence of mature oocytes for females (Pérez-González et al. 2009; Yusnaini et al. 2019), and presence of mature spermatozoa in testes for males (Atherley et al. 2021). The gonads can be categorised at different gonad maturity levels (GML), using gonadal shape and size that occur before and after release of spermatophore or eggs (Salim et al. 2019). Additionally, the gonadosomatic index can be calculated and used to assess the stage of maturity (Salim et al. 2019). Gonadosomatic index (GSI) examines the development of the gonads resulting from the ratio of gonad weight (WG) to body weight (WB) expressed in percentage (Salim et al. 2019). The equation is as follows:

$$GSI = WG/WB \times 100\%.$$

The GSI is used to acquire information on spawning seasons and reproductive cycles in a range of crustaceans (Minagawa and Sano 1997). For management of fisheries resources related to stock status, it is important to find out the size at which the gonad of an individual first matures, and the condition of the gonad pre and post spawning (Salim et al. 2019). The size of sexual maturity in crustaceans may change over time, and therefore periodic assessments are recommended so that appropriate adjustments to the minimum legal size can be made, especially in heavily fished populations (Öndes et al. 2017).

Figure 8. The different stages of gonad (ovary) development in three *Panulirus* species with the stages of maturity. A *P. ornatus* (ripe); B *P. versicolor* (mature); and C *P. longipes* (early maturation). Stages of gonad maturation described by Kizhakudan (2014). (Images A: ©George Shedrawi, SPC; B-C: ©Prakriti P Rachna, SPC.)

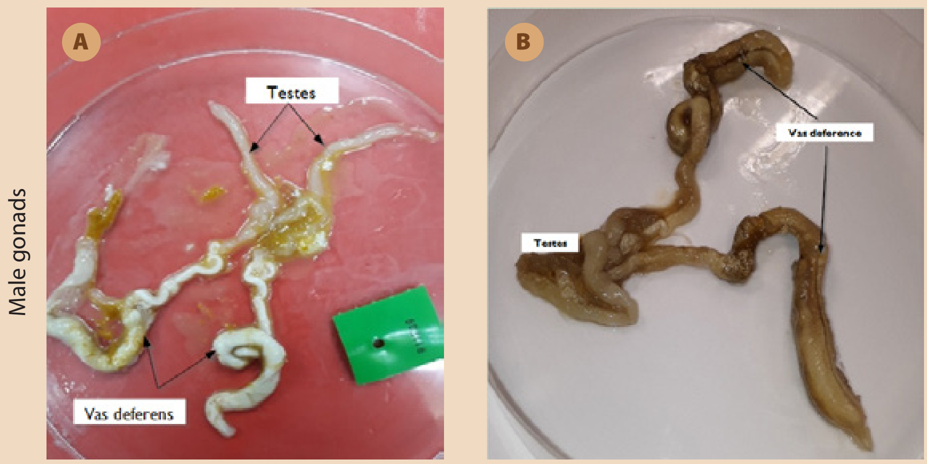

Figure 9. The reproductive tract of a male lobster, vas deferens and testes of A *P. longipes* and B *P. pencillatus*.

(Image A–B: ©Prakriti P Rachna, SPC.)

C. Gastric mill ossicle and eye-stalks as a potential for age determination in spiny lobster

After opening the cephalothorax, the gastric mill ossicles were firstly removed, cleaned, and stored for age examination (Fig. 10). The gonads were carefully removed, weighed, and photographed. The eye socket was also removed to examine the eye-stalk for determining if the ageing method can be applied.

Direct anatomical ageing methods for crustaceans are not available. Previous and indirect methods of ageing in crustaceans was done by captive rearing of known-age individuals, and tag and recapture in the wild (Leland and Bucher 2017). There were several challenges using the latter method, especially because of the seasonality of reproductive cycles or recruitment events, and it was only applicable if growth increments and intermoult periods did not vary too much among individuals (Becker et al. 2018).

Using eye-stalks to age crustaceans is used mainly in krill and shrimps; however, for the larger decapod crustaceans, the endoskeleton structures in the foregut – called gastric mill ossicles – have been explored (Becker et al. 2018). Leland (2011) developed a new anatomical approach to ageing crustaceans, which has been increasingly applied over the last decade. In this method, the strongly calcified cuticular structures and bands were observed in the cross-sections of the endocuticle as annual growth increments. For some species, the number of endocuticular bands increases with body size (Becker et al. 2018; Leland et al. 2011), and a larger and older individual will thus have more endocuticular bands (Fig. 10).

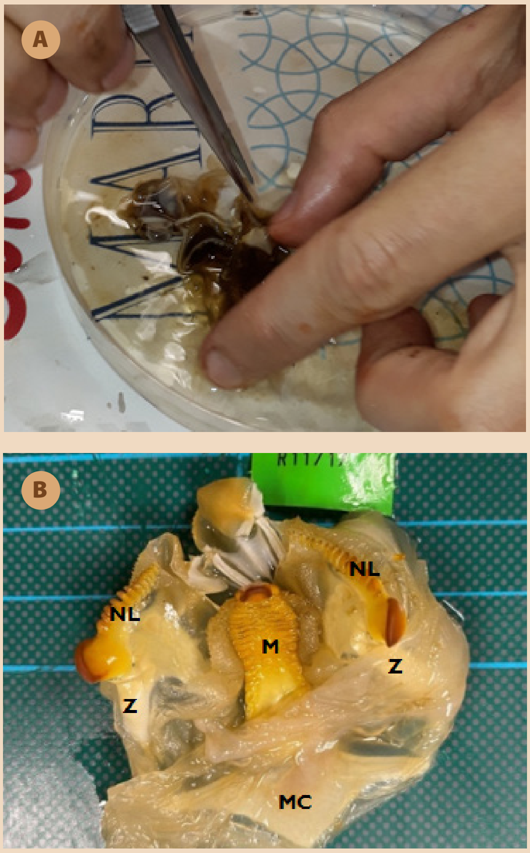

Figure 10. A Cleaning of the foregut, and B ventral view of the gastric mill from a 159-mm carapace length (CL) *P. ornatus*, with the medial tooth (M); new lateral teeth formed during the premoult period (NL); zygocardiac ossicles (Z); the mesocardiac ossicle (MC). The parts of gastric mill described by Sheridan et al. (2016). (Images A: ©Prakriti P Rachna, SPC; B: ©George Shedrawi, SPC.)

Next steps

1. Produce a set of well-designed sampling protocols and training programmes to enable Pacific Island countries and territories to collect these data effectively and efficiently.
2. Develop a biological sampling database where data can be centralised and managed for member countries and territories.
3. Develop a set of spawning potential ratio (SPR) indicators for use in fisheries management.

Conclusion

Invertebrates are an understudied resource across the Pacific, yet they are a crucial food source in most communities. Lobsters are a significant component of the invertebrate fauna and command a high price in markets, making them a highly targeted group. Limited resources in fisheries management are usually focused on finfish, which form the bulk of coastal fisheries catches. Nevertheless, SPC continues to design and implement effective and efficient methods to assist PICTs with their invertebrate resource assessments. Biological information and data accumulated through standardised protocols such as those illustrated here will enable members to develop effective management plans for sustainable coastal fisheries.

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Nondestructive monitoring of soft-bottom fish and habitats using a standardized, remote and unbaited 360° video sampling method[1]

Delphine Mallet,[2] Marion Olivry,[3] Sophia Ighiouer,[4] Michel Kulbicki[5] and Laurent Wantiez[6]

Abstract

Lagoon soft bottoms are key habitats within coral reef seascapes. Coral reef fish use these habitats as nurseries, feeding grounds and transit areas. At present, most soft-bottom sampling methods are destructive (trawling, longlining, hook and line). We developed a remote, unbaited 360° video sampling method (RUV360) to monitor fish species assemblages in soft bottoms. A low-cost, high-definition camera enclosed in a waterproof housing and fixed on a tripod was set on the sea floor in New Caledonia from a boat. Then, 534 videos were recorded to assess the efficiency of the RUV360. The technique was successful in sampling bare soft bottoms, seagrass beds, macroalgae meadows and mixed soft bottoms. It is easy to use and particularly efficient, i.e., 88% of the stations were sampled successfully. We observed 10,007 fish belonging to 172 species, including 45 species targeted by fishers in New Caledonia, as well as many key species. The results are consistent with the known characteristics of the lagoon soft-bottom fish assemblages of New Caledonia. We provide future users with general recommendations and reference plots to estimate the proportion of the theoretical total species richness sampled, according to the number of stations or the duration of the footage.

1. Introduction

Soft-bottom habitats constitute a major part of the coral reef seascape. These habitats make up extensive areas of mud, sand or rubble that marine plants can colonize [1,2]. In a lagoon environment, they are the key corridors between coral reefs, playing an essential role in ensuring connectivity and energy transfer within a mosaic of reef and perireefal habitats [3,4]. Many fish species, along with several emblematic species such as sea turtles or dugongs, use these habitats. Fish use such habitats as nurseries, feeding grounds or transit areas [5,6]. This very complex seascape is under increasing anthropogenic pressure, in particular due to the growing population and increased impacts such as fishing, coastal development, tourism, input from watersheds, the transformation of coastal landscapes, and marine aquaculture.

Few studies have been devoted to soft-bottom habitats compared to the other ecosystems of this seascape such as coral reefs or mangroves [7]. One of the main reasons for this is that soft-bottom fish assemblages are difficult to sample as individuals are scattered over very large areas and are often associated with significant depths. Most of the available data come from experimental fishing (essentially hook and line or trawl) or fish landings (e.g. [7–11]), which are extractive

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A blue-spotted stingray (*Neotrygon kuhlii*) glides by the camera (image: ©VISIOON) methods and present the typical problems of representativeness, sensitivity and repeatability. While standardized and nondestructive sampling methods such as underwater visual census (UVC) are extensively used on coral reefs, these approaches are not adapted to soft-bottom habitats because of the low occurrence of fish, specific fish behavior as well as the extent or the depth of these habitats. In New Caledonia, soft-bottom fish assemblages are, at present, known only from earlier programmes based on experimental catch data [11–16] and fisheries survey data [17–19].

The recent development of underwater video systems [20,21] provides an opportunity to develop a standardized method to monitor fish assemblages over large areas such as soft-bottom habitats. This tool has the advantage of being nondestructive for the environment, has little influence on fish behaviour, and can record for long periods at various frequencies. Different video techniques exist to sample fish, such as remote underwater video, whether baited or not, diver-operated video or towed video (see [21] for a review on video techniques). At present, the most widely used approach in perireefal habitats is the "BRUV" technique (Baited Remote Underwater Video) that attracts fish around the camera with bait (see [22–25] for applications on seagrass beds). In New Caledonia, video systems have been mainly used in censuses of coral reef fish [26–28] or sharks [29,30]. Pelletier et al. [26] used video techniques on soft-bottom habitats, but the performance of the method (required number and duration of videos) was not tested.

Pilot studies on method efficiency are important to validate and optimize sampling methods, as part of developing cost-effective and statistically robust monitoring programmes. However, most sampling designs based on video techniques are used without such pilot studies, which may compromise their results [31–33]. Considerable variability in sampling times and number of replicates characterize published studies [21]. Recently, Garcia et al. [35] studied the possible trade-off between the number and the length of remote videos used in a rapid assessments of reef fish assemblages. With 46 videos on five sites, they indicated that increasing the sampling coverage in the reef area may be more effective than just extending the video length.

The objective of this study was to perform a pilot study to present a standardized sampling protocol to monitor the diversity, abundance and structure of perireefal fish assemblages during daytime, in relation to the environment. We used a remote and unbaited 360° video system (RUV360). The 360° camera records simultaneously all the area around each sampling point. The aim of this pilot study was to assess: (1) the limits of the RUV360 sampling method (cost, visibility, current, bottom topography); (2) the fish species targeted by the technique; and (3) the optimal recording time per station and the number of stations required to obtain representative, stable and reproducible data on perireefal fish communities.

2. Material and methods

2.1. Study area and sampling design

The main island of New Caledonia is one of the largest coral reef lagoons in the world (19,385 km²). It includes 16,874 km² of nonreef habitat, with certain areas listed as a UNESCO World Heritage site [34]. This very complex seascape is under increasing anthropogenic pressure, in particular due to the growing population (268,767 inhabitants in 2014 compared to 230,789 in 2004)[7], and increased impacts such as fishing, coastal development, tourism, mining and marine aquaculture. The study was conducted from the 3rd May until the 18th July, 2018, in the Southwest Lagoon of New Caledonia. The study area is an 18.5 km long and 4 km wide transect from the coastline to the barrier reef (Fig. 1). This area is representative of the coral reef seascape of the main island, near Nouméa, the capital city. The lagoon includes 67.5 km² of soft-bottom habitats and two rows of coral reefs and coralline islets along a shore-barrier reef gradient. Coral heads are scattered on the lagoon bottom. Habitats with more than 50% hard substrate were excluded from the sampling..

In order to assess the optimal recording time for each station and the number of stations required to get representative and reproducible data on soft-bottom fish assemblages, we had to oversample the area. A systematic sampling protocol including 609 stations within a grid of 300 m wide cells was used. The distance between stations was sufficient to avoid overlap due to fish swimming from one station to another. The stations were sampled during daylight, at least one hour after sunrise and one hour before sunset, to avoid possible crepuscular variation in fish assemblages [36].

2.2. Sampling technique and images analysis

This study used an autonomous, remote and unbaited video technique named "RUV360" (Fig. 2). The camera was a low-cost camera (€250) from KODAK (model PIXPRO SP360 4K) which can record videos in very high definition (1440 × 1440 pixels, 30 fps), featuring a spherical lens with a 360° horizontal and a 235° vertical view, pointed directly upward (Fig. 2). The camera was enclosed in a waterproof housing (limited to 60 m depth, €50), fixed to an aluminum tube 17 cm above the seafloor. A tripod system was used to position and stabilize the camera on the sea floor (Fig. 2). The video system was deployed from a boat without the need for the crew to enter the water. This method allowed us to maximize the number of observations while minimizing disturbance to the environment (no boat and no human were present near the video system during the recordings). To evaluate the minimum recording duration required to have representative observations, we fixed the recording duration at 25 minutes. This time was sufficient to observe sedentary

[7] www.isee.nc (accessed in 2019)

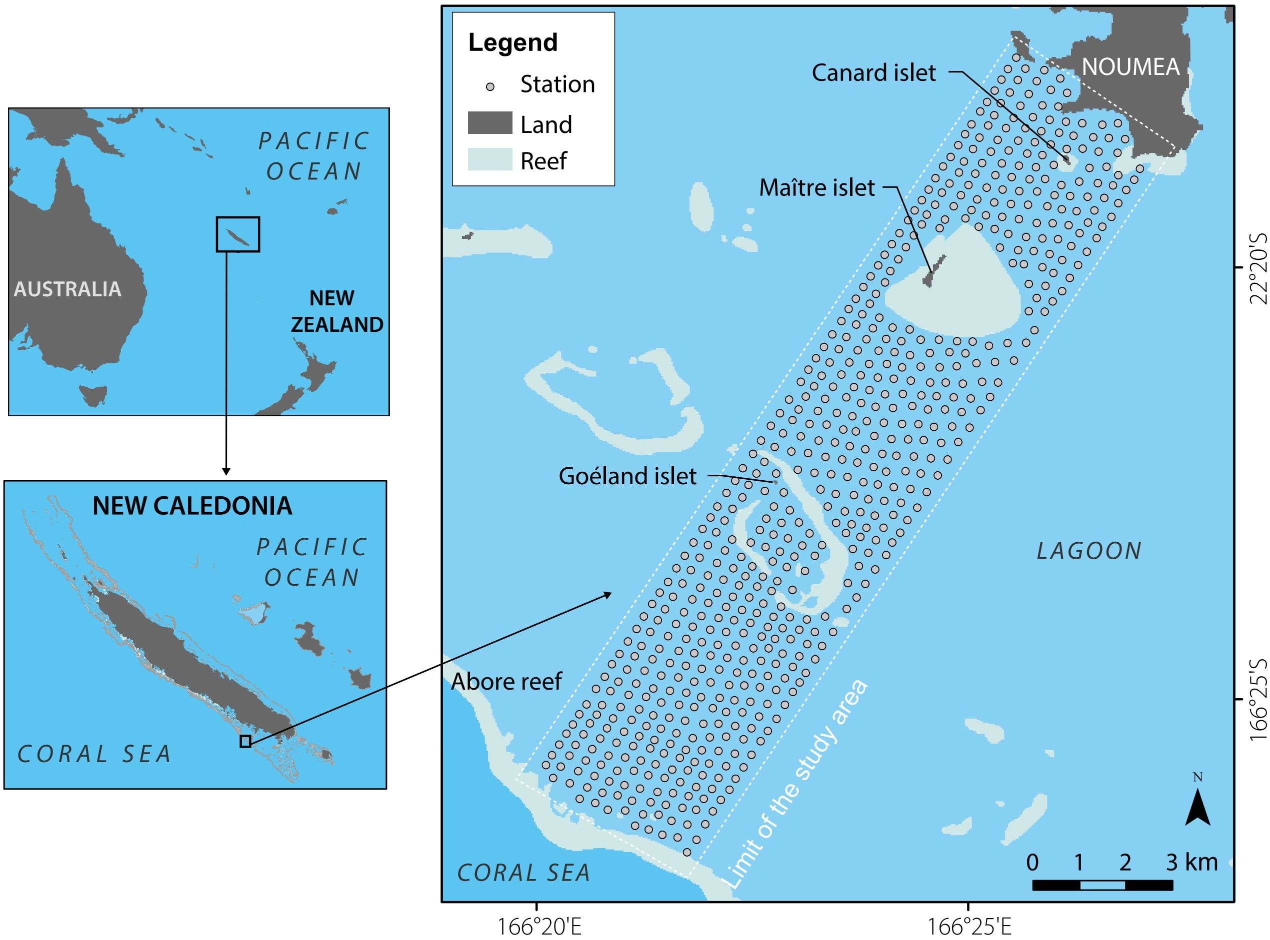


Figure 1. Studied area and sampling design. Each dot represents a station.

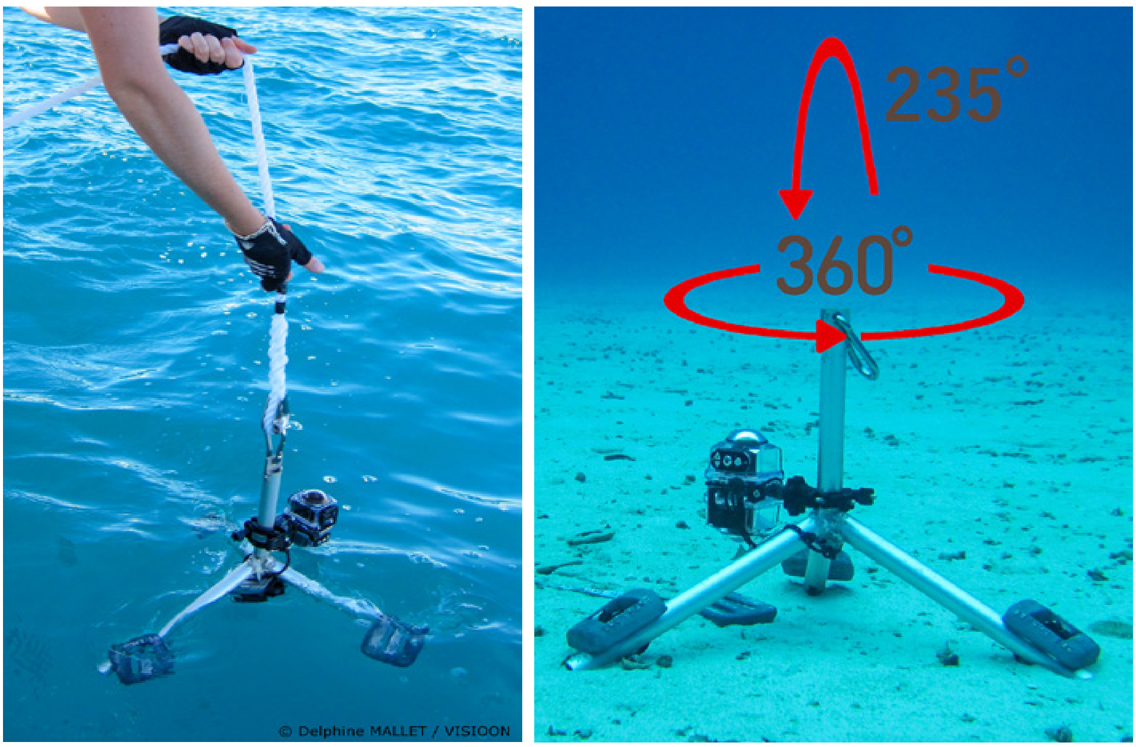


Figure 2. The remote underwater video system.

fish and then assess the amount of additional information (passing fish) obtained over time.

To optimize sampling at sea, we used four video systems deployed by two people aboard a small boat (<8 m). After each sampling day at sea, all videos were checked to assess (1) an appropriate field of view (visibility >5 m), (2) an appropriate orientation of the camera allowing for a clear view of the seabed, (3) a stable camera during filming and (4) that the habitat sampled was mainly soft (<50% of hard bottom). When a video was found to be invalid, a second attempt was made the following day.

All videos were analyzed by the same experienced observer using the camera software (Kodak Pixpro SP360 PC software, v1.7.0). The habitat was characterized by estimating the percentage of abiotic and biotic coverage over the 360° images using the "MSA" protocol [37]. The abiotic cover was classified as bare sediment (mud, sand, gravel and small boulders < 30 cm) or nonliving hard substrate (dead corals, coral slab, blocks > 30 cm). The biotic cover (live substrate) was classified as live corals (carbonated edifices that were still in place and present a coral shape) or "marine plants" (seagrass and macroalgae). The videos did not allow us to differentiate systematically between seagrass (*Cymodocea* sp., *Halophila* sp., *Halodule* sp., *Syringodium* sp., *Thalassia* sp.) and macroalgae (*Caulerpa* sp., *Halimeda* sp., *Lobophora* sp., *Sargassum* sp., *Turbinaria* sp.).

All fish were counted and identified at the lowest possible taxonomic level. To avoid counting the same fish several times, we used a conservative measure of relative abundance: "MaxN" [38]. This measure of abundance is the maximum number of individuals of the same species appearing at the same time throughout the entire video. To study the influence of camera soak time on species composition and abundances, we calculated MaxN (by species) every 30 sec. This protocol made it possible to study the number of new species and new individuals observed within each time interval. Some fish species from the same genus are similar and only differ in small details (eyes colour, small colour dots, etc.). These species are therefore difficult to distinguish on videos unless they are close enough to the camera. For our video analyses, we aggregated these species into groups (gp) as (i) *Amphiprion* gp for *Amphiprion akindynos* and *Amphiprion clarckii*; (ii) *Lethrinus* gp for *Lethrinus variegatus* and *Lethrinus genivittatus*; (iii) *Nemipterus* gp for *Nemipterus peronii*, *Nemipterus furcosus* and *Nemipterus zysron*; (iv) *Parapercis* gp for *Parapercis australis* and *Parapercis millepunctata*, and (v) *Pomacentrus* gp for *Pomacentrus amboinensis* and *Pomacentrus moluccensis*.

2.3. Sampling cost

We estimated the cost of sampling by the time required for fieldwork and videos analysis. The total time required for fieldwork each day included preparing the boat, the trip to the sampling area and the time spent within the sampling area (set-up of the video systems, deployment and retrieval of video systems, travel between stations). The time required to characterize the habitat, then identify and count the macrofauna on the videos was noted for each video during the video analysis.

2.4. Data analysis

2.4.1. Typology of the habitat and fish assemblages

We selected all stations composed of less than 50% hard bottoms for our study on soft-bottom habitats. To identify the typology of the habitat, we performed a principal component analysis (PCA) on raw data and a hierarchic ascending classification (HAC) on the first three axes of the PCA (100% of the inertia), using the squared Euclidean distance and Ward's aggregation method [39].

In order to verify the discriminating nature of the type of soft bottom on the fish assemblages, a CAP (canonical analysis of principal coordinates) was carried out on the Bray Curtis similarity matrix between the stations according to species abundance, using habitat type as a classifier. We applied a square root transformation on the dataset prior to analysis to downweight the importance of the outlier species [40]. The results of the CAP were validated by a PERMANOVA (999 permutations).

2.4.2. Influence of soak time and number of stations sampled on fish assemblages

The relationship between soak time and the number of species or individuals recorded was modelled using species accumulation curves and cumulative abundance curves. Species richness and abundance were calculated at 30-second intervals until the 25 minutes of soak time elapsed, for the entire area and per habitat.

The species accumulation models used a rarefaction method based on raw data added in ascending order. The rarefaction model known as Mao Tau's estimate [41] is a powerful tool for detecting species richness [42]. Abundance accumulation models used the time required to reach MaxN at each station added in ascending order. The estimate of the theoretical total number of species or individuals in the area studied was calculated by fitting a nonlinear Michaelis–Menten model [43] (the most accurate of the models tested) to the accumulation data: $y = (Vm \times t) / (K + t)$, where "y" is the number of species or individuals after "t" min of recording, "Vm" is the theoretical total number of species or individuals in the study area, and "K" is the number of stations where half of the theoretical total number of species or individuals have been detected in the videos.

We calculated the proportion of the theoretical species richness (SR) according to the number of stations and the duration of the footage. These proportions were calculated as the average of the SR obtained by 180-second intervals using 999 draws (without replacement) of the required number of stations in the overall data set (534 stations).

3. Results

3.1. Sampling cost

We validated 534 stations out of the 609 stations of the sampling protocol in the area, between 1 and 25 m depth (mean ± SE = 12.9 ± 0.3 m). Fifty stations, located in a coral habitat (more than 50% of live coral), were excluded from the study. It was not possible to position the camera correctly at 58 stations due to the relief of the seabed. The visibility of the water was too low for 8 stations and the current was too high for 52 stations (especially in the channels). Depending on wind, wave and depth conditions, the preparation of the boat and the trips took between 19 min and 113 min (mean ± SE = 46 min ± 3 min) (Table 1). Each 25 min of video required an additional 10 min to set up, deploy and retrieve the video system. This time was reduced by using four RUV360 systems simultaneously, resulting in a total time of 40 min to 92 min to sample a set of four stations (mean ± SE = 40 min ± 3 min). The variations in time are mostly due to the requirement for correct positioning of the system on the seabed (depending on the percentage of hard corals, the depth and the relief) and the distance between two stations. The analyses of the 534 videos took 425 h in all. The time to analyze one video was between 24 min and 78 min (mean ± SE = 49 min ± 3 min), depending on the complexity (number of species and abundances) of the biodiversity in the video.

3.2. Typology of the habitat

The stations were mainly composed of bare sediment and marine plants. Overall, 31 stations were almost exclusively composed of bare sediment (more than 90% of the habitat), and 66 were almost exclusively composed of marine plants (more than 90% of the habitat); 119 stations had living corals, which never exceeded 35%, and nonliving hard substrate (max 20%) was present at 52 stations.

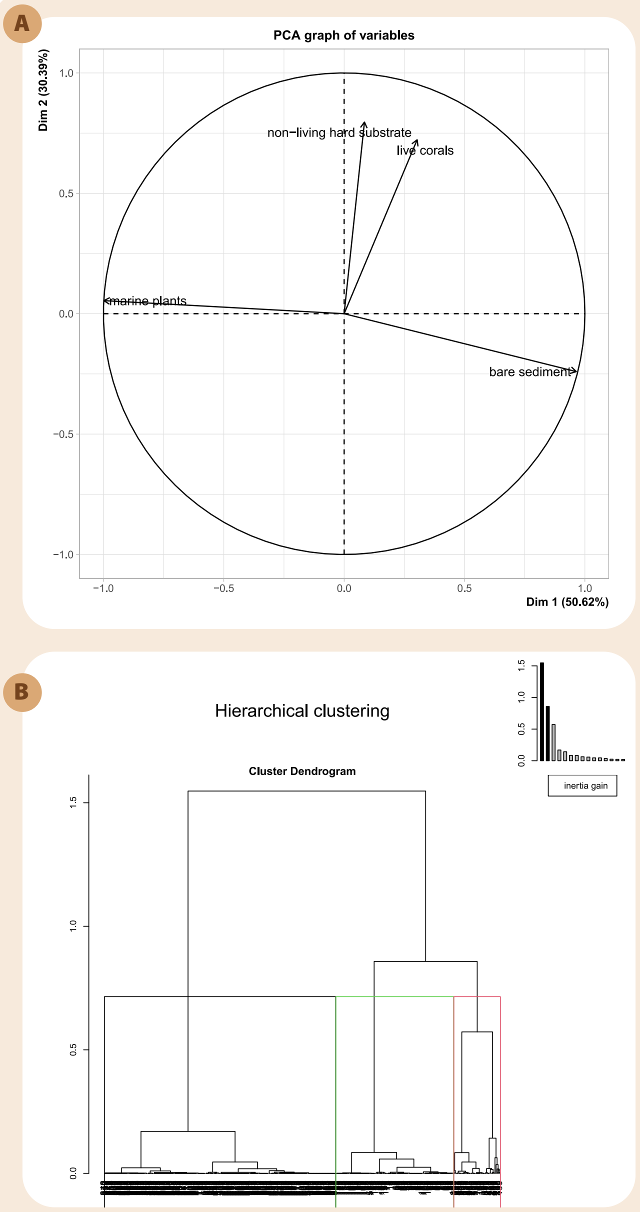


Figure 3. Principal component analysis of the habitats characteristics per station (A) and typology of the habitat (B)

Table 1. Sampling cost. Min, max and mean (± SE) correspond to the time required per day in minutes for fieldwork preparation, per set of four stations and per station for video analysis. Totals correspond to the time required to sample and analyze the 534 videos of the study.

Time required (min)	Fieldwork		Analysis of one video
	Daily preparation of boat and material+ trips to the sampling area	Sampling a set of four stations	
Min	19	40	24
Max	113	92	78
Mean ± SE	46 ± 3	40 ± 3	49 ± 3
Total	1123	7839	25,494

It was possible to identify three habitats in the studied area (Fig. 3). The “vegetated soft-bottom habitat” (317 stations) was dominated by marine plants (from 52% to 100%) and very little hard substrate (from 0% to 10% of living corals and from 0% to 5% of nonliving hard substrates). The “bare soft-bottom habitat” (160 stations) was dominated by bare sediments (from 50% to 100%), very little hard substrate (from 0% to 10% of living corals and from 0% to 5% of nonliving hard substrates) and a lower percentage of marine plants (from 0% to 50%). The “mixed soft-bottom habitat” (57 stations) was characterized by hard substrate (from 10% to 40%), including nonliving hard substrate (from 0% to 20%) and/or scattered living corals (from 0% to 35%).

3.3. Fish assemblages

In all, 10,007 fish belonging to 172 species (98 genera and 37 families) were observed; 3534 fish (26% of the fish) observed at 330 stations (62% of the stations) could not be identified, because they were too small (1774 - 50%), were located in the upper water column (607 - 17%) or were at the limit of detectability (506 - 14%). The rest of the unidentified fish showed no distinctive signs (361 - 10%), were blurred (260 - 8%) or swam too quickly (26 - 1%) to be identified.

Among the fish identified, the most frequent and abundant families were the Lethrinidae (frequency of occurrence (freq) = 33%, MaxN summed across all deployments (total MaxN) = 992), Pomacentridae (freq = 26.8%, total MaxN = 3390), Labridae (freq = 26.4%, total MaxN = 1175) and Mullidae (freq = 25.8%, total MaxN = 811). Most of the species were carnivores (99 species, 4184 fish). Plankton feeders were second in terms of MaxN (3866 fish), but were also the least diverse (18 species) (Table 2).

On average, the video recorded 4.1 species and 19 fish per station for the full 25 minutes of deployment (Table 3). There were important variations between stations, from no fish at 119 stations to a maximum of 28 species and 269 fish at one station. Commercial species made up 29% of the fish species per station and 33% of the individuals per station. The most diverse (34% of the commercial species) and abundant (30% of the MaxN of the commercial fish) commercial fish were Lethrinidae. Scaridae (21% of the spe-

Table 2. Number of families, genera, species and abundance of fish (MaxN) per trophic group.

Trophic group	Families	Genera	Species	MaxN
Carnivores	22	58	99	4184
Herbivores-detritus	7	14	29	1507
Piscivores	7	18	26	450
Plankton feeders	7	12	18	3866

Table 3. Mean specific richness and abundance per station (± SE) for all the ichthyofauna, for the commercial species and for the four more frequent commercial families.

	Species richness per station	Abundance per station (MaxN)
Total ichthyofauna	4.1 ± 0.2	19.0 ± 1.4
Commercial species	1.2 ± 0.1	6.3 ± 0.6
Lethrinidae	0.41 ± 0.03	1.86 ± 0.20
Scaridae	0.25 ± 0.03	1.44 ± 0.24
Carangidae	0.13 ± 0.02	0.95 ± 0.34
Acanthuridae	0.13 ± 0.02	0.53 ± 0.15

A school of longnose trevallies (*Canrangoides chrysophrys)* passes close to the camera. (image: © VISIOON) cies and 23% of the MaxN of commercial fish), Carangidae (11% of the species and 15% of the MaxN of commercial fish) and Acanthuridae (11% of the species and 8% of the MaxN of commercial fish) followed in order of importance.

The fish species richness and MaxN were significantly influenced by habitat (PERMANOVA, $p = 0.001$). Species richness and MaxN were higher in the mixed soft-bottom habitat than in the bare or vegetated soft-bottom habitats (paired comparisons, $p < 0.001$). The fish assemblages were different on the three soft-bottom habitats (PERMANOVA, $p = 0.001$). A canonical analysis was carried out on the first 42 axes of the analysis in principal coordinates (98.54% of the total inertia) (Fig. 4). The CAP was validated ($p = 0.001$) and indicated an overall percentage of correct and stable classification of 63%. First, the model discriminated mixed soft-bottom communities (88% correct classification). The discrimination of the assemblages in the two other habitats was lower, i.e., 59% on the vegetated soft bottoms and 59% on the bare soft bottoms. These assemblages shared more similarities (75% misclassification between them). The mixed soft-bottom fish assemblage was the most diverse. This assemblage was characterized by the presence of hard-bottom species associated with corals, such as damselfish (*Dascyllus aruanus* and unidentified damselfishes), butterfly fish (*Chaetodon mertensii*), angelfish (*Centropyge tibicen*), parrotfish (*Chlorurus sordidus*, *Scarus schlegeli* and unidentified parrotfish), one wrasse (*Thalassoma lunare*), one triggerfish (*Sufflamen chrysopterum*) and coral trout (*Plectropomus leopardus*). Several ubiquitous species also characterized this community, such as goatfish (*Parupeneus barberinoides*, *Parupeneus multifasciatus*) and sea bream (*Gymnocranius* sp.). The presence of species associated with seagrass beds or algae meadows characterized the vegetated soft bottom fish assemblage, in particular two emperors (*Lethrinus variegatus* and *Lethrinus genivittatus*), one leather jacket (*Paramonacanthus japonicus*) and two wrasses (*Oxycheilinus bimaculatus* and *Suezichthys devisi*). The bare soft-bottom fish assemblage was the least diverse. Its main characteristic was the absence of hard-bottom species or vegetated soft-bottom species. The only fish observed on these bottoms were specimens moving between the other habitats of the lagoon. However, this assemblage was characterized by the presence of spangled emperors (*Lethrinus nebulosus*), which frequent the large areas of the lagoon with a preference for sandy bottoms, where they find their food.

3.4. Influence of soak time and number of stations sampled on fish assemblages.

The deployment duration had a significant effect on the species richness (SR) and abundance (MaxN) observed by station (Friedman test, $p < 0.001$). The average number of species observed per station increased from 1.2 ± 0.6 (SR ± SE) species with 30 sec of observation to 4.2 ± 1.5 species with 25 min (Fig. 5A). The SR was stable after 7.5 min of observation (pairwise comparisons test, $p > 0.05$). The MaxN per station also increased significantly over time (MaxN ± SE = 8.0 ± 6.6 fish after 30 sec and 18.8 ± 10.5 fish after 25 min) (Friedman test, $p < 0.001$). The MaxN was stable after 1.5 min (pairwise comparisons test, $p > 0.05$). The SR increased very quickly over time at the beginning of the recording (Fig. 5B), before dropping progressively to reach an asymptote corresponding to the total theoretical species richness ac-

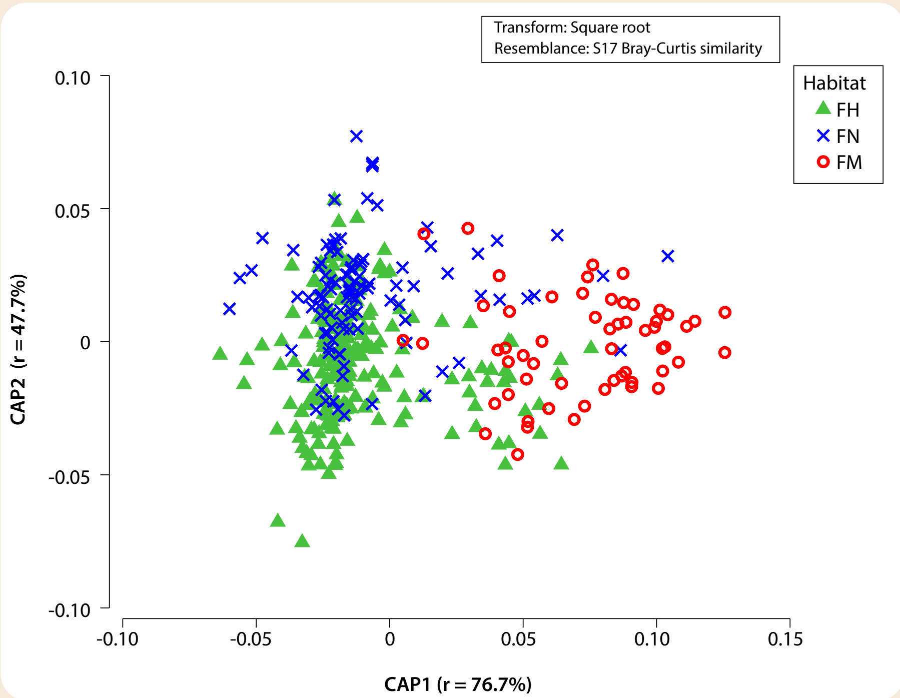


Figure 4. Canonical analysis of principal coordinates (CAP) of fish assemblage between stations, under constraint of habitat type. Species with a correlation ≥ 0.35 to the first factorial design are specified for each habitat.

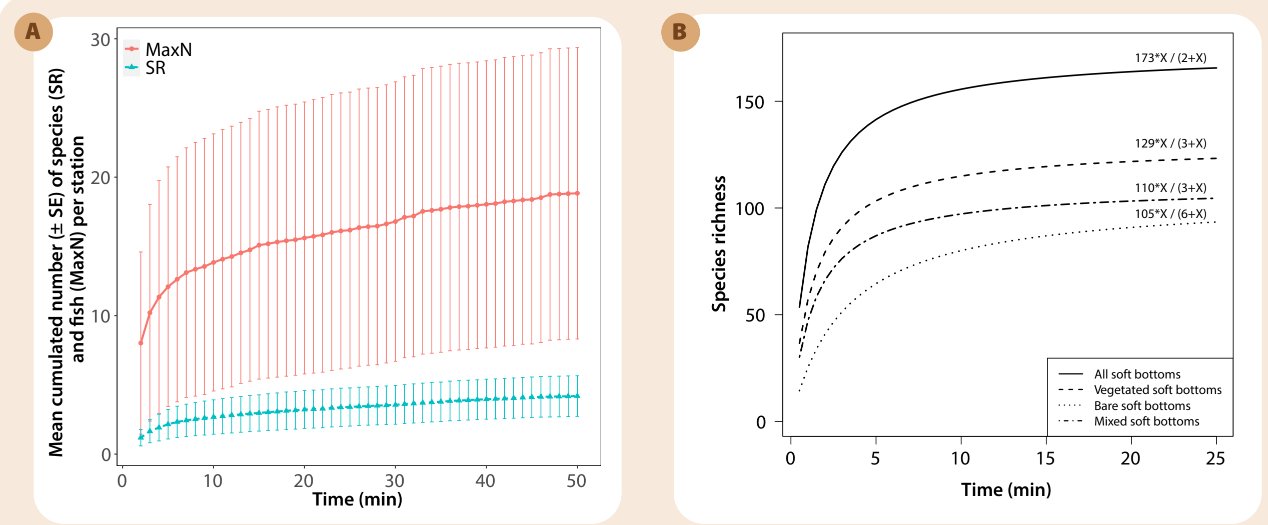


Figure 5. A Mean cumulated number (± SE) of species and fish per station in 30 sec time intervals up to 25 min. B Species accumulation curves in 30 sec time intervals up to 25 min for all soft bottoms and by habitat (see legend). Equation of the curve for each habitat is given on the corresponding curves.

cording to the footage duration (Michaelis–Menten model, theoretical SR-time = 173 species) in the study area: 80% of the theoretical SR-time was observed after 5 min and 95% of the theoretical SR-time after 14 min (Table 4). The theoretical SR-time was not significantly different between habitats (Chi-squared test, $p > 0.05$). Within the vegetated and mixed soft bottoms, SR progressed very quickly at the beginning of the recordings: 80% of the theoretical SR-time was observed after 5 min on the vegetated soft bottoms and 4.5 min on the mixed soft bottoms (Table 4). In contrast, the SR on the bare soft bottoms increased more slowly at the beginning of the recordings: 11 min were necessary to observe 80% of the theoretical SR-time on this habitat. However, 95% of the theoretical SR-time on the bare soft bottoms was observed within 17 min, which was only 1.5 to 2.5 min more than for the other soft-bottom habitats.

There was no significant link between the number of stations and the estimates of SR or MaxN observed per station (Spearman correlation, $p > 0.05$). Indeed, the mean number of species observed per station was relatively stable regardless of the number of stations sampled. It varied from 3.9 species on average per station with 2 stations to 4.1 species on average per station with 534 stations. On the other hand, the standard error (SE) decreased significantly as the number of stations increased (SE for 2 stations = 2.5 and SE for 534 stations = 0.2). The average abundance (MaxN) per station followed the same trend. It was relatively stable and ranged, on average, from 19.0 fish per station for 2 stations to 18.9 fish per station for 534 stations. The SE of relative abundance per station also decreased significantly as the number of stations increased (SE for 2 stations = 13.4 and SE for 534 stations = 1.4). The SR gradually increased

Table 4. Deployment duration necessary to observe 50, 80, 85, 90, 95% of the theoretical SR-time. Deployment durations were evaluated from the accumulation curves calculated as a function of time over all the stations and by habitat.

Proportion of the theoretical SR-time (%)	Deployment duration			
	All soft bottoms	Bare soft bottoms	Vegetated soft bottoms	Mixed soft bottoms
50	1 min 06	3 min 15	1 min 15	1 min 18
80	5 min 00	11 min 00	5 min 00	4 min 30
85	7 min 00	14 min 00	9 min 00	7 min 30
90	10 min 00	15 min 30	11 min 30	10 min 30
95	14 min 00	17 min 00	14 min 30	15 min 30

depending on the number of stations sampled (Fig. 6). The total theoretical SR according to the stations sampled (theoretical SR-station) estimated by the model within the study area was 195 species. Eighty per cent of the theoretical SR-station was observed with 369 stations (6.2 stations/km^2 in the study area) while 88% was observed with all the stations sampled (534 stations or 9 stations/km^2) (Table 5). The theoretical SR-station was not significantly different between habitats (Chi-squared test, $p > 0.05$). Within the vegetated and mixed soft bottoms, SR progressed more quickly than for bare soft bottoms. Eighty per cent of the theoretical SR-station was observed with 265 stations (7.5 stations/km^2) on the vegetated soft bottoms and 70 stations (11.1 stations/km^2) on the mixed soft bottoms (Table 5). Again in contrast, the SR on the bare soft bottoms increased more slowly depending of the number of stations sampled: 320 stations (17.9 stations/km^2) were necessary to observe 80% of the theoretical SR-station on this habitat.

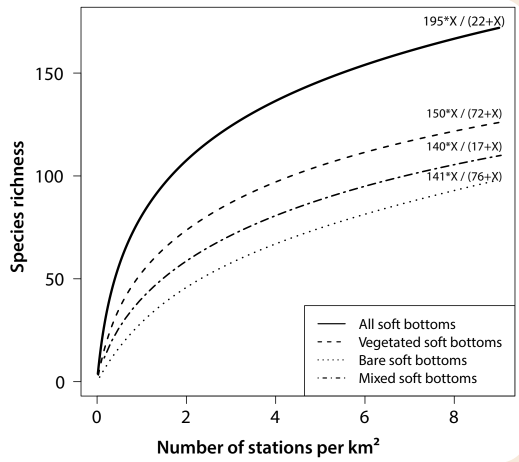


Figure 6. Species accumulation curves per number of stations/ km^2 for all soft bottoms and by habitat (see legend). Equation of the curve for each habitat is given on the corresponding curves.

Table 5. Number of stations per km^2 required to observe 50, 80, 85, 90 and 95% of the theoretical SR-station. The number of stations per km^2 was estimated from the accumulation curves calculated for each habitat over 25 min.

Proportion of the theoretical SR-station (%)	Number of stations per km^2			
	All soft bottoms	Bare soft bottoms	Vegetated soft bottoms	Mixed soft bottoms
50	1.6	4.3	2.0	2.7
80	6.2	18.0	7.5	11.1
85	7.8	24.4	11.5	15.9
90	14.1	38.8	18.2	24.6
95	29.5	83.7	38.4	55.6

Young tiger shark (*Galeocerdo cuvier*) (image: © VISIOON)

4. Discussion

An unbaited video technique was selected because we did not want to attract fish to the camera. Using bait to attract fish would modify the fish assemblage because fish species react differently to bait [21,33,44,45]. The objective was to get a less biased representation of the assemblage during daytime. A 360° video technique was selected to sample in all directions simultaneously and record all fish in the sampling area.

4.1. Fieldwork implementation and costs

The RUV360 was easy to use and particularly efficient, since 88% of the initially selected stations were successfully sampled. The approach appears to be more efficient than other unbaited, multidirectional video systems. For instance, the "STAVIRO" (rotating video system), described by Pelletier et al. [26], for use on hard- and soft-substrate habitats successfully sampled 70% of the stations during a pilot study and reached 81% validation in a subsequent studies. More recently, the "compact video lander" developed by Watson and Huntington [46] was used on rocky reefs, and successfully sampled 70% of the stations. When deploying video systems directly from a boat, one of the main causes of nonvalidation is an inappropriate orientation of the camera towards the seabed. Only 3.1% of nonvalidated stations of the present study were attributed to seafloor relief issues. Such problems were reduced with the RUV360 because (1) we targeted only soft bottoms, which are less complex than hard substrate, and (2) the camera had a 235° vertical field of view (V-FOV), compared to cameras generally used in other video techniques (BRUV, RUV or STAVIRO), that have a V-FOV of 60° for the wide angle lens of the latest Sony (specification of the model FDR-AX700 on www.sony.com) and 94.4° for the wide angle lens of the latest GoPro (specification of the model HERO8 Black on www.gopro.com). The RUV360 was also efficient in terms of other typical causes of nonvalidation. It was particularly stable (only 0.3% of nonvalidated stations were attributed to its instability) and could be used in channels where tide currents occurred. The impact of a low visibility was limited because the FOV was good (only 0.7% of nonvalidated stations were attributed to the visibility).

The cost associated with the use of the RUV360 method was evaluated as a combination of the time required for sampling and video analyses. Fieldwork was estimated for the simultaneous deployment of four RUV360s within a systematic sampling grid of 300 m width and a 25 min video recordings per station using one boat (< 8 m, two persons minimum). The RUV360 appears to be an efficient alternative to other video systems, although comparisons are complicated, as very few studies provided cost information related to the use of their video system. From a literature review on video techniques, we found four studies providing details on the performance of their video systems: Pelletier et al. [26] for STAVIRO, Gladstone et al. [31], Santana-Garcon et al. [47] and Langlois et al. [48] for BRUVs. The size of the boat (small boat between 5 and 10 m), the number of persons required at sea (two persons minimum) and video analysis (one person assisted by experts as required) were common to all approaches. The number of stations sampled per day varied between studies (from 10 to 30 stations/day) depending on the number of systems used simultaneously, the duration of the footage and the distance between stations. Two to ten video systems were used per boat, with footage lasting from 9 min [26] to 180 min [47] and distance between stations varying from 200 to 500 m. The time required to analyze videos depends on the complexity of the habitat, as well as the diversity and abundance of fish. The analysis of RUV360 video was faster (49 min for a 25 min video on average, corresponding to 2 min per minute of video) than for STAVIRO video (43 min for a 9 min video on average, corresponding to 4 min 47 per minute of video) [26], because all fish present are visible within one frame, whereas six sectors of 60° are necessary for STAVIRO

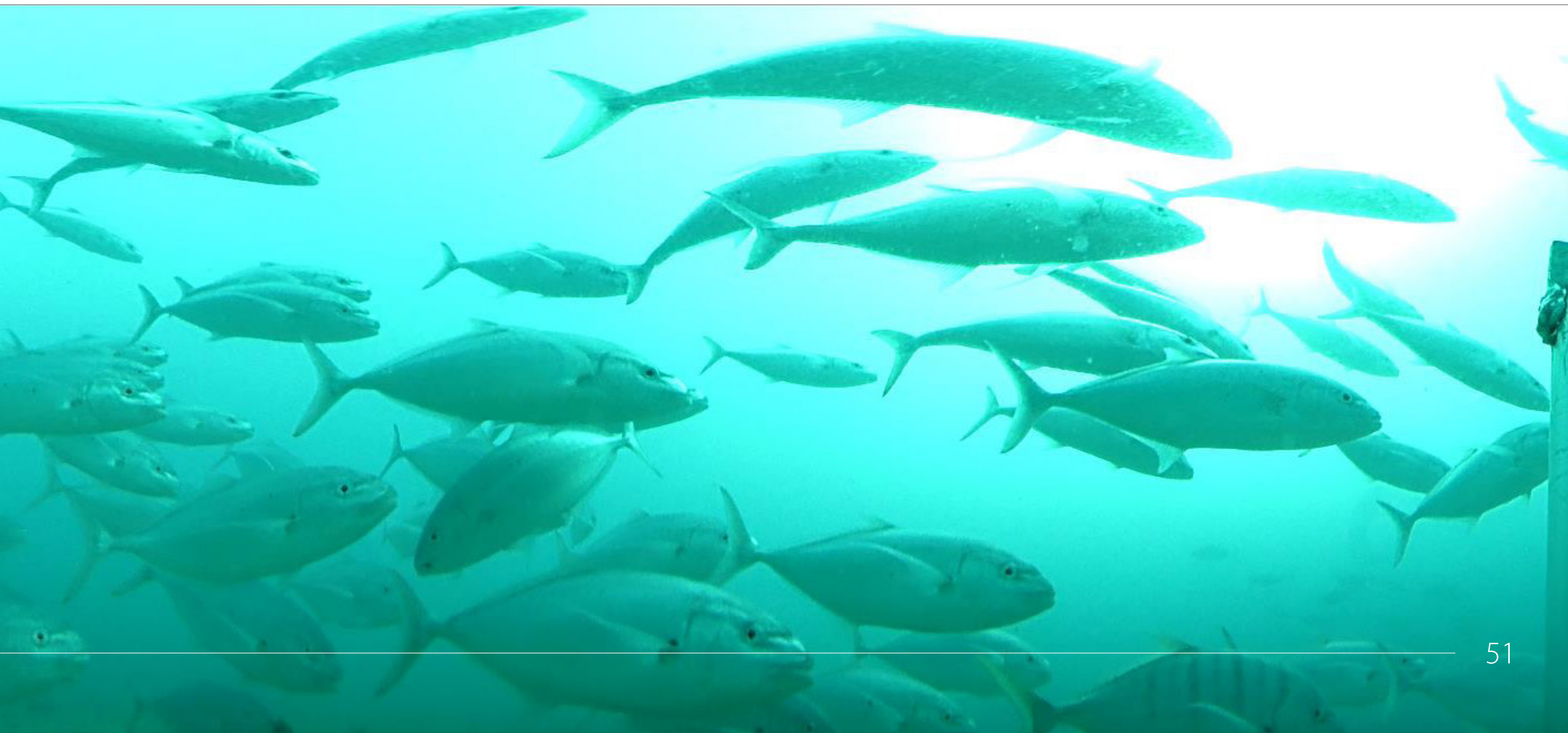
Large school of *Carangoides chrysophrys* and other species of trevallies (image: © VISIOON)

to get a 360° frame. The RUV360 takes longer to analyze than the BRUV (65 min for a 60 min video on average which correspond to 1 min per minute of video [31,47]) because fish are attracted to the camera with BRUV and easier to identify, whereas greater zooming in is necessary with the RUV360 for species identification. The performance of the RUV360 was also linked to the nature of the videos analyzed, as soft bottom habitats are easier to analyze than complex habitats such as coral reefs.

4.2. Biodiversity sampled

The RUV360 method was successful at sampling bare soft-bottom habitats, seagrass beds, macroalgae meadows and mixed soft bottoms. The fish assemblages were significantly different according to the type of the soft-bottom habitat. The differences were mainly driven by the presence of hard substrate, corroborating the observed relationship between the complexity of marine habitats and the composition of fish assemblages [2]. Structurally more diverse habitats are known to sustain fish communities that are more diverse and functionally complex in comparison with habitats with monotonous bare substrates [49]. The fish assemblages were first discriminated in the mixed soft bottoms (88% of correct classification), followed by vegetated or bare soft-bottom habitats (59% of correct classification for each habitat). There were no clear boundaries between the vegetated soft-bottom and the bare soft-bottom assemblages, which form a continuum along a plant density gradient. Within the studied area marine plants were common (only 3% of the stations had less than 10% plant cover). Therefore, even if bare soft-bottom habitats were mainly composed of bare bottom, they also included marine plants to a lesser extent (< 50%). The presence of marine plants on these habitats, and their associated species, can explain the difficulty of better discriminating fish assemblages between the vegetated and bare soft-bottom habitats. It appears that fish communities change along a gradient of marine plant abundance.

We recorded 10,007 fish belonging to 172 species (98 genera and 37 families), including 45 species (3365 individuals) targeted by fishing in New Caledonia and many emblematic species such as rays, sharks, turtles and dolphins; 104 sea snakes were also observed in the study area. For video analysis, several species were aggregated into groups, because they are similar in appearance and difficult to distinguish from each other. Grouping species that share specific traits in relation to their habitat, biology, behavior and ecology is common for studies using video techniques [31,47,50,51]. Another group of species seen in videos during this study could not be identified (26%), as they were too small or at the limit of the detectability (too far or too high in the water column from the camera). The observation of cryptic fish such as gobies (Gobiidae) and blennies (Blenniidae) is challenging using video, as they are too small and were often too far from the camera to be identified [21]. These two families represent a large number of species throughout New Caledonia (255 species on reefs and soft bottoms; [52], a number of the unidentified individuals in this study belonged to these two families. The difficulty of undertaking a census of cryptic fish species is not only related to the video analysis technique applied; it has also been reported in other, nonextractive sampling methods such as underwater visual censuses (e.g. [53]). Our results are consistent with previous knowledge of the biodiversity of lagoon soft bottoms in New Caledonia. Invertivores species dominate the assemblages, ahead of herbivores, piscivores and plankton feeders [1,11]. We observed 156 species out of the 542 species (28%) recorded on soft bottoms in New Caledonia using trawls or underwater visual census techniques (MK, pers. comm) [1,11,54]. The videos captured 16 additional species: 10 were hard-bottom species observed on mixed soft bottoms. Two were ubiquitous species, two were sharks and two were rays. The differences between videos and these other techniques are linked to the study area (location and size) and the techniques themselves. Bottom trawls census fewer hard-bottom species because mixed soft



bottoms cannot be trawled when the seafloor becomes too irregular, and most large species will avoid the trawl [54]. Video techniques are not adapted to census cryptic species [31,47,50,51]. Pelagic species are more frequently censused using UVCs than video techniques, and these species are seldom targeted by bottom trawls [55].

Consumer grade, spherical camera systems are significantly less expensive than high-cost underwater cameras. However, the resolution may be sacrificed for the large field of view. Consequently, the range to which fish are identifiable will likely be reduced compared with high-cost standard cameras, and this effect could be species-specific. Previous field tests using underwater benchmarks for distances indicated that we can identify fish at a typical maximum range of 8 m from the cameras [50]. As species size also has an impact on detectability, we propose a list of species identifiable on the habitat sampled and have grouped similar species together.

4.3. Optimization of the sampling design using RUV360

In order to optimize the sampling design (recording time per station and number of stations) using the RUV360, we had to collect representative, stable and reproducible data on soft-bottom fish communities. During our study, 99% of the theoretical total species richness according to footage duration (= "theoretical SR-time") was censused by the RUV360 in the area, using footage of 25 minutes. This demonstrates that it is not necessary to extend the duration of the footage, as 95% of the theoretical SR-time was observed within 14 min. The duration of footage varies greatly between studies, depending on the video technique used and the purpose of the study (from 8 min to several days) [21,33]. None of the studies referenced here specified the proportion of theoretical SR recorded, according to the duration of the footage taken. Therefore, subsequent results are strongly linked to the length of the selected footage. For example, according to the review on BRUVs by Whitmarsh et al. [33], 32% of BRUV studies used 60 min, 25% used 30 min and 17% used soak times greater than 90 min.

The RUV360 also recorded 88% of the theoretical species richness in the study area according to the station sampled, using nine stations/km^2. Very few studies using video investigated the optimal number of stations required to obtain stable observations of the biodiversity, and none of them reported this number in relation to the surface of the area studied. To the best of our knowledge, no experiments have investigated the impact of replicate spacing on observed assemblages ([33] for BRUV). For example, Santana-Garcon et al. [47] gave an optimal sample size of at least eight replicates per treatment in sampling a pelagic fish assemblage with a BRUV technique, while Gladstone et al. [31] concluded that for BRUV, there is no optimal value related to sampling precision, with values needing to be set by researchers, according to the specific objective.

When designing a sampling strategy for soft-bottom fish communities using the RUV360, it is possible to adapt footage duration and sampling effort. Therefore, it is possible to favour a strategy of either "short videos on many stations", or "long videos on a limited number of stations". Based on the data obtained in this study, we propose two reference plots to help in this process (Fig. 7). The choice will be a compromise between achieving acceptable precision, the variables and/or species of interest, and the need to manage costs [31,56].

5. Conclusion

The results of this study support the proposed sampling protocol to monitor fish communities in perireefal habitats during the daytime. To date, most attention in the scientific literature has focused on reefs, mangroves and seagrass habitats within the coral reef seascape. The sampling protocol described here offers the opportunity to obtain data on perireefal habitats that are comparable in space and time (specific richness, abundance)using a consumer grade 360° video camera. The results are consistent with the known characteristics of the lagoon soft-bottom fish assemblages, and the impacts of irregular seafloors, current and visibility were limited. We provide reference plots to estimate the proportion of the theoretical total species richness, according to the number of stations or the duration of the footage. The approach can also discriminate the structure of fish assemblages in relation to habitat typology. Further development should include the refinement of the method to collect body-size data from stereo video or other means. Body-size and length data are valuable for a range of ecological studies, from those focused on the impact of fishing to those on ontogenetic shifts of fish assemblages.

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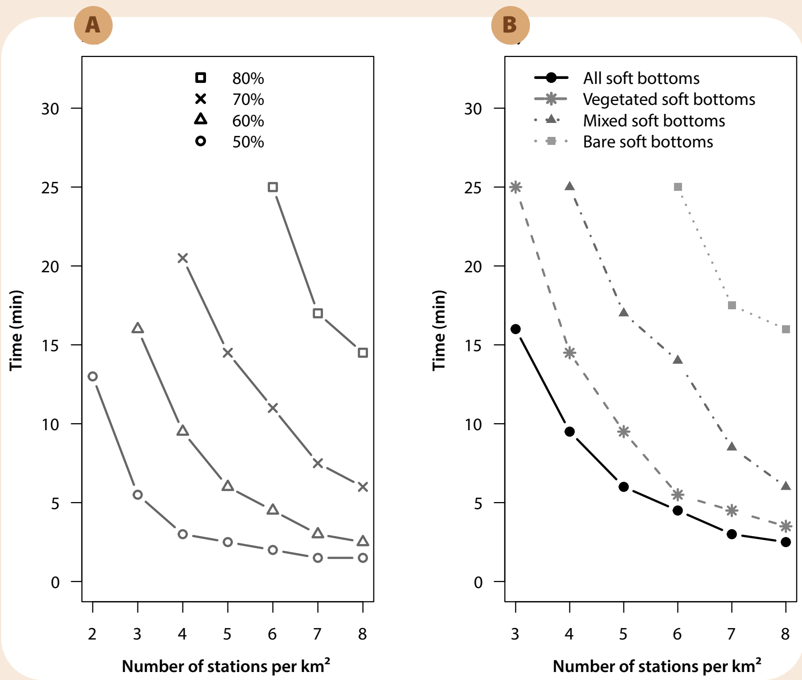

Figure 7. A Proportion of the theoretical SR-station depending on the duration and the number of videos recorded within the studied area.
B 60% of the theoretical SR-station per habitat depending on the duration and the number of videos sampled.

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Olive-headed seasnake (*Hydrophis major*). (image: © VISIOON)

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