Study of the interaction of derelict FADs on coral communities in the Indian Ocean

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Foreword

In 2018, our purse seine fishery for skipjack in the Indian Ocean was certified against the MSC Standard for Sustainable Fishing. One of the components comprising the Standard relates to the impact of the fishery on habitat. Initially, we did not meet the standard for the three performance indicators (PI) comprising Component 2.4. This led to the definition of three conditions to certification.

The condition on management (PI2.4.2) was closed at the second annual surveillance audit while that on outcome (PI 2.4.1) was found to meet the standard at the third annual audit (TASA). The condition on PI2.4.3 remains open.

The main concern is the potential damage to vulnerable coral communities from interaction with "lost" dFADs that become derelict on coral reefs. Indeed, this issue has generated controversy within the stakeholder community, with some considering it crucial when proposing a prohibition on the use of dFADs in the Indian Ocean.

While we accept that "lost" dFADs may become derelict on coral communities, there is limited evidence and knowledge of the extent, scope and nature of interactions. Several factors are relevant in considering this issue: the type of dFAD; the location of coral communities; ocean currents; the type of coral and their susceptibility to dFAD interaction; and the presence of other underlying pressures.

Along with other purse seine companies fishing tunas in the Indian Ocean, we have already adopted mitigation measures to reduce the potential risk: non-entangling dFADs; a reduced number of dFADs; the development of biodegradable materials in dFAD construction; and activities to recover lost dFADs before they become derelict (FADWATCH).

Our policy to go beyond MSC requirements led us to contract AZTI to complete independent research to improve knowledge and understanding of the issue and identify additional mitigation measures. A two-step approach was adopted.

Desk research to confirm the parameters relevant to understanding the potential nature and scale of interactions between dFADs and coral communities; and

Complete field work in the Seychelles to improve understanding of the nature of the damage.

Echebastar Sustainability Working Group

February 2023

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We are grateful to Echebastar for funding this project and considering AZTI for this study. To South Indian Ocean Tuna Initiative (SIOTI) and the Basque Government for their contributions of funds to carry out this project.

We would also like to thank the Seychelles Ministry of Fisheries, Seychelles Bureau of Standards and Seychelles Fishing Authority for providing us with the permits to carry out the fieldwork.

Above all, we thank Save Our Seas Foundation (SOSF) and its Team for the support to complete the fieldwork on the island of D'Arros and St. Joseph. It was a great opportunity for mutual learning and knowledge sharing.

AZTI
February 2023

CONTENTS

EXECUTIVE SUMMARY

This report presents the "Study of the interaction of derelict FADs on coral communities in the Indian Ocean".

The overall objective of the study was:

> **To identify if interaction with derelict dFADs with coral communities could risk their structure and function being affected to a point where serious or irreversible damage may occur.**

The twin aims were:

> **To improve understanding of the potential impacts of dFADs with coral reef communities; and**
>
> **Support a science based strategic approach to mitigating the potential impacts of dFADs and identify potential required mitigation measures.**

The study comprised two parts:

> **Desk research to identify the parameters that will support the design of any strategic approach; and**
>
> **Field work to examine the situation in a selected site in the Seychelles archipelago.**

Desk research

There were several activities:

- The mapping of coral locations in the Indian Ocean using generalized grid data set at 500 m resolution as developed by the World Resources Institute (https://www.wri.org/). In addition, dFAD use and drift were analysed to better understand their dynamics, with identification of possible beaching location by region. Finally, an analysis of data based on a risk assessment approach identified the areas/regions that could be most affected by beaching of dFADs. The analysis incorporated different parameters e.g., dFAD losses, deactivation, densities, and beaching.
- A literature review to gain scientific background on coral reefs, their function, and major threats in general and, specifically, in the Western Indian Ocean (WIO), to provide a context to understanding the relative potential impacts of dFADs on coral communities. Among the main threats worldwide are climate change, coastal development, pollution, and unsustainable fishing practices. In the WIO, climate change and fishing activities are the most significant. A bibliometric analysis using VosViewer provided an understanding of how research on the impacts on coral reefs in the WIO has evolved over time.
- The identification of the potential risk to corals from derelict dFADs in the Seychelles and to distinguish factors that could be extrapolated or related to the impacts generated by them. A literature review using the information previously gathered and the fieldwork (see below)

were valuable in completing the work. The limited existing evidence on the impacts of dFADs on coral reefs focus on damage caused by nets that may entangle coral reefs, shading and suffocating coral species. The fieldwork allowed the identification of the other parts of the dFAD (e.g., attractors) that may also have impacts on corals. This activity also aimed at identifying and describing other factors that may determine the vulnerability of species to dFADs interactions, including, conservation status, environmental factors (e.g., depth range), and growth rate. A simulation exercise was carried out with a set of coral species of Seychelles to visualize how different species may interact with dFADs, with some species having the potential to better cope with such interactions than others.

- Identification and analysis of potential mitigation measures to reduce the risk of damage to corals through interaction with dFADs. A questionnaire survey was designed and implemented with the expert team of AZTI. A workshop provided expert judgment on possible measures to mitigate identified impacts i.e. dFAD design (e.g., avoid the use of nets and attractors), materials (e.g., use of biodegradable materials), and management (e.g., better control of dFADs to improve their management).
- The review of current and potential IOTC policy on the recovery of lost or abandoned dFADs. To this end, using the same questionnaire survey as above, key stakeholders (institutions, experts, industry, NGOs) were consulted.

Field Work

Field work was undertaken in D'Arros and St. Joseph islands to provide empirical evidence on the nature and extent of damage to corals resulting from interaction with derelict dFADs. The objective was to assess the potential impact of derelict dFADs on reef communities; and to test an approach that may be used in a large-scale study. A set of methods to assess impact was tested underwater.

After method comparison, it is suggested that the use of line intercept method and static visual fish counts are the most appropriate methods for this type of research. Although the number of dFADs studied was very limited, it seems that the interaction of dFAD-coral reefs may be associated with lower coral cover, or higher number of broken colonies. Yet, this cannot be either concluded not extrapolated due to the limited sample size; another study with higher number of dFADs is required.

Through this research, major advances have been made towards better understanding the effects of the interactions dFADs-coral reef communities. This has allowed the identification and proposal of possible measures that could help to mitigate the potential impacts of dFADs on coral reefs.

Discussion In the Indian Ocean, Seychelles has the highest propensity for dFAD interaction with coral communities. While such interaction is not a major global threat to the corals, local pressures may reduce their resilience to withstand the impact of other parameters such as climate change. According to stakeholders "bad fishing practices" include the use of destructive fishing gears, inadequate governance and management, marine litter (including ALDFG), bycatch, the use of dFADs, oils spills, and anchoring, among others.

Existing policy is aligned with the need to manage local pressures; several regulations have been implemented on the fisheries sectors and good fishing practice guidance documents are available.

The tuna purse seine fisheries industry, including Echebastar, has implemented and voluntarily adopted several measures to reduce their impact. There is a general downward trend in all significant indicators of dFAD activity.

In addition to reducing the number of dFADs deployed, a multi-disciplinary team of researchers and external stakeholders highlight the potential to limit the impacts of dFADs by considering dFAD design, materials and monitoring aspects.

Specific measures proposed, include limiting dFAD numbers, better recovery and management plans, no usage of nets, reduced size (length and volume), use of small and detachable weights, use of biodegradable materials, material/design specification for attractors.

Echebastar itself has already adopted some of these measures (e.g., reduced the number of dFADs, modified dFADs design, replaced materials with biodegradable materials or contributed to the FAD Watch programme).

Recommendation

On the basis of findings, the authors make a number of recommendations on dFAD data, interaction with coral communities, dFAD design, materials and management, and dFAD mitigation measurement and implementation. These complement previous research recommendations in this field (ISSF, 2018; Zudaire et al., 2018; Moreno et al., 2023; Murua et al., 2023).

Some of the recommendations may be implemented by individual companies, while others will require shared effort by a range of stakeholders, supported as appropriate by IOTC regulations.

1. INTRODUCTION

The increased use of dFADs in the Indian Ocean over past years has led to concern being voiced over the potential damage when they are lost and become derelict on coral communities, as it is perceived they may cause irreversible damage to them to the detriment of related ecosystems and the livelihoods of people dependent on activities such as fishing and tourism.

Yet, many of the views expressed are based on limited knowledge of the location and structure of coral communities that may interact with dFADs and the nature and extent of any potential damage.

To correct that situation, this paper reviews the various parameters that may be considered while also presenting the results of a pilot project designed to provide empirical evidence on the actual effect of the dFAD-coral community interactions.

2. CORAL COMMUNITIES: NATURE, LOCATION, STATUS AND THREATS

Authors: Maria C. Uyarra, Iker Zudaire and Josu Santiago

2.1 Introduction

A bibliometric analysis (using VosViewer software) and a literature review were used to:

- Understand what coral reefs are, their distribution, function, and services that they provide, as well as their status, threats and trends worldwide.
- Identify risk factors (e.g., climate change, pollution, marine debris, anchoring impacts from recreational and fishing boats) that may reduce coral reef structure and function to a point where severe or irreversible damage may occur.
- Identify the potential impacts of dFADs on coral reefs that may occur in the context of other threats.

2.2 Coral Reefs: Nature

Corals are small animals (polyps) that belong to the Phylum Cnidaria (Hickman et al. 2008). Polyps live in symbiosis with zooxanthellae algae, which exist within the tissue of corals. The coral provides shelter to the algae while the algae carry out the photosynthesis providing the coral with nutrients. Since zooxanthellae algae contain pigments, these algae are also responsible for the colour of corals. Furthermore, these algae trigger the ability of corals to draw calcium carbonate from seawater to form the skeleton (Hoegh-Gulberg et al. 2007).

Most corals live attached to the substrate, where they form colonies (Humann & Deloach, 1996). They slowly build skeletal structures and form the reef structure, providing home (e.g., shelter, nursery habitats, feeding grounds) to numerous species, and developing reef ecosystems.

Obtaining an accurate estimate of coral reef diversity is a challenging task; it requires taxonomists, knowledge, economic investment, technology, etc. However, and even though the real diversity of coral reefs is unknown, they are considered the most diverse, complex, and productive marine ecosystem worldwide (Connell, 1973; Spalding, et al., 2001, Burke et al. 2011). With a relatively low number of reef building species (less than 1,000) (Veron 1995), Spalding et al., (2001) suggest that coral reefs may support about one million species and Burke et al. (2011) indicate that they support 25% of all marine species.

2.3 Coral Reefs: Distribution & Typology

The distribution of tropical coral reefs is limited by the polyp-zooxanthellae symbiosis, which is specific in terms of the environmental condition requirements and the sensitivity to minor changes in those environmental conditions resulting from a variety of stressors (e.g., changes in temperature, salinity, quality, etc.).

Corals require warm and rather stable sea temperatures, with optimal growth occurring at between 23 ºC and 29 ºC (NOAA, 2021). Although the presence of corals has been reported in areas with temperatures both below and above those limits, minor changes as 1-2º C above summer monthly mean temperatures can cause coral bleaching (Reaser et al. 2000) that results in the alteration of the symbiosis between the coral and the algae. Corals also require salinities that range between 32 and 42, as well as shallow and clear waters that allow zoothantellae accessing sunlight to perform the photosynthesis.

With these specific temperature, salinity and light requirements, the distribution of coral reefs is latitudinally limited to 30º N to 30º S; yet, large areas within these limits are not suitable for coral growth due to e.g., depth, water quality, etc. (Hickman et al., 2008).

The Global Coral Reef Monitoring Network (GCRMN) identifies ten major coral reef regions: Australia, Caribbean, Eastern Tropical Pacific, Red Sea and Gulf of Aden (PERSGA), South Asia, Brazil, East Asian Seas, Pacific, Regional Organization for the Protection of the Marine Environment (ROMPE) and Western Indian Ocean (Figure 1). Based on research carried out by GCRMN, coral reefs occupy around 260,000 km^2, which is less than 0,2% of the seafloor (Souter et al., 2020), or 0,07%, if calculated with reference to Costello et al. (2015) sea surface and seabed world areas.

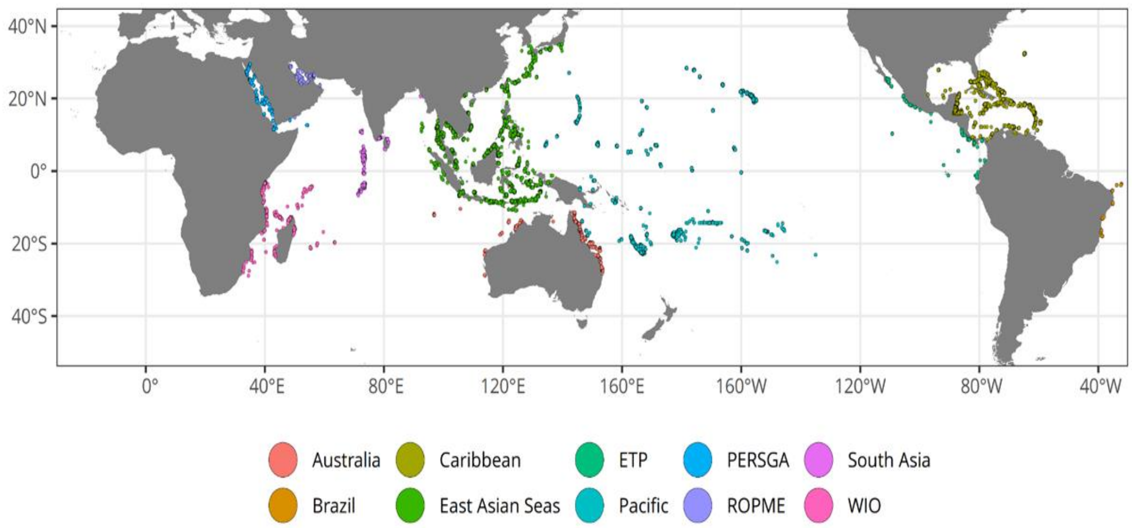

FIGURE 1.MAP OF THE DISTRIBUTION OF CORAL REEFS OF THE WORLD (SOUTER ET AL. 2020)

Most traditional classifications of reef types, classifies reefs into three groups that respond primarily to their morphology, size, and connection with the neighbouring land.

- **Fringing Reefs**: the reef grows directly from the shore towards the sea, skirting coasts and islands. They normally communicate with the shoreline, and they are structured into forereef (the closest and shallowest part of the reef), reef crest (where the drop off is produced), and the backreef (deeper reef).
- **Barrier Reef**: this reef is similar to the fringing reef, but there is normally a deep lagoon that separates the shoreline from the reef. The Great Barrier Reef is the largest of this type.
- **Atolls**: they are circular or oval-shaped reefs, which are thought to have been formed by the continuous growth of a fringing reef around a volcanic island, that at some point sinks below the sea. As a result of this process, they surround a lagoon".

A fourth group has been recently added:

- **Patch or Platform Reefs**: small, isolated reefs that grow up from the open bottom of the island platform or continental shelf. They usually occur between fringing reefs and barrier reefs. They vary greatly in size, and they rarely reach the ocean surface.

Different reef typologies dominate in the distinct regions. While in the Caribbean fringing reefs are the most dominant, in Australia the barrier reef is of note and atolls are typical of the Eastern Tropical Pacific as well as in several islands of the WIO.

2.4 Coral Reefs: Ecosystem Services Provided

About 40% of the world´s population (2.4 billion people) live within 100km from the coast, of which 850 million are found within 100 km from coral reefs and 275 million within 30km and at less than 10m above sea level (Burke et al. 2011). Coral reefs provide tropical and subtropical populations and indigenous communities with several services, and it is likely that many livelihoods are highly dependent on this ecosystem (Eddy et al. 2021). According to Burke et al. (2011), the most reef-dependent areas correspond to small island states in the Pacific and Caribbean.

Moberg & Folke (1999) made one of the first coral reef services analysis and, since then, even if coral reefs´ ecosystem services are better understood, the type and their classification has not significantly changed (Woodhead et al., 2019).

The ecosystem services provided by coral reefs, according to CICES (Common International Classification of Ecosystem Services), are:

- **Provisioning**. In addition to abiotic row materials (e.g., pharmaceutical products, coral sand, etc.) (Costanza et al. 1997), it is worth highlighting corals' role in providing seafood that in coral reef areas represents the main source of animal protein (UN 2017; Eddy et al. 2021). For the population in Pacific Islands countries and territories, seafood represents 50% - 90% of all animal protein intake, 50% in West Africa and 37% in southeast Asia (Eddy et al. 2021). For indigenous communities, seafood is very important, as their fish consumption is 15 times higher than that of non-indigenous communities (Eddy et al. 2021). Furthermore, in addition to food provisioning, coral reefs support one-fourth of the world´s small-scale fisheries (Teh et al. 2013), and recent estimates indicate that about 6 million fishers operate on coral reefs worldwide (Eddy et al. 2021), specifically, in developing countries in the Pacific (Burke et al. 2011).

- **Maintenance and regulating**. Coral reefs play a major role in maintaining and regulating ecosystem functioning, climate, nutrients dynamics, pollution, hydrodynamic, etc. Indeed, coral reefs support almost one million species providing them with shelter, nursery, breeding and/or feeding grounds (Spalding et al. 2001; Fisher et al. 2015). Coral reef ecosystems also play an important role in carbon cycling, and therefore on climate regulation (Kennedy et al. 2016). They also reduce wave energy by 97%, providing protection along more than 150,000 km of shoreline in about 100 countries and territories (Burke et al. 2011) and to the 275 million people that live in proximity to coral reefs (Burke et al. 2011; Ferrario et al. 2014).
- **Cultural**. Coral reefs offer multiple cultural ecosystem services. Among others, they provide the base for relevant research, including the exploration of biochemical compounds for medicinal purposes (Motuhi et al. 2016), spiritual connection (Gregg et al., 2015), and recreation (Brander et al., 2007). Recreation is often associated with tourism. At least 94 countries and territories benefit from reef tourism (including: i) on-reef tourism, such as diving and ii) indirect benefits from reef tourism, such as calm waters and white beaches), the annual value of which has been estimated at US$ 38,5 billion (Spalding et al. 2017). The benefits that coral reefs provide through tourism represent more than 15% of gross domestic product for 23 countries (Burke et al. 2011).

When explored from the benefits perspective, the wide range of ecosystem services that coral reefs provide have been valued at US$2,7 trillion annually (Souter et al. 2020). Yet, over recent decades, coral reefs ecosystems have been severely degraded, altering the services and the benefits that may provide now and, in the future (Hoegh-Guldberg et al. 2019; Souter et al. 2020; Eddy et al. 2021).

2.5 Coral Reefs: Status, Threats & Trends

The latest updates on the status, threats, and trends of coral reefs of the world are available in the Sixth GCRMN Status of corals reefs of the World: 2020 (Sauter et al. 2020) and Reefs at risks Revisited (Burke et al. 2011).

It is estimated that globally coral reefs occupy around 259,647 km^2 across tropical regions. This cover has changed over time, with major declines over recent decades, due to:

- Local threats that result from human activities occurring near the reef with direct and relatively localized impact.
- Global threats that affect reefs indirectly, through human impacts on global climate and ocean chemistry (Burke et al. 2011).

Research indicates:

- The average global coral cover prior to the first mass coral bleaching event in 1998 was higher than 30%.
- Since 1998, coral reef cover has undergone both decline and increase, but an overall deterioration is observed.
- The 1998 mass bleaching event led to the loss of 8% of the coral.
- Subsequently, coral reefs recovered and reached an average 33.3% coral cover.

- However, from 2009 to 2018, on average 14% of coral cover disappeared, except for the Coral Triangle (the epicentre of coral diversity), where coral cover increased with respect to 1983.
- Currently, coral reefs cover 259,647 km^2 worldwide (about 0,07% of the world´s seabed).
- The proportion of threatened reefs and the level of threat to which they are exposed has increased since 1997-2007.
- The main global and local threats to coral reefs are:
    - Global warming and acidification.
    - Coastal development (including infrastructure, sewage discharge, tourism, etc.), watershed-based pollution, marine-based pollution, and damage.
    - Overfishing and destructive fishing practices.
- Approximately, 75% of the worlds´ reefs are classified as threatened when considering local and global threats together. Southeast Asia leads with 95% of their reefs being in jeopardy (i.e., 50% highly or very highly threatened).
- Local threats alone directly affect 60% of total world reefs.
- The pressure from overfishing and destructive fishing activities (no specific mention of FADs is made when referring to this activity and its impacts) has increased by 80% since 1998.
- It is expected that current warming and ocean acidification will place more than 90% of the reefs under threat by 2030 and almost all reefs will be threatened by 2050, if there is no change to local threats.

Among the different global threats, disease, invasive species, and climate change (i.e., bleaching, acidification and increased frequency and intensity of cyclones/hurricanes) are the most relevant. The effect of climate change on coral reefs received most attention at COP26.

Coral reefs have become a flag ecosystem to raise concern and awareness, as it is estimated that by 2050 almost all reefs could be threatened by climate change, more specifically by warming and acidification (Burke et al. 2011). Higher CO_2 emissions have been associated with increases in the temperature of the atmosphere, and consequently, that of the sea.

Warming is responsible for a stress response - coral bleaching. This leads corals to lose their pigmented symbiotic algae (Zooxanthellae), and their colour as only their white skeletons are visible. Furthermore, CO_2 emissions are responsible for ocean acidification which diminishes the ability of corals to grow their skeleton.

Under climate change scenario, CO_2 emissions are expected to continue increasing, expanding the intensity and magnitude of threat to coral reefs. In addition, higher frequency/intensity of storms have shown to cause severe damage.

Reefs exposed to local human threats are more vulnerable to global threats (Burke et al., 2011; Obura 2012; Hughes et al., 2017).

Although the overall declining trends of coral cover and increase of algal cover are primarily triggered by global threats (especially, climate change), minimizing local pressures that act directly on coral reefs can play an important role in boosting their resilience, letting them "buy-time" to face climate change. Thus, efforts are needed to manage local threats such as coastal development (including infrastructure, sewage discharge, tourism , trampling), watershed-based pollution (e.g., run-off nutrients from agriculture/livestock farming, sedimentation, pollutant inputs from industry), marine-based pollution and damage (e.g., oil spills, anchoring, discarded or loss fishing gear, litter), and overfishing and destructive fishing practices that directly impact coral reefs (e.g. dynamite fishing or trawling).

3. <u>CORAL REEFS IN THE WESTERN INDIAN OCEAN</u>

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3.1 Overview

A bibliometric analysis (using VosViewer software) and a literature review were used to gain specific understanding of coral reefs in the Western Indian Ocean.

Literature on coral reefs in the WIO is not consistent. Hence, the definition used in the Status of Coral Reefs of the World: 2020. This considers that the WIO incorporates ten states, including Africa mainland countries (Somalia, Kenya, Tanzania, Mozambique, South Africa), island states (Mauritius, Madagascar, Comoros, Seychelles) and overseas territories (Reunion Island).

The WIO region has different climates. The North-Eastern part is exposed to monsoons, while the western part is bordered by arid areas (Bullock et al. 2021). These contribute to a high level of aquatic endemism (15% of all aquatic species) and diversity (Bullock et al. 2021). Indeed, the region is considered a hotspot for coral reef diversity, with varying levels of reef-building species richness that range from 174 - 184 in Seychelles (Obura, 2012; Fassbender et al. 2021) to 297 in Mozambique (Obura, 2012). Currently, coral reefs in the WIO cover 15,179 km2, which represents 5.85% of the worlds´ coral reefs (Souter et al 2020).

In the past, the combination of low population densities and economic development favoured the status of the coral reefs in the area. But there was limited research. Thus, despite the increasing number and intensity of threats in the WIO posed by development and growth in the surrounding countries (Bullock et al., 2021), the greatest uncertainty in the global assessment of the status of coral reefs is in this area. Bullock et al. (2021) assessed 4,167 marine species present in the WIO (including 32 countries and territories, and encompassing areas e.g., such the Red Sea and Sea of Oman) and considered 17% were Data Deficient, especially affecting fish. The authors classified 8% of all marine species under different "threatened" category levels (i.e., Critically endangered, Endangered, and Vulnerable). Specifically, all five species of sea turtles and 24% species of reef-building corals were categorised as threatened.

The level of threat changes when focusing on specific regions. Indeed, 65% of WIO coral reefs are classified as threatened by local activities, with 35% under high or very high threat (Burke et al. 2011).

3.2 Bibliometric analysis

To understand the main drivers for coral reef decline. the key word string "impact* AND "coral* AND Western Indian Ocean" was searched in Web of Science (i.e., scientific library), leading to 231 references. These references were analysed using VosViewer (version 1.6.16), which is software that allows visualisation of their content by highlighting the most used terms in them, as well as defining through visual lines how the different terms relate to each other. The larger the nod, the higher the number of times that the term is used. This analysis allows an understanding of the main themes covered in the literature in relation to the main drivers for coral reef impact. This is then used as a proxy to understand the main real threats to coral reefs in the WIO.

The main topics explored in the literature can be separated into five groups.(Figure 2).

- Reef ecosystem functional groups (blue).
- Monitoring (red).
- Climate change (yellow).
- Fish and fisheries (green).
- Ecosystems and ecosystem services (purple)

In addition, when focusing on key terms, important conclusions can be drawn:

- Research on the "impact* AND "coral* AND Western Indian Ocean" mainly focuses on fisheries and climate change (Figure a).
- When focus is placed on benthic elements (i.e., coral community, Acropora, algae), the bibliography links those to two key topics (fisheries and climate change) (Figure b, c, d).
- When the focus is on climate change pressure, links are mainly established with bleaching, temperature, etc. (climate change related terms), and fisheries related terms (Figure e).
- When the focus is on fisheries/fishing the links are more diverse, finding relationship with climate change, reef ecosystem functional groups and fisheries/fish itself (Figure f).

In addition, bibliometric analysis allows exploration of how the literature has evolved overtime. While initial research on "impact* AND "coral* AND Western Indian Ocean" focused on fisheries and reef ecosystem functional groups (blue/purple colour in Figure 3) in more recent years the focus has shift towards climate change (yellow/green colour in Figure 3).

3.3 Key Findings in the Literature

The conclusions of the most recent reports that focus on the status/trends of coral reefs in the WIO align with the outputs of the bibliometric analysis. Of all local threats, fisheries are the most relevant activity affecting negatively coral reefs either through direct targeted fisheries and illegal, unreported, and unregulated fisheries, or indirect bycatch and habitat degradation.

It is estimated that overfishing alone affects around 60% of the reefs. This activity has led to raising the threat category level in many areas, which were previously classified as low threat and are now classified as threatened (Burke et al. 2011). Other pressures, even if they are more localized, are increasing in the area. For example, watershed pollution, which is currently threatening Madagascar´s reefs due to massive deforestation (and land erosion), is becoming more common where coastal developing is rapid. Also in these areas, the lack of mitigation measures, such as the construction of sewage treatment plants, is threatening coral reefs with increasing nutrients, and consequently algal growth. More specific pressures are not analysed separately in these summary reports; these are integrated within four main local threats. So, ship anchoring damage is integrated within "marine-based pollution and damage", reef trampling is integrated within "coastal development" (that includes unsustainable tourism practices), or unsustainable fishing practices, which are integrated within "overfishing and destructive fishing".

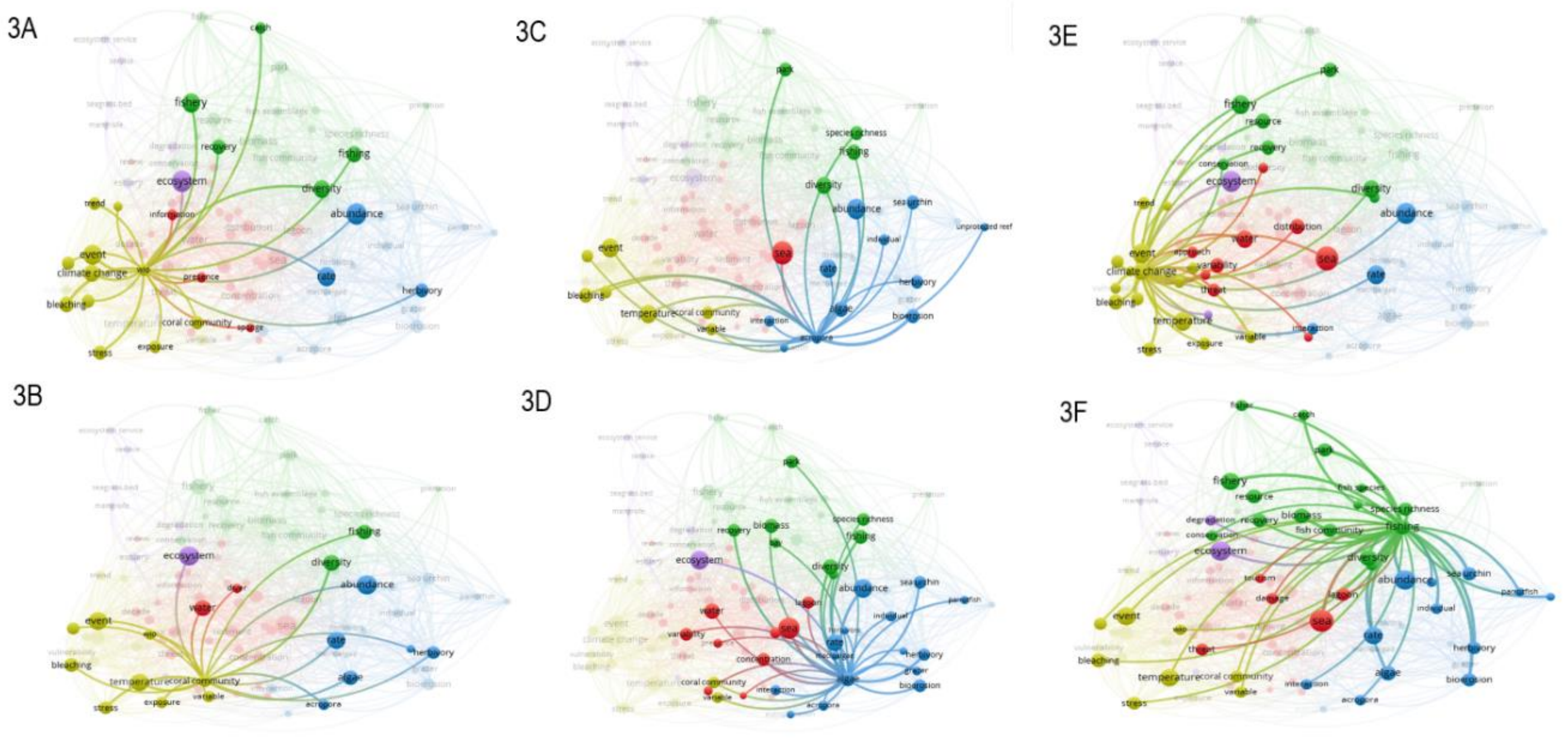

FIGURE 2 VOSVIEWER NETWORKS OF THE KEY TERMS OF THE WESTERN INDIAN OCEAN LITERATURE ON IMPACTS ON CORAL REEFS. FIG A. WESTERN INDIAN OCEAN NETWORK; FIG B. CORAL REEF COMMUNITY NETWORK; FIG C. ACROPORA NETWORK; FIG D. ALGAE NETWORK; FIG E. CLIMATE CHANGE NETWORK; FIG F. FISHING NETWORK.

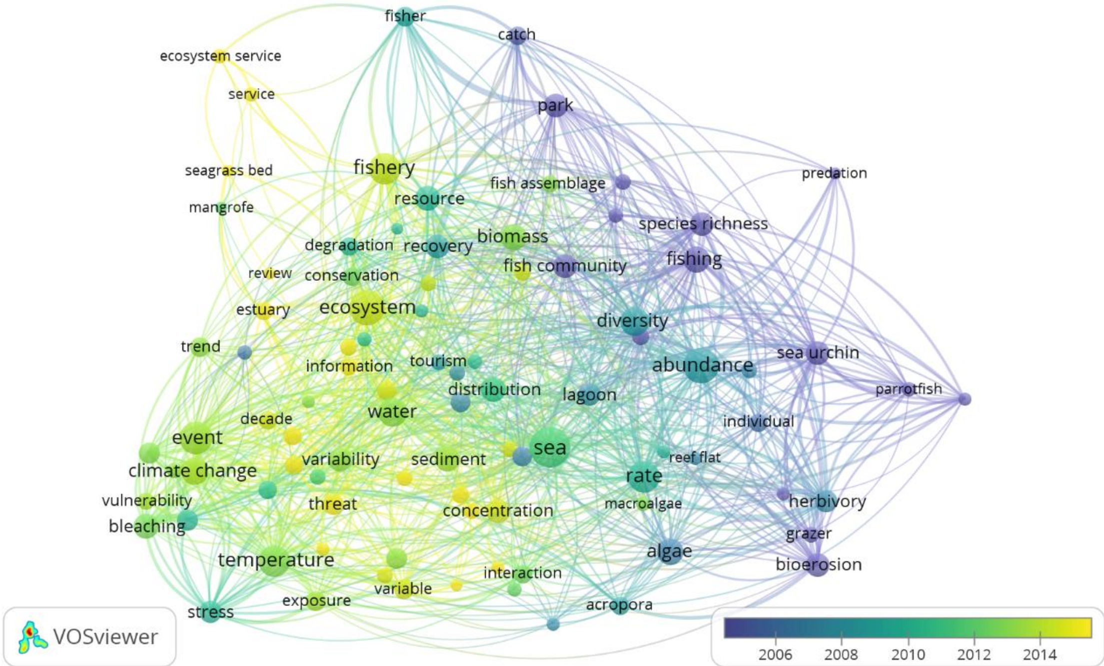

FIGURE 3 **NETWORK OF TERMS (TERMS AND INTERACTIONS) OBTAINED FROM THE 231 REFERENCE RETRIEVALS THAT RESPOND TO THE "IMPACT* AND "CORAL* AND WESTERN INDIAN OCEAN" IN WEB OF SCIENCE AND ORGANIZED ACCORDING TO TIME OF PUBLICATION.**

It is worth noting that while the local threat "biological resource use" (including fisheries) poses the major hazard to coral reefs at the species level, climate change (warming and acidification) is the most important one affecting coral reefs as included in the species threat list used by the International Union for Conservation of Nature and Natural resources (after "pollution" and "residential & commercial development") (Burke et al. 2017; Bullock et al., 2021).

Coral reefs in the region are being severely affected by warming; however, the real damage that global threats are having on reefs are difficult to assess due to a high level of uncertainty. It was the massive bleaching event in 1998 that triggered coral reef research in the area. At that time, coral reef cover in the area declined from 28.8% to 26.5%. It took six years for reefs to start recovery so that in 2012 coverage was 32.3%. Further bleaching events, pushed coral reefs down to 29.4% during 2013-2017.

Thus, even if there have been bleaching events, there may be the impression that the net balance in coral reef growth has not changed (or may have even increased) overtime at the regional level. However, this apparent increase contrasts with other literature that suggest that before 1998, coral cover was higher than 40% in the area.

Whether this mismatch is explained by the lack of information in the area prior to 1998 or other factors, future climate change scenarios will increase the proportion of threatened reefs to 85% by 2030, and to 100% by 2050; about 65% will be highly or very highly threatened.

The resilience of the reefs to global threats will be determined by the intrinsic characteristics of the reefs (e.g., coral reproduction, genetic connectivity, fish dynamics) but also, by other factors/pressures (e.g., fisheries, diseases, outbreaks, currents) (Burke et al. 2017).

Hence, considering that 65 million people live within 30 km of the coastline in the WIO (with this population increasing) with a high proportion of these likely dependent on coral reefs for subsistence and livelihoods (through e.g., fisheries and tourism) (i.e., livelihoods opportunities and income for local communities $ 8.4 billion / year), it becomes critical to increase coral reef resilience through managing local pressures. Only by doing so, coral reefs will gain some time while climate change solutions are found and implemented (Souter et al. 2020).

3.4 Other new challenges to Seychelles coral reefs: marine litter

Although marine litter, and specifically as in relation to dFADs, did not show up in the literature review as an important source for damage to coral reef communities, research carried out in this field in Seychelles has recently been published, and thus, it is worth mentioning.

Duhec et al (2015) studied the characteristics and sources of marine debris in Alphonse Island and concluded that most litter had been originated in Southeast Asia and Somalia. Furthermore, they suggested that most debris had land-based origin and had entered the sea as a result of inadequate waste management. Only 2% of the total number of marine debris items corresponded to 'Fishing items' including rope and net fragments and plastic buoys, many of which were from trawl and long-line fisheries as well as fragments of net from FADs (Fish Aggregating Devices) used by tuna vessels. Also ubiquitous were polystyrene fragments, plastic bottles and pieces of flip-flops used as surface floats that we attributed to artisanal fisheries.

In Aldabra, situation has shown to be rather different. Burt et al (2020) after removing 25 tonnes of marine litter (out of 538 estimated tonnes), concluded that in terms of weight, 60% (15.8 tonnes) corresponded to fisheries-related items (buoys, nets, FADS and ropes), followed by plastic shoes (mainly flip-flops). Of the fishing floats sampled, 28% (n = 50) had 'Made in Taiwan' inscribed on them, while the remaining floats were branded but had no clear origin. Of the fish-aggregation devices or FADs (n = 13), seven had clearly decipherable identification codes, which allowed identifying five from Seychellois vessels, one Spanish and one French vessels. Most of the fishing gear abandoned by "purse seine" fisheries likely relate to regional fishing activity around Seychelles. But abandoned gear from longline fisheries may have drifted in from as far afield as western Australia. Furthermore, in a recent report for the Indian Ocean Tuna Commission, in which they investigated 214 individual FADs that had arrived on or entered near-shore waters of a number of islands in Seychelles: 76% of the FADs were from Spanish owned or flagged vessels, licensed to fish in Seychelles. These results indicate that waste generated by the fishing industry within Seychelles is polluting island ecosystems within the same nation state.

The most recent published study in this topic Vogt-Vincent N. & A. Burt (2023) modelled the flow of plastic debris in the Indian Ocean between 1993 and 2019 and traced it to its source. Similarly, they conclude that a large proportion of the beached marine litter in Seychelles comes from Asia, and especially Indonesia, except for inner islands, where India and Sri Lanka are the primary sources.

These findings imply long travel distances (more than six months), which could bring additional problems such as the introduction of pathogens and invasive species through marine litter. Regarding the debris with maritime origin, they highlight that Seychelles, due to its location within fishery grounds and maritime transport lines, it is at high risk of suffering from this type of debris. Indeed, they suggest that shipping lines would explain for the debris found with origin in Thailand, Malaysia and especially, China. They associate the marine debris from purse seine fisheries activities to Seychelles itself. In contrast, longline fragments could have their origin in the Southern Indian Ocean.

These papers focus on understanding the sources (terrestrial/marine), origin (countries) and trajectories of marine litter beaching in Seychelles. They highlight the fact that the location of Seychelles makes it sensitive to litter beaching, which sets up new emerging challenges to which the oceans, and specifically in this context, coral reefs are facing, and in which maritime activities could play an important role.

4. ANALYSIS OF THE DYNAMICS OF dFADS

Authors: Josu Santiago, Iker Zudaire and Maria C. Uyarra

4.1 Introduction

This analysis concentrates on dFADs that are lost and may become derelict on coral communities in the Indian Ocean. As such, it:

- Analyses dFAD drift to understand the dynamics and identify possible beaching locations by region.
- Identifies coral locations in the Indian Ocean using generalized grid data set at 500 m resolution, as developed by the World Resources Institute (https://www.wri.org/).
- Reviews available information on the structure of reefs and species composition in the potential main affected regions.
- Analyses data through a risk matrix assessment approach, where probability and susceptibility are estimated to assess the risk at the areas/regions affected by the beaching of dFADs. The matrix incorporates different parameters e.g., number of dFADs in EEZ, number of beaching events in EEZ, square kilometres of coral reef and square kilometres of EEZ at each of those regions.

4.2 dFAD Dynamics in the Indian Ocean.

Data from the echosounder buoys of the ECHEBASTAR fleet operating in the Indian Ocean in 2016 - 20 as provided by the buoy manufacturing companies directly to AZTI were used. AZTI receives these data monthly, with a two-month delay, with the main objective of monitoring the number of active buoys (Santiago et al., 2017). The data are in .csv files and contain daily records of all active buoys managed by each individual vessel. The information included in the .csv files is:

- Date [dd-mm-yy].
- Time [hh.mm].
- Individual unique buoy identification code.
- Latitude and longitude [expressed in degrees and minutes in decimal values].
- Speed [knots].

Data analysis allowed a better understanding dFAD dynamics, especially lost dFADs that are likely to become derelict, and their potential impact on coral communities in the context of the coastal areas / regions where potential impacts may be more significant.

The following definitions were used to estimate required indicators:

- **Total buoys:** Total number of buoys monitored throughout the year (number of different buoy's codes in the Database (DB)).
- **yyyy buoys:** Buoys that were active at the beginning of the year (in the DB the 1st of January, or 30th or 31st of December).
- **New buoys:** Buoys that were not active at the beginning of the year (not in the DB the 1st of January, or 30th or 31st of December).
- **Daily Active:** Average number of buoys monitored per vessel throughout the year (number of different buoys' code associated with each vessel).
- **Number of deployments**: A record is considered a deployment when the buoys' code appears for the first time in the DB or the time interval with the previous record of the same buoy is at least 30 days. The deployment is counted only if the number of days between the first and the last record of the corresponding buoy trajectory is at least 40 days.
- **Number of buoys deployed**: Number of different buoy codes in the deployments.
- **Number of deactivations**: Buoys that have been deactivated by the buoy provider companies at the request of the vessel owner. A buoy can be deactivated several times in its lifetime.
- **Lost:** A buoy is considered lost when its code no longer appears in the DB (the current year and the first semester of the following year). Beaching events are counted within this group together with those sunk, stolen, etc.
- **Beached:** A buoy is considered beached when its code no longer appears in the DB and the last presence occurs on land.

These indicators and their trends over the defined period were considered in an analysis of dFAD drift in order to study their dynamics and identify areas with potential strandings by region in the IOTC convention area (Figure 4).

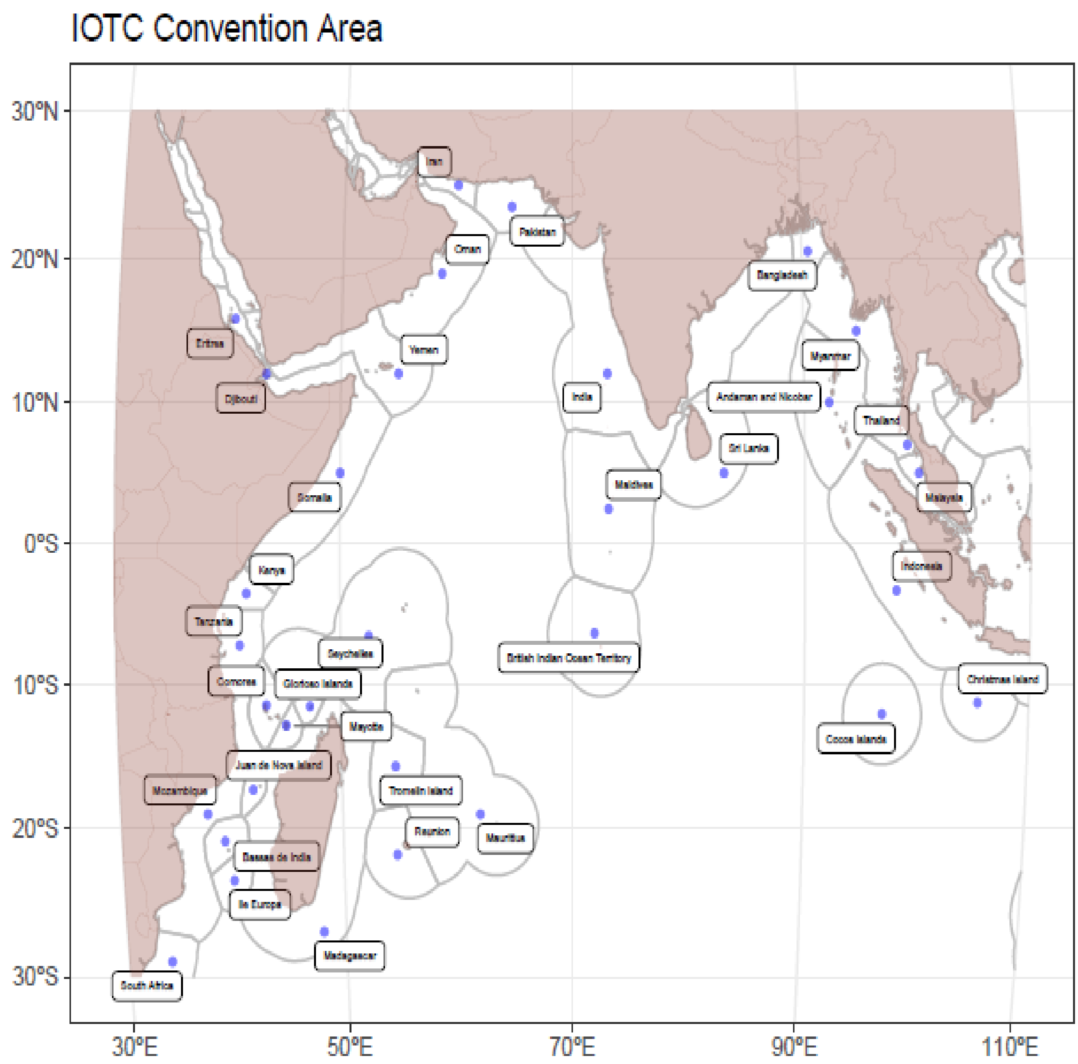

FIGURE 4: IOTC CONVENTION AREA WHERE DFAD DYNAMIC INDICATORS WERE ASSESSED

The total number of deployments analyzed showed a decreasing pattern from 2016 to 2019 (Table 1) with respect to previous year data. For example, in 2017, 20% fewer deployments were made with respect to 2016, and in 2018, 10% less with respect to 2017.

Only 2020 showed an increase in the number of deployments with respect to 2019 (16% increase). However, comparing 2020 data with the mean value of previous years (2016 - 2019), the increase was just 2%.

TABLE 1: EVOLUTION OF THE ECHEBASTAR VESSELS´ DEPLOYMENTS AND BUOY DEPLOYED, BUOY DEACTIVATION, LOST BUOYS AND BEACHED BUOYS IN THE INDIAN OCEAN 2016 – 2020

	2017	2018	2019	2020
Deployments	-20%	-10%	0%	+16%
Buoys deployed	16%	10%	-2%	-4%
Deactivated	29%	5%	2%	14%
Lost	10%	10%	7%	-7%
Beached	-29%	51%	-31%	14%

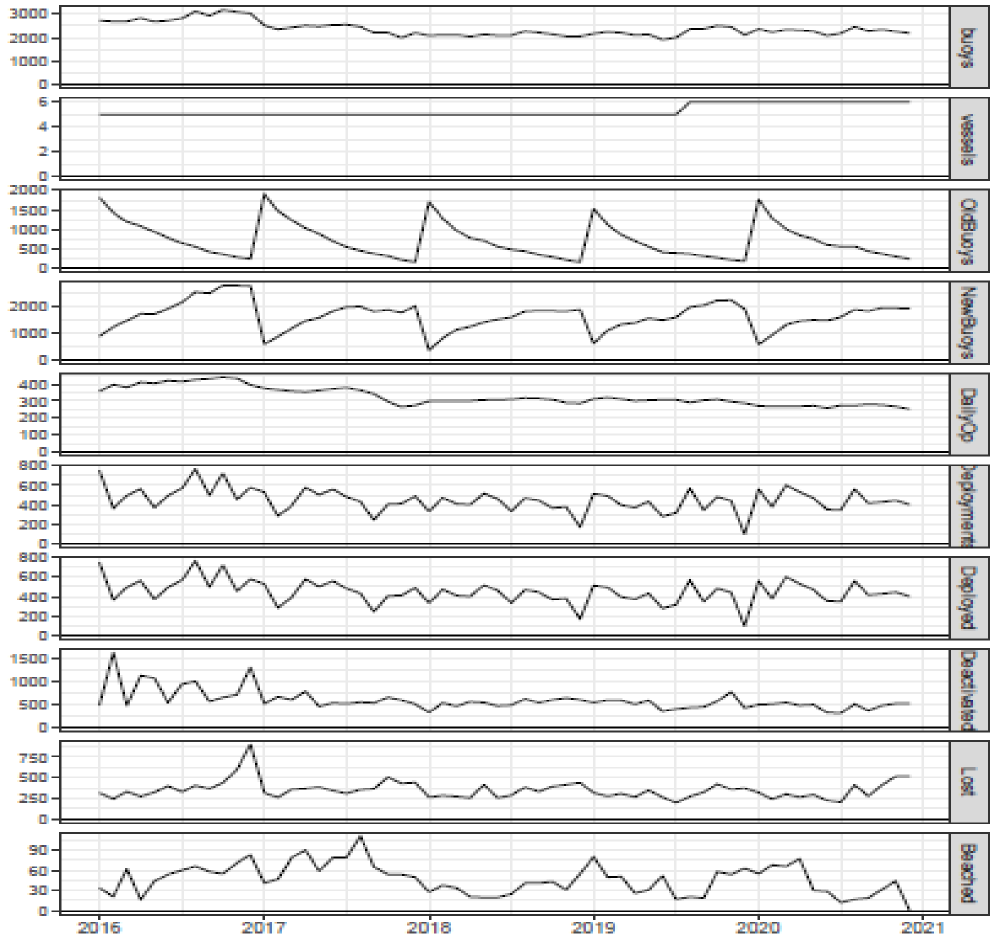

FIGURE 5. EVOLUTION OF INDICATORS FOR THE ECHEBASTAR FLEET IN THE INDIAN OCEAN (2016 -20).

This overall decreasing trend is linked to the adoption of IOTC Resolutions (for example IOTC Res. 19/02) limiting the number of buoys. In fact, the analysis of the monthly evolution of active buoys shows marked declines in January 2017 and October 2017, when Resolutions 16/01 and 17/08 entered into force (Figure 5). Another factor is the management measure restricting the catch of yellowfin with the consequent shift from free school to dFAD effort.

A similar decreasing trend was observed with the number of buoys deployed, deactivated, and lost. The deactivations followed the same pattern (Table 1). Like deployments, the main decrease observed in deactivation estimates were from 2016 to 2017 with a reduction of 29%. From 2017 to 2018 the fall was less significant with a decline of 5%, and a higher number of deactivations was observed again from 2019 to 2020 (14% decrease). Comparing the annual deactivation data with the average of previous years, the downward trend continues to be pronounced.

The number of lost buoys also showed a decreasing trend from 2016 to 2020. However, this reduction was not as significant as for previous indicators, with around 10% reduction each year except for 2020 with an increase of 7% with respect to 2019 observed (Figure 2). Except for 2020, comparing annual data with the average of previous years, the decreasing trend in the number of lost during period is clear.

Contrary to all other indicators, the number of beached buoys showed an overall decreasing trend, but not continuous. This number increased by 29% from 2016 to 2017, to decrease by 51% in the following. The beached numbers increased by 31% in 2019 and subsequently decreased by 14% in 2020 (Table 1).

The reduction in the number of deactivations, lost buoys and beaching events likely results from adoption of IOTC Resolutions limiting the number of buoys and are in accordance with the decreasing pattern in deployments. The resolutions in force are reducing the number of dFADs through time, and the conservation and management measures adopted have impacted on the fishing strategy as they significantly constrain free school fishing.

However, the fleet may have adapted to this change by maintaining the maximum number of dFADs in the effective fishing area, which can lead to an increase in the number of deactivations, lost (the case in 2020) and beaching events (the case of 2019), related to dFADs that drift outside the fishing area. At the same time, it should be noted that Echebastar has voluntarily reduced the number of dFADs used by its individual vessels to levels that are below the maximum allowed by the IOTC.

5. AREAS POTENTIALLY INTERACTING WITH LOST dFADs

Authors: Iker Zudaire, Maria C. Uyarra and Josu Santiago

5.1 Indian Ocean

This study looks to understand dFAD dynamics, especially that of lost dFADs which may become derelict on coral communities in the Indian Ocean (Figure 6).

The impact of dFADs was assessed using a risk assessment approach, which has matured into a powerful analytical tool, and projectable in ever-wider applications in policy making and regulation. This approach determines possible mishaps, the likelihood and consequences, and the tolerances for such events.

In the case of this analysis, the likelihood or probability of occurrence was defined as the probability a beaching, which was estimated by the proportion between the number of beaching events observed in a specific region (EEZ) and the number of buoys observed in the EEZ. The consequences or severity was considered as the susceptibility of having beaching events, estimated from the proportion of the area of coral reef (km2) and the area (km2) of EEZ at each studied region. The goal was to provide a comprehensive screening of risk for a set of predetermined measurable attributes. The risk of impacts on coral reef derived from beaching dFAD at each region was estimated as the product between likelihood and the susceptibility and allowed a ranking of regions where according to estimated indicators could be “more” or “less” affected.

In addition, other indicators such as density of losses, deactivations, buoys per 1000 km2 and beaching of dFADs per 100 km of coastline were estimated together with the estimation of coastline and percentage of coral reef (Figure 7). The highest value for these variables was indicated in the matrix with 1 and the lowest with 0. These indicators allowed the interpretation of the result from the risk assessment approach, where a ranking of countries was produced for the Indian Ocean.

According to the risk score shown in Table 2, Tanzania, Maldives, Mozambique, Yemen, and Sri Lanka obtained the highest risk scores and are considered more vulnerable regions to dFAD beaching impacts on coral reef.

In the case of Tanzania, the high ratio of coral reef to EEZ seems to be the main driver for scoring the highest, as it is not the country with the greatest probability of a stranding event.

On the other hand, countries such as Somalia and Sri Lanka, while the probability of stranding is high in relation to the other countries studied, their low susceptibility minimises the risk of impact on corals. Particularly striking is Somalia which has the highest values for densities of lost, deactivated, and stranded dFADs.

Thus, and considering the complexity of the dynamics of dFAD use, it is difficult to accurately estimate the risk in each country, and the values shown in Table 2 should be studied with caution as it has not been possible to assess whether the values obtained in the risk score are transferable to a scale of high to low risk.

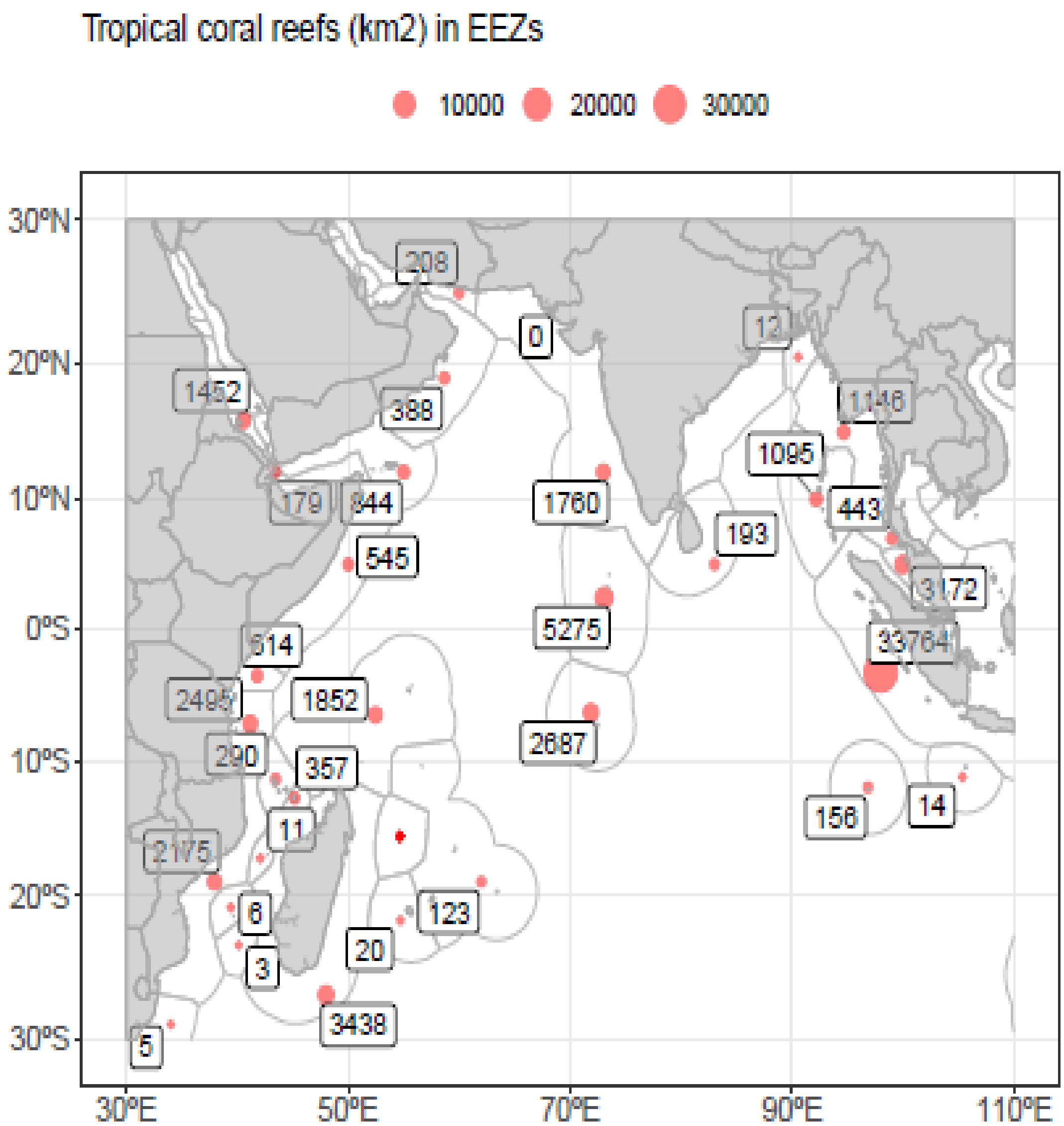

FIGURE 6. DISTRIBUTION OF CORAL COMMUNITIES IN TERMS OF SURFACE AREA IN THE STUDY REGIONS IN THE INDIAN OCEAN.

TABLE 2 RANKING OF EEZ BASED ON THE ESTIMATED DFAD USE IMPACTS ACCORDING TO THEIR % OF REEF IN THE INDIAN OCEAN.

Country	Probability Occurrence	%	Susceptibility	Risk
Tanzania	0.05	5%	0.0103	0.00049123
Maldives	0.07	7%	0.0057	0.00037454
Mozambique	0.05	5%	0.0038	0.00020272
Yemen	0.07	7%	0.0016	0.00010753
Sri Lanka	0.27	27%	0.0004	0.00009739
Somalia	0.14	14%	0.0007	0.00009423
Comores	0.04	4%	0.0018	0.00007489
Kenya	0.02	2%	0.0037	0.00006102
India	0.05	5%	0.0011	0.00005559
Indonesia	0.01	1%	0.0056	0.00005237
UK*	0.01	1%	0.0042	0.00004253
Madagascar	0.01	1%	0.0028	0.00003182
Oman	0.02	2%	0.0007	0.00001101
Seychelles	0.01	1%	0.0014	0.00000796
Mauritius	0.00	0%	0.0001	0.00000039
Andaman and Nicobar	0.00	0%	0.0016	0.00000000
Bangladesh	0.00	0%	0.0001	0.00000000
Bassas de India	0.00	0%	0.0000	0.00000000
Christmas Island	0.00	0%	0.0000	0.00000000
Cocos Islands	0.00	0%	0.0003	0.00000000
Djibouti	0.00	0%	0.0248	0.00000000
Eritrea	0.00	0%	0.0185	0.00000000
Ile Europa	0.00	0%	0.0000	0.00000000
Iran	0.00	0%	0.0010	0.00000000
FR**	0.00	0%	0.0002	0.00000000
Malaysia	0.00	0%	0.0062	0.00000000
Mayotte	0.00	0%	0.0054	0.00000000
Pakistan	0.00	0%	0.0000	0.00000000
Reunion	0.00	0%	0.0000	0.00000000
South Africa	0.00	0%	0.0000	0.00000000
Thailand	0.00	0%	0.0015	0.00000000
Tromelin Island	0.00	0%	0.0000	0.00000000

**FR:Juan de Nova Island

Country	Losses	Deactivations	Densities	Beached	Coastline	% reefs
Andaman and Nicobar	0.00	0.00	0.00	0.00	0.04	0.09
Bangladesh	0.00	0.00	0.00	0.00	0.06	0.00
Bassas de India	0.07	0.08	0.09	0.00	0.00	0.03
British Indian Ocean Territory	0.09	0.10	0.08	0.07	0.01	0.64
Christmas Island	0.01	0.02	0.01	0.00	0.00	0.02
Cocos Islands	0.01	0.02	0.01	0.18	0.00	1.00
Comores	0.68	0.66	0.69	0.97	0.01	0.10
Djibouti	0.16	0.17	0.00	0.00	0.01	0.07
Eritrea	0.00	0.00	0.00	0.00	0.06	0.07
Ile Europa	0.04	0.03	0.04	0.00	0.00	0.02
India	0.09	0.08	0.02	0.01	0.31	0.02
Indonesia	0.01	0.02	0.00	0.00	1.00	0.10
Iran	0.01	0.02	0.00	0.00	0.11	0.01
Juan de Nova Island	0.13	0.13	0.33	0.16	0.00	0.12
Kenya	0.56	0.56	1.00	0.16	0.03	0.06
Madagascar	0.06	0.06	0.06	0.01	0.18	0.06
Malaysia	0.00	0.00	0.00	0.00	0.17	0.06
Maldives	0.84	0.83	0.19	0.54	0.04	0.44
Mauritius	0.03	0.03	0.05	0.06	0.01	0.04
Mayotte	0.35	0.37	0.00	0.00	0.00	0.32
Mozambique	0.19	0.19	0.09	0.04	0.13	0.05
Oman	0.04	0.05	0.04	0.01	0.05	0.02
Pakistan	0.00	0.00	0.00	0.00	0.05	0.00
Reunion	0.00	0.00	0.00	0.00	0.00	0.01
Seychelles	0.35	0.33	0.30	0.28	0.01	0.41
Somalia	1.00	1.00	0.39	1.00	0.07	0.02
South Africa	0.01	0.00	0.00	0.00	0.04	0.00
Sri Lanka	0.18	0.19	0.02	0.12	0.05	0.01
Tanzania	0.62	0.63	0.62	0.19	0.06	0.12
Thailand	0.00	0.00	0.00	0.00	0.13	0.01
Tromelin Island	0.00	0.00	0.04	0.00	0.00	0.36
Yemen	0.31	0.30	0.18	0.19	0.06	0.04

FIGURE 7. RISK MATRIX INCORPORATING THE INDICATORS OBTAINED BY EACH INDIAN OCEAN COASTAL COUNTRY.

Despite the uncertainty of the ranking of countries with the highest risk of dFAD impact on corals, this was used to select the countries where measures could be introduced to mitigate the impacts of derelict dFADs on corals.

5.2 Other Ocean Areas

The operating area of ECHEBASTAR is the WIO but dFADs move with the currents and may be found outside that region a long way from where were deployed.

If lost dFADs migrate beyond the WIO, they may become derelict on various type of coral communities elsewhere (e.g., atolls, patchy and fringing reefs), that have different environmental conditions (i.e., optimal for potential recovery), status (i.e., moderate status with coral coverage at around 26%), and human pressures, including climate change. Fisheries and coastal development are area specific and coral reef conditions (e.g., higher biodiversity and coral cover) and other pressures (e.g., intensive coastal development in India) may be completely different. This may lead to more vulnerable or resilient reefs, which in turn may determine the real impact of the interaction between them and derelict dFADs. This research has not considered this aspect.

6. THE RISK TO CORAL COMMUNITIES FROM INTERACTION WITH DERELICT DFADS.

Authors: Maria C. Uyarra, Iker Zudaire and Josu Santiago

6.1 Introduction

This section considers the potential risk to corals from derelict dFADs and to identify factors that could be extrapolated or related to the impacts generated by dFADs. Additional aims are to identify and describe other parameters such as physical damage, vulnerable species and recovery times of coral communities.

Scarce existing research on the potential impacts of dFADs on coral communities has been complemented with observations made during fieldwork (see below). Understanding the potential physical damage of dFADs on coral reeds requires considering the different factors that could affect the response of the various species to potential interaction (i.e., conservation status of species, growth type and growth rates).

The work has been focused on Seychelles, in line with the area selected for the field work, to visualize what could potentially be done with more detailed information.

6.2 Background

This report highlights that the main threats to WIO coral reefs are climate change, coastal development, unsustainable fisheries, and illegal and unreported fisheries. Existing literature does not make specific mention to dFADs.

Several studies explore and model dFAD trajectories and beaching (Davis et al. 2017; Maufroy et al. 2018; Báez et al. 2020; Curnick et al. 2021; MacMillan et al. 2022). Others, suggest dFADs as a source of marine litter (Gaertner et al. 2016; Imzilen et al. 2022), causing ghost fishing (Filmalter et al. 2013), potentially introducing invasive species (Curnick et al. 2021), or directly damaging the environment and organisms (Davis et al. 2017; Curnick et al. 2021), including coral reefs.

Some studies propose mitigation measures to minimize those impacts (e.g., Davis et al. 2017; Zudaire et al. 2018; Escalle et a. 2019; Imzilen et al. 2021; Moreno et al. 2023). Yet, few studies focus on assessing the impacts of dFADs on coral reefs (see Balderson & Martin 2015; Zudaire et al. 2018; Banks & Zaharia 2020; Consoli et al. 2020).

According to those few studies that explore these impacts, damage on coral reefs is primarily caused by the nets used in the dFADs (i.e., structure and/or tails), but observations in the fieldwork (see below) identify structure, ropes, attractors, and weights as potential sources (Table 3).

TABLE 3: EVIDENCE OF IMPACTS OF DFADS ON CORAL REEFS, FOUND IN LITERATURE REVIEW.

Part of equipment	Type of interaction	Type of damage	Bibliographic evidence
Buoys	None		
Structure	Collision Shading Entanglement	Coral injuries	Fieldwork
Nets (e.g., aggregator nets, structure nets, sausage nets)	Shading Entanglement	Coral entanglement / injuries	Balderson & Martin, 2015 Consoli et al. 2020 Banks & Zaharia 2020 Zudaire et al. 2018 Fieldwork
Ropes	Shading Entanglement	Coral entanglement / injuries	Fieldwork
Attractors	Entanglement	Coral entanglement / injuries	Fieldwork
Weight	Collision Shading Entanglement	Coral injuries	Phase 2

6.3 Type of DFADs Impacts on Coral Reefs & Influencing Factors

The type of impacts that dFADs can generate can be classified into three categories (definitions derived and adapted from Burns et al. 2018):

- **Scraping / Abrasion**: scarring to the live coral tissue caused by the collision of dFADs with the reef.
- **Breakage:** pieces of broken coral that appear scattered on the benthos caused by the collision of dFADs with the reef.
- **Tissue mortality**: any pieces or area of coral tissue that exhibited complete tissue mortality because of a collision, contact, or suffocation caused by the dFADs.

Whether the interaction between dFADs and coral reefs results in one type of injury or another, and consequently, their ability to recover, depends on the intensity and duration of the interaction, the part of dFAD involved, environmental factors (e.g., reef structure), species involved in the interaction, and other pressures that may be specific to the area.

The greater the intensity of the contact, which may be affected by e.g., wind and current speed, wave height, and the length of exposure to contact, the more severe is the damage. Intense contact interaction may result on removal of the tissue, providing other organisms the opportunity to settle and compete with corals for space. Long exposure of corals to direct contact may prevent the symbiotic zooxanthellae algae of the coral from accessing light; this hinders the photosynthesis, which may result in suffocation and ultimately, coral mortality.

The design of dFAD may influence the type of damage that can generate. The reviewed literature and the observations made during fieldwork (see below) suggest that nets (e.g., cage nets, sausage nets[1]) forming part of the dFAD are generally involved with damage to corals (Balderson & Martin, 2015; Banks & Zaharia, 2020; Consoli et al. 2020; Zudaire et al. 2018).

Since the net can easily become entangled with the reef, and even continue drifting generating further tension, it may lead to abrasion, breakage, or coral mortality. The permanent contact of the net (or any other part of the dFAD) may potentially result in coral mortality. This may occur while beaching if the surface structure sinks over the reef. Other parts of the structure that may negatively interact with corals are the suspended weight, which may collide with corals causing injuries and/or breakage, and attractors, which easily entangle with coral reefs.

Environmental conditions such as water currents and wind are determinant on where dFADs aggregate and beach (Imzilin et al. 2019; Kahn et al. 2020). In addition, reef structure and zonation may be important factors influencing how reefs may be affected by dFADs.

Banks & Zaharia (2020) identify the following reef zones:

- **Reef crest** is the highest point of the reef that breaks waves and receives the full impact of wave energy. It can be exposed the atmosphere at low tide, with harsh living conditions for the coral (KSLOF, 2014),
- **Fore reef** is the part of the reef that extends from the reef crest into the ocean. It slopes downward and can reach great depths (KSLOF, 2014). It can be interrupted by terraces or sediment flats. It is exposed to high wave energy in the shallow zone and low in the intermediate zone (5-20 m).
- **Back reef** is the area that slopes into a lagoon. Often shallow, it can be exposed at low tide (KSLOF, 2014). It is exposed to low wave energy.
- **Lagoon and lagoonal reefs:** a pool of seawater highly or partially enclosed within a reef formation (atolls) or between a reef and shorelines (barrier reefs) (KSLOF, 2014**).** Area exposed to low wave energy, tidal fluctuations, shallow currents, and can have complex bottom structures (coral pillars, pinnacles and boomies) (Barott et al., 2010)
- **Reef flats:** area behind the reef crest that is protected from the wave action. It can extend from meters to kilometres. Low wave energy, low dissolved oxygen, high temperatures and exposed to air at low tides (KSLOF, 2014).

[1] The use of netting materials in dFAD construction is prohibited (IOTC Resolution 19/02)

Banks & Zaharia (2020), in a study exploring the benefits and costs of dFADs in the Western and Central Pacific, found that dFADs primarily beach on reef flats, followed by fore reef and lagoonal reefs. According to KSLOF (2014), of these habitats, the fore reef is the most sensitive, as in its intermediary zone it has the highest coral growth and species diversity.

Furthermore, whether the corals are soft (octocorals or gorgonians / sea plumes) or hard corals (scleratinians) may determine the type of damage that may result from dFADs interactions. Hard corals may suffer from scaring and breakage, while branching and plate-like corals are more susceptible to breakage (Au et al. 2014). Soft coral may either cope with the interaction, or break (depending on the species).

7. SIMULATION OF POTENTIAL THREAT OF DFADS TO CORAL REEFS IN SEYCHELLES

Authors: Maria C. Uyarra, Iker Zudaire and Josu Santiago

7.1 Introduction

The most common coral species in Seychelles belong to the following genera: Acropora, Favia, Favites, Goniastrea, Pavona, Porites, Pocillopora, as well as Goniopora, Stylophora, Galaxea. To visualize the status of these species, and their risk to damage and potential for recovery, an exercise exploring several species of these genera was carried out.

As the guide to coral reefs of Seychelles does not reach the level of species, selection of the species followed Obura (2015). For those genera that are considered abundant in Seychelles (and therefore, more likely to be exposed to contact with dFADs), species known to be present in the WIO were selected. This list was compared with the Red Data List of the International Union for the Conservation of Nature (IUCN) (https://www.iucnredlist.org/), by which it is possible to identify the locations where the species have been reported (i.e. those that were not reported for Seychelles were excluded).

According to the IUCN, the conservation status of a species can be classified into:

- Data Deficient (DD).
- Least Concern (LC).
- Nearly Threaten (NT).
- Vulnerable (VU).
- Endangered (EN).
- Critically Endangered (CR).
- Extinct in the Wild (EW).
- Extinct (EX).
- Not Evaluated (NE).

For the selected species, the conservation status (based on the above) and depth range were extracted from the Red Data List from the IUCN (https://www.iucnredlist.org/). The growth type and growth rate were obtained from the Coral Trait Database (https://coraltraits.org/) (Table 4).

TABLE 4: A SELECTION OF SPECIES PRESENT IN SEYCHELLES, AND BELONGING TO SOME OF THE MOST ABUNDANT GENERA, FOR WHICH THE IUCN CONSERVATION STATUS, THE DEPTH RANGES, GROWTH TYPE AND ANNUAL GROWTH RATE ARE PROVIDED.

Genera *Species*	IUCN conservation status	Depth ranges (m)	Growth type	Growth rate (mm yr-1)
Acropora				
Acropora humilis	NT	0-11	Digitate	9.6-26.7
Acropora retusa	VU	1-5	Digitate	
Acropora secale	NT	2-15	Branching	
Acropora gemmifera	LC	1-15	Digitate	24
Acropora clathrate	LC	8-20	Tables/Plates	
Acropora Cytherea	LC	3-25	Tables/Plates	20.9-93.2
Favia				
F. speciosa	LC	0-40	Massive	4.5-8.5
F. lizardensis	NT	1-20	Massive	
F. helianthoides	NT	1-20	Submassive	
F. matthaii	NT	1-30	Massive	
F. stelligera	NT	0-20	Massive	10
Favites				
F. pentagona	LC	0-25	Submassive	
F. flexuosa	NT	1-25	Massive	
F. abdita	NT	0-40	Massive	0.8
F. complanate	NT	1-30	Massive	
F. halicora	NT	0-20	Massive	
F. vasta	NT	1-20	Massive	
Goniastrea				
G. retiformis	LC	0-20	Massive	6-7.95
G. peresi	NT	2-25	Massive	
G. pectinate	LC	0-40	Submassive	
G. edwardsi	LC	0-30	Massive	6.95-12.5
Pavona				
P. cactus	VU	3-20	Digitate	28
P. decussata	VU	3-15	Digitate	
P. frondifera	LC	3-15	Digitate	
P. clavus	LC	2-15	Columnar	4.86-23
P. duerdeni	LC	3-15	Massive	8.6-11.8
P. explanulata	LC	3-25	Laminar	
P. varians	LC	2-80	Encrusting	3-5
P. venosa	VU	2-20	Encrusting	
P. maldivensis	LC	5-20	Columnar	11-13.1
Porites				
P. lutea	LC	0-30	Massive	3-23.91
P. somaliensis	NT	1-20	Massive	
P. cylindrica	NT	1-20	Encrusting with long uprights	7.4-25
P. nigrescens	VU	0.5-20	Branching closed	17.8
Pocillopora				
P. eydouxi	LC	2-20	Branching open	20-50.4
P. Indiana	VU	2-20	Branching closed	
P. verrucosa	LC	1-54	Branching closed	17.88-37.9

7.1 RISK matrix

Based on this information, a risk matrix was created. Considering that all the selected species occur within a depth range in which the interactions of dFADs could occur, this variable has been excluded from the matrix. The other three variables have been integrated, and transformed into 1 (low), 2 (medium), 3 (high) vulnerability scores.

In the case of the IUCN conservation status, it was considered that LC and NT species were below the "threat" threshold, and a 1-score value was assigned. VU species were assigned a 2-score value, and all the other categories (including DD category, following the precautionary approach), a 3-score value.

Regarding growth and according to the literature, encrusting species were considered the least vulnerable to damage (1-score), followed by massive species (2-score), which may be prone to scarring, and branching / plate / leaf / columnar (3-score), which are more exposed to breakage.

Finally, the growth rates could be considered as a proxy for the potential to recover. Those species with very slow growth rates (0-10 mm yr-1) were allocated a 1-score value; growth rates ranging between 11-20 mm yr-1, were assigned a 2-score value; and species with growth rates > 20 mm yr-1, were assigned a 3-score value. While, in assigning these values, the "slowest" growth rates reported were considered as a way of applying the precautionary approach, this aspect should be carefully reviewed.

This scoring system led to a matrix to aid understanding of the potential threat that dFADs may pose to the species for which all the information is available (Table 5).

In the matrix, values between 1 and 3 values signifies low potential threat; 4 to 8 medium potential threat; 9 serious potential threat; and 12, 18 and 27, high potential threat.

Accordingly, this exercise suggests that dFADs could potentially present a high threat to one of the selected species (due to a structure that is more vulnerable to dFADs, medium growth rate, and VU conservation status) and pose a serious threat to a further two species.

However, the following limitations to this type of simulation need to be considered:

- The species included correspond to some of the most abundant genera in the WIO. Nevertheless, the specific abundance of those individual species in the Seychelles is unknown.
- The IUCN classifications correspond to global classifications. Thus, the effect of dFADs at the local scale could be different (as they may depend on the conservation status of species at local scale, even if this is unlikely to be available).

TABLE 5: SIMULATION OF THE POTENTIAL DFAD THREATS TO CORAL SPECIES, ACCORDING TO IUCN CONSERVATION STATUS CLASSIFICATION, TYPE OF GROWTH AND ANNUAL GROWTH RATE.

Species	IUCN status	Growth type	Growth rate (mm yr-1)	dFAD threat to coral species
Acropora humilis	1	3	3	**9**
Acropora gemmifera	1	3	1	**3**
Acropora cytherea	1	3	1	**3**
Favia speciosa	1	2	3	**6**
Favia stelligera	1	2	3	**6**
Favites abdita	1	2	3	**6**
Goniastrea retiformis	1	2	3	**6**
Goniastrea edwardsi	1	2	3	**6**
Pavona cactus	2	3	1	**6**
Pavona clavus	1	3	3	**9**
Pavona duerdeni	1	2	3	**6**
Pavona varians	1	1	3	**3**
Pavona maldivensis	1	3	2	**6**
Porites lutea	1	2	3	**6**
Porites cylindrica	1	1	3	**3**
Porites nigrescens	2	3	2	**12**
Porites eydouxi	1	3	2	**6**
Porites verrucosa	1	3	2	**6**

- The scoring system applied to growth rates have been rather arbitrary. Setting up these limits would require coral expert judgement agreement.
- Finally, the potential interaction of dFADs with coral reefs may co-occur with other activities and pressures happening in the area. The presence of e.g., diseases, algal dominance habitat type, outbreaks, abnormal high sea surface temperatures, etc., may reduce the capacity of the species to recover from physical damage (Chong-Seng et a. 2014).

7.2 Potential Recovery of Coral Reefs from Interaction with DFADS

Generally, corals have very slow growth rates (https://coraltraits.org/) and difficulties to recover from physical damage (Rogers & Miller 2006; Lirman et al. 2010; Bellwood et al. 2012). Yet, some studies indicate that they may do so.

The recovery of corals depends on the type of damage (Hall 2001). A study on two species indicated that the amount of regeneration was four times higher on scraped corals than broken and dead corals. The rate of recovery of broken corals also depends on the species themselves and their growth rate. Furthermore, the regeneration is highly dependent on the level of algae colonization (Hall 2001), an important competitor to corals. Generally, damaged corals, even when the tissue of the coral may still be alive, are more sensitive to algae colonization, diseases, bleaching events or other pressures (Chong-Seng et al. 2014; Osborne et al. 2017). Thus, even if the collision or contact with a dFAD may not directly cause mortality, the coral may become less resilient to other pressures. Thus, minimizing the interaction between dFADs and coral reefs is relevant.

8. IDENTIFICATION AND ANALYSIS OF MEASURES TO REDUCE THE POTENTIAL IMPACTS ON CORAL COMMUNITIES FROM DERELICT DFADS.

Authors: Iker Zudaire, Maria C. Uyarra, Maitane Grande, Jefferson Murua and Josu Santiago

8.1 Introduction

This section identifies and analyses possible measures to mitigate the risk of damage to corals from interaction with dFADs (e.g., biodegradable dFAD, reduction of the number of dFAD, counting of dFAD). A literature review identified the best existing scientific knowledge to support proposed measures.

8.2 Approach

Three main topics in the field of dFAD sustainability were identified:

- dFAD design,
- dFAD construction materials, and
- dFAD management.

A questionnaire was structured around these three topics to which AZTI experts responded and then was adapted to gain the opinion of a range of stakeholders.

8.3 Results

8.3.1 AZTI Experts

Questionnaires were completed by AZTI experts with various fields of expertise (Figure 8). Gathered information was analysed by experts in a workshop held at AZTI (Sukarrieta).

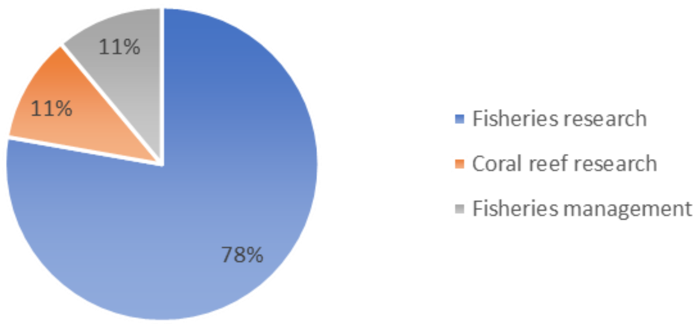

FIGURE 8. AZTI TEAM EXPERTS' FIELD OF EXPERTISE

The AZTI experts identified the main impacts that derelict dFADs could potentially generate and the element of a dFAD that may be responsible for those impacts.

The main impacts identified were "Damage in coral reefs", "Plastic pollution" and "Wild fauna entanglement", and to a lesser extent, "Contaminants in biota", "Fish catchability", and "Change on fish community structure" (Table 6).

TABLE 6 LIST OF KEY IMPACTS IDENTIFIED BY THE AZTI TEAM EXPERTS SURVEYED.

Key impacts of dFADs	Number of responses
Damage in coral reefs	7
Plastic pollution	7
Wild fauna entanglements	5
Contaminants in biota	3
Fish catchability	3
Change on fish community structure	2
Damage of species	1
Habitat damage	1
Vector for introduction of invasive species	1

In addition, those parts of the dFAD considered responsible for generating the most negative impacts were considered. The experts identified the "net" and "the use of non-biodegradable materials" as the two most harmful elements, followed by the "ropes" and the "ballast weight" (Table 7).

TABLE 7 LIST OF MOST DAMAGING PART OF DFAD IDENTIFIED BY THE AZTI TEAM EXPERTS SURVEYED.

Most damaging parts	Number of responses
Nets	6
Non-biodegradable materials	3
Ropes	2
Weights	2
Long tails	1
Submerged structure	1
Tail	1
Tails (nets)	1

The experts made recommendations for each of the action lines: design, material and management.

The two main recommendations were "the use of biodegradable materials" and "material reduction" in the construction of FADs. The next measures proposed were "build shorter tails" and "avoid the construction of entangling FADs". Constructing "easy to release ballast weights" was also identified as a measure that would contribute to the sustainability of dFADs (Table 8).

TABLE 8 LIST OF DESIGN RECOMMENDATIONS IDENTIFIED BY AZTI TEAM EXPERTS.

Design recommendations	Number of responses
Use of biodegradable materials	6
Reduce amount of material	5
Shorter tails	4
No entangling FADs	3
No use of nets	2
Detachable weight	2
Reduce weights weigh	2
No use of subsurface structure or weights	1
Reduce weights´ size	1
Less number	1
Designs to avoid dFAD loss	1
Use of natural products	1
Smaller mesh size	1
No use of aggregators	1

Regarding materials to be used in the construction of dFADs, "biodegradable materials" and "organic materials" were the main recommendations, followed by using "non-entangling" materials. The experts also recommended reducing the quantity of "plastics" and “material” in general (Table 9).

TABLE 9 LIST OF MATERIALS RECOMMENDATIONS IDENTIFIED BY AZTI TEAM EXPERTS.

Materials recommendations	Number of responses
Use of biodegradable materials	7
Organic FADs	4
No entangling FADs	3
No nets	2
Recycled materials	1
Reduce amount of material	1
Reduce plastic	1

The experts identified “dFAD recovery”, “dFAD number limitation”, and the ”use of biodegradable materials" as the main management measures to mitigate dFAD potential impacts on corals. Another measure identified was to use "new dFAD design" (Table 10).

TABLE 10 MANAGEMENT RECOMMENDATIONS IDENTIFIED BY AZTI TEAM EXPERTS.

Management recommendations	Number of responses
FAD recovery	5
dFAD number limitation	5
New materials (mandatory bio-degradable)	4
Limit the area where used	3
New designs (mandatory non-entangling)	2
Collaboration among fishing companies (accounting and recovery)	1
Continuous dFAD tracking	1
Control of management measures	1
Forbid dFAD discards	1
Industry training (designs & materials)	1
Promotion of best-practices in management plans	1
Traceability	1

Finally, the identified impacts were classified according to the different actions: dFAD design, dFAD construction materials and dFAD management.

Each of the impacts were analysed to propose solutions including specific measures to mitigate the potential negative effects on corals. The potential period of implementation (i.e., short, medium or long term) as well as the feasibility level for the industry were also considered for each of the proposed measure (Table 11; Table 12; Table 13). Finally, to support the proposed measures with the best scientific knowledge, references to existing (available) scientific literature were included.

TABLE 11: SUMMARY OF IMPACTS, SOLUTIONS, DFAD ELEMENT INVOLVED, IMPLEMENTATION PERIOD AND FEASIBILITY OF THESE MEASURES FOR THE INDUSTRY REGARDING THE DFAD DESIGN ACTION LINE.

<table>
<tr><th>IMPACTS</th><th>SOLUTIONS /RECOMMENDATIONS</th><th>dFAD element (Raft/Tail/Weight)</th><th>Short</th><th>Medium</th><th>Long</th><th>Feasibility</th></tr>
<tr><td rowspan="2">Netting designs (damage to corals and entanglement of species)</td><td>Elimination of netting elements in the construction</td><td>Raft and Tail</td><td>X</td><td></td><td></td><td>100%</td></tr>
<tr><td colspan="6">Observation and supporting bibliographic references:
The use of netting materials in dFAD construction is forbidden in the Indian Ocean since 1st January 2020 (IOTC Resolution 19/02). ECHEBASTAR has signed a voluntary Code of Good Practice agreement where this fleet agreed not to use netting materials in dFAD construction (Grande et al., 2021). There are scientific studies (Filmater et al., 2013) showing negative effects of netting materials in entanglement of sensitive species such as sharks.</td></tr>
<tr><td rowspan="2">Large dimension designs - deep tails (extended coral damage).</td><td>Decrease dFAD dimensions and reduction of tail size</td><td>Raft and Tail</td><td>X</td><td></td><td></td><td>80%</td></tr>
<tr><td colspan="6">Observation and supporting bibliographic references:
dFADs have undergone a progressive increase in size since their inception in the 1980s. DFADs are fully man-made constructions, characterized by increased dimensions and heavy reused nylon purse seine netting, other plastic components, floating materials like bamboo and net corks, and pieces of metal wire or metal rings for ballast (Murua et al., 2018).</td></tr>
</table>

Submerged structure design - dredge or cages (coral damage and entanglement)	Redesign dFAD models with dredge/cage in case this focus of impact is observed.	Raft and Tail		X		60%
	Observation and supporting bibliographic references: A dredge or cage on the bottom of the dFAD is an element that, when it hits and entangles with the coral reef, can generate a significant impact. For this reason, it is necessary to redesign this element and consider the potential impact and propose alternative designs that mitigate the possible negative effect. Detachable dredge or cubes.					
Large ballast designs and consistent mooring (damage and entanglement in corals).	Design reduced ballast dimensions with release systems to avoid stranding.	L – Lastre		X		90%
	Observation and supporting bibliographic references: Large ballast designs without automatic release systems are elements that have a major impact on corals once the dFAD impacts the coral and becomes entangled in it. It is therefore necessary to modify their design to make them smaller and with automatic release, so once it gets caught in the reef it could generate sufficient tension to detach from the tail.					

TABLE 12 SUMMARY OF IMPACTS, SOLUTIONS, DFAD ELEMENT INVOLVED, IMPLEMENTATION PERIOD AND FEASIBILITY OF THESE MEASURES FOR THE INDUSTRY REGARDING THE DFAD MATERIAL ACTION LINE

<table>
<tr><th>IMPACTS</th><th>SOLUTION/RECOMMENDATION</th><th>dFAD element (Raft/Tail/Weight)</th><th>Short</th><th>Medium</th><th>Long</th><th>Feasability</th></tr>
<tr><td rowspan="2">Use of durable non-biodegradable materials (e.g., plastics, metal, synthetic materials in general).</td><td>Use of biodegradable materials and elimination of plastic from netted construction elements</td><td>Raft and Tail</td><td>X</td><td>X</td><td></td><td>60%</td></tr>
<tr><td colspan="6">Observation and supporting bibliographic references:
DFADs are fully man-made constructions, characterized by increased dimensions and heavy reused nylon purse seine netting, other plastic components (e.g., bait buckets, sub-surface attractors, colourful plastic ribbons, tattered salt sacks), floating materials (like bamboo and net corks), and pieces of metal wire or metal rings for ballast (Murua et al., 2018). Large scale trials have been conducted to test biodegradable materials in dFAD construction in the Indian, Atlantic and Pacific oceans (Zudaire et al., 2020; Murua et al., 2022; Moreno et al., 2022; Zudaire et al., 2023).</td></tr>
<tr><td rowspan="2">Netting material in dFAD construction.</td><td>Elimination of netting material in dFAD construction.</td><td>Raft and Tail</td><td>X</td><td></td><td></td><td>100%</td></tr>
<tr><td colspan="6">Observation and supporting bibliographic references:
The use of netting materials in dFAD construction is forbidden in the Indian Ocean since 1st January 2020 (IOTC Resolution 19/02). ECHEBASTAR has signed a voluntary Code of Good Practice agreement where it agreed not to use netting materials in dFAD construction (Grande et al., 2021). Scientific studies (Filmater et al., 2013) show the negative impact of netting materials in the entanglement of sensitive species such as sharks.</td></tr>
</table>

<table>
<tr><td rowspan="2">Use of ropes and attractors with ribbons and looped elements</td><td>Use of materials that do not contain any elements with loops or that facilitate entanglement on the coral reef.</td><td>Raft and Tail</td><td>X</td><td>X</td><td></td><td>60%</td></tr>
<tr><td colspan="6">Observation and supporting bibliographic references:
The field work carried out in this project has shown that the elements used as attractors, such as ribbons and frayed coloured ropes, can have a negative impact on corals as they easily get entangled with the coral colonies, causing breakage. To our knowledge there are no scientific papers analysing this type of material and its effects on corals.</td></tr>
<tr><td rowspan="2">Use of high-volume ballast material.</td><td>Look for materials such as cement that may encourage coral settlement.</td><td>Ballast Weight</td><td></td><td>X</td><td></td><td>60%</td></tr>
<tr><td colspan="6">Observation and supporting bibliographic references:
The use of materials such as cement that favour the settlement of corals has been proven by scientific studies (Jaap 2000). Finding a type of design (cement blocks), heavy but with little volume, built with materials that promote coral settlement seems to be the most suitable to replace the ballast currently used in the construction of dFADs.</td></tr>
</table>

TABLE 13 SUMMARY OF IMPACTS, SOLUTIONS, DFAD ELEMENT INVOLVED, IMPLEMENTATION PERIOD AND FEASIBILITY OF THESE MEASURES FOR THE INDUSTRY REGARDING THE DFAD MANAGEMENT ACTION LINE.

<table>
<tr><th>IMPACTS</th><th>SOLUTION/RECOMMENDATION</th><th>dFAD element (Raft/Tail/Weight)</th><th>Short</th><th>Medium</th><th>Long</th><th>Feasibility</th></tr>
<tr><td rowspan="2">Beached dFAD</td><td>Assess specific areas to implement dFAD recovery programmes</td><td>--</td><td></td><td>X</td><td>X</td><td>30%</td></tr>
<tr><td colspan="6">Observation and supporting bibliographic references:
dFAD recovery initiatives have been restricted in time and space due to high cost and logistic difficulties/challenges associated with working in remote oceanic areas with limited resources (Moreno et al., 2018; Escalle et al., 2021). However, dFAD retrieval programs implemented in specific regions like the FAD-Watch pilot project, involving multi-stakeholder regional cooperation and the commitment of purse seiner vessel operators, could be a potential solution to partially reduce dFAD stranding, including beaching events (Zudaire et al., 2018). This approach is also currently under development in Palmyra atoll in the Western and Central Pacific Ocean (Escalle et al., 2021).</td></tr>
<tr><td rowspan="2">Discarded /abandoned dFAD</td><td>Assess specific areas to implement FAD Watch-type recovery programmes.</td><td>--</td><td></td><td>X</td><td>X</td><td>60%</td></tr>
<tr><td colspan="6">Observation and supporting bibliographic references:
Projects similar to the FAD-Watch Pilot Program – Zudaire et al., 2018 and Palmyra atoll (Escaller et al., 2021) could be a potential solution to partially reduce dFAD stranding, including beaching events (Zudaire et al., 2018). A recent study in the Indian and Atlantic oceans has proposed coastal dFAD recovery programs as they estimated 20% of the abandoned, lost or discarded dFADs passed within 50 km of the major ports (Imzilen et al., 2022). These programs should be defined considering environmental information, such as ocean modelling and dFAD buoy trajectories, and waste management plans, including ways to transport and allow proper disposal and/or recycling in accordance with MARPOL Annex V (MARPOL 73/78).</td></tr>
</table>

Inadequate governance and management.	Develop at company level mechanisms to encourage the removal of dFADs from the sea.	--	X	X		40%
	Observation and supporting bibliographic references: Fleet/company level initiatives could be explored to encourage the collection of dFADs at sea. The study of suitable areas (accumulation areas) and times for recovery would help implement such actions more efficiently (Moreno et al., 2018).					
Habitat destruction (corals, mangroves, etc.).	Identify dFAD areas with a high probability of stranding. Adapt dFAD designs to minimise impacts.	--		X	X	60%
	Observation and supporting bibliographic references: dFAD recovery initiatives have been restricted in time and space due to high cost and logistic difficulties/challenges associated with working in remote oceanic areas with limited resources (Moreno et al., 2018; Escalle et al., 2021). However, dFAD retrieval programs implemented in specific regions like the FAD-Watch pilot project, involving multi-stakeholder regional cooperation and the commitment of purse seiner vessel operators, could be a potential solution to partially reduce dFAD stranding, including beaching events (Zudaire et al., 2018). This is also currently under development in Palmyra atoll in the Western and Central Pacific Ocean (Escalle et al., 2021).					
Marine litter.	Develop at company level mechanisms to encourage the removal of dFADs from the sea.	--	X	X		80%
	Observation and supporting bibliographic references: Fleet/company level initiatives could be explored to encourage the collection of dFADs at sea. The study of suitable areas (accumulation areas) and times for recovery would help to implement such actions more efficiently (Moreno et al., 2018).					

Ghost fishing, entanglement of sensitive species.	Responses in Design and Materials Tables	--	**X**	**X**		**80%**
	Observation and supporting bibliographic references: Promote actions to encourage the removal of all types of mesh material from the construction of dFADs. The use of netting materials in dFAD construction is forbidden in the Indian Ocean since 1st January 2020 (IOTC Resolution 19/02). ECHEBASTAR has signed a voluntary Code of Good Practice agreement where this fleet agreed not to used netting materials in dFAD construction (Grande et al., 2021). There are scientific studies (Filmater et al., 2013) showing negative effect of netting materials in entanglement of sensitive species such as sharks.					

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8.3.2 Stakeholders

Institutions, experts, industry, NGOs (figure 9) were also contacted to obtain views on alternative actions to mitigate any potential negative interactions between coral communities and abandoned dFADs.

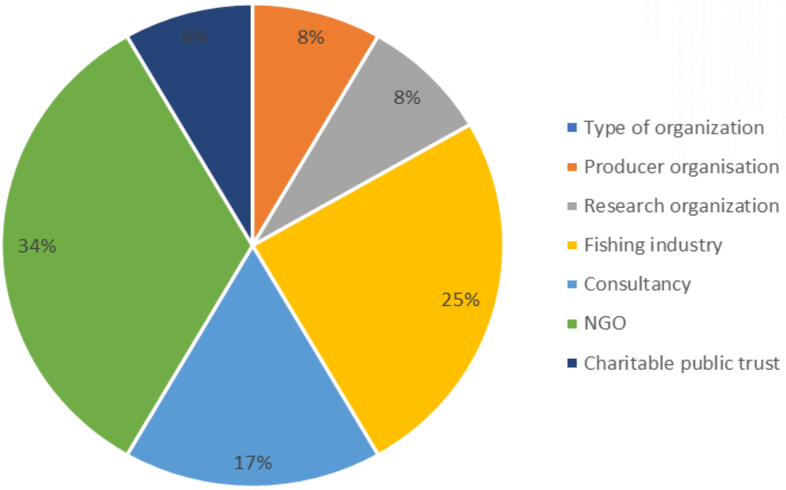

FIGURE 9. TYPE OF ORGANISATION OF EXPERTS CONTACTED

The questionnaire was completed by 12 people with expertise in fisheries management, coral reef research, the fishing industry, conservation NGOs and fisheries research (Figure 10). These experts confirmed that they were familiar with the Indian Ocean and some, had knowledge of specific countries such as Seychelles, Kenya and Tanzania.

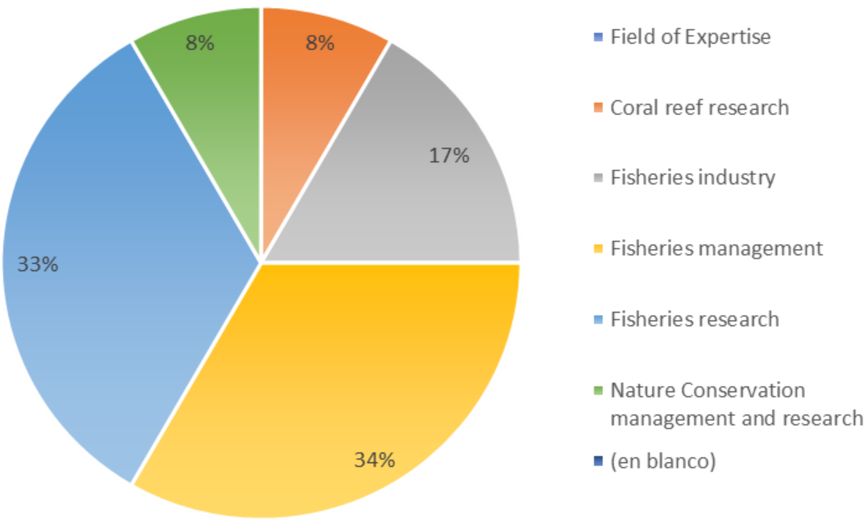

FIGURE 10 FIELD OF KNOWLEDGE OF EXPERTS CONTACTED

8.4 Responses

To facilitate the interpretation and core of the responses obtained, the responses were summarised and grouped into different categories.

8.4.1 Q1. Recent research indicates that some of the main risks to coral reefs in the Indian Ocean include climate change, coastal development, and "bad" fisheries practices. Could you please indicate examples of "bad" fisheries practices?"

The two main "bad" fishing practices identified were "destructive fishing gears" and "inadequate governance and management". The experts also agreed when identifying Abandoned Loss Discarded Fishing Gears "ALDFG", "Bycatch" and "dFAD" as examples of bad fisheries practices. Three experts identified "Littering" and "Overfishing" as bad fisheries practices (Table 14).

TABLE 14 QUESTION 1: RECENT RESEARCH INDICATES THAT SOME OF THE MAIN RISKS TO CORAL REEFS IN THE INDIAN OCEAN INCLUDE CLIMATE CHANGE, COASTAL DEVELOPMENT, AND "BAD" FISHERIES PRACTICES. COULD YOU PLEASE INDICATE EXAMPLES OF "BAD" FISHERIES PRACTICES?"

Examples of "bad" fishing practices provided by experts	Number of responses	%
Destructive fishing gears	6	17.6
Inadequate governance and management	5	14.7
ALDFG	4	11.7
Bycatch	4	11.7
dFADs	4	11.7
Littering	3	8.8
Overfishing	3	8.8
Oil spills	2	5.9
Anchoring in reef areas	1	2.9
FAD fishing	1	2.9
Overcapacity-overfishing	1	2.9

8.4.2 Q2. As you may know, drifting FADs (Fish Aggregating Devices) are used by purse seiners to catch tuna. Sometimes, these devices get lost at sea. Have you ever seen any drifting, entangled or beached FAD? If yes, please, describe the environment of the place you found the FAD.

Responses covered most of marine environmental habitat were dFAD can be seen, for example, drifting at sea in open ocean, beached dFADs in beaches, coral reefs, coastline in general (Table 15).

TABLE 15: QUESTION 2: AS YOU MAY KNOW, DRIFTING FADS (FISH AGGREGATING DEVICES) ARE USED BY PURSE SEINERS TO CATCH TUNA. SOMETIMES, THESE DEVICES GET LOST AT SEA. HAVE YOU EVER SEEN ANY DRIFTING, ENTANGLED OR BEACHED FAD? IF YES, PLEASE, DESCRIBE THE ENVIRONMENT OF THE PLACE YOU FOUND THE FAD.

FAD sightings
Beached FADs
Coastlines
Coral reefs entanglement
Wildlife entanglement
Coral reefs between 5 and 20 m depth
On outer reefs
Drifting FADs near coral reefs
Drifting in open ocean
Entangled in open sea

8.4.3 Q3. Based on your knowledge or observations, please indicate whether the effects of derelict FADs on Fish, Coral, Environment and Ecosystem functioning is Positive/Neutral/Negative.

All agreed that the impacts of derelict dFAD on corals and environment were negative. Regarding fish, all but one identified negative impacts. Apart from two respondents that reported a neutral impact, experts identified dFADs with negative impacts on ecosystem functioning (Figure 11).

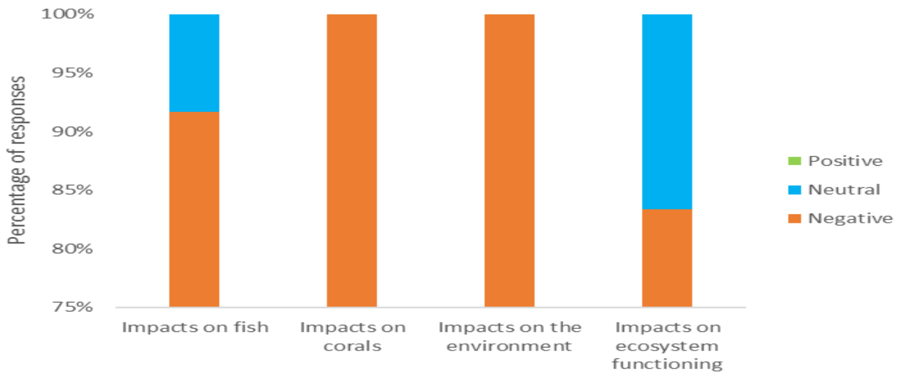

FIGURE 11 Q3. BASED ON YOUR KNOWLEDGE OR OBSERVATIONS, PLEASE INDICATE WHETHER THE EFFECTS OF DERELICT FADS ON FISH, CORAL, ENVIRONMENT AND ECOSYSTEM FUNCTIONING IS POSITIVE/NEUTRAL/NEGATIVE.

8.4.4 Q4. Based on the answers to the previous question, please explain the most relevant effects (a minimum of THREE) of dFADs on fish, corals, environment and/or ecosystem functioning

Most of the experts identified “Wild fauna entanglements”, “Damage on corals” and “Plastic pollution” as the main relevant impacts of dFADs on fish, corals, environment and/or ecosystem functioning (Table 16).

TABLE 16 Q4. BASED ON THE ANSWERS TO THE PREVIOUS QUESTION, PLEASE EXPLAIN THE MOST RELEVANT EFFECTS (A MINIMUM OF THREE) OF DFADS ON FISH, CORALS, ENVIRONMENT AND/OR ECOSYSTEM FUNCTIONING

Identified relevant impacts	Number of responses
Wild fauna entanglements	9
Damage on corals	8
Plastic pollution	6
Habitat damage	4
Change of behaviour patterns (migration, schooling)	2
Additional cumulative pressure	1
Change on fish structure	1
Juvenile fish mortality	1
Neutral damage on ecosystem functioning	1
New habitat	1
Vector for introduction of invasive species	1
Lack of ecosystem indicators to identify the effects of derelict FADs	1

8.4.5 Q4. Which is the part of the FAD that you think is responsible of most of the negative impacts (if any) that they can cause?

The experts identified the "Tail" and the "Use of non-biodegradable materials" as the main elements of the dFAD responsible for the majority of the negative impacts that could be generated on the ecosystem (table 17).

TABLE 17 WHICH IS THE PART OF THE FAD THAT YOU THINK IS RESPONSIBLE OF MOST OF THE NEGATIVE IMPACTS (IF ANY) THAT THEY CAN CAUSE?

dFAD damaging part	Number of responses
Non-biodegradable materials	3
Tails	3
Tails (nets)	3
Submerged structure	2
Raft	2
Weights	2
Nets	1
Aggregator	1

8.4.6 Q5. To minimize the impacts of dFADs, the DESIGN of FADs could be improved by?

Most of the experts identified the reduction of different elements of the dFAD or volume in general and the use of biodegradable and non-entangling materials as the main recommendations to minimize the impacts of dFAD in terms of design (Table 18).

TABLE 18 TO MINIMIZE THE IMPACTS OF DFADS, THE DESIGN OF FADS COULD BE IMPROVED BY?

Design proposals	Number of responses
Shorter tails	4
Use of biodegradable materials	3
Non-entangling FADS	3
No use of nets	2
Reduce the volume	2
Include escape panels	1
Larger mesh size	1
No use of aggregators	1
No use of subsurface structure or weights	1
Weaker materials	1

8.4.7 Q6. To minimize the impacts of dFADs, the MATERIALS used in the FADs could be improved by?

All experts agreed that the use of biodegradable and organic material in dFAD construction is the main recommendation to minimize dFAD impacts in terms of materials used in construction (Table 19).

TABLE 19 TO MINIMIZE THE IMPACTS OF DFADS, THE MATERIALS USED IN THE FADS COULD BE IMPROVED BY?

Material proposal	Number of responses
Use of biodegradable materials	11
Organic FADs	1

8.4.8 Q7. To minimize the impacts of dFADs, the MANAGEMENT of FADs could be improved by

Most experts agreed that the main recommendation is “Reduce the number of dFADs”, followed by “Continuous dFAD tracking” and “dFAD recovery” (Table 20).

TABLE 20 Q7. TO MINIMIZE THE IMPACTS OF DFADS, THE MANAGEMENT OF FADS COULD BE IMPROVED BY

Management proposals	Number of responses
Reduce the number of FADs	7
Continuous FAD tracking	3
FAD recovery	3
Limit the area where dFADs can be used	2
New designs	2
Align FAD deployment and recovery	1
Ban remote activation and deactivation (RFMO level)	1
Full FAD identification (not just buoy)	1
Improve FAD data	1
Incentives to prevent dFAD losses	1
Installing AIS (track FAD owners)	1
Limit the time while can be used	1
Marking system independent of buoys	1
New materials	1
Promotion of best practices in management plans	1
Spatio-temporal management	1

8.4.9 Q8. In general, to minimize the impacts of dFADs, the "best thing to do" would be to?

There was less agreement between experts on this question, with "Reduce the number of dFAD" as the main recommendation followed by "Polluter pay principle", "Ban dFAD fishing" and "use of biodegradable materials" (Table 21).

TABLE 21 IN GENERAL, TO MINIMIZE THE IMPACTS OF DFADS, THE "BEST THING TO DO" WOULD BE TO?

Key ways to reduce impact	Number of responses
Reduce the number of FADs	3
Apply polluter pay principle	2
Free schooling tuna fisheries (no FAD use)	2
Use of biodegradable materials	2
Better designs	1
Develop effective management measures	1
dFAD management enforcement	1
dFAD management plan minimize loss and damage	1
Identification of the complete FAD	1
Limit the tail length	1
More intelligent and efficient deployment strategies	1
Recovery program	1
Reduce the number of FADs (RFMO)	1
Use of remotely piloted (with solar panels) FADs	1

9. POLICY ON THE RECOVERY OF LOST / DERELICT DFADS

Authors: Maitane Grande, Maria C. Uyarra, Iker Zudaire and Josu Santiago

9.1 Introduction

Due to the lack of direct reference in the literature to recovery of lost/derelict dFAD in IOTC policy, a more comprehensive review was conducted covering multiple factors affecting the use of dFADs and the implications of lost and abandoned dFADs

9.2 Fishing Companies

In November 2014, the companies ANABAC and OPAGAC-AGAC agreed that all vessels operating in the Indian Ocean should freeze and not increase the number of dFADs used. According to the voluntary agreement, the total number of dFADs corresponded to the quantity of operational beacons[2] they could have at any one time, which was set at a maximum of 550. The agreement established that the verification of the volume of the operational instrumented buoys would be carried out by AZTI and for this purpose the daily GPS positions were used among other high-resolution data.

9.3 IOTC

Since 2015, IOTC has adopted management measures to reduce the number of operational buoys.

IOTC adopted:

- Resolution 15-08: established an operational buoy limit of 550 and yearly purchase limit of 1,100.
- Resolution 16-01: reduced the number of operational buoys at any one time to 425 with an annual purchase limit of 850.
- Resolution 19-02: the number of operational buoys at any time per vessel was set at 300 and the maximum number of purchases to 500. The buoys must be activated on board the tuna fishing vessel or associated tender. In addition, this resolution includes measures limiting the number of instrument buoys (equivalent to the total number of buoys in stock and operational) per vessel at any time to 500 buoys. Also, the registration of the instrument buoys on board is required before and after each fishing trip (Res19-02, paragraph 7). A reactivation of a buoy will only be possible once it has passed through the port (Res19-02, paragraph 8).

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[2] Any instrumented buoy, previously activated, switched on and deployed at sea on a drifting FAD or log, which transmit position and any other available information such as eco-sounder estimates (IOTC Res 19/02).

IOTC Reg 23/02 has not been taken into account in this summary.

9.4 RFMOs

Considering potential impacts on the pelagic and coastal habitats and sensitive species interacting with the purse seine fishery, RFMOs have adopted measures to progressively replace the entangling material in FAD construction by non-entangling and biodegradable material (Table 22).

- IOTC: Res 15/08[3]: the FAD must be constructed of non-mesh material which will be gradually incorporated from 2014. Res. 19/02, requires that non-entangling FAD construction guidelines be fully implemented by January 1, 2020. In addition, to reduce the potential marine debris generated by FADs, from 2022 CPCs should encourage their flag vessels to use biodegradable materials in FAD construction. Vessels should also remove from the water and dispose in-port all FADs not meeting the standard.
- ICCAT. Rec. 19-02 includes provisions regarding FAD construction, bearing in mind their potential impacts on both pelagic and coastal habitats, and ETP species. Among those provisions, Rec. 19-02 includes mitigation measures such as the use of non-entangling FADs and biodegradable materials for its construction. The use of non-entangling raft and subsurface structures is intended to reduce the risk of entanglement of sharks, sea turtles and any other species. The principles set in Annex 5 of Rec. 19-02 are shown in Table 12.

[3] https://www.iotc.org/cmm/resolution-1508-procedures-fads-management-plan-including-limitation-number-fads-more-detailed

TABLE 22 MAIN RESOLUTIONS INCLUDING FAD CONSTRUCTION GUIDELINES IN THE FOUR TUNA RFMOS ADOPTED IN THE LAST 5 YEARS, REGARDING NON-ENTANGLING AND BIODEGRADABLE MATERIAL.

RFMO	Resolution(s)	Non-entangling material	Biodegradable FADs	FAD recovery requirements
IOTC	Res. 15-08 Res. 17-08 Res. 18-08 Res. 19-02	From 2014 vessels should progressively use in FAD construction non-entangling designs and materials, which should be fully implemented by 2020: • The surface structure of the FAD shall not be covered, or only covered with non-meshed material • If a sub-surface component is used, it shall not be made from netting but from non-meshed materials such as ropes or canvas sheets.	To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials in FAD construction should be promoted. CPCs shall encourage their flag vessels to use biodegradable FADs, except for materials used for the instrumented buoys, by their flag vessel from 1 January 2022.	From 1 January 2022, encourage their flag vessels to remove from the water, retain onboard and only dispose of in port, all traditional FADs encountered The Commission shall establish a DFAD tracking and recovery policy at its annual session in 2021, on the basis of recommendations from the ad-hoc FAD working group

ICCAT	REC. 14-01 REC. 15-01 REC. 16-01 REC. 19-02 REC. 21-01	The surface structure of the FAD should not be covered, or only covered with non-meshed material. If a sub-surface component is used, it should not be made from netting but from non-meshed materials such as ropes or canvas sheets.	To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials (such as hessian canvas, hemp ropes, etc.) for drifting FADs should be promoted. Endeavor that as of January 2021 all FADs deployed are non-entangling, and constructed from biodegradable materials, including non-plastics, except for materials used in the construction of FAD tracking buoys	
IATTC	C-16-01 C-18-05 C-17-02 C-19-01 C-20-06 C-21-04	By 2019 the floating or raft part (flat or rolled structure) of the FAD can be covered or not. If it is covered with mesh net, it must have a stretched mesh size less than 7 cm and the mesh net must be well wrapped around the whole raft so that there is no loose netting hanging below the FAD when it is deployed. 2. The design of the underwater or hanging part (tail) of the FAD should avoid the use of mesh net. If mesh net is used, it must be tied as tightly as practicable in the form of sausages or have a stretched mesh size less than 7 cm in a panel with weight at the end.	To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials (such as hessian canvas, hemp ropes, etc.) for drifting FADs should be promoted	- Recover within 15 days prior to the start of the closure period a number of FADs equal to the number of FADs set upon during that same period.

WCPFC	CMM-18-01 CMM-20-01	From 2020, CCMs shall ensure that the design and construction of any FAD to be deployed in, or that drifts into, the WCPFC Convention Area shall comply with the following specifications: • The floating or raft part (flat or rolled structure) of the FAD can be covered or not. To the extent possible the use of mesh net should be avoided. If the FAD is covered with mesh net, it must have a stretched mesh size less than 7 cm (2.5 inches) and the mesh net must be well wrapped around the whole raft so that there is no netting hanging below the FAD when it is deployed. • The design of the underwater or hanging part (tail) of the FAD should avoid the use o mesh net. If mesh net is used, it must have a stretched mesh size of less than 7 cm (2.5 inches) or tied tightly in bundles or “sausages” with enough weight at the end to keep the netting taut down in the water column. Alternatively, a single weighted panel (less than 7 cm (2.5 inches) stretched mesh size net or solid sheet such as canvas or nylon) can be used.	To reduce the amount of synthetic marine debris, the use of natural or biodegradable materials for FADs should be promoted. The use of non-plastic and biodegradable materials in the construction of FADs is encouraged.	

- They were first adopted in 2015 by 14-01 and then modified. By 2021, CPCs in the Atlantic Ocean shall endeavor to ensure that all FADs deployed are non-entangling and constructed from biodegradable materials, including non-plastics, apart from materials used in the construction of FAD tracking buoys (Rec. 19-02, p. 40). Contrary to what is stated in measures of other RFMOs, in ICCAT the definition of the entangling material does not refer to the presence of meshed materials or mesh size. In 2022, with the adoption of the Rec-21-01 the validity of the measures is extended to 2025.
- IATTC / WCPFC. If open mesh is used in FAD construction the mesh size is restricted to 7 cm and if it is above 7 cm it must always be well rolled in coils to minimize the entangling potential, both in the submerged and floating part. In the IATTC area, all FADs must meet the criteria established as of January 1, 2019 (C-18-05, p. 10) and continue in place during 2022 (C-21-04), while in the WCPFC reference is made to January 1, 2020 (CMM-2018-01).

9.5 Stakeholders

9.5.1 ISSF

For a FAD to be completely non-entangling, it must use no netting materials either in the surface structure (raft) or the submerged structure. Lower entanglement Risk FADs are those using netting but built to minimize entanglement: use only small mesh netting (< 7 cm stretched mesh) or any mesh size if tightly tied into sausage-like bundles. Non-entangling and biodegradable FADs are constructed with any netting and natural materials that degrade without causing impact on the ecosystem.

ISSF adopted conservation measures for the use of lower entanglement risk or non-entangling FADs and testing of biodegradable FADs (i.e. measures 3.5[4] and 3.7[5]).

- Since 2016 all vessels should avoid the use of entangling materials for FAD construction.
- By 2023 the companies should conduct trials with biodegradable FADs and/or recovery programs.
- By 2024 purse seiner vessel should only use and deploy non-entangling FADs regardless of the ocean in which they operate.

ISSF also published an updated guide for non-entangling FADs, classifying them according to the entanglement risk of each design based on the mesh size and configuration (ISSF, 2015, updated in 2019) (Table 22), where non-entangling FADs, included no netting materials, are expected to have no risk of causing entanglement (ISSF, 2015, 2019). In addition, other standards such as the UNE 195006:2016 for Tuna from Responsible Fishing include an obligation to use of non-entangling FADs,

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[4] https://www.iss-foundation.org/vessel-and-company-commitments/conservation-measures-and-auditing/our-conservation-measures/3-bycatch-mitigation/3-5-transactions-with-vessels-that-use-only-non-entangling-fads/

[5] https://www.iss-foundation.org/vessel-and-company-commitments/conservation-measures-and-auditing/our-conservation-measures/3-bycatch-mitigation/3-7-transactions-with-vessels-or-companies-with-vessel-based-fad-management-policies/

which defined a non-entangling FADs as having non-meshed materials, or, if it is present in open panels the mesh size should be <7 cm, or if >7cm it should be rolled in coils.

9.5.2 UNE 195006:2016 for Tuna from Responsible Fishing

It is agreed that the raft structure that keeps the device afloat must:

- Be free of elements (uncovered); or
- Be covered with a non-entangling material (such as hessian or thickly woven cloth); or
- Be covered with netting which mesh size is below 7 cm (2.5 inches),

All items hanging from the raft must be non-entangling. These items may be made of:

- Simple ropes, or
- Netting with a mesh size below 7 cm, or
- Netting with a mesh size of over 7 cm but tied into coils or "sausages", or
- Any other non-mesh material (such as canvas).

Submerged structures may present additional pieces and dangling attractors (e.g., palm leaves, netting panels), provided that their mesh size is below 7 cm.

9.5.3 Zudaire et al., 2018

A BIOFAD will be composed of non-netting from renewable lignocellulosic materials (i.e. plant dry matter) and/or bio-based biodegradable plastic compounds, prioritizing those materials that comply with international relevant standards or certification labels for plastic compost ability in marine, soil or industrial compost environments. In addition, the substances resulting from the degradation of these materials should not be toxic for the marine and coastal ecosystems or include heavy metals in their composition. This definition does not apply to electronic buoys attached to FADs to track them.

9.5.4 JWGFAD-02 - Meeting report

t-RFMOs should accelerate progress to reduce contributions of FADs to marine litter and mitigate negative impacts on coastal habitats and marine ecosystems, and on ETP species, such as use the of FADs without netting and those made with biodegradable materials, as well as mechanisms and incentives for recovering FADs.

9.5.5 Hampton et al., 2017

For a FAD to be completely non-entangling, it must use no netting materials either in the surface structure (raft) or the submerged structure. Some organizations also consider non -entangling FADs (NEFADs) to be those using netting but built to minimize entanglement such as using netting tied in bundles or using small size netting (<7 cm stretched mesh); these are sometimes called LERFADs (Lower Entanglement Risk FADs).

10. PILOT PROJECT: EMPIRICAL EVIDENCE ON THE NATURE AND EXTENT OF POTENTIAL DAMAGE TO CORALS RESULTING FROM INTERACTION WITH A DFAD.

Authors: Maria C. Uyarra, Iker Zudaire, Ekaitz Erauskin, Alex Salgado, Robert Bullock, Henriette Grimmel and Josu Santiago

10.1 Introduction

The second phase of the overall research comprised a pilot project designed to assess the potential impact of derelict dFADs on reef communities; and to test an approach that may be used for large-scale studies.

10.2 Approach

The approach defined to conduct the pilot project comprised:

- Definition of a location for the field research in accordance with needs and the agreement of the relevant authorities.
- A "pre-survey" allowing identification of the location of derelict dFADs.
- A first phase to complete research.
- A second phase to follow – up and confirm results.

10.3 Location of fieldwork

The selection of the study area was determined by six main criteria i.e.

- Be in the proximity of tuna fisheries operating grounds.
- Be an area where presence of derelict dFADs could be guaranteed.
- Be an area where coral reef habitats would be available.
- Have diving infrastructure available.
- Be an area where external risks would be minimal.
- Have an NGO in the field that would be willing to collaborate and support the project.

To meet the first three criteria, results as described above were used with potential hotspots for beached dFADs being identified. From the different potential study sites (Somalia, Comoros, Coco Islands, Maldives, Seychelles, Yemen, Tanzania and Kenya) Seychelles was selected as:

- It is the country in the WIO area with the highest number of buoys deployed in the EEZ;
- It is one of the top five countries with the highest number of beached FADs by 100 km of coast: and
- Coral reefs are present in the area.

Furthermore, Seychelles offers a diving and health infrastructure, while external risks are limited.

This led to an agreement with Save Our Seas Foundation (SOSF) with the objective of completing fieldwork on the islands of D'Arros and St Joseph. These are part of the Amirante Islands within the Outer coralline Islands of Seychelles.

The anthropogenic pressures on the two atolls are limited. It is privately owned and have recently been declared (March 2020) as Zone 1 (no extractive use), with St Joseph Atoll part of a larger Zone 2 (conditional use). These two conditions limit fishing activity, habitat destruction, pollution (including eutrophication), ensuring that the majority of most common human pressures are almost inexistent. Although, the area has not suffered from repeated mass coral bleaching events, in 2016, there was an episode of mass bleaching by which, more than 40% hard corals were lost; corals recovered rapidly to pre-bleaching levels. Although coral diseases in the area have never been assessed, recent observations suggest that white patch diseases outbreaks are affecting Porites.

D´Arros Island and Saint Joseph Atoll (16 islands) are separated by a one kilometre long and 70 m deep channel and are considered as a single ecological unit. Saint Joseph Atoll islands are in shallow waters, encircling a central lagoon, which is 3.5 km long and 3 m deep on average. The lagoon is largely affected by the tides, limiting the access to the inside part of the lagoon to two hours before and after the high tides. Monsoon winds can also limit the access to the lagoon, as they raise the wave height, making the channel difficult to cross. Temperatures range between 25ºC and 35ºC, with most precipitation concentrated in December to March. The sea surface temperature is only a few degrees less, ranging from 24ºC in winter to 31ºC in summer.

As such, this location was ideal to assess the potential impacts of dFADs on coral reefs, to design a methodology to study the impacts of dFADs on coral reefs and provide scientific evidence on the nature and magnitude of those impacts.

10.4 Pre-survey

To identify dFADs that could have drifted towards d´Arros Island and Saint Joseph Atoll, ANABAC (ECHEBASTAR, PEVASA and ATUNSA), SAPMER and CFTO were requested to provide data on activated dFAD buoys within a buffer area of 1º square grid around the D'Arros island for the period 2015-2021. A total of 13 dFADs were localized within these areas, of which four were within the area of D´Arros Island and Saint Joseph Atoll (Table 23).

The dFAD coordinates were provided to SOSF, whose scientists searched for them and for additional dFADs in the area. This led to three valid dFADs being identified prior to fieldwork, located within the lagoon (two on patch reef areas, and one on seagrass). An additional dFAD was identified by the SOSF team on the reef, which was removed, but marked, prior to fieldwork. Non-valid dFADs were considered when their specific locations limited the research (e.g., too deep, buried in sand). This resulted in five non-valid dFADs being identified on D´Arros beaches, one underwater around D´Arros island, and an additional dFAD in the lagoon that was buried in sand. It was noted by the SOSF team that additional dFADs are beached in Saint Joseph Atoll; these could not be visited due to bad weather conditions.

TABLE 23: DFADS IDENTIFIED THROUGH THE BUOY GPS COORDINATES PROVIDED BY FISHING COMPANIES

Last date	latitude	longitude
29/01/2017	-5.41132	53.29782
31/01/2017	-5.4211	53.2976
22/12/2017	-5.4537	53.2153
01/05/2018	-5.4542	53.3397
07/07/2018	-5.4908	53.2593
23/02/2020	-5.493	53.301
25/09/2020	-5.43303	53.28773
03/10/2020	-5.43087	53.29788
17/01/2021	-5.4102	53.3043
21/02/2021	-5.4453	53.3408
21/02/2021	-5.4562	53.3387
04/03/2021	-5.4857	53.3115
08/03/2021	-5.4455	53.329
20/08/2021	-5.4427	53.361
09/10/2021	-5.4933	53.2703

10.5 Phase 1

10.5.1 Design and Implementation

The first phase was designed to:

- Assess the potential impact on corals and fish communities that may result from the tension generated by waves/currents/winds between the floating part and the snagged tail of a derelict dFAD.
- Analyse changes in live and dead coral cover, scaring, and breakage by comparing “dFAD” versus “control” sites.
- Explore differences on richness and abundance of fish between “dFAD” sites and “control” sites.

The first phase of the fieldwork was scheduled to start in March 2022. However, due to different factors this was postponed until May 10 – 27, 2022.

The pilot project was conducted using four existing derelict dFADs in conjunction with parallel control sites with a similar coral community located approximately 100 m from each “dFAD” site. Since each dFAD beached at different depths, paired comparisons between “dFAD” *versus* “control” (which were at same depth) were carried out.

The following points are to be noted:

- During fieldwork the characteristic of the dFAD (design, material & mesh size) were recorded.
- At each dFAD and control site, underwater surveys were conducted to study corals and fish communities.
- Despite different methodologies were designed prior to fieldwork, this was adapted to the real conditions once *in situ.*
- The initial work plan comprised:

  A first survey to:

  - Assess coral conditions using both transects and photo quadrats, to allow identifying the performance of both methodologies for this type of studies. Both methodologies were applied across all dFAD sites and control sites.
  - Record within quadrats and transects, benthic cover (i.e., live coral, dead coral, rubble, rock, sand, algae, other); whenever possible, live coral identification was carried out to genera/species level.
  - Define the best methodology to study potential impacts of dFADs and have preliminary results of what the impacts of dFADs may be on coral reef communities.

  The second survey was to:

  - Focus on the fish communities.
  - According to conditions, it was decided to study stationary visual surveys.
  - Abundance and species of fish were be recorded *in situ* both at dFAD and control sites.
  - Data recording was carried out *in situ,* but complemented with underwater camera recordings to facilitate later identification of some species of fish.

10.5.2 Approach

<u>dFAD Characterisation</u>

To characterise the dFADs, an excel template was designed based on one currently being used by onboard fisheries observers. The content and structure of the existing template was maintained to the maximum extent, so the information from this research is compatible with that from other projects. However, some additional fields of special relevance to this research were added.

The template was structured in three parts:

General information.

This section aims at coding and making the dFAD unique. The following information was collated.

- FAD number: correlative numbers are assigned to each dFAD found.
- FAD code: the identification number of the GPS code of the buoy.
- Type of FAD: to be selected between "cage" or "tail" shape dFAD structures.
- Observer: name of the person that completes the excel template
- Date: the dates when the specific dFAD was sighted.
- Latitude: to be included in decimal degree format.
- Longitude: to be included in decimal degree format
- Habitat type: a drop-down menu is available to select the most dominant habitat type where the dFADs are found
- Depth: this field is available to enter the depth (in metres) at which the dFAD contacts the substrate.

dFAD structure

This part of the excel file aims are recording specific information on the different parts of the dFAD, which mainly considers four parts:

- **Floating part**: this includes the different components from the buoy to the raft (excluded). For these elements the following information is recorded:
    - Length: the length of the rope that attaches the buoy to the raft.
    - Presence of the following elements: beacon, rope, sausage net, floating devices (i.e., buoys, floating sausages, other).
    - Number of floating elements (e.g., number of floats) of each type.
- **Raft**: this section describes the different components and materials available.
    - Raft description: the material of the raft (i.e., bamboo canes, metallic, plastic, other).
    - Superior coverage: is the raft covered, and what type of cover (e.g., net, canvas). In the case of being covered with net, the mesh size should also be measured.
    - Inferior coverage: same information as that from the superior coverage is recorded.
    - dFAD sank: where the raft is laying on the substrate, information on the type of substrate, apparent damage and entanglements with organisms should be described.
- **Subsurface structure**: covers the dFAD elements hanging from the raft, excluding the weight.
    - Subsurface structure availability

  - Length: the length from the raft to the weight.
  - Type of subsurface structure: if this part is available, it will need to be indicated whether it is a sausage net, an open net, a single net pieces, or a rope.
  - Net size: in the case that the subsurface structure is made with a net, the mesh size is to be measured.
  - Subsurface structure laying on the substrate: when that is the case, information on the type of substrate, apparent damage and entanglements with organisms should be recorded.
  - Presence of attractors: when available attractors, the number of bag pieces, colour belts or other materials is to be recorded.
  - Biodegradable materials: when biodegradable materials are recognized within this part of the dFAD, this should be noted indicating which part is biodegradable.
- **Weight**: this section is to describe the type of weight that is used in the dFAD:
  - Weight availability
  - Type: this field is to describe the type of weight used (e.g., piece of motor, iron chain, etc.).
  - Weight laying on the substrate: when that is the case, information on the type of substrate, apparent damage and entanglements with organisms should be recorded.
  - Other pieces: dFADs often include other elements such as pieces of wood, corks, etc. This section considers whether elements have been attached to the dFAD.
- **Observations**: finally, there is a field for including any relevant information that may be considered of interest (environment, additional information on the dFAD, situation in which you found the dFAD, entanglements, etc.).

Benthic and fish survey experimental design

The impacts of dFADs on coral reefs are poorly studied. Scientific research focuses on defining areas were dFADs drift, accumulate and beach and on describing entanglements with marine life (e.g., with turtles). The present study aimed at providing a standard methodology for the characterisation of the potential impacts of dFADs on coral and fish communities. Several methodologies were tested, from which those selected are described below. These methodologies are suitable to seagrass, patch reefs and bank reef habitats, so allowing standardization of future studies aimed at assessing the impacts of dFADs on reef habitats. This protocol should be adapted to steep reef habitats and reef cliffs as it could lead to “yo-yo” diving, which would compromise the diving security of the research.

Coral reef benthic surveys

Coral reef benthic underwater surveys were conducted by three divers at dFAD and control sites. The control site was selected at a minimum distance of 60m from the dFAD site, in an area of same habitat type and characteristics (e.g., depth). It would be recommendable to increase the minimum distance from the dFAD to 150m, especially if the habitat area is flat, where the dFAD may move with the current in different directions.

Once the dFAD and/or the control site were identified, the following steps were carried out to complete the coral reef benthic survey:

- Step 1. Record the GPS coordinates.
- Step 2. Mark the dFAD/control site using a marking buoy in the centre of the study site. The following cases were possible:
    - dFAD available and raft is floating: the marking would be located at the point where the weight or the furthest extreme of the subsurface structure (when weight not available) would get in contact with the substrate.
    - dFAD available and surface structure laying on the substrate: the marking would be in the middle of the surface structure. This would be normally facilitated by the presence of ropes.
    - dFAD not present due to removal to avoid potential damage on the reef: in case of dFAD removal, it was suggested to mark the point where the dFAD contacted the reef, so this point can be used for marking the central point for the surveys.
    - Control site: at control sites, the buoy mark would be placed in a similar habitat, substrate type and depth to that of its corresponding dFAD site.
- Step 3. Note the general characteristics of the area, including habitat type, dominating species, depth, visibility, and any interesting feature of the location.
- Step 4. Line intercept transect. To implement this methodology, it was determined that 10 m transects was the adequate length size. Due to the expected trajectory of the dFAD it was considered that rather than placing parallel transects at a continuous depth, they should be placed considering how to best capture any potential damage. To do so, a first transect was laid down starting from the centre of the study site, following exactly the main trajectory of the dFAD. This trajectory was determined either by the presence of the dFAD tail or visible damage. The direction of this first transect would be noted. Then, three additional 10m transect would be laid down following a 90º, 180º and 270º from the first transect line. Thus, in total, four 10m transects were laid down at each study site (dFAD and control), starting at the centre using one single transect line that would be moved after finishing each

transect survey[6]. For each transect, the benthic type (e.g. sand, rubble, dead coral, algae, seagrass, sponges, soft coral, hard coral, other organisms, etc.) available immediately under the transect line as well as the length of the intercept point (the point where the substrate changes) would be noted. When transferring this information into an excel file, these data could be transformed into percentage cover of each substrate type. For hard coral, whenever possible, identification was carried out to the species level. To support *in situ* identification, the transects were also filmed using Go Pro Hero. This allowed contrasting any doubt that may have been encountered during underwater coral identification.

- Step 5. Photo quadrat methodology. In addition to the line intercept method, photo quadrats were used to assess the extent of the potential damage. Quadrats of 50cm x 50cm were placed along the transect line (leaving the transect line always at the same side of the quadrat) at 0m, 2,5m, 5m, 7,5m and 10m fix distances. Photos each quadrat were taken using Olympus T6 in an underwater housing. These photos were later processed in the computer to calculate the percentage cover of the different substrate types. After applying both the line intercept method and the photo quadrat method, the transect lines would be removed.
- Step 6. Damaged area: To estimate the overall extent of the damage, and after visual observation, the furthest points from the marking buoy where damage was visible, were localized. Using transect lines, the width and length would be measured laying down the transect lines in such way that they would pass over the central point. The damaged area (in m2) would be calculated.
- Step 7. Turned over colony count. Within the affected area (and corresponding area in the control sites), a survey would be carried out counting the number of “turned over colonies”; that is, coral colonies that have been completely detached from the substrate. The colony count would be carried out using the transect lines deployed under Step 6, to be used as a reference. The three divers would swim first along one side of the transect line that measured the length of the area and return along the other side. During this swim, each diver would focus on a specific size range of broken colonies: 0-25 cm, 26-50 cm, and > 50 cm. To avoid biased between divers in size estimates, the divers will bring with themselves a reference (e.g., small rope with the specific length, or marks on the slate). After this work, the transect lines would be removed.

[6] Since this method implies diving changing depths, in order to avoid any risk the following recommendations are provided. This method is only recommended for dFADs located at maximum depths of 20m. In all cases it is recommended to start the survey following the first transect, which is the one following the trajectory of the dFAD and normally the transect that reaches the deepest points. In the case of significant slope, the transect located at 180º could be skipped to avoid a ”yoyo” dive profile. Furthermore, this transect is expected to present the least damage (trajectory has stopped). This protocol should be modified and adapted to deep dFADs and reef cliff habitats.

Fish surveys

Fish surveys were carried out both at dFADs and control sites using as reference the marking buoys. After visual observation of different dFADs, it was considered that neither transect lines nor cylinder fish counts were adequate methods for this type of assessment. Instead, it was judged more adequate to carry out static fish counts. For this fish counts the following steps were taken:

- Step 1. Determine the correct distance for the survey. The underwater visibility determines largely the distance at which the survey can be carried out successfully. In the case of the lagoon (i.e., patch reef and seagrass sites), where the visibility was very poor, the adequate distance to maintain with the reference point (the buoy mark) was 2.5m. In contrast, at reef sites, where the visibility was much better, the adequate distance for the survey was established at 5m. Thus, after having marked the study site with a line and a buoy, the divers would place themselves at the specific distances and wait 3-5 minutes for fish to re-establish their normal activity.
- Step 2. Fish counts. For 3 minutes one diver would count and identify all the fish living at or passing between the diver and the reference point, considering a visual angle that cover 2.5m each side of the reference point. Both swimming and benthic fish were noted. After this, the divers would get close to the substrate for another 150 seconds to count and identify those fish leaving in the crevices/dFAD within this same area. This procedure was repeated from the opposite side of the buoy mark. Thus, the total time counting and identifying fish would be 10 minutes in total, plus additional time for fish to re-establish their normal activity after diver movement in the area at the start of the survey and after changing side. An additional diver would film the fish activity using a GoPro Hero 8 as means to be able to cross check any doubt that may emerge during the fish identification[7].
- Step 3. Abundance and species richness were recorded on an excel file for analysis.

Impact assessment of dFADs on benthic and fish communities

The impact assessment of dFADs on coral reefs was carried out using the information from four dFADs, and by comparing coral and fish composition between dFAD sites and their corresponding control sites. Due to the high variability in i) type of habitat where the dFADs were found (i.e., one on seagrass, two in patch reefs, and one on the reef) and ii) survey conditions (the entry to the lagoon was determined by the tides, and therefore, the time of survey which could potentially affect the fish abundance and richness could not be controlled) and the limited number of dFADs (N=4), the outputs of this study cannot be integrated and therefore, used to make conclusions nor to extrapolate. Thus, the outputs are presented independently for each dFAD (and its corresponding control site).

[7] Fish identification was mostly completed at the species level. However, in the seagrass area identification was poor due to lack of guides for juveniles, which represent most of the fish present in that habitat type.

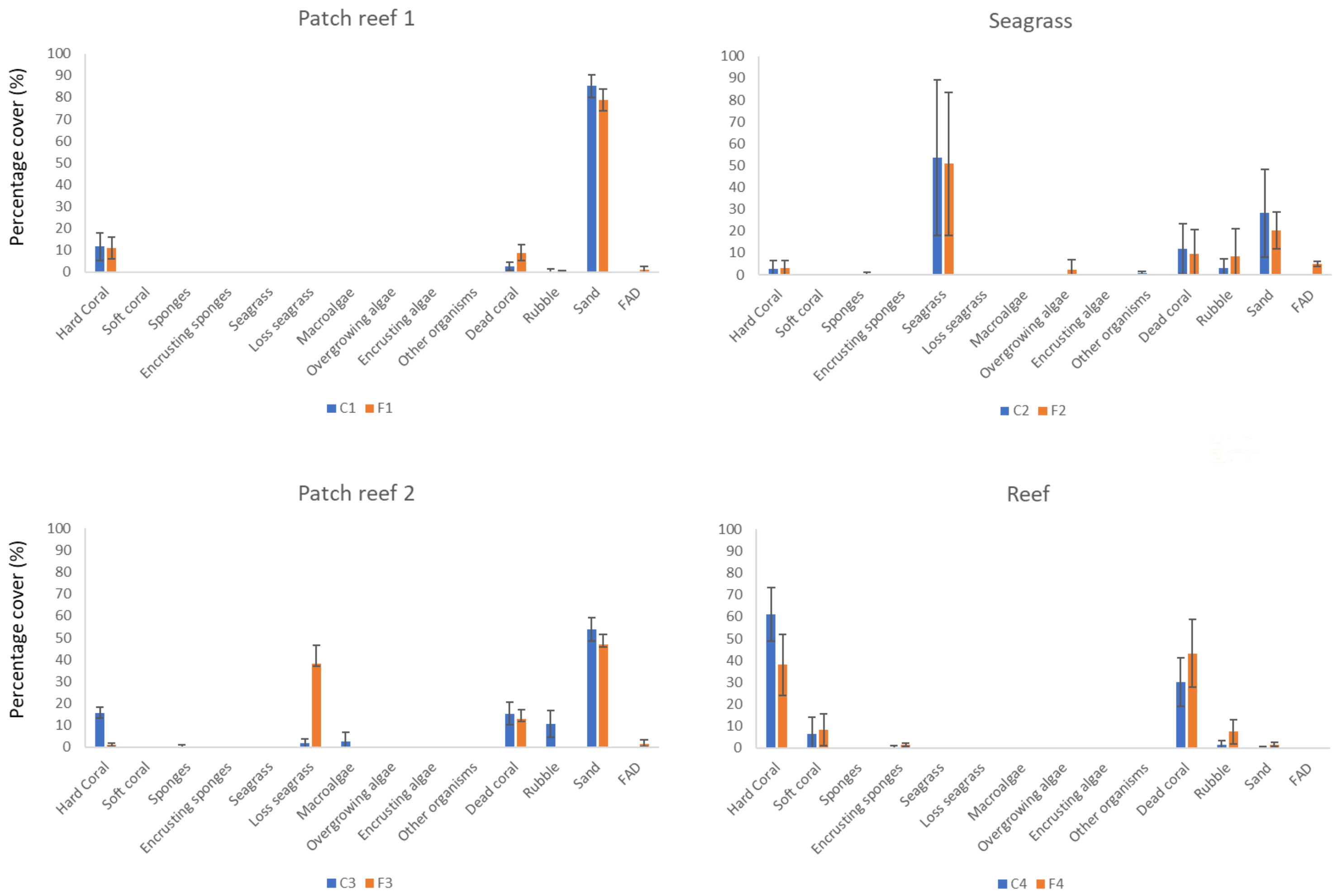

Figure 12: Benthic composition (measured in percentage cover) obtained through the implementation of the line intercept method. Blue bars correspond to values for the control sites, and orange bars are values for the dFAD site. Error bars represent the Standard error. *Loss seagrass refers to floating seagrass that is detached from the substrate.

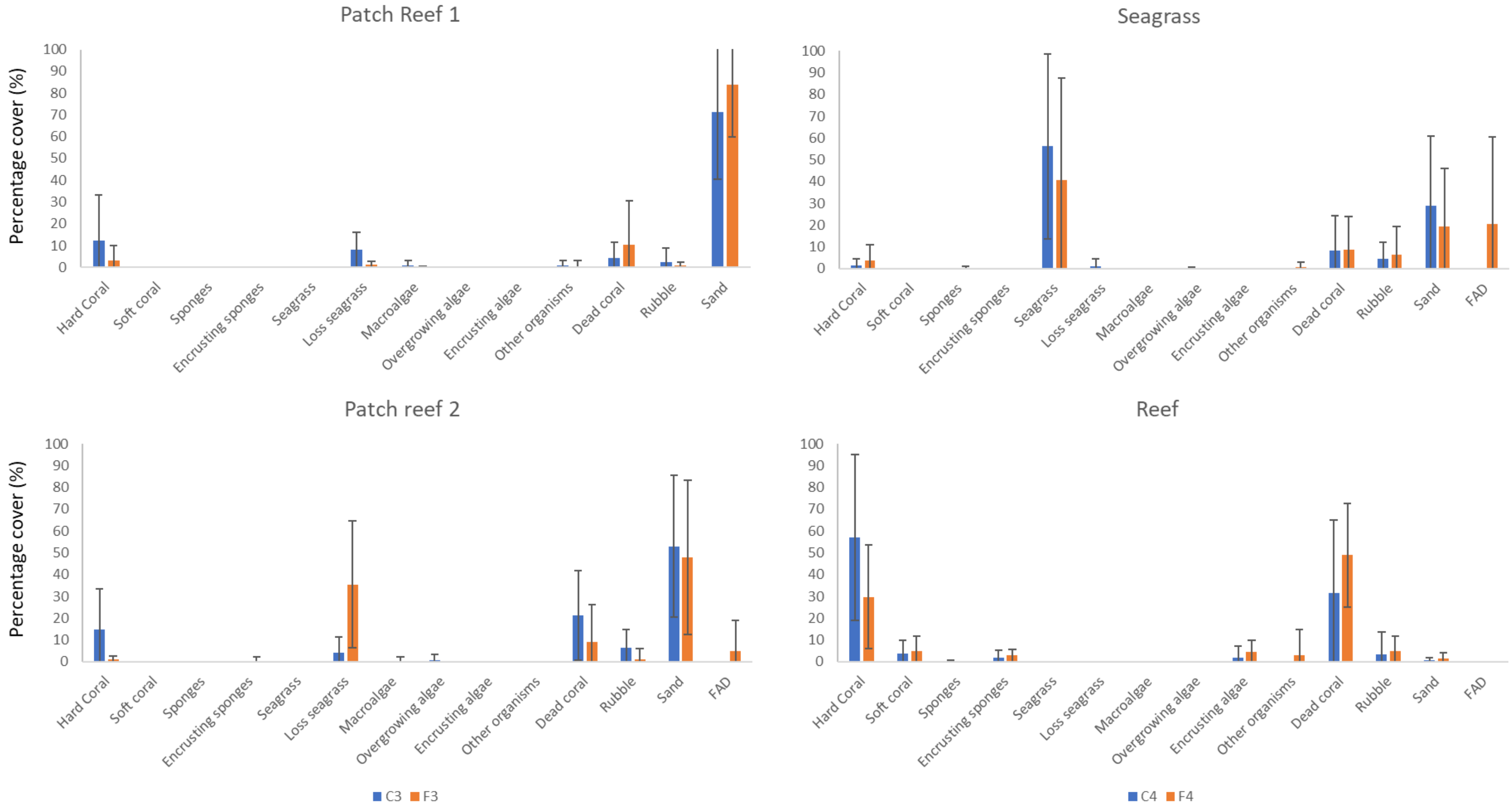

FIGURE 13: BENTHIC COMPOSITION (MEASURED IN PERCENTAGE COVER) OBTAINED THROUGH THE IMPLEMENTATION OF THE PHOTO QUADRAT METHOD. BLUE BARS CORRESPOND TO VALUES FOR THE CONTROL SITES, AND ORANGE BARS ARE VALUES FOR THE DFAD SITE. ERROR BARS REPRESENT THE STANDARD ERROR. *LOSS SEAGRASS REFERS TO FLOATING SEAGRASS THAT IS DETACHED FROM THE SUBSTRATE.

10.5.3 Results

Coral reef benthic surveys

As indicated in the previous section, the impact of dFADs on coral reefs was investigated using two different methodologies.

The outputs obtained from the implementation of both methodologies are presented in Figure 12 (line intercept method) and Figure 13 (photo quadrat method). Overall, both figures highlight the diversity of habitats in which the study was carried out. While the dominant benthic component at the patch reef was sand (both in dFAD and control sites), at the seagrass habitat, it was the seagrass itself, and on the reef site, the dominant benthic component was hard coral.

From all benthic components, generally high cover of hard and soft coral, seagrass, coralline algae, sponges, indicate healthy habitats. Opposite, high amounts of dead coral, rubble, overgrowing algae, are associated with poorer quality habitats.

In this sense, at each site, it is possible to observe in both figures, that there was higher amount of hard coral at control than at dFAD sites, except for the seagrass dFAD site, where the proportion of seagrass was higher at the control site than at its corresponding dFAD site. The cover of dead coral or rubble did not always follow the expected pattern; higher cover at dFAD sites than a control sites.

Since the habitats in which the dFADs were found were so different, it was not possible to combine the results to perform statistical analysis. Therefore, the outputs obtained should be considered as observations rather than concluding results.

In addition, within each site, there was high variance between the replicates (either transects or photos), which can be observed in the large standard error bars.

Despite the similarities in the results found with the two methodologies, those obtained through the photo quadrat method showed higher variance. This is explained by the fact that in the line intercept method, the transect functions as a unit, integrating all the information from the whole transect into one single value per benthic component. However, with the photo quadrats, in this structured designed, it was possible that some of the photos would be in an area with high coral cover, and other photos on sand. Since each photo is a replicate, the variability increases greatly.

In the design of the experiment, it was hypothesized that placing a transect over the supposed trajectory would capture the “maximum” damage generated by the dFAD, and that, by contrasting the benthic component coverage of this transect with one located completely opposite, differences could be observed. For example, one would expect lower coral cover at the dFAD site along the transect that followed the hypothetical dFAD trajectory than that at its opposite transect, or any of these two transects in the control site.

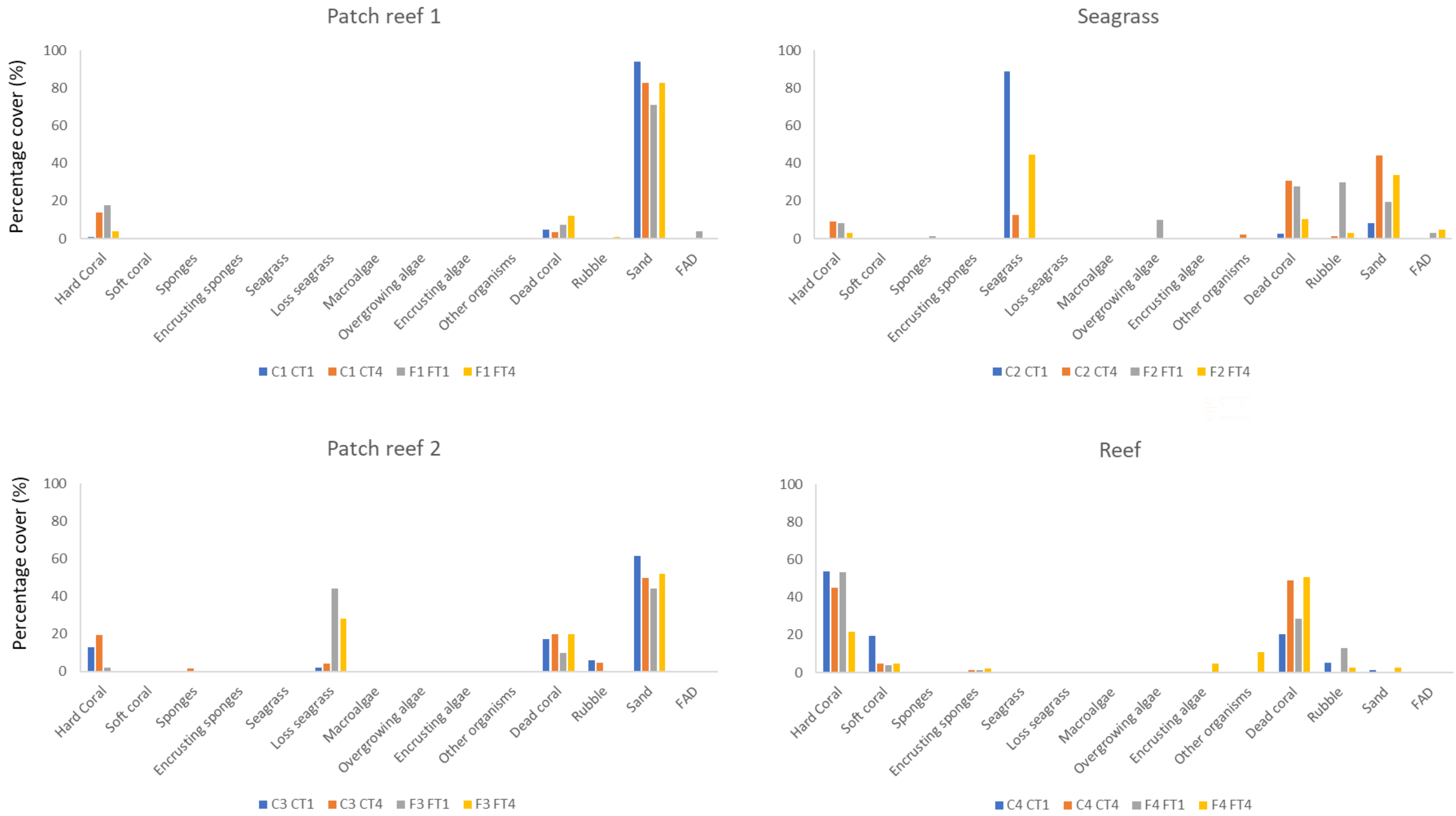

Figure 14: Benthic composition (measured in percentage cover) obtained for opposed transects (blue: control "dFAD hypothetical trajectory transect" – CT1; orange: control "opposed transect" - CT4; grey: dFAD "dFAD trajectory transect" - FT1; yellow: dFAD "opposed transect" - FT4) through the implementation of the line intercept method.

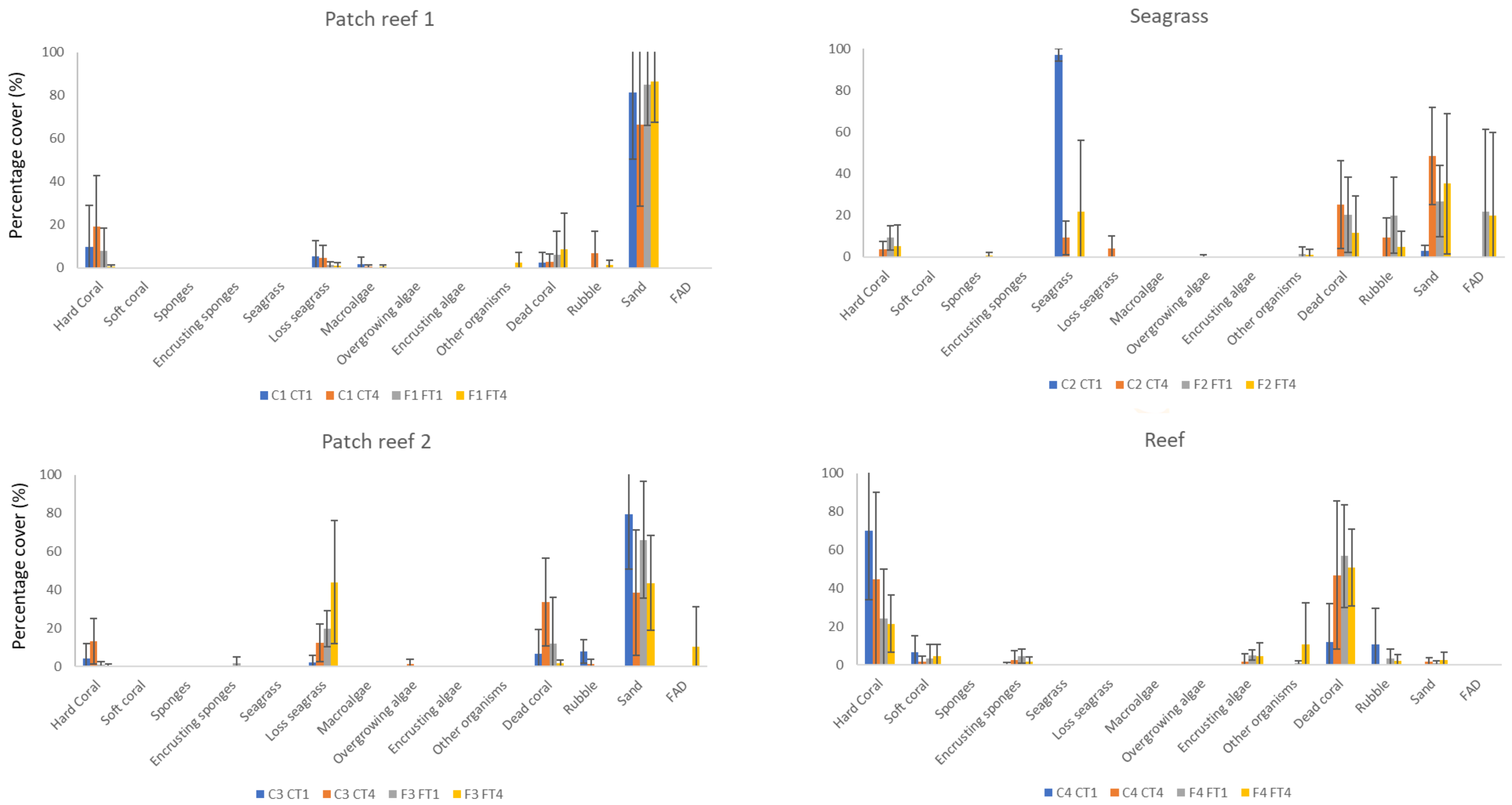

Figure 15: Benthic composition (measured in percentage cover) obtained for opposed transects (blue: control "dFAD hypothetical trajectory transect" – CT1; orange: control "opposed transect" - CT4; grey: dFAD "dFAD trajectory transect" - FT1; yellow: dFAD "opposed transect" - FT4) through the implementation of the photo quadrat method. Error bars represent the Standard Error.

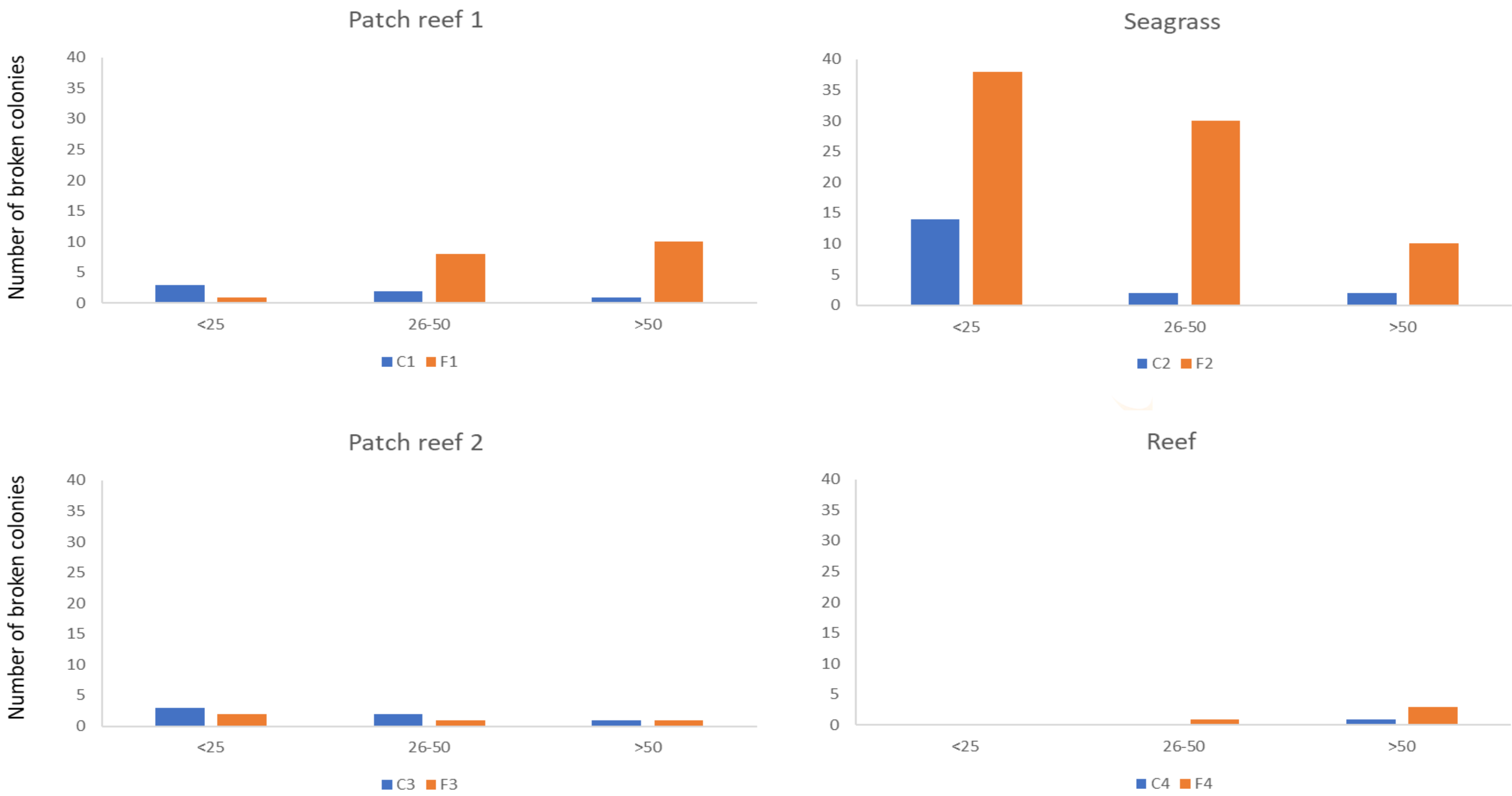

FIGURE 16: NUMBER OF BROKEN COLONIES COUNTED AT EACH SITE, SPLIT BY SIZE (< 25 CM; 26-50 CM; > 50 CM). BLUE BARS CORRESPOND TO THE NUMBER OF BROKEN COLONIES FOUND AT THE CONTROL SITE AND THE ORANGE BAR WITH THOSE IN THE DFAD SITE.

Figure 14 and Figure 15 do not show such a pattern. This does not imply that dFADs did not cause any damage. The most plausible explanation for not observing any pattern is again that these outputs are an artifact of the low sample size (i.e., one per habitat type). Furthermore, this work was designed for a reef with a slope, for which it is expected that once the dFAD would get entangled with the reef, it would not ascend, and therefore, would not cause damage to shallower reefs. However, all the dFADs explored were on flat areas, which facilitates the movement of the dFAD in all directions, and the impact could expand in any direction, being that captured by the other transects.

Finally, when looking at the number of broken colonies at each site, except for the patch reef 2, the number of broken/dead colonies was larger at dFAD sites than at their controls (Figure 16). Although these results could suggest significant damage derived from dFAD, the sample size is too small to make such conclusion. If "broken colony" count is to be included in future studies, such could be limited to those located directly under the transect, rather than on the entire area, as this was time consuming, an important limitation in underwater research.

The idea behind testing two methodologies was to identify which methodology reflected best what was observed *in situ.* At the level of benthic components composition, it can be concluded that both methodologies are suitable for this kind of study, as the outputs are similar.

The benefit of using photo quadrats is that it allows performing damage extent analysis more easily. Furthermore, taking photos to quadrats is easier than filming the transect line in case that either of those are needed for posterior identification of species.

The intercept transect method would be the preferred methodology for steep and cliff reefs since the quadrat is difficult to be placed. Furthermore, the standard error gets reduced, and underwater, reducing the equipment (e.g., not carrying the quadrat) is always a bonus. Under all circumstances it is recommended that, whenever possible, to carry out *in situ* identification, for which high coral identification expertise is required. Otherwise, both photo and video processing can be time consuming.

This study does not allow concluding whether the patterns observed on the benthic composition derive directly from the impact of dFAD. However, most importantly, this study has allowed making *in situ* observations of the behaviour of dFAD on coral reefs, identifying how the different parts of dFADs interact with the fish and benthic communities, which will be highly important to provide advice on alternative dFAD designs, materials, and management.

10.5.4 Fish surveys

The fish surveys carried out at each dFAD/control site turn into a unique value of fish abundance and fish species richness for each site. That is, there were no replicates and therefore, no error bars are provided. Since a major source of variability on fish abundance and fish species richness are the tide and the time of the day at which the surveys are carried out, and it was not possible to control for this variability in the field (i.e., the time of entry into the lagoon was dependent of many other factors, but especially wind and shifting tides), the outputs obtained should be looked at carefully and not lead to conclusions.

In total, 86 species of fish were detected (Annex A), of which 75 fish were associated to the level of species, and 11 were distinctively identified but not found in the reference guide. It is possible that this number could be higher. At the seagrass site, a high number of juvenile fish were found, and the identification of those fish was not possible due to the lack of reference guides.

Overall, the reef site was the habitat with the highest species richness (N = 33), and the seagrass the lowest (N = 10) (Figure 17). No pattern was found in the comparison dFAD *versus* control. Patch reef 1 and Reef had higher species richness at the control than at the dFAD (in absolute values), Patch reef 2 and Seagrass had higher species richness at the dFAD site than at their corresponding controls.

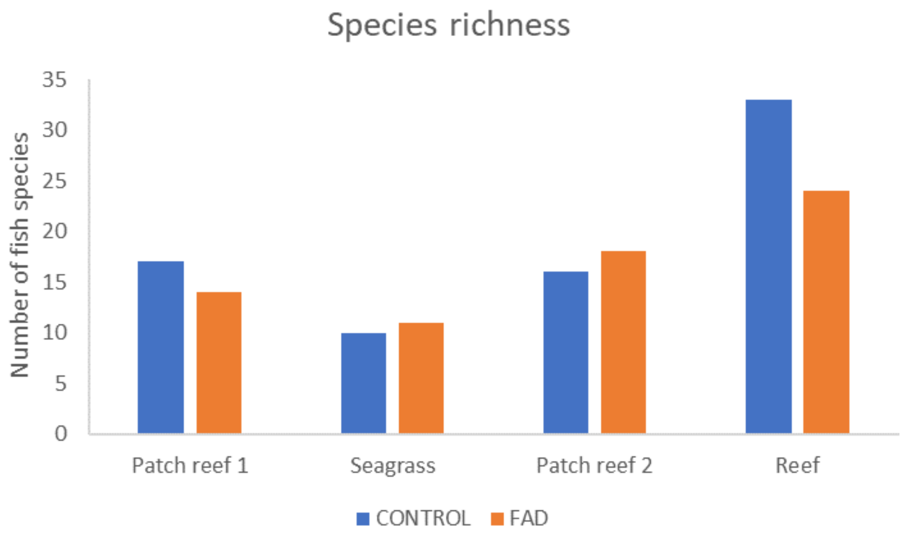

FIGURE 17: FISH SPECIES RICHNESS AT CONTROL (BLUE BARS) AND dFAD SITES (ORANGE BARS)

In the case of fish abundance, for all sites the abundance of fish was lower at the dFAD site than at its corresponding control site (Figure 18). The highest abundance of fish was available at the Seagrass site (N = 323), followed by that at the Reef site (N = 285). The lowest abundance was found at the dFAD site of Patch reef 2 (N = 90).

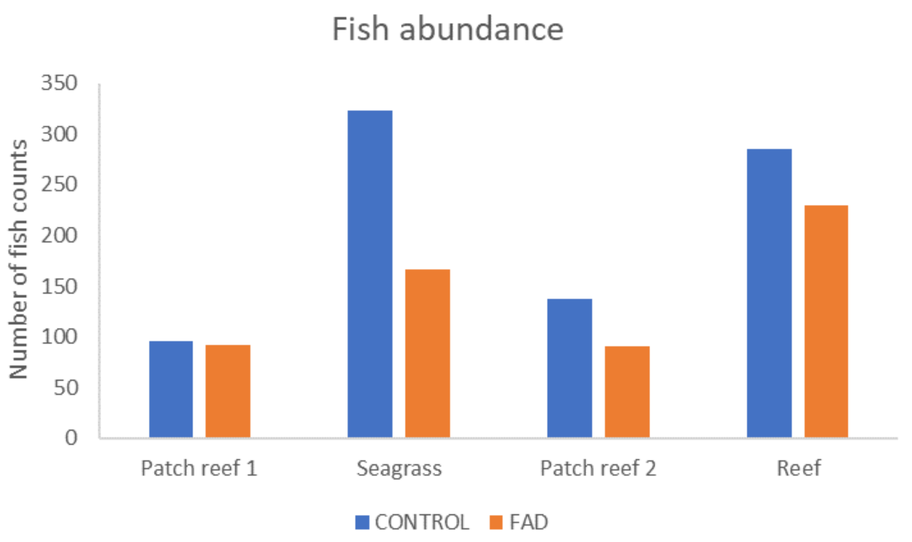

FIGURE 18: FISH ABUNDANCE AT CONTROL (BLUE BARS) AND dFAD SITES (ORANGE BARS)

It would be necessary to expand this experiment being consistent with the habitat type (i.e., reef sites), and time of day, to arrive at conclusions on the effect of dFADs on fish.

10.6 Fieldwork – Part 2

A second phase of the field survey was scheduled for December 2022. However, in November 2022, Seychellois Coast Guards removed all FADs found around the area of D´Arros during a dFAD removal programme. Thus, the second phase of the fieldwork was postponed. In 2023, a new dFAD search in the area determines whether it is possible to carry out phase 2. If so, this would use a single survey methodology, but only implemented if five or more dFADs are derelict in the study area. Following completion of any second phase, the tails and / or dFADs would be removed, with their destination recorded.

11. CONCLUSIONS & RECOMMENDATIONS

Authors: Iker Zudaire, Maria C. Uyarra and Josu Santiago

This study makes an important contribution to the understanding of the interaction of dFADs with coral reefs and identifying how any risk may be mitigated.

It indicates that while the impacts of derelict dFADs on coral communities is relatively minor compared to those from other threats, they may have local effects that can affect the resilience of corals facing major global threats, such as climate change and man-made pollution. Local negative effects from dFADs may be mitigated if certain measures are taken.

Various options for mitigation are identified in the document. The implementation of some of these measures, such as the removal of non-biodegradable material or the downsizing of dFADs, is the responsibility of individual companies to implement IOTC regulations, potentially pro-actively to display company commitment to improving its sustainability credentials. However, the implementation of other measures is not so straightforward.

This section highlights the main conclusions and recommendations of this study arising from the desk and fieldwork research.

11.1 Conclusions

11.1.1 Desk Research

- While WIO coral reefs represent 5.85% of the global total, as yet, there has been limited coral reef research in the area, with this ecosystem being poorly studied.
- The main threat affecting coral reefs in the WIO is climate change, which has been the main driver for coral reef research in the area.
- Of all local pressures, overfishing and ”bad” fishing practices are the ones that most highly affect the reefs.
- According to stakeholders “bad fishing practices” include the use of destructive fishing gears, inadequate governance and management, marine litter (including ALDFG), bycatch, the use of dFADs, oils spills, and anchoring, among others.

- Research into threats and risks to which coral reefs in the WIO are exposed does not specifically mention dFADs as a major driver. However, specific research refers to dFADs as a potential cause of damage.
- The literature suggests that the recovery of coral reefs from physical damage is slow and difficult, and the recovery of fish assemblages may even be more complex.
- The recovery of coral reefs depends on various factors, including environmental conditions, species specificities (e.g., growth rates, structure), co-occurring pressures, etc., making some species more vulnerable than others to dFADs interactions.
- Since it is essential for coral reefs to better cope with the impacts of climate change, the importance of managing local pressures as means to increase coral reefs´ resilience is significant.
- Existing policy is aligned with the need to manage local pressures; several regulations have been implemented on the fisheries sectors and good fishing practice guidance documents are available.
- The tuna purse seine fisheries industry, including Echebastar, has implemented and voluntarily adopted several measures to reduce their impact. There is a general downward trend in all significant indicators of dFAD activity.
- This reduction is more notable in buoy activations, deployments and deactivations than in buoy losses and beaching (ECHEBASTAR fleet).
- In addition to reducing the number of dFADs deployed, a multi-disciplinary team of researchers and external stakeholders highlight the potential to limit the impacts of dFADs by considering dFAD design, materials and monitoring aspects.
- Specific measures proposed, include limiting dFAD numbers, better recovery and management plans, no usage of nets, reduced size (length and volume), use of small and detachable weights, use of biodegradable materials, material specification for attractors.
- ECHEBASTAR itself has already adopted some of these measures (e.g., reduced the number of dFADs, modified dFADs design, replaced materials with biodegradable materials or contributed to the FAD Watch programme).

11.1.2 Field work

- The outputs obtained from the implementation of two different methodologies for the field work are comparable.
- The line intercept method for the study of the impacts of dFADs on coral reefs is faster and can be adapted to variable topographies, requires less equipment and it generates reduced standard error among samples.
- Photo quadrats are the preferred option when identifying the extent of damage.
- The use of four transect, located at 90º of each other, is adequate to best capture the damage of dFADs. However, since it implies ascends/descends, careful design is important to

avoid risks. Furthermore, it would not be suitable for dFADs anchored at depths deeper than 21m with pronounced slopes.

- Despite field work observations, (higher coral cover at control sites than at dFADs), it is not possible to derive conclusions due to limited sample sites and the high habitat variability within/between sites.
- Similarly, the trends observed from fish, (higher abundance of fish at control sites than at dFAD sites), are likely to be a result of the time of the tide and day at which research activity took place as opposed to the effect of dFADs, which could also have an effect, but the limited sample size would prevent us for making such assumption.
- Despite the restriction of the study resulting from the limited sample size, the observations made cast light on several uncertainties regarding the behaviour of dFADs in contact with the reefs.
- These observations have been taken into consideration when making recommendations on the design, materials, and management of dFADs.

11.2 Recommendations

The following recommendations result from the evaluation data in this document, and support and complement previous research (ISSF, 2018; Zudaire et al., 2018; Moreno et al., 2023; Murua et al., 2023):

11.2.1 dFAD data:

- Encourage the sharing of dFADs among the fleet and/or other potentially interested fisheries that could exploit those dFADs that are deactivated when they leave the fishing area and the probability their returning is low.
- Where possible, efforts should be made to distinguish buoys identified that may beach from those that have actually beached.
- Estimating recovery time by area to assess the effectiveness of the 6-month period for identifying the rate of dFAD loss could help to refine the value.
- Extending the period beyond 6 months could be an option to check if the estimated number of lost buoys is overestimated.
- Study the dynamics of deployment, loss, deactivation and beaching events in fishing areas, to identify ways to reduce beaching events and better manage those areas.

11.2.2 dFAD – coral reef interaction

- Generally, more spatial-temporal research is needed in the field of coral reefs in the WIO (e.g., coral species distribution, abundances, status at local level) and the effects of multiple pressures.
- Larger scale studies are needed to allow for adequate statistical analysis and reaching conclusions on the impacts of dFADs on coral reefs.

- Any main project on this topic should focus on reef habitats only (i.e., patch reefs respond differently), in waters no deeper than 21m, applying the line intercept method for benthic composition assessment, performing broken colony counts under the transect line (instead of in the total area), and carrying out the fish counts as done in this study.
- This type of fieldwork research requires high level of expertise on coral and fish identification, as existing guides do not provide all the necessary information required for the identification of species.

11.2.3 dFAD design, materials, and management:

- Conduct studies to find simplified structures that meet the needs of the fleets.
- Modify dFAD design in the short to medium term by increasing effort in the design and compulsory introduction of biodegradable dFADs.
- Simplify the structure of the dFAD as much as possible, reducing their size (length and volume).
- Remove any netting material, design detachable weights, and carefully select materials used for the attractors to reduce dFAD potential negative effect on coral reefs.
- Where possible (other fisheries) should seek commitment and collaboration from end-users to retrieve dFADs.

11.2.4 dFAD mitigation measurement and implementation.

- Before the implementation of any pilot project or mitigation measures in Small Island Developing States (SIDS), the development of a specific risk/impact assessment (e.g., pre-evaluation of beaching rates or dFAD beaching density in the area), as proposed by Herrera et al. (2019), is required.
- The factors to be considered for evaluating the need and feasibility of the programme in each area should be the interaction with other activities as tourism, existence of fishing agreements, biodiversity, cost, governance or country status and presence of organizations for conducting the fieldwork.
- A feasibility index should be conducted for the election of appropriate area/country for the successful implementation of improvement measures. As an example, we conducted an analysis following Herrera et al. (2019):
    - The classification of countries for programme implementation in the Indian Ocean was completed from highest to lowest feasibility index based on the ranking of countries previously selected by the dFAD use impact analysis.
    - In the Indian Ocean, Seychelles gained the highest feasibility score (Figure 19). This result supports the decision taken by SIOTI – AGAC and associated fleet and industry to develop the FADWATCH programme in that country. It was the first dFAD retrieval program in the world with the participation of different stakeholders, including the fishing industry, to prevent and mitigate dFAD beaching events.

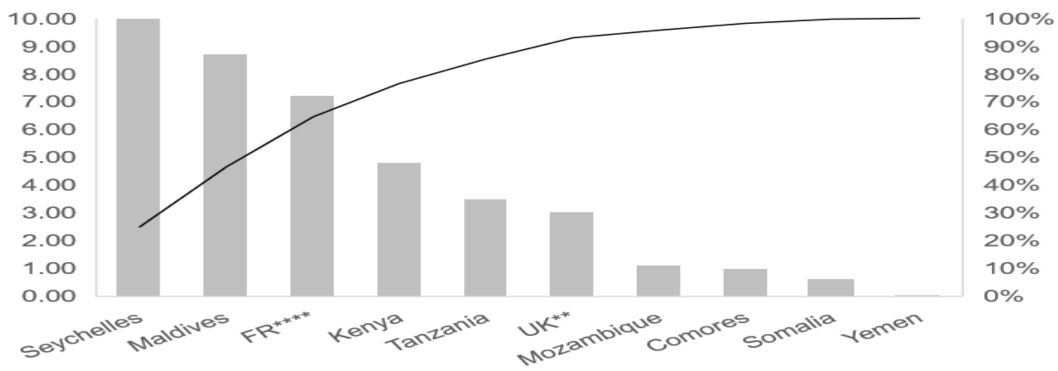

FIGURE 19 COUNTRY CLASSIFICATION ACCORDING TO THE RESULTS FOR THE MEASURES IMPLEMENTATION FEASIBILITY INDEX ASSESSMENT CONDUCTED IN THE INDIAN OCEAN.

- Recovery programs for beached dFADs or drifting dFADs in coastal areas requires (i) agreement with and commitment of competent authorities, as well as, (ii) adequate facilities and infrastructures to support realisation of the measure; and (iii) there should be effective collaborative networks between industry and research centres or environmental organisations.

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13. ANNEX A – List of fish species identified during fieldwork in D´Arros (Seychelles)

Fish Species identified during the fish survey at the four dFAD sites and their corresponding control sites in D´Arros (Seychelles).

Latin Name	Common Name
Abudefduf sexfasciatus	Scissortail sergeant
Abudefduf vaigiensis	Sergeant major damsel
Acanthurus blochii	Bloch´s surgeonfish
Acanthurus leucosternon	Powder-blue surgeonfish
Acanthurus nigrofuscus	Dusky surgeonfish
Acanthurus thompsoni	Night surgeonfish
Amblygobius semicinctus	White-barred reef goby
Arothron immaculatus	White-spotted pufferfish
Balistapus undulatus	Orange-striped triggerfish
Caesio teres	Yellow-tail fusilier
Canthigaster valentine	Saddled pufferfish
Carangoides fulvoguttatus	Yellow-spotted trevally
Caranx ignobilis	Blue-fin trevally
Carcharhinus melanopterus	Black-tip reef shark
Cephalopholis argus	Peacock grouper
Chaetodon Auriga	Thredfin butterfly
Chaetodon falcula	Double-saddle butterflyfish
Chaetodon interruptus	Zanzibar butterflyfish
Chaetodon kleinii	Brown Butterflyfish
Chaetodon meyeri	Meyer´s Butterflyfish
Chaetodon trifascialis	Chevron butterflyfish
Chaetodon trifasciatus	Pin-striped butterflyfish
Chaetodon xanthocephalus	Yellow-head butterflyfish
Cheilodipterus quinquelineatus	Five-line cardinalfish
Chlorurus sordidus	Bullet-head parrotfish
Chromis atripectoralis	Blue-green puller
Chromis fieldi	Two tone puller
Chromis weberi	Weber´s puller
Chrysiptera brownriggii	Surge damsel
Corythoichthys flavofasciatus	Yellow-banded pipefish
Ctenochaetus striatus	Fine-line bristtletooth
Dascyllus aruanus	Hambug damselfish
Dascyllus trimaculatus	Domino humbag damselfish
Dascylus carneus	Indian humbag damselfish
Epinephelus fuscoguttatus	Flower groupper
Epinephelus merra	Honeycomb groupper
Gomnothorax breedeni	Black-cheeck morey eel
Gomphosus caeruleus	Bird-mouth wrasse
Halichoeres trispilus	Indian write wrasse
Heniochus acuminatus	Reef banner fish
Heniochus diphreutes	Schooling bannerfish
Hipposcarus harid	Long-nose parrotfish

Latin Name	Common Name
Labroides dimidiatus	Blue-streak cleaner wrasse
Lethrinus enigmaticus	Seychelles black-eye emperor
Lutjanus bohar	Red snapper
Lutjanus fulvus	Humback snapper
Lutjanus kasmira	Blue-striped snapper
Mulloidichthys flavolineatus	Square-spot goatfish
Myripristis kuntee	Epaulette soldierfish
Naso vlamingii	Big-nose unicornfish
Odonus niger	Redtooth triggerfish
Ostorhinchus cyanosoma	Yellow-stripped cardinal fish
Paracirrhites forsteri	Freckled hawkfish
Parupeneus barberinus	Dash-and-dot goatfish
Plagiotremus rhinorhynchos	Tube-worm fangblenny
Plagiotremus tapeinosoma	Piano fangblenny
Plectorhinchus albovittatus	Giant sweetlips
Plectroglyphidodon johnstonianus	Johnston´s damsel
Plectroglyphidodon lacrymatus	Jewel damsel
Pomacanthus imperator	Emperor angelfish
Pomacentrus caeruleus	Golden-tail damselfish
Pseudanthias squamipinnis	Golden anthias
Pterocaesio tile	Neon fusilier
Sargocentron caudimaculatum	White tail squirrelfish
Sargocentron diadema	Crown squirrelfish
Stegastes nigricans	Dusky farmerfish
Stegastes punctatus	Blunt-snout farmerfish
Stethojulis strigiventer	Silver-streaked wrasse
Sufflamen chrysopterum	Half-moon triggerfish
Synodus dermatogenys	Grey-streak lizardfish
Thalassoma hardwicke	Six bar wrasse
Thalassoma lunare	Moon wrasse
Variola louti	Lyretail grouper
Zanclus cornutus	Idol
Zebrasoma scopas	Brown tang
Sp1.	Fish non ID1
Sp2.	Fish non ID2
Sp3.	Fish non ID3
Sp4.	Fish non ID4
Sp5.	Fish non ID5
Sp6.	Fish non ID6
Sp7.	Fish non ID7
Sp8.	Fish non ID8
Sp9.	Fish non ID9
Sp10.	Fish non ID10
Sp11.	Fish non ID11

14. ANNEX B: KNOWLEDGE TRANSFER

An aim of the project was to make the knowledge available SOSF and the tuna fishing community. The following actions were carried out.

- **dFAD characterization training with SOSF**: After developing the excel template (see above), a training session was carried out with SOSF. A dFAD that had already been retrieved from the reef. Trainees were shown the different parts to be recorded in the excel file. SOSF will apply this when finding any other dFAD at sea.
- **dFAD underwater survey training with SOSF**: A specific training session on the objectives and methodology for carrying out the underwater surveys between AZTI and SOSF. The methodology was first explained on land, and then implemented at sea. Four members of SOSF participated, allowing them to carry out this type of impact assessment. Prior to the underwater session, it was determined which member of the SOSF team would perform each task (including all the specific details such as, who would lay down the type measure) to avoid underwater confusion. During the training session, the AZTI team, using a slate, guided the different steps of the survey. In addition, each member of the SOSF team had a slate to raise any issues encountered.
- **Scientific knowledge transfer to other scientist**: the outputs of this study will be presented in other scientific fora, so the methodology can be implemented in future studies. This systematic approach would allow to be standardized and scaling up the study to bring more solid conclusions.
- **Knowledge transfer to the tuna fishing industry**: this report will be presented in different fora where we share working space with fishing industry such as SIOTI FIP, and similar expecting that the outputs will help the tuna fishing community to progress towards sustainability.

15. ANNEX C: PROJECT PHOTOGRAPHS

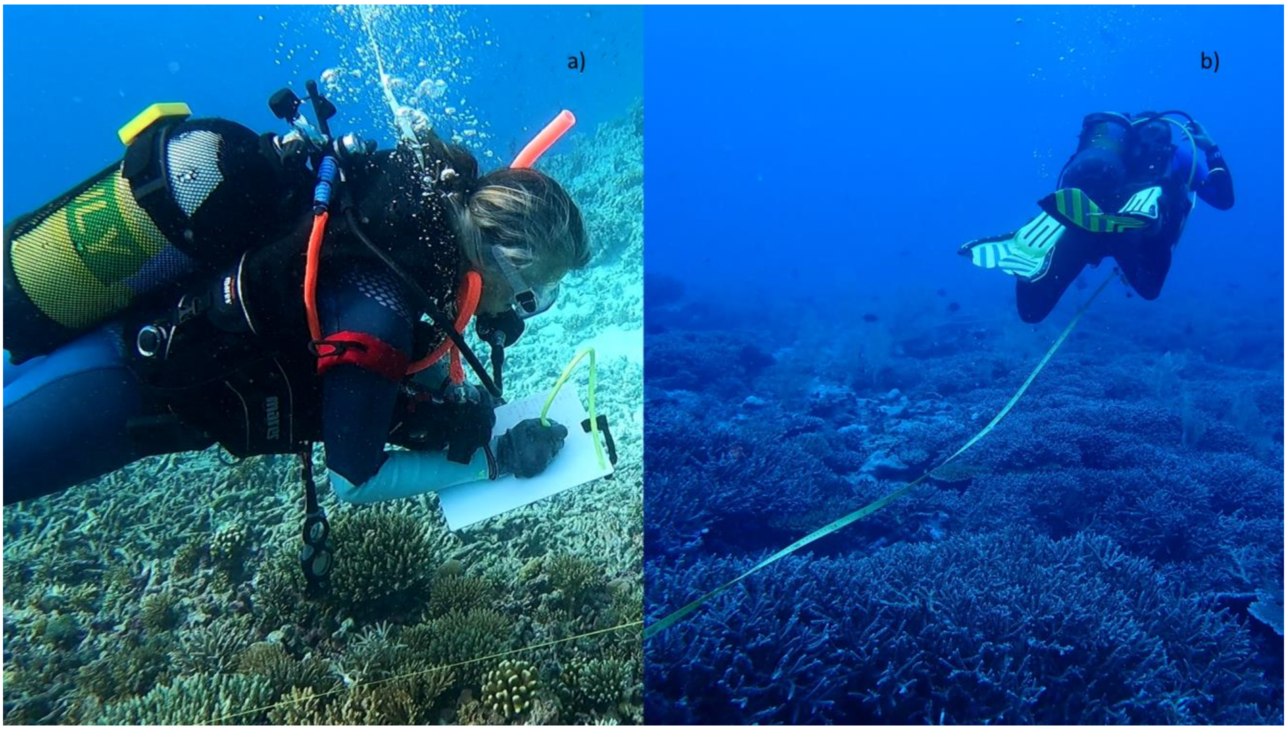

PHOTO 1: Line intercept method for the status of coral reefs. A) Data collection; B) Transect line deployment. Photo credit: Ekaitz Erauskin|. © AZTI

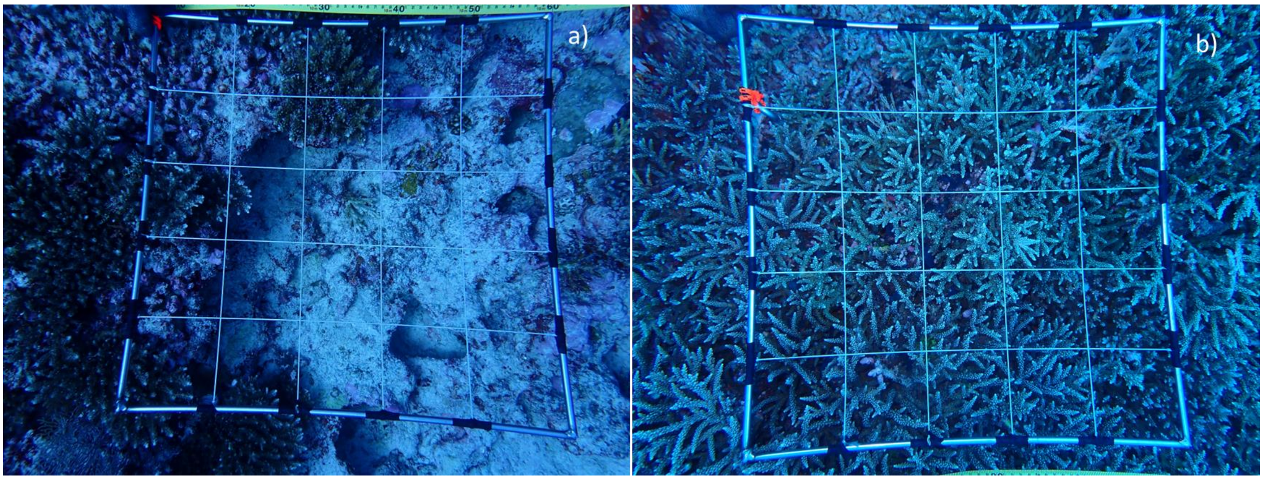

PHOTO 2: Implementation of the photo quadrat method to coral reefs. Two photo quadrats taken at the control reef site. Photo credit: Maria C. Uyarra|. © AZTI

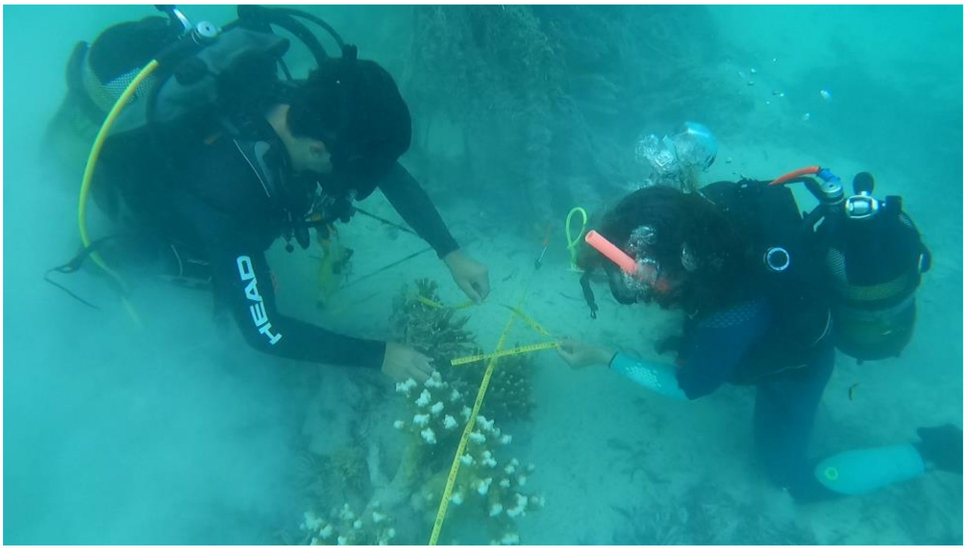

PHOTO 3: Underwater surveys carried out to measure broken colonies at dFAD and control sites. Photo credit: Alex Salgado|. © AZTI

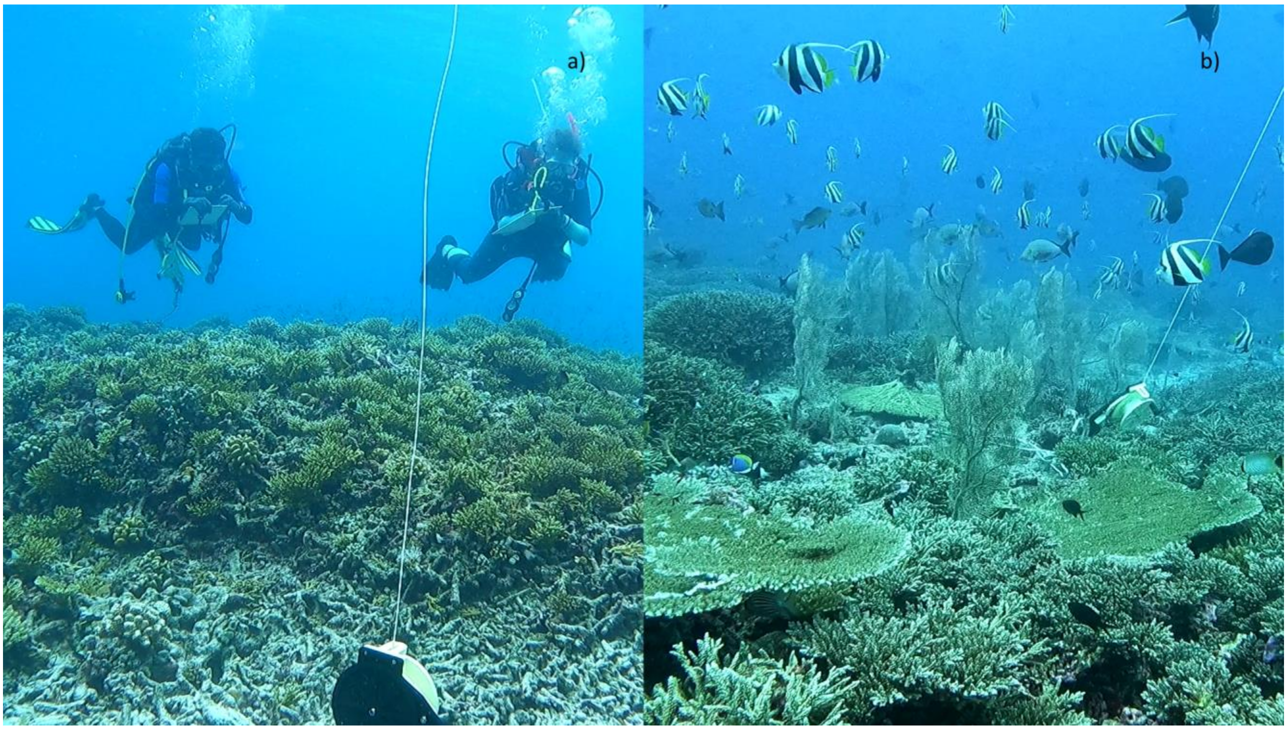

PHOTO 4: Fish surveys. A) Fish data collection; B) Fish community at the control reef site. Photo credit: Ekaitz Erauskin|. © AZTI

PHOTO 5: DFAD FISH SURVEY TRAINING SESSION CARRIED OUT BY THE AZTI TEAM WITH THE SOSF TEAM. PHOTO CREDIT: EKAITZ ERAUSKIN|. © AZTI

PHOTO 6: SOSF AND AZTI COLLABORATING TEAM IN D´ARROS, SEYCHELLES. PHOTO CREDIT: HENRIETTE GRIMMEL |. © SAVE OUR SEAS FOUNDATION