Australian Government
Great Barrier Reef
Marine Park Authority

Fish aggregating devices and artificial reefs

Literature review of benefits and negative impacts for the Great Barrier Reef

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Acronyms and AbbreviationsAcronyms/ Abbreviation	Description
AR	artificial reef
the Department	Department of Agriculture, Water and the Environment
DES	Department of Environment and Science
FAD	fish aggregating device
EPBC Act	Environmental Protection and Biodiversity Conservation Act 1999
FAO	Food and Agriculture Organization
the Reef	Great Barrier Reef
the Marine Park	Great Barrier Reef Marine Park
the Authority	Great Barrier Reef Marine Park Authority
the World Heritage Area	Great Barrier Reef Marine Park World Heritage Area
the region	Great Barrier Reef Region
MPA	Marine Protected Area
NOAA	National Oceanic and Atmospheric Administration
NEBA	Net Environmental Benefits Analysis
NSW	New South Wales
pdf	portable document format
SARA	Queensland State assessment and referral agency
scuba	self-contained underwater breathing apparatus
SDAP	Queensland State development assessment provisions
the Marine Park Act	Great Barrier Reef Marine Park Act 1975
the Sea Dumping Act	the Environment Protection (Sea Dumping) Act 1981
TOR	terms of reference
USA	United States of America
USD	United States Dollar
WA	Western Australia

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1. SUMMARY

Structures to aggregate marine life, such as artificial reefs (ARs) and anchored fish aggregating devices (FADs), have a long history of use throughout marine ecosystems, including in Australian waters. However, ARs remain rare in the Great Barrier Reef Marine Park (the Marine Park), and there are currently no FADs deployed for recreational fishing. The Great Barrier Reef Marine Park Authority (the Authority) are seeking to develop a policy position on FADs and ARs. ARs are also relevant to the *Environment Protection (Sea Dumping) Act 1981* (Sea Dumping Act).

The primary objective for this study is to prepare a national and global literature review of existing knowledge about anchored FADs and ARs to evaluate the benefits and negative impacts of these structures in relation to the objects of the *Great Barrier Reef Marine Park Act 1975* (the Marine Park Act), including the environment, biodiversity and heritage values of the Great Barrier Reef World Heritage Area (the World Heritage Area). The literature review is intended to inform the development of the Authority's policy position on ARs and FADs.

A systematic review of the literature, including screening and the application of relevance criteria, resulted in 568 documents (mostly peer-reviewed papers, but also technical reports) that contained information useful to the assessment of benefits and negative impacts of ARs and FADs in a context relevant to the World Heritage Area. Only three documents referred to ARs or FADs within the Marine Park itself. Approximately 71 per cent of these articles documented benefits and/or negative impacts that could be examined for relevance to the Marine Park Act. Others were useful in collating information about the effects of ARs and FADs on ecological, socioeconomic and management of marine ecosystems in a way that could assist with decision-making.

The design of AR structures can range from small and simple rock piles or concrete blocks to large structures and complex arrangements; most modern ARs are specially designed modules or structures crafted to the ecological requirements of individual species or user objectives. In contrast, the design of anchored FADs is relatively simple, as it includes a predetermined set of essential components: an anchor, attachment lines, floats and, in most cases, attractants. The placement of ARs and FADs interacts with physical characteristics (hydrodynamics, temperature, depth) of the environment to affect ecological processes such as recruitment, the movements of target species, the process of colonisation and succession, fish behaviour, sediment type and biodiversity. Combined ARs and FADs are also deployed in some cases, where the AR serves as a more complex anchor for the FAD.

Throughout the literature, a recurring debate is whether ARs and FADs simply attract fish away from natural habitats or change the attributes of an area to effectively "produce" more fish. The goal of installing FADs is almost always fisheries-oriented, and as per the most common definition, the structures serve to attract and aggregate fish for capture. Because ARs are more complex, with habitat qualities such as structural complexity, there is evidence to support the premise of ARs increasing production, among other pros and cons. We review the arguments for both; the literature on FADs points to attraction being the main mechanism, but the attraction-production question around ARs is more complicated and can only be assessed on a case-by-case basis for each AR, and validated after their installation.

The primary object of the Marine Park Act is to "*provide for the long-term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region*". Most of the literature on FADs and ARs was focused on aspects of biology and ecology relevant to this object, especially papers that compared ecological communities on ARs to those of nearby natural habitats. In fact, 257 documents were

found to be relevant to the primary object of the Marine Park Act, and a further 105 documents presented topics that were relevant to the primary object in combination with other objects (e.g., papers that studied aspects of biodiversity and recreational use).

The effects of ARs on environmental protection were mixed. ARs change the habitat to increase structural complexity above the seabed where the natural habitat may be degraded or seen to be "lacking". This can create productivity hotspots for species that may not otherwise occur or reside in the area, which in turn provides new or accessible areas that are popular for recreational activities such as fishing and diving, with supplementary tourism and economic benefits. ARs also have potential detrimental negative impacts, such as attracting fish away from natural habitats and providing stepping-stones for invasive species, as well as increased management requirements associated with activities around artificial structures. For FADs, the benefits were primarily socioeconomic and, in developed countries, related to the convenience and enjoyment of recreational fishing. Potential negative impacts were FAD loss and marine debris, fish attraction and the potential for overfishing of both adults and juveniles where fishing is not well regulated. Both structures have the stated potential to reduce fishing pressure on natural habitats, with literature from ARs also claiming reduction of diving pressure, although documented empirical evidence for the achievement of this purpose is scarce.

Benefits and negative impacts of both ARs and FADs were mostly ranked as High or Moderate, mostly due to the high likelihood of occurrence. The largest number of benefits and negative impacts in the literature pertain to the effects of ARs on the first object of the Marine Park Act. ARs present a large number of potential risks to the protection of values in the World Heritage area, but also offer a large number of benefits, mainly to the sub-ordinate object of the Marine Park Act. This is not the case for FADs, where only a small number of high-level benefits were found in the literature, against a larger number of extreme, high and moderate level risks. The most certain effects were the enhancement of user enjoyment of ARs/FADs, the aggregation and disproportionate fishing risk to juvenile fishes of FADs, and the general lack of data to ensure that FAD fishing is sustainable.

It is important to note, however, that the balance of benefits and negative impacts should not be read as a "numbers game"; that is, even one of the risks could be serious enough to negate any number of benefits. Furthermore, some of the benefits repeatedly stated in the literature (e.g. the use of FADs to reduce fishing pressure on reefs) were based on very little quantitative evidence. The risk assessment was conducted with an assumed lack of mitigating circumstances or actions in place. However, appropriate planning, monitoring and compliance, as outlined in much of the relevant literature, is likely to reduce at least some of the negative impacts considerably.

Examples and precedents exist in the literature of well-managed ARs and FADs; these suggest the success is dependent on setting clear goals and engaging stakeholders and community members from the beginning. The mitigation measures for many of the risks and ways to optimise benefits discussed in the literature include consultation, placement, design, management and compliance. For example, user conflict can be avoided through stakeholder and public consultation before the deployment of structures, and subsequently through zoning, allocating specific activities to individual ARs or FADs, or through a licensing system. The greater versatility of ARs compared to FADs may lend itself to a larger variety of available mitigation measures to enhance potential benefits and diminish potential negative impacts.

Key Findings:

- The exhaustive literature search resulted in 568 documents about ARs and FADs that were relevant to one or more of the objects of the Marine Park Act.

- The attraction-production debate is easily resolved for FADs but is more complicated for ARs. Generally, the literature indicates:
    - FADs attract and aggregate fish.
    - ARs also attract and aggregate fish, but may also contribute to fish production.
- For ARs in the context of the Reef, the literature suggests that:
    - The greatest negative impact stems from a likelihood of poor management and compliance, leading to user conflict and overuse. There are also likely biodiversity negative impacts of overfishing, the spread of invasive species and the replacement of soft sediment habitats.
    - The greatest benefit is the enjoyment of recreational divers and fishers through the provision of convenient diving and fishing sites, followed by potential benefits of increased density and biomass of plants and animals, and higher habitat complexity and biodiversity.
- For FADs in the context of the Reef, the literature suggests that:
    - The negative impacts include overfishing pelagic species, including juveniles; disrupting movement and migration and attracting fish from other habitats, as well as overcrowding and user conflict issues.
    - The benefits include providing convenient fishing locations and the potential of taking pressure off overfished coastal species, although the literature offers little evidence for this.
- The risk assessment identified five key stages where mitigations for both optimising potential benefits and minimising potential negative impacts of a proposal for ARs/FADs could be considered: 1) consultation, 2) design, 3) placement, 4) management and monitoring, and 5) compliance. Examples of all stages being adopted in the FAD/AR deployment, in the literature, are rare.

2. INTRODUCTION

2.1. Project Background

The Great Barrier Reef (the Reef) is the world's largest coral reef ecosystem, extending over 2,300 km along the north-east coast of Australia and composed of approximately 3,000 individual reefs and 900 islands (GBRMPA, 2019b). The Great Barrier Reef Marine Park (the Marine Park), designated in 1975, is a multiple-use marine park that regulates human use across the ecosystem (Figure 1). The Marine Park is protected through various measures, including a zoning system that spatially partitions uses such as commercial marine tourism, fishing, recreation and scientific research. Over 30 per cent of the Marine Park is protected from extractive use through no-take zones. The Great Barrier Reef Marine Park Authority (the Authority) manages pressures and threats to the Marine Park through the *Great Barrier Reef Marine Park Act 1975* (the Marine Park Act). The main object of the Marine Park Act is "*to provide for the long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region*" (the region). Other objects of the Marine Park Act relate to the sustainable use of the region and are subordinate to the main object; that is, they are provided for so long as they are consistent to the main object. The main object of the Marine Park Act, other objects and values of the region are presented in Table 1.

The Reef's status, health and pressures are reviewed every five years in an evidence-based Outlook Report. This Report assesses key values of the region to provide a regular and reliable means of assessing reef health and management in an accountable and transparent way (GBRMPA, 2019b). The values of the region, as stated in the Outlook Report can be broadly classified into biodiversity, ecosystem health and heritage. The Outlook Report also outlines commercial and non-commercial uses, which are directly related to social and economic values (Table 1). Activities allowed within the Marine Park are managed under permits, policies and/or plans developed by the Authority. This includes controls over where fishing can occur and managing tourism and environmental threats such as dredging and sewage discharge. The Authority also develops position statements on issues outside the direct regulatory control of the Authority, such as fishing, terrestrial runoff and climate change (GBRMPA, 2021c). The region was declared a World Heritage Area in 1981 because of its 'outstanding universal value'. This recognised the region as being one of the most remarkable places on Earth, with global importance and natural worth.

In 2011, the Authority developed guidelines (now revoked) for the management of artificial reefs (ARs) in the Marine Park (GBRMPA, 2011). These guidelines define ARs as "*any structures people build or place on the seafloor, in the water column or floating in the sea surface for the purpose of either creating a new attraction for divers or to concentrate or attract plants and animals for the purpose of fishing*". With an emerging trend of fish aggregating devices (FADs) being deployed around Australia (NSW Government, 2021; Queensland Government, 2021a) and heightened interest in the possibility of deploying anchored FADs in the Marine Park, on 28th October 2020 the Marine Park Authority Board put in place a moratorium and Interim Policy position that no FADs and ARs are to be deployed. The primary purpose of the moratorium is to enable development of a policy position on FADs and ARs to be informed by existing knowledge of their benefits and negative impacts against the values of the region, with a focus on the main object of the Marine Park Act.

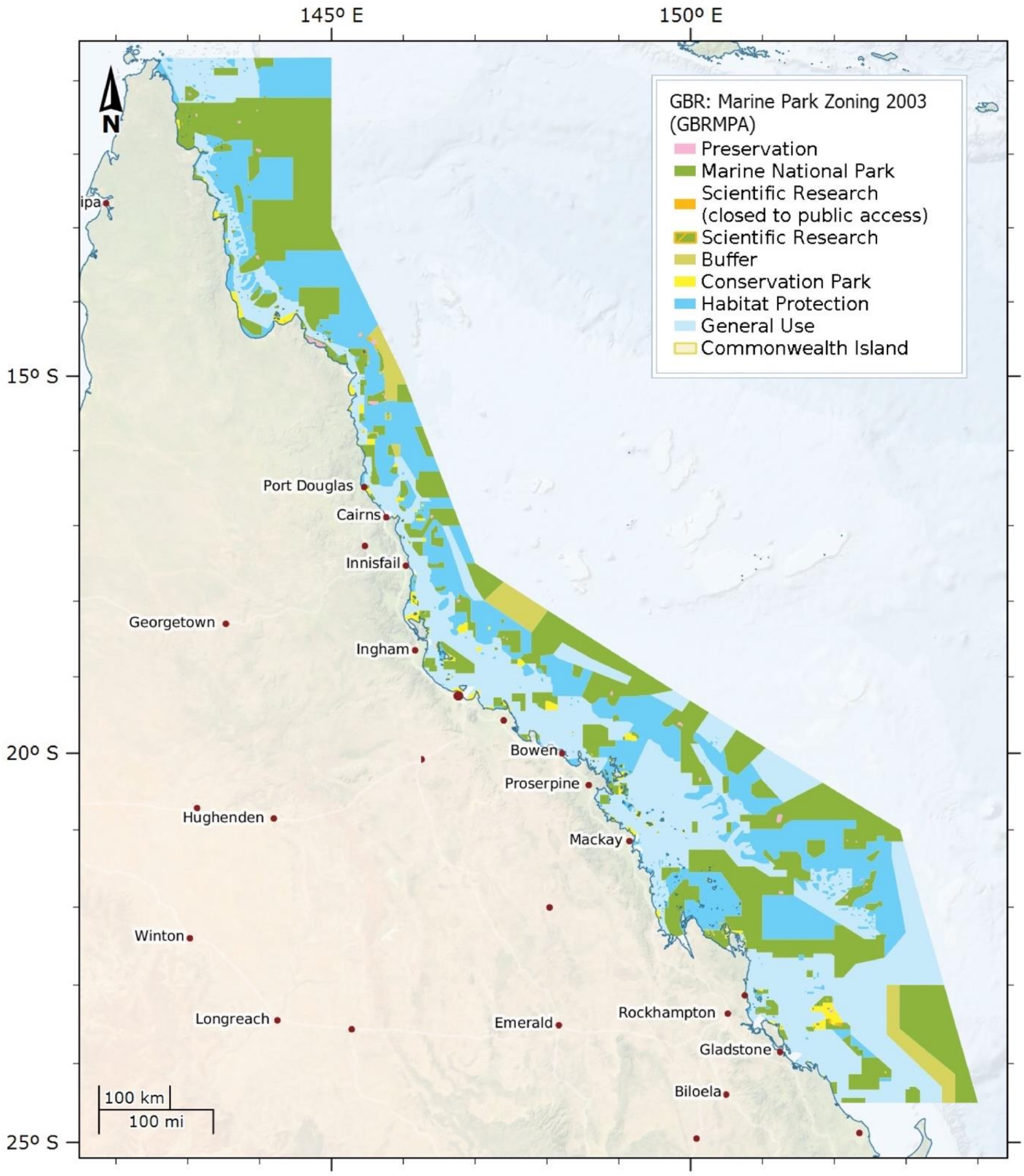

Figure 1 **Great Barrier Reef Marine Park with management zones (From https://eatlas.org.au/data).**

Table 1 Objects and values as referenced in the *Great Barrier Reef Marine Park Act 1975*. It is assumed that heritage values include cultural values. Values are sourced from GBRMPA (2019b).

GBRMP Act paragraph	GBRMP Act sub-paragraph	Relevant GBRMP values
(1) The main object of this Act is to provide for the long-term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region.		Biodiversity values Ecosystem health values Heritage values
(2) The other objects of this Act are to do the following, so far as is consistent with the main object:	(a) allow ecologically sustainable use of the Great Barrier Reef Region for purposes including the following: (i) public enjoyment and appreciation; (ii) public education about and understanding of the Region; (iii) recreational, economic and cultural activities; (iv) research in relation to the natural, social, economic and cultural systems and value of the Great Barrier Reef Region;	Heritage values Social values Economic values
	(b) encourage engagement in the protection and management of the Great Barrier Reef Region by interested persons and groups, including Queensland and local governments, communities, Indigenous persons, business and industry;	Biodiversity values Ecosystem health values Heritage values Social values Economic values
	(c) assist in meeting Australia's international responsibilities in relation to the environment and protection of world heritage (especially Australia's responsibilities under the World Heritage Convention).	Biodiversity values Ecosystem health values Heritage values Social values

2.2. Objectives

The purpose of this study is to prepare a national and global literature review of existing knowledge about anchored FADs and ARs to inform the development of the Authority's policy position (**Appendix A**). The key goal of the literature review is to evaluate the potential benefits and negative impacts of these structures in relation to the objects of the Marine Park Act, especially the protection of the environment, biodiversity and heritage values of the region (GBRMPA, 2019b).

To achieve this goal, the specific objectives of this literature review are to:

1. conduct a desktop literature review of peer-reviewed and non-peer-reviewed literature,
2. consider different terminology used to define ARs and FADs in the available literature,
3. summarise the types of deployment mechanisms, materials and designs, including the purpose of the ARs and FADs, effectiveness against the stated purpose and positive and negative impacts of ARs and FADs,
4. analysis and evaluation of benefits and negative impacts of ARs and FADs against the objectives of the Marine Park Act and the values of the region,
5. review existing management, governance and lessons learned from the reviewed information to inform the Policy process, and
6. identify information gaps in the literature.

3. METHODS

Existing literature containing information about ARs and/or FADs was collated using online search engines (Web of Science Core Collection, Current Contents Connect, Biosis, Scopus), Google Scholar and the internal search functions of fisheries, management and conservation organisation websites[1]. The search term ("fish aggregat* device*" OR "artificial reef*") was initially tested on 10 key documents (5 peer-reviewed and 5 "grey literature" reports), to make sure it was capable of detecting the relevant literature. Equal consideration was shared between peer-reviewed and grey literature during the search in recognition that information on ARs and FADs often appears in documents designed for use by fisheries or management agencies, rather than solely for academic purposes. All results were uploaded to the online software Cadima, which assists with detecting duplicates, screening and data extraction.

After the initial literature search and duplicate exclusion, the resulting 4300 documents were screened for relevance by title and abstract against a predetermined list of criteria designed for maximum relevance to the objects of the Marine Park Act (Table 2). Of the resulting 2424 articles, those with only abstracts, or if the same study was described in more than one document, were excluded. Final screening resulted in 904 references, with full-text portable document format (pdfs) available for 568 articles. Data were extracted from these 568 articles, including information about the publication (e.g. author, year), the type of structure referred to (FAD or AR), the relevant object(s) of the Marine Park Act, the values of the region, location, the definition used, materials used, purpose stated, field of research and stated benefits and negative impacts. To further assess the relevance of each document to the object(s) of the Marine Park Act and values of the region, a relevance score from 1 to 5 was applied to each document (Table 3). Consideration was given to the situation (e.g., recreational fishing in developed nations, as opposed to artisanal fisheries in developing nations), the environment (e.g., tropical or temperate), and to the inclusion in the document of information about the benefits and negative impacts of FADs and ARs. The score was a measure of how directly relevant the document was to the environment or situation of the Marine Park, with a score of 1 representing low relevance and 5 being directly relevant.

Dedicated efforts were made to access research and monitoring results of FADs and AR deployed in Australian waters by relevant government agencies, including in Queensland, Western Australia and New South Wales. This included searches of websites and also direct email requests for data reports or anecdotal information. In the absence of a response, we made use of the online information describing the programs, but this did not include monitoring results or data about of the success (or otherwise) of the programs.

[1] E.g., https://pacificdata.org/

Table 2 Criteria for literature screening. Literature "included" was used to extract information against the objects of the Marine Park Act. Literature "excluded" was considered of low relevance to the Reef environment and the purpose of this review. Some literature of marginal relevance was retained ("also considered") to provide important background and context.

Include	Also consider	Exclude
Anchored FADs in developed nations	Anchored FADs developing nations	Drifting FADs
ARs ~2010-2020	ARs pre-2010 if relevant	FADs for industrial tuna fisheries
Shipwrecks	ARs used for reef restoration if pros and cons are relevant to objects of the GBRMP Act	Small (< 2m^3) structures used for coral reef restoration (e.g.. structures to stabilise rubble on existing coral reefs to enable coral recruitment).
	Reviews about FADs and ARs	Offshore structures for energy production (e.g. oil and gas platforms, wind farms)
	Underwater viewing structures for education	Sea farms and cages
		Cables and pipelines
		Breakwalls, marinas and coastal protection infrastructure
		ARs designed for waves / surfing

Table 3 Relevance scores given to documents against the GBRMP Act objects and values of the region as defined in Great Barrier Reef Marine Park Authority (2019b) (i.e. each document received two scores).

Score	Definition
1	Low relevance to GBRMP Act Object / Value due to situation (e.g. FAD to enhance fisheries in developing countries) **and** ecosystem (e.g. temperate seas)
2	Low relevance to GBRMP Act Object / Value due to situation **or** ecosystem (e.g. FAD to enhance fisheries in developing countries (not relevant) on tropical continental shelf (relevant); AR for recreational fisheries (relevant) in temperate seas (not relevant)
3	Moderate relevance to GBRMP Act Object / Value (e.g. AR for habitat modification or stock enhancement in subtropical seas, descriptive or experimental studies)
4	High relevance to GBRMP Act Object / Value (e.g. FAD or AR for recreational fishing, with some mention of benefits and / or risks)
5	Directly relevant to GBRMP Act Object / Value (e.g. FAD or AR for recreational fishing, specifically testing effects on biodiversity, ecosystem health, heritage or socioeconomic values).

4. RESULTS

4.1. Literature review results

Out of 568 documents that contained relevant information (see Table 2), 366 (64.4 per cent) referred to ARs, 193 (33.9 per cent) to FADs and nine documents (1.6 per cent) discussed both structures. The vast majority of references were peer-reviewed articles, partly due to the limited availability of full-text files for technical reports and other document types (Figure 2). The geographic areas that yielded the largest volumes of relevant literature were the USA (primarily the Gulf of Mexico and Florida), Brazil, the southern Mediterranean (especially Sicily), China, Australia, the Philippines and Indonesia (Figure 3) (see also Fabi et al., 2011; Lima et al., 2019).

4.1.1. Objects of the GBRMP Act and values of the region

Studies on ARs and FADs that were relevant to the objects of the Marine Park Act and values of the region were overwhelmingly dominated by ecological and biological research (299 documents), followed by fisheries and socioeconomic research (112 and 85 documents, respectively; Figure 4). There were numerous review-style documents, including book chapters and conference papers that reviewed different aspects of FADs and ARs. The largest number of documents referred to ARs and FADs installed for fisheries purposes only, either commercial or recreational. The next largest number of studies were those with multiple stated purposes for the FADs and ARs (e.g., fisheries and habitat restoration), followed by studies that had the stated objective of “habitat enhancement” by placing objects in locations that previously lacked relatively large, above-seabed, three-dimensional structure, usually by placing materials on soft-sediment habitats (Table 4).

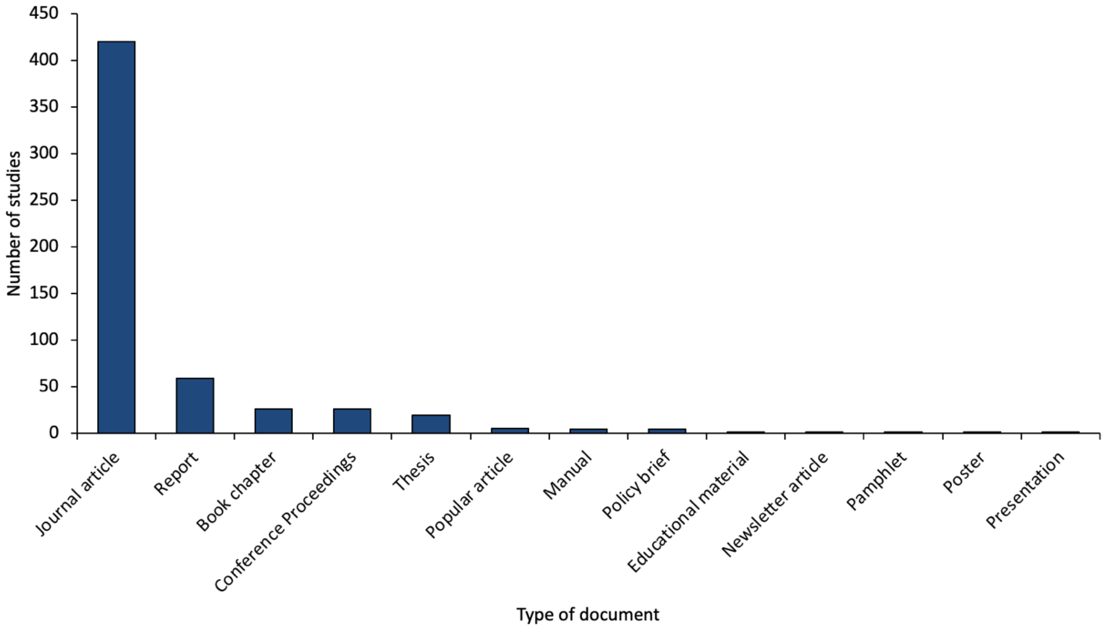

Figure 2 Distribution of the types of documents available for review (N = 568).

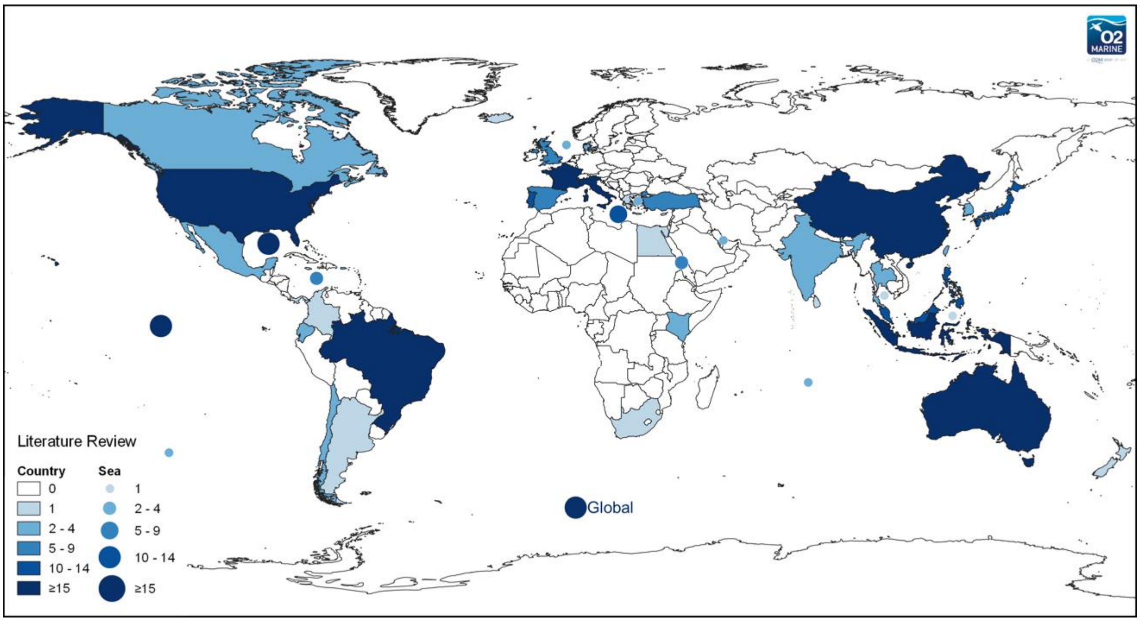

Figure 3 **Map presenting the distribution and number of reference sources found in the literature search available for review. "Global" refers to studies that either used information from around the world, or non-site-specific discussions or modelling**

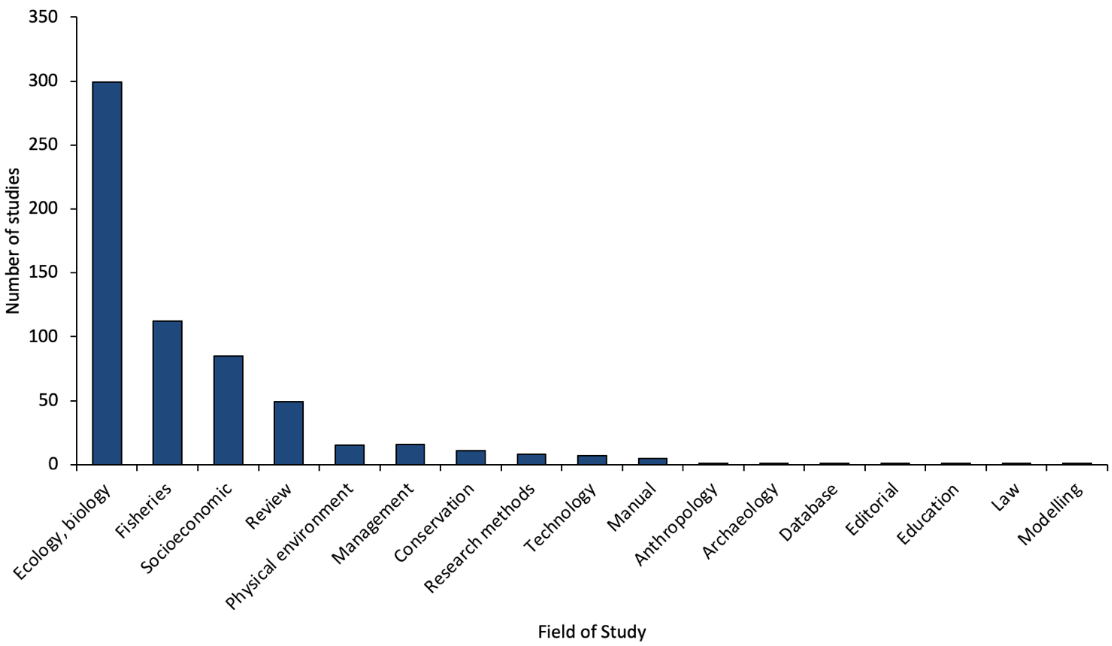

Figure 4 **Distribution of the fields of study represented in the documents available for review (N = 568). Note that the total is larger than 568 because some papers spanned two or more fields of study.**

Table 4 Stated purpose of ARs and FADs in relevant studies

Structure	Stated purpose of structure	Number of studies
Artificial reefs	Fisheries (enhance commercial or artisanal catch)	65
	Multiple (more than one of the purposes listed here)	52
	Enhance habitat	44
	Recreational fishing	42
	Recreational diving	31
	Habitat remediation / restoration	24
	Experimental	23
	Accidental shipwrecks	18
	Unclear	17
	Anti-trawling	11
	Energy production	10
	Enhance abundance of target species	9
	Environmental offset	9
	Increase fish populations	8
	Tourism	7
	Enhance benthic habitat/ Enhance production/ Habitat protection	3
	Enhance biological resources/ Heritage/ Increase local biodiversity/ Marine ranching/ Waste disposal, ship scuttling	2
	Conservation/ Increase habitat complexity/ Reduce user pressure on natural reef/ Research/ Restore fish stocks	1
Artificial reefs & fish aggregating devices	Fisheries	7
	Experimental/ Multiple	1
Fish aggregating devices	Fisheries	187
	Experimental	2
	Enhance habitat/ Increase fish production	1
Other	Oceanographic data buoys	3

4.1.2. Materials Used for Building Artificial Reefs and Fish Aggregating Devices

The most common materials used for ARs in the literature were especially designed concrete modules (Table 5), probably due to the selection of studies from the last decade, when these modules have become more frequent in comparison with other materials (e.g., tyres, scuttled ships) or simple concrete blocks. This was followed by studies that either focused on ARs built from a combination of materials or compared different types of ARs. Shipwrecks, both accidental and intentionally sunk as ARs, were the third most common structure encountered in the relevant literature (Table 5).

Table 5 Number of studies describing each of the different types of AR materials used

Materials	Number of studies
Concrete modules	108
Multiple	88
Shipwrecks / vessels	59
Concrete blocks	33
Unclear	18
Steel	15
Rocks or boulders	12
Rocks	10
Oil rigs	9
Shell or oyster reef	5
Concrete pipes	4
Concrete and shells/ Limestone/ Tires	3
Cinder blocks/ Wood/ Rubble	2
Concrete culverts/ Fibreglass/ Mussels/ Plastic/ Wind farm/ Concrete pyramids/ Bricks/ PVC pipes	1

Documents about ARs were dominated by research relevant to the main object of the Marine Park Act, especially studies relating to the effects of FADs and ARs on aspects of environment protection. Research on FADs, on the other hand, had a greater number of studies relevant to sustainable use objects (Figure 5a). Similarly, research relevant to biodiversity values dominated the AR literature, while studies relevant to social and economic values were more abundant among papers on FADs (Figure 5b). The bulk of the literature was therefore most relevant to gauging the effects of ARs and FADs on GBRMP Act objects 1 (the protection of biodiversity, ecosystem health and heritage) and 2(a)iii (allowing for sustainable use in the form of recreational, economic or cultural activities). Most studies were conducted in subtropical or tropical environments, and primarily in shallow coastal habitats, and were therefore relevant to the ecosystem of the Reef. Most ecological or biological studies focused on fish, especially fisheries target species; few studies considered the effects of FADs or ARs on other fish, other taxa more generally (e.g., invertebrate communities) or the physical environment (e.g., hydrodynamics, sediment transport). Non-biological studies on FADs were primarily about fisheries-related benefits and negative impacts. Because research on drifting FADs and industrial tuna fisheries were excluded (since these were likely to have low relevance to the Reef), it meant that the non-biological studies largely focused on small-scale artisanal fisheries in the Pacific, Caribbean and Mediterranean. Although these types of fisheries do not operate within the Marine Park, many studies contained information that was pertinent to benefits and negative impacts that may eventuate around anchored or moored FADs, should these be deployed within the Marine Park.

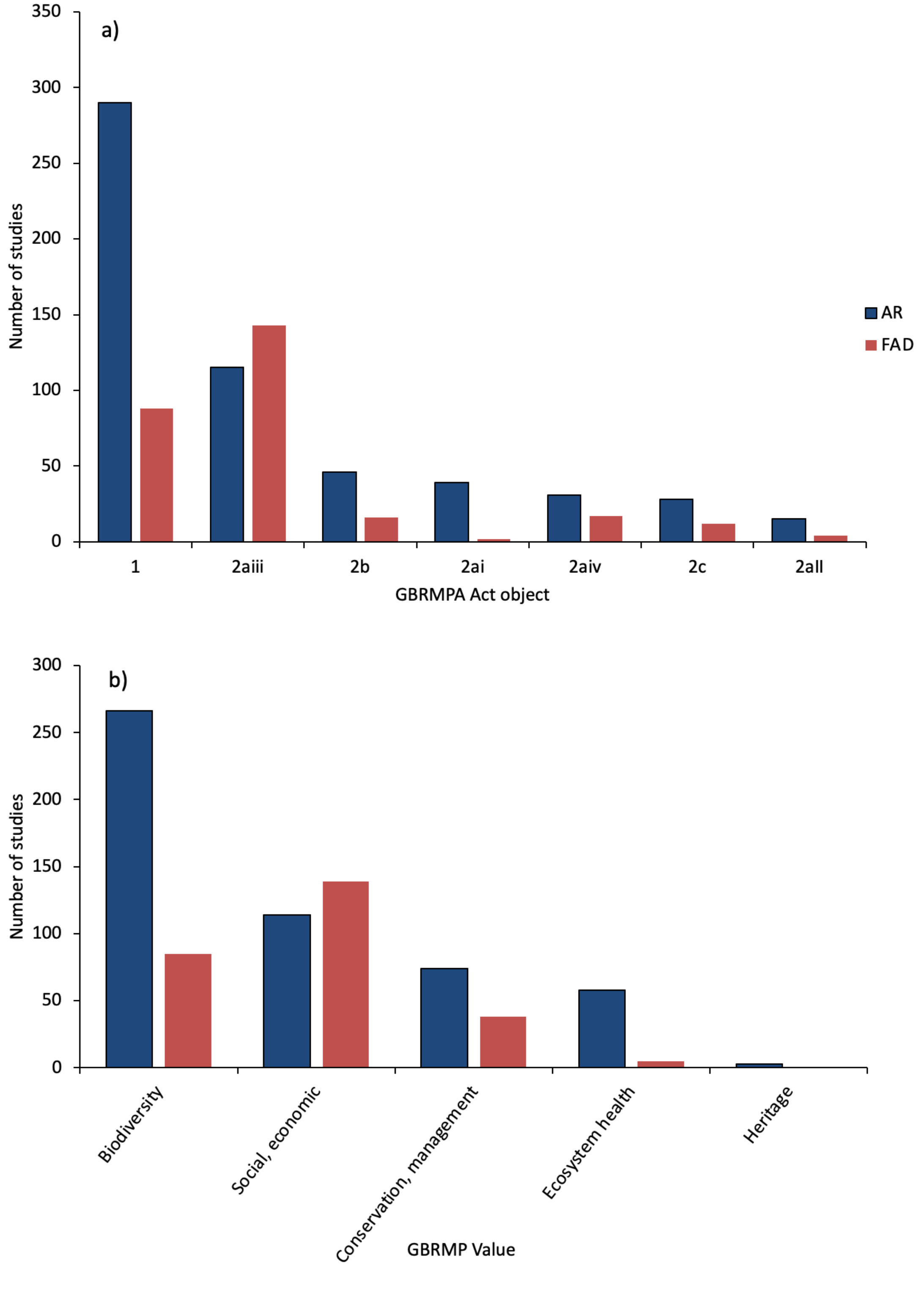

Figure 5 **Number of studies a) relevant to each object of the GBRMP Act (N = 568), and b) relevant to the region's values. Note that the total is larger than 568 because some papers were relevant to two or more objects of the Marine Park Act, or two or more values.**

4.2. Definition and context

FADs are anchored or free-floating structures placed in the open ocean; this review considers only anchored FADs. Within the available literature, FADs are not often explicitly defined, because the description of their purpose is inherent in the name itself (see **Appendix B** for full list of definitions provided in the literature). Out of 193 documents about FADs, 30 (15 per cent) provided a definition. These definitions could be grouped into those that included a reference to their use in fisheries, and those that did not. The majority of definitions included a reference to human use, and a recurring theme was a variant of the definition provided in Amos et al. (2014): "*Humanmade objects deployed at sea to concentrate pelagic fish in an area for capture*". Therefore, FADs can be defined according to their purpose of aggregating pelagic fish specifically to enhance the ease of capture by fisheries, including industrial-scale tuna fisheries in the open ocean (not considered in this review), artisanal and small-scale fisheries and, less often, recreational fisheries (Perez et al., 2020). For the purposes of this review, anchored FADs to support catches for livelihoods and food security are not directly relevant, but documents on this topic were included if they considered broader positive and negative impacts of FADs on biodiversity, ecosystem health, social and economic values.

For the purposes of the Authority, ARs and anchored FADs must be considered in the context of the *Environment Protection (Sea Dumping) Act 1981* (the Sea Dumping Act), which the Authority is subject to, where the definition of artificial reef reads:

> "*artificial reef means a structure or formation placed on the seabed:*
>
> a) *for the purpose of increasing or concentrating populations of marine plants and animals; or*
> b) *for the purpose of being used in human recreational activities; and includes anything prescribed by the regulations to be an artificial reef for the purposes of this definition, but does not include anything prescribed by the regulations not to be an artificial reef for the purposes of this definition*."

Definitions of ARs could be grouped under both purposes stated in the *Sea Dumping Act*, with extra variants related to habitat repair and protection of habitat from trawling. Definitions therefore ranged from the very explicit *("… a man-made structure, mostly in hard materials like concrete, ceramic etc., in different shapes and designs so as to suit the required purposes and aims to serve various needs ranging from conservation, production, protection, mitigation, adverse impact reduction, reconstruction of natural habitats and ecosystems, sometimes serving more than one purpose."* (Kasim, 2017)) to the more succinct ("… *a submerged structure intentionally placed on the seabed that mimics characteristics of natural reefs.*" (Firth et al., 2016)).

In most of the listed definitions (**Appendix B**), there is no logical distinction between ARs and FADs, except when there is a description of their physical structure. Unless specifically paired with FADs, ARs consist entirely of submerged hard material placed on the seabed, usually for the purpose of attracting or producing (depending on the mechanism described by the individual documents; see also Chapter 6) benthic primary producers (e.g. corals and macroalgae) which provide the foundation for coastal food webs. In the case of FADs, the focus point of the intended purpose of the structure is the floating (either mid-water or on the surface) component, with less attention to the anchor structure placed on the benthos.

The purpose of the individual studies reviewed was not always aligned with the purpose of the structure being deployed. For example, many papers described ecological studies on changes in populations of plants and animals from accidental shipwrecks, decommissioned oil and gas platforms or anti-trawling reefs, although the provision of habitat for these plants and animals was not the structure's stated purpose (e.g. Bumbeer & da Rocha, 2012; dos Santos et al., 2010). Documents have been included in this review if, irrespective of the structure or its intended purpose, they were concerned with a change in the populations of plants and animals caused by the structure, or with some aspect of human recreational use (excluding artwork and most restoration literature) and they were within contexts that were relevant to the Marine Park.

5. DEPLOYMENT, USES, DESIGN AND PLACEMENT

5.1. History of Artificial Reefs and Fish Aggregating Devices

Artificial structures submerged to aggregate marine life have a long history of use throughout temperate, subtropical and tropical ecosystems. The first recorded use of ARs is in Japan during the 1600s, when land-based rock and rubble were deployed to aggregate fish and grow kelp (Stone, 1982). Much of the literature describes the design, deployment, management and application of ARs in the United States of America (USA) where log huts were first deployed off South Carolina in 1830 to facilitate fishing (Bohnsack & Sutherland, 1985). During the 1950s, ARs in USA became more widespread, as individual fishermen deployed disposable objects, such as tires and concrete, to enhance their fishing opportunities and success. Since the 1960s and 1970s, ARs have also become a tool with the goal of habitat restoration (Fariñas-Franco & Roberts, 2014), enhancement of fisheries resources (Akeda, 2016) and rebuilding overfished stocks (Mbaru et al., 2018). Artificial reefs are also common in the Mediterranean (Jensen, 2002; Fabi et al., 2011), Africa (Seaman et al., 2011), South America (Hackradt et al., 2011), Asia (Chen et al., 2019; Ito, 2011) and parts of Australia (Becker et al., 2020; Hardiman & Burgin, 2010).

In Australia, the deployment of ARs began in 1965, when the Victorian Department of Fisheries and Wildlife placed 300 waste concrete pipes in Port Phillip Bay near Melbourne (Branden et al., 1994). The Federal and State Governments, as well as private individuals and organisations, funded the construction of numerous ARs in South Australia from 1984 to 1986. Most early ARs were either made of tires or sunken vessels (Branden et al., 1994). In Queensland, deployment of ARs began with sunken vessels in Hervey and Moreton Bays in the late 1960s (Branden et al., 1994).

The documented use of anchored FADs began in Roman times in the Mediterranean, and at least as early as the 20th century in south-east Asia (Taquet, 2013). Early FADs were made entirely from natural objects to mimic floating material that naturally accumulates around eddies and fronts, and were known by fishermen to attract fish. One of the first modern FADs constructed with artificial materials was anchored in deep water off Hawai'i in 1977 (Taquet, 2013). Tens of thousands of drifting FADs (not covered in this review) are now used by industrial tuna fisheries throughout the open ocean, both within national exclusive economic zones (EEZs) and in areas beyond national jurisdiction. In contrast, anchored FADs are generally located near coastal communities as aids for traditional or artisanal fisheries, and, especially in developing countries, these are deployed with the intention of enhancing local food security, fishing safety, nutrition and livelihoods (Beverly et al., 2012). Globally, there has been an increasing use of anchored FADs since the 1990s, resulting in an estimated 81000 to 121000 new FADs deployed each year (Schneider et al., 2021), effectively changing the pelagic habitat on some continental shelves and nearshore environments both at the scale of habitats surrounding individual FADs, and at the scale of FAD networks (Perez et al., 2020). Information on the deployment of FADs for recreational fishing in developed countries is limited and mostly online, including for a number of Australian states (NSW Government, 2021; Queensland Government, 2021a; Recfishwest, 2021).

Following introduction of the recreational fishing licence in 2001, the New South Wales (NSW) Department of Primary Industries trialled five FADs in 2002 using a large floating buoy anchored to the seafloor, designed to provide a dedicated and productive fishing location for recreational fishers. Following the initial enthusiasm from fishers and reports of increased catches, FAD design was refined and the pilot program was expanded to ten FADs in 2003 and then 30 FADs, which are currently deployed and maintained by the Department from Tweed Heads in the state's north to Eden in the south (NSW

Government, 2021). FADs were also recently deployed off south-east Queensland and Weipa. A policy exists on the deployment of ARs and FADs in NSW marine parks (see Chapter 9). There was no information available, in the form of reports or publications, on the outcomes of monitoring or other research (e.g., tagging) resulting from the FAD programs in NSW and Queensland.

In the Marine Park, underwater artificial structures are comprised of accidental, historic and wartime shipwrecks (e.g. WWII ships and airplanes) (GBRMPA, 2021a), two underwater art installations, coral nurseries and small structures to stabilise damaged reefs; no ARs or FADs are currently installed specifically for the purposes of concentrating marine life for recreational fishing or diving. The closest AR to the Marine Park is the HMAS Tobruk, which was sunk in 2018 between Hervey Bay and Bundaberg in the Great Sandy Marine Park to create a dive site.

5.2. Design and Placement

5.2.1. Artificial Reef Design and Placement

The design of AR structures can range from small and simple rock piles or concrete blocks to complex arrangements of specially designed modules or structures crafted to the ecological requirements of individual species (Figure 6). A global review of ARs found that concrete was the most common material used in the construction of ARs, in the form of cubes, blocks or pipes (Baine, 2001). The literature reviewed for this study also found concrete to be the dominant material (40 per cent of studies), but because it was filtered to post-2010 studies, many of the articles documented the use of specially designed concrete modules (28 per cent of studies). Concrete was also used in combination with other materials, such as rocks, vessels, tires or plastic. The next most common form of AR described in the literature for this review was sunken ships (16 per cent). The most common purposes for which ARs were deployed was to increase fishing and/or recreational diving opportunities by adding three-dimensional hard structure above the seabed to “enhance” marine habitats.

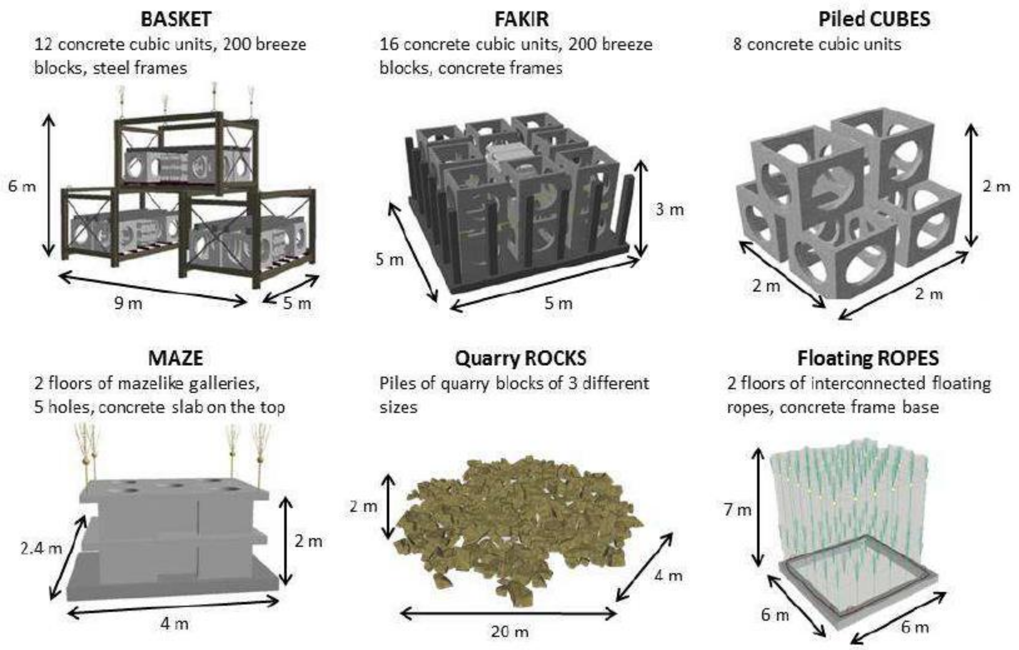

Figure 6 Six examples of AR design used in Marseille, France. Reproduced from Rouanet et al. (2015).

A number of studies compared different AR designs and tested the effect of each on the resulting benthic communities (Rouanet et al., 2015; Schroeter et al., 2015) or fish assemblages (Lemoine et al., 2019). The most common finding was that different materials and designs will result in different biological assemblages (Lemoine et al., 2019), and that, in many cases, these will also differ from those of natural reefs. Many articles stressed the importance of structural complexity, configuration, size, volume and area for ARs attempting to modify habitat to increase benthic and fish assemblages (Baine, 2001; Showstack, 2001). Discussions on habitat complexity centred around the provision of shelter through holes and crevices of the correct sizes for attracting specific organisms, or of many different shapes and sizes for maximising diversity (Garner et al., 2019). The structural integrity and stability of ARs, the type of material used, the provision of void space, bottom relief, height and shading were further important design considerations (Gatts et al., 2014).

Together with design, the question of AR placement is also common in the literature, both in the context of achieving the goal of attracting marine life, and in the mitigation of risks commonly associated with ARs (see Chapter 8). Depending on their placement, ARs interact differently with physical characteristics (hydrodynamics, temperature, depth) of the environment to affect ecological processes such as recruitment, the movements of target species, the process of colonisation and succession, fish behaviour, sediment deposition and transport, and biodiversity (Jaxion-Harm & Szedlmayer, 2015; Komyakova et al., 2019; Mousavi et al., 2015). The risk of attracting fish away from nearby reefs, for example, can be mitigated by maximising the distance of ARs from natural reefs (Bohnsack et al., 1997). There is also the potential for “ocean sprawl”, a term coined to describe the accumulation of multiple artificial submerged structures over a small area, which can change the characteristics of marine habitats and affect ecological assemblages, hydrodynamics and connectivity (Bishop et al., 2017). This effect can also be controlled by careful planning of how ARs and FADs are placed in relation to each other, to other artificial structures and to natural habitats (Bishop et al., 2017).

The literature presents a complex combination of ARs that are carefully designed and placed (Seaman et al., 2011), and those where design and/or placement prevented the achievement of their goals or resulted in negative environmental or socioeconomic negative impacts (Becker et al., 2018; Lemoine et al., 2019). Relevant articles stress the importance of planning ARs in conjunction with present and future users and stakeholders, and according to the best available understanding of the socioeconomic benefits and negative impacts of ARs (Gordon & Ditton, 1986). Modelling can serve to test hypothetical options for AR placement at varying distances from natural reefs to achieve specific fish attraction outcomes and to minimise the negative impact of redistributing fish biomass (Smith et al., 2015). It is clear from previous reviews and overviews that the most effective ARs are those where the design, placement and management are tailored to the local physical, ecological, social and economic situation (Baine, 2001). This is also a key recommendation provided by a previous review of the potential effects of ARs on the Marine Park (Pears & Williams, 2005).

The interaction between ARs and FADs with management objectives is discussed in Section 7.3.

5.2.2. Fish Aggregating Device Design and Placement

The design of anchored FADs is relatively simple, as it includes a predetermined set of essential components: an anchor, attachment lines, floats and, in most cases, attractants. The simplest FADs exclude attractants and mimic simple vessel moorings or buoys. Anchors can be large stones or rocks, as was common among early FADs in south-east Asia and the Mediterranean, but are currently most often concrete blocks. Attached to the anchor is light and durable polypropylene line, which is attached to floating buoys or other positively buoyant objects. Floats are usually at the surface but can be positioned in mid-water, or at both locations (Figure 7). Attractants are usually palm fronds or other organic material, but can also be made of plastic or rope netting (Dickson & Natividad, 2000).

FAD loss is one of the primary ecological and socioeconomic concerns associated with FADs and can occur due to a number of factors, including mooring rope failure caused by environmental forces, boat strike, inadequate buoyancy or insufficient anchor holding capacity (Shainee & Leira, 2011; Vogt, 2020). These are all issues that must be considered during the design and construction phase. When FADs are lost, many of the components fail to break down and can cause entanglement, ghost fishing and pollution; marine debris from FADs is now a global issue (Sinopoli et al., 2020; Vogt, 2020). Derelict FADs can travel long distances, as was the case with a FAD from NSW that was intercepted on the Reef in 2019, after travelling over 1800 km (L. Fernandes, pers. comm.).

Because anchored FADs are stationary, as opposed to drifting FADs, their placement requires a number of considerations. The planning required for the deployment of FADs as part of an integrated fisheries program is detailed in Anderson and Gates (1996) and requires considerations of existing fisheries and fisheries management, the state of local resources, pelagic species composition, environmental variables, and available resources for monitoring and management. If placed in an unfavourable location, a FAD may attract pelagic fish, but not aggregate them, and therefore fail in its fish catch enhancement objectives (Girard et al., 2004). Other negative impacts, such as the attraction and entanglement of turtles and cetaceans, may also depend on placement (MRAG, 2011). FAD placement is especially important when deploying networks of FADs (Bell et al., 2015), which tend to be more effective at aggregating fish than single FADs, but can also enhance the problems of overfishing if unregulated or under-regulated (Samples & Hollyer, 1989). There is also the question of whether fish recruiting to FADs anchored close to natural reefs reduce recruitment to the natural reef, or enhance it (Le et al., 2019). User conflict and congestion can also be exacerbated or mitigated depending on FAD placement (Firth et al., 2016). Currently, the tuna longline industry has expressed concern to the Queensland Government regarding a decision to proceed with the deployment of a network of recreational FADs in Commonwealth waters off south-east Queensland which overlap with commercial fishing grounds (Tuna Australia, 2021). The development of FAD programs to avoid the haphazard proliferation of FADs has been discussed since the early 1990s (Chapman et al., 2005; SPC, 1995).

Research about the effectiveness of FAD networks, as opposed to single FADs, focuses on the optimal placement of the FADs to maximise the retention of fish (usually tuna) within the network, in order to enhance capture rates (Filous et al., 2020). The documents describe methods such as acoustic telemetry to study the movements and residency times of tuna within the network (Holland et al., 2000), and the propensity for tuna to return to the network after they move away (Govinden et al., 2013). In the Pacific, FADs located in deeper water (>1,000 m) have been more successful at attracting yellowfin tuna than those closer to the reefs (which, depending on topography, could be as close as 6 km) (Filous et al., 2020). In Hawai'i, a distance of 18 km between FADs ensured that adult yellowfin tuna navigated directly between them and revisited the same FADs regularly over time (Brill et al., 1999). However, the technology advances to make FADs more effective for catching fish have outpaced the development of FAD management (Schneider et al., 2021). Management of the interaction between ARs and FADs are discussed in Section 7.3.

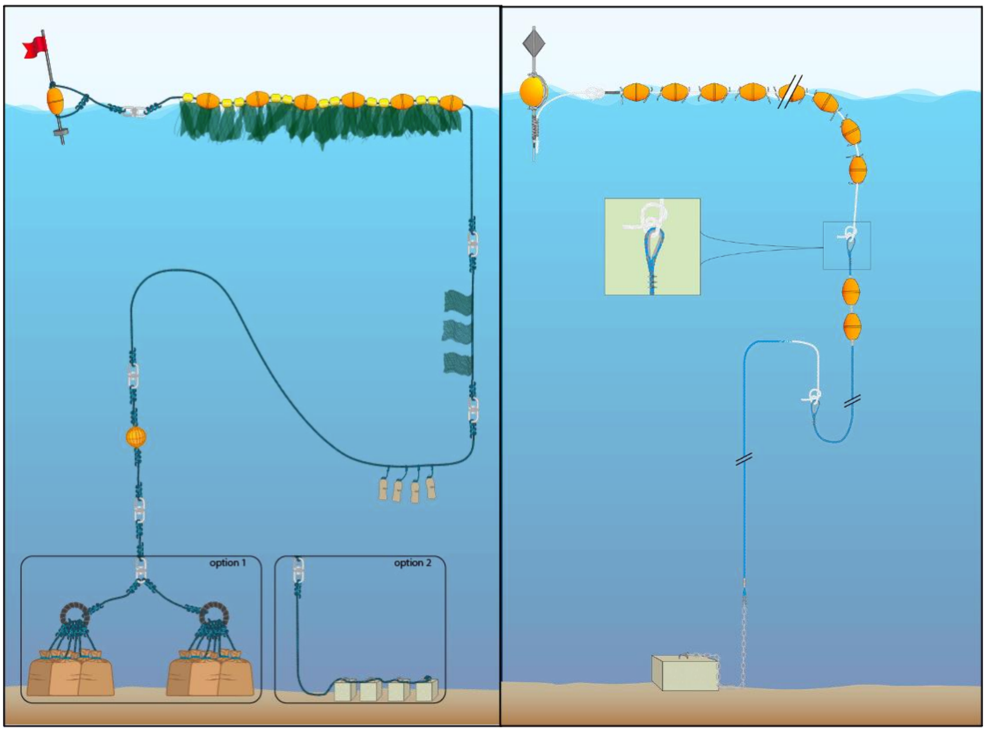

Figure 7 **Two examples of FAD designs used in the Pacific, using surface and mid-water attractants in Vanuatu (left) and buoys in French Polynesia (right). From Sokimi et al. (2020).**

6. THE ATTRACTION-PRODUCTION DEBATE

Throughout the literature, a recurring debate is whether ARs and FADs simply attract fish away from natural habitats or change the attributes of an area to effectively "produce" more fish. The goal of installing FADs is almost always fisheries-oriented, and as per the most common definition, the structures serve to attract and aggregate fish for easier capture. In contrast, the goal of AR deployment is often stated as "increasing fish production" or "enhancing habitat quality", with the view that the provision of this artificial habitat will produce, rather than simply attract, fish and other marine life (Baine, 2001). Efforts to address the attraction-production question have largely focused on measuring changes in fishery target species and comparing secondary production per unit area on ARs to natural reef habitats (Smith et al., 2016). There is consensus in the literature that FADs attract fish and do not contribute to production (Beverly et al., 2012), but the discussion concerning attraction or production around ARs is more complex. The most serious drawback associated with the attraction and aggregation of fish on FADs and ARs is the creation of "fishing traps", concentrating fishing pressure and risking overexploitation (Kasim, 2017).

FADs attract pelagic fish through a number of mechanisms, which vary depending on the species attracted (Table 6). The "shelter hypothesis" suggests that schools of small pelagic species hide from predators behind the FAD line, which confuses predatory fishes (Anderson, 1996; Anderson & Gates, 1996; SPC, 1995). The "orientation hypothesis" indicates that pelagic fishes use FADs to orient themselves in an otherwise featureless ocean (Holland, 1996). The "forage base hypothesis" states that FADs provide a base from which tunas travel to forage and return to for schooling and safety (Anderson, 1996; Sri & Kirubagaran, 2015). The "meeting point hypothesis" suggests that fish could make use of FADs to increase the chances of encounters between conspecifics, helping individuals to form larger schools (Josse et al., 2000; MMR, 2000; SPC, 1995). Finally, the "ecological trap hypothesis" indicates that pelagic fishes could become trapped within networks of FADs due to their strong associative behaviour (Robert et al., 2013). Tests of these hypotheses are few and largely inconclusive; the different hypotheses are not mutually exclusive and may operate in tandem. FADs themselves do not increase productivity; in fact, early literature stressed that FADs will "not attract fish where fish do not already occur" (SPC, 1995). Floating objects naturally collect around eddies and fronts that are natural productivity hotspots, and it is hypothesised that this has contributed to the evolution of tuna associating FADs with concentrations of food (Leroy et al., 2013).

Table 6 Attraction mechanisms of FADs

Hypothesis	Description
Shelter hypothesis	Schools of small pelagic species use the FAD line, which confuses predatory fishes, to hide from predators. (Anderson, 1996; Anderson & Gates, 1996; SPC, 1995).
Orientation hypothesis	Pelagic fishes use FADs to as orientation points in an otherwise featureless ocean (Holland, 1996).
Meeting point hypothesis	FADs increase the chances of encounters between conspecifics, helping individuals to form larger schools (Josse et al., 2000; MMR, 2000; SPC, 1995).

The argument for ARs contributing to the production of some targeted, "desirable" fish species assumes, in part, that habitat for those species is limiting (Bortone et al., 1997), and an increase in their preferred habitat leads to the settlement of organisms that would otherwise perish during their pelagic larval stage (Amaral et al., 2010; Özgül et al., 2019). Bohnsack (1989) conducted a review of about 100 peer-reviewed papers to conclude an increased production has been shown for habitat-limited, demersal, philopatric, territorial and obligatory reef species (Bohnsack, 1989; Folpp et al., 2020; Smith et al., 2016). Production can be inferred if large proportions of juveniles are recorded during AR surveys, and has been demonstrated for some high-value target species in the Gulf of Mexico (Streich et al., 2017a). Proponents also suggest that production has been demonstrated for site-attached species that dominate the ornamental fish trade (Wilson et al., 2001). The presence of artificial structures, such as shipwrecks, can increase concentrations of phytoplankton in an otherwise oligotrophic environment, which may, in turn, support higher production of higher-order organisms (dos Santos et al., 2010). The benefits of this concept were used by proponents in Japan through building “upwelling reefs”, which, when deployed at depths of 60-150 m, effectively led to changes in water flow and increased zooplankton concentrations throughout the water column above the structure (Okano et al., 2011).

Fish attraction to ARs has been demonstrated in situations where exploitation rates are high both on ARs and nearby natural reefs; and for recruitment-limited (as opposed to habitat-limited), pelagic or semi-pelagic, highly mobile, partially reef-dependent and opportunistic reef species (Bohnsack, 1989). Fish attraction is more likely to occur on ARs with some connectivity to natural reefs than isolated ARs, which may be more dependent on the development of primary producer communities in order to then attract fish. The dominance of pelagic species (Bortone et al., 1997) and a relatively low abundance of smaller adult size classes (Bayle Sempere et al., 2001) recorded on ARs are both used as evidence of attraction in the literature.

Smith et al. (2016) compared biomass flux to standing stock biomass at an AR off Sydney, Australia. The annual flux of biomass across the AR was ~380 times greater than the standing stock biomass, meaning that it was mostly made up of fishes attracted from elsewhere. The authors indicated that this was proof that production was minimal compared with attraction, which made the fish visiting the AR vulnerable to overfishing (Smith et al., 2016). Distinguishing new production of target fish from a redistribution of existing production (attraction) requires an understanding of surrounding habitats and fish movements at a range of spatial and temporal scales, and few studies endeavour to measure these factors (Brickhill et al., 2005; Smith et al., 2016). Measuring these factors on fished reefs is especially difficult, as fishing mortality confounds the potential effects of secondary production, whereby the fish stock may be enhanced through production, but may be in decline through fishing at the same time (Roa-Ureta et al., 2019).

Critically, in the case of ARs, much of the available literature indicates that production and attraction may not be mutually exclusive (Bohnsack, 1989). In fact, some studies report evidence for both processes occurring at the same AR complex. Syc and Szedlmayer (2012) interpreted a positive correlation between the mean age of red snapper (*Lutjanus campechanus*) caught near an AR and the age of the AR as evidence of enhanced production, and explained the presence of fish older than the AR as evidence of increased attraction. They did not, however, compare their study ARs (n = 40) to natural reefs, making it difficult to ascertain how their size and age structure data might compare with natural populations of red snapper. Simon et al. (2011) compared two natural reefs and two ARs, and found high recruit abundances of the tomtate (*Haemulon aurolineatum*) on both the natural reefs and the ARs, an indication that production is occurring. However, they also recorded high concentrations of adult predatory demersal fishes (*Mycteroperca* spp. and *Lutjanus* spp.) that were less abundant on comparable natural reefs, an indication of attraction. Attraction and production could occur in tandem, with aggregations of attracted fishes creating a biogeochemical hotspot by locally increasing nutrients through their waste products, which could, in turn, increase production (Babcock et al., 2020; Cheung et al., 2010; Layman et al., 2016).

The attraction-production debate is focused on how these mechanisms may provide fishery benefits in the form of higher and more accessible target fish biomass. In the context of managing the Marine Park, the wider implications of ARs and FADs need to be understood. Available information on the benefits and negative impacts of ARs and FADs, as they relate specifically to the objects of GBRMP Act and the values of the region, is reviewed in the Sections below.

7. ARTIFICIAL REEFS, FISH AGGREGATING DEVICES AND THE MARINE PARK ACT

The following Sections discuss the benefits and negative impacts of ARs and anchored FADs, as described in the relevant literature, in relation to the individual objects of the Marine Park Act (Table 1). The quality of research described in the literature varied widely; 30 haphazardly chosen studies revealed few consistent patterns with regard to sampling design (from opportunistic sampling on a single AR or FAD to fully orthogonal designs) or replication (from one AR or FAD to 26). Two-thirds of the sampled studies did not use controls, and 13 studies (43 percent) described a single sampling period. Therefore, where relevant, we offer some detail on the study design used to arrive at the various conclusions.

7.1. Protection of Values of the Region

The primary object of the Marine Park Act is to "*provide for the long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region*". Most of the literature on FADs and ARs was focused on aspects of biology and ecology relevant to this object, especially papers that compared ecological communities on ARs to those of nearby natural habitats. In fact, 264 documents were found to be relevant to the primary object of the Marine Park Act, and a further 108 documents presented topics that were relevant to the primary object in combination with other objects (e.g., papers that studied aspects of biodiversity and recreational use). Less than half of these papers provided an assessment of benefits and/or negative impacts of ARs and FADs in relation to environment, biodiversity and heritage protection.

A summary table is provided at the start of each sub-section described below for a quick reference guide of the key benefits and negative impacts for each value.

7.1.1. Biodiversity

Biodiversity values, as defined in GBRMPA (2019), are "*the variety of all living things, including plants, animals and microbes (and their genetic information). Biodiversity forms an important component of natural heritage and is integral to ecosystem resilience*." These values are also articulated in Lucas et al. (1997) in listing the outstanding universal value of the World Heritage Area. Here, we review the effects of ARs and FADs on aspects of marine biodiversity – primarily plants and animals – and consider how these structures may affect the first object of the Marine Park Act in relation to biodiversity values. Evidence of how ARs and FADs may affect threatened species is presented in Section 7.4.

Summary	
AR	**Benefits** > Add structural complexity to otherwise barren or degraded habitat, and can sometimes mimic natural reefs > Can be designed to enhance populations of species of interest > Enhanced biodiversity, unique communities, enhanced fish density and/or biomass, enhanced invertebrate density and benthic cover, infauna and meiofauna > Enhanced benthic and fish recruitment > Divert user pressure from natural habitats or protect habitats from trawling
AR	**Negative Impacts** > Risk of overfishing; unlikely to benefit heavily exploited or overfished species without extra management; AR effect undermined by fishing pressure

Summary	
	> Replace soft sediment habitats and associated species assemblages; habitat fragmentation > ARs are not surrogates for natural reefs > Alter fish communities on nearby reefs and divert fish arriving from inshore nursery habitats from settling on natural reefs > Destruction of habitat below and sometimes adjacent to the AR footprint; benthic and pelagic 'ecological halo' or 'footprint' of the AR can be up to 15 times the area of the actual reef > Corridors or stepping-stones for invasive species > Lower fitness of fish; modified fish behaviour > Increased catch rates of juveniles and small individuals.
FAD	**Benefits** > Act as nursery structures; enhanced recruitment to nearby reefs > Increased density and biomass of fish > Reduced pressure on coastal ecosystems
FAD	**Negative Impacts** > Attraction and aggregation of pelagic fish from other habitats; increased risk of overfishing, including disproportionate catch of juveniles > Change in fish feeding behaviour > Fad loss, ghost fishing; pollution; marine debris > Species become dependent on the FADs > Unknown bycatch issues > Entanglement of marine fauna

Benefits of Artificial Reefs to Biodiversity Values

The documented benefits of ARs for enhancing local biodiversity are most evident in studies where the structures are placed in areas naturally lacking in visible structure above the seabed, or where natural habitats have been degraded and their three-dimensional complexity reduced (Delgadillo & Toro, 2018; Hylkema et al., 2020; Kasim, 2017; Suyatna et al., 2019). The consideration of AR effects in the context of reef restoration is beyond the scope of this report, but has been extensively reviewed in Boström-Einarsson et al. (2020). However, it is worth noting that the effects of artificial structures placed on degraded habitat that were more complex in the past may be similar for many reef species as structures placed where reefs or complex habitats are naturally lacking (Kotb, 2013). Puspasari et al. (2020), in a review of AR literature from studies conducted around Indonesia, reported that most studies had found increases in reef health indicators such as coral cover and fish species richness, which, they argued, are expected to promote reef resilience.

In cases of placement of structures with the intention of rehabilitating existing or destroyed habitat, it has been suggested that ARs can successfully increase the local biodiversity of sessile and mobile invertebrate and fish assemblages (Boerseth, 2016; Giansante et al., 2010). While the growth of sessile invertebrates is a sign of production, in most cases it remains unclear whether increased biomass or species richness of fishes on ARs is due to attraction or production (see Chapter 6). A recent study in a subtropical estuary provides a rare test of these mechanisms that includes measuring changes not just on the ARs, but on nearby rocky reefs (Folpp et al., 2020). Using a sampling design that included three estuaries and multiple ARs and natural reefs in each, they found that the abundance of sea breams (Sparidae) increased on both ARs and natural rocky reefs, and total fish abundance increased at ARs with no evidence of change at nearby natural rocky-reef sites (Folpp et al., 2020). They suggest that where fish are limited by the availability of hard substrate, increasing their preferred habitat leads to greater production of fish abundance.

A number of studies show that ARs can successfully mimic or even exceed the attributes of natural habitats in temperate and subtropical regions (Jessee et al., 1985; Logan & Lowe, 2018; Wu et al., 2019). Sufficiently large ARs can supply equivalent resources (e.g. food and shelter) to associated fishes to those provided by natural habitats, and therefore adequately meet fish life-history demands (Granneman & Steele, 2014; Logan & Lowe, 2019) and support similar fish assemblages to natural reefs (Charbonnel & Bachet, 2011; Granneman & Steele, 2015). Even when benthic assemblages on ARs do not mimic those on natural reefs, Carvalho et al. (2013) argue that the presence of ARs contribute to a regional increase in biodiversity. They show that ARs host different assemblages of native species, with a 50 per cent overlap in taxa between ARs and natural reefs, and argue that the presence of species exclusively associated with artificial structures may effectively contribute to an increase in the regional species pool (Carvalho et al., 2013). Studies that describe ARs that fulfil goals of enhancing marine life to a degree comparable with natural reefs refer to an individual large AR covering over 1 km^2 (Jessee et al., 1985; Logan & Lowe, 2018) or extensive AR complexes covering thousands to millions of cubic metres and including multiple module designs (Charbonnel & Bachet, 2011; Wu et al., 2019). The performance of smaller and/ or single AR modules in providing habitat equivalent to natural reefs is more ambiguous (see Negative impacts sub-section below).

A common goal of ARs is to restore depleted populations of exploited species; this can be successful, especially for species with high site fidelity (D'Anna et al., 2011; Herbig & Szedlmayer, 2016). However, increased fishing effort on ARs can rapidly negate any of the reported benefits (see Negative impacts sub-section below); some authors admit that ARs work best to increase target species when coupled with extra management (Collins et al., 2015). In the Gulf of Mexico, some studies even discuss the benefits of keeping at least some ARs “hidden” from the fishing community so that they may serve as refuges for exploited species (Addis et al., 2016).

Fish assemblages around both artificial and natural reefs are usually dominated by planktivorous and omnivorous species (Becker et al., 2019). Planktivores can be an important component of marine AR fish assemblages, as they provide an important pathway linking low trophic levels with higher-order exploited species (Champion et al., 2015). Large pelagic and reef-associated predators have been shown to increase on ARs, due to either attraction, production or both (Paxton et al., 2020; Sanguansil et al., 2018). However, while much of the literature points to an increase in reef-associated and pelagic fishes directly on and around ARs, the effect is thought to be highly localised, with even mobile pelagic species not detected >30 m from the AR (Scott et al., 2015).

Negative Impacts of Artificial Reefs on Biodiversity Values

On the Reef, ARs are currently primarily comprised of accidentally sunken ships and airplanes. Other artificial deployed subsea structures on the Reef include underwater artworks and a small number of coral nurseries; very little research exists on their effects on the Reef’s biodiversity. There is concern among Australian researchers that there is insufficient evidence to rule out over-exploitation of target species through use of ARs (Hardiman & Burgin, 2010; Pears & Williams, 2005). In South Australia, where there was initially the largest number of ARs, ARs were no longer considered a suitable mechanism for fisheries enhancement by 2010, due in part to evidence that target species were more vulnerable to overfishing (Hardiman & Burgin, 2010). Evidence of ARs where attraction is the primary mechanism for increasing fish populations underpins the concern that fish communities on ARs are vulnerable to overexploitation, which has implications for fish stocks more generally (Bayle Sempere et al., 2001; Bortone et al., 1997; Feary et al., 2011).

Information on how the deployment of ARs affect nearby natural reefs is largely lacking (but see Folpp et al., 2020), because studies that include comparisons between ARs and natural reefs assume that the natural reef will continue to behave "naturally" (e.g. Mohd et al., 2013; Wu et al., 2019; Zhang et al., 2015) and therefore offer a meaningful reference point for comparison (Carr & Hixon, 1997). This is surprising, given that one of the key concerns about ARs is the reduction of fish on nearby natural reefs (e.g. Figure 8). Hammond et al. (2020) provided a rare comparison of a newly installed AR with three control sites (although two of the controls were a breakwater and a shipwreck, and the third was the bay itself as there were no natural reefs available for comparison), both before and at several times after the AR installation at Port Coogee in Western Australia. The four sites were sampled once before and three times (3, 11 and 20 months) after the AR installation. Fish species richness and abundance increased at the AR site and remained stable at the other sites, indicating that the AR was not causing a net migration of fish away from pre-existing artificial structures or the non-reef habitats of the bay.

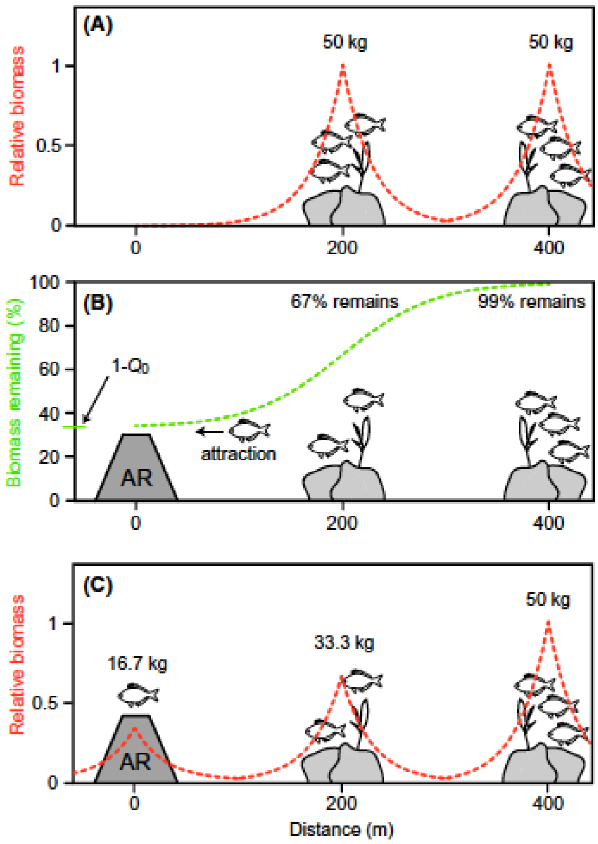

Figure 8 A hypothetical example illustrating two potential mathematical functions that drive the distribution and attraction of fish biomass in Smith et al. (2015). (A) two natural reefs (NRs) before AR deployment with equal biomasses of fish, distributed with distance from their natural reef (red line); (B) an AR is deployed and attraction occurs according to a logistic function; the closer an NR is to the AR, the more attraction occurs (i.e., the less biomass remains on the NR), to a maximum attraction of when distance approaches zero; (C) the attracted fish biomass is then distributed around the AR according to the exponential function (red line). In this example, 100 kg of fish is in the system and 15 percent is redistributed due to attraction to the AR.

Many of the studies outlining the biodiversity benefits of ARs (e.g., increased production, fish abundance, species richness of fishes and invertebrates) came with caveats, usually about design, placement, age and protection of the AR from unregulated fishing (Charbonnel & Bachet, 2011; Granneman & Steele, 2015; Le Diréach et al., 2015). Examples exist of ARs failing to affect fish abundance due to unfavourable placement or unsuitable design, such as the lack of small holes for the settlement of recruiting fishes (Komyakova & Swearer, 2019). A comparison of habitat-forming kelp development on artificial and natural temperate reefs found that canopy-forming seaweeds tended not to colonise the AR as readily as natural habitats, and questioned whether the 10 years since AR deployment were sufficient to encourage a climax community (Tsiamis et al., 2020). A 16-year study comparing concrete block reefs with natural reefs in the south of Portugal found that the ARs had distinct epibenthic assemblages with different composition, structure and trophic function than those found on natural reefs (Carvalho et al., 2013). Comparisons of benthic assemblages on shipwrecks and natural habitats nearby caution that these assemblages differ significantly, even after as long as a century, and cannot be seen as adequate replacement for damaged or degraded habitats (Hiscock et al., 2010).

Other studies found that fish assemblages on ARs did not mimic those on natural reefs (Kilfoyle et al., 2013), and tended to host greater abundances of opportunistic, generalist and pelagic species; most of these studies were simple comparisons that did not specify whether the observed AR communities had developed as a result of production or attraction (Becker et al., 2017; Bortone et al., 1997; Mills et al., 2017; Streich et al., 2017b). The settlement of fish onto natural or artificial habitat can be subject to species-specific habitat preferences (Komyakova & Swearer, 2019). Where habitat is not limited (e.g. where there are natural reefs in the vicinity), larvae may be attracted away from higher-quality natural habitat to settle onto ARs, where some species experience lower fitness advantages (Komyakova & Swearer, 2019). Fecundity and reproductive output, for instance, was found to be much lower for red snapper *Lutjanus campechanus* on ARs than on natural reefs; this was thought to be due to the higher densities of females on ARs leading to more intense competition for resources, impacting fertility (Glenn et al., 2017; Kulaw et al., 2017). Furthermore, ARs designed to increase the abundance of heavily exploited species were unlikely to fulfil their role without extra management or protection (Altizer, 2013; Bohnsack, 1989; Pascaline et al., 2011).

Evidence from the remote Pacific reefs of Palmyra and Kingman indicates the possible negative impacts of using vessels as ARs because they can release hydrocarbons and other pollutants into the water, and can promote the establishment of invasive species overgrowing the natural benthic communities (Carter et al., 2019; Davis et al., 2018; Work et al., 2018). Multiple studies also caution against "ocean sprawl", where artificial structures proliferate and alter marine ecosystems over large areas (Bishop et al., 2017). For example, the northern Gulf of Mexico had over 4000 artificial structures by 2016 in an area just over 1 Million km^2 (Schulze et al., 2020). Soft-sediment communities are destroyed directly beneath the ARs (Bishop et al., 2017), and incorrect placement, or inadequately secure ARs (e.g. piles of tires), can result in movement of AR components, impacting other reef and non-reef habitats nearby (Cabral & Primeau, 2015). Marine sediments and the pelagic habitat above them can be rich in biodiversity, and artificial structures can alter the composition and abundance of sediment-dependent taxa, including microbes, invertebrates, and benthic-feeding fishes (Heery et al., 2017). However, marine sediment habitats are typically extensive compared to reef habitats and the size and scale of ARs.

Benefits and negative impacts of Fish Aggregating Devices on Biodiversity Values

The effects of FADs on biodiversity have received little attention, given their clear goal of fish attraction and aggregation specifically to make them easier to catch. There is ample evidence of increased density and biomass of pelagic fishes around FADs, and of the propensity of FADs to attract juveniles of certain species (Andaloro et al., 2007; Bailey et al., 2012). Depending on placement, they can host over 300 species of fish (Schraader, 2013), although most studies indicate that they tend to attract a small number of pelagic species (Rochman et al., 2019).

It is often stated that the biodiversity conservation benefit of FADs may be indirect, in that they reduce fishing pressure on reef-associated fishes by diverting catches to pelagic fishes. However, although most of the literature on Pacific Island FADs state, as a goal or benefit of FAD deployment, the reduction of fishing pressure on coastal or reef resources, no data were presented on changes in catch rates of reef and pelagic fishes as a result of FAD deployment (Albert et al., 2014; Beverly et al., 2012; de Sylva, 1982; Rajeswari, 2012). Early research in La Réunion showed that the expected reduction of fishing pressure on demersal species was not achieved through the deployment of FADs, with no significant drop in demersal landings despite a large increase in pelagic species caught (Detolle et al., 1998). More recent studies in the Solomon Islands, Kenya and Timor-Leste showed an increase in the catch of pelagic species after FAD deployment, but either did not measure corresponding trends in the catch of reef species (Albert et al., 2014; Mbaru et al., 2018), or showed that reef catch per unit effort did not change as a result of FAD deployment (Tilley et al., 2019). Bell et al. (2015) offer a sampling design to measure whether FAD deployment leads to a reduction in fishing pressure on reefs, but no study was found that has put this method to use.

Some studies reported that the use of FADs by artisanal fishers was inversely proportional to the availability of nearshore reef resources, which is likely to confound the results of fisheries studies that neglect to take reef fishing rates and the state of reef resources into account (Albert et al., 2015). Recent research in the Caribbean argued (although this was not measured) that the assumption FADs will relieve reef fishing pressure is unachievable without simultaneous efforts to improve reef fisheries management, as small-scale fishers employ multiple fishing methods which vary depending on weather, accessibility and market demand (Wirth & Warren, 2019).

The success rate of FADs in attracting and aggregating pelagic fish is also dependent on elements of FAD construction (Altinagac et al., 2010; Kawamura et al., 1996), seasonality (Andaloro et al., 2007), environmental conditions (de Sylva, 1982; Folpp & Lowry, 2006), their position in relation to major hydrodynamic features (Doray et al., 2009) and the interaction between FADs and the attraction effect of nearby islands or reefs (Dagorn et al., 2007).

The most ubiquitous negative impact of FADs is the increased risk of overexploitation of the fish species they attract and aggregate, and the concomitant depletion of those species (Sala, 2017). Unless FADs are installed in protected areas, the nursery effect can be especially detrimental, as it leads to overfishing of juveniles (Aprieto, 1991; Bailey et al., 2012). The removal of juveniles from a population leads to future declines or failure in recruitment (Najmudeen & Sathiadhas, 2008).

FADs have been shown to affect fish behaviour and population dynamics, including changes in diet and predator-prey relationships (Sinopoli et al., 2015), especially in areas with higher densities of anchored FADs (Perez et al., 2020). This has the potential to change the structure of pelagic food webs and disrupt movement, foraging and migration patterns (see sub-section 7.1.2 for further discussion). The foraging behaviour of some seabird species has also been shown to be affected by FADs (Jaquemet et al., 2004). In addition, bycatch rates of sharks and catch and entanglement threats to turtles are higher around FADs than in comparable areas without FADs (Anderson et al., 2012; Leroy et al., 2013).

7.1.2. Ecosystem health

Indicators of marine ecosystem health are usually physical (e.g. currents, freshwater inputs, light, temperature, sea level), chemical (salinity, pH, nutrient cycling) and ecological processes (primary production, food-web related processes, recruitment, competition, connectivity), as well as disease and introduced or invasive species (GBRMPA, 2019b). Sound can also form an important part of the physical environment, especially in reef systems, where many species use sound to navigate and to guide settlement of planktonic larvae onto reef habitats (Vermeij et al., 2010).

Research on FADs focuses primarily on the interaction between physical and chemical processes and the ability of FADs to attract fish. There is also research on trophic interactions between species around FADs, recruitment to FADs and connectivity between FADs. Research on ARs cover a broader range of ecosystem health indicators, including effects of ARs on hydrodynamics, nutrient cycling, introduced species and a range of ecological processes. Because many studies use these indicators to discuss the effects of FADs and ARs on habitats and species, their relevance to ecosystem health may overlap with their relevance to aspects of biodiversity (see sub-section 5.2.1).

Summary

AR **Benefits**
- Enhanced primary and/or secondary production
- Improved connectivity
- Increased benthic recruitment
- Divert user pressure from natural habitats or protect habitats from trawling

AR **Negative Impacts**
- Lack of evidence for recruitment and acting as nursery habitat, more evidence for attraction
- Risk of overfishing; unlikely to benefit heavily exploited or overfished species without extra management; AR effect undermined by fishing pressure; reduction in overall ecosystem health from declining populations
- Replace soft sediment habitats and associated species assemblages; habitat fragmentation
- ARs are not surrogates for natural reefs
- Destruction of habitat below, and sometimes adjacent to, the AR footprint; benthic and pelagic ‘ecological halo’ or ‘footprint’ of the AR can be up to 15 times the area of the actual reef
- Can divert fish arriving from inshore nursery habitats from settling on natural reefs
- Alter hydrodynamics, sound, sediment and water quality, including nutrient enrichment, chemical contamination and altered microbial communities and processes
- Corridors or stepping-stones for invasive species
- Barriers to the movement of organisms, material and energy

FAD **Benefits**
- Enhanced production
- Act as nursery structures; enhanced recruitment to nearby reefs
- Reduced fishing pressure on coastal ecosystems

Summary

FAD **Negative Impacts**

- Attraction and aggregation of pelagic fish from other habitats
- Assist range shifts
- Alter pelagic environments
- Fad loss, Ghost fishing; pollution; marine debris

Benefits of Artificial Reefs for Ecosystem Health Values

The most often cited positive effect of ARs on ecosystem health indicators is increased primary and/or secondary production (Cresson et al., 2014; Okano et al., 2011). Increasing the habitat complexity of an area has been shown to lead to increased productivity through benthic colonisation and succession (Liu et al., 2017; Rouanet et al., 2013; Toledo et al., 2020), either natural or assisted by the transplantation of foundation species such as kelp or coral onto the structures (Fariñas-Franco & Roberts, 2014). Although not within the scope of this review, a large proportion of the literature on ARs discusses the use of artificial structures as a means to restore previously damaged hard substrate such as degraded reef areas (Blakeway et al., 2013; Puspasari et al., 2020).

In suitable habitats and favourable locations, ARs can concentrate nutrients in the water column, contributing to growth of benthic and planktonic biomass, which form the basis for pelagic food webs (Alam et al., 2020; Xu et al., 2019; Yu et al., 2015). This can occur through nutrient cycling generated by waste from fish attracted to the AR (Alam et al., 2020), algal growth and detritus produced by benthic animals colonising the AR (Xu et al., 2019) or changes in hydrodynamics caused by the physical structure of the AR that can concentrate phytoplankton (dos Santos et al., 2010) or, if large enough, create localised nutrient upwelling (Ito, 2011). This provides resources for juvenile (Streich et al., 2017a) and adult reef-associated and pelagic fishes (Hammond et al., 2020).

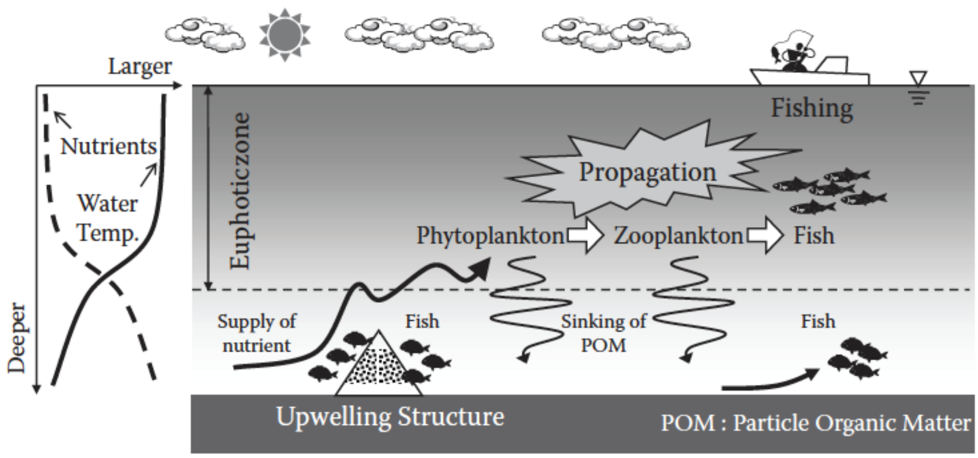

Figure 9 **The mechanism by which ARs are thought to promote upwelling, used by proponents in Japan. Reproduced from Ito (2011).**

A number of countries employ ARs specifically to deter trawling, reducing human disturbance to the seabed (Ali, 2004). This can be highly effective in aiding the recovery of biodiversity and ecosystem health where trawling would otherwise occur. A 16-year study comparing two large continental shelf areas (one where trawling was banned and one where it continued) of the Cantabrian Sea before and after the deployment of dozens of ARs (in both areas) measured an increase in sessile and mobile invertebrates, biomass and species richness of fish and the abundance of large fish as a result of the trawling ban (Serrano et al., 2011).

Some studies on ARs measured growth rates and condition of fishes attracted to ARs to be equal to that of natural reefs and have also shown that fish populations can develop higher site fidelity to ARs than to nearby natural reefs (Becker et al., 2019; Keller et al., 2017). Species that travel from coastal nursery grounds to offshore reefs during different stages of their life cycles may benefit from improved connectivity, whereby ARs provide “stepping stones” between distant reef patches (Le et al., 2019). The reduced flow and sediment accumulation around ARs can result in an increase in meiofauna and soft-bottom macrofauna, but these effects are usually highly localised (Magro et al., 2017; Yang et al., 2019).

Negative impacts of Artificial Reefs on Ecosystem Health Values

A recent review on the negative impacts of artificial structures on soft-sediment ecosystems determined that the spatial scale of the physical, chemical and ecological influence of ARs can be 10s to 100s of meters beyond the boundary of the physical AR footprint (Heery et al., 2017). Ocean sprawl (see sub-section 0) can alter the overall habitat, to the point of forming barriers or diversions to movement for some organisms, creating new stepping-stones for other organisms and changing predator-prey interactions at multiple scales (Bishop et al., 2017). Additionally, both on the subtropical USA continental shelf and in the Mediterranean, it was found that ARs aid in cultivating more tropical habitats, as many warm-water species appeared to favour artificial over natural habitats (Paxton et al., 2019). Where species’ ranges are limited by the availability of hard substrate, ARs can facilitate range extensions, which, in a changing climate, could have both positive and negative repercussions (Coolen et al., 2015).

A major concern in the literature is the role of ARs in facilitating the spread of invasive and non-native species (De Mesel et al., 2015; Sheehy & Vik, 2010). Where soft-sediment habitats can serve as a barrier to dispersal to non-native species, ARs can effectively serve as stepping-stones for these same species (Bieler et al., 2017; Sheehy & Vik, 2010). However, whether every non-native species colonising ARs could replace native species on nearby natural habitat following disturbance events remains unknown (Schulze et al., 2020). Some documented and problematic invasions in the Caribbean and Gulf of Mexico, assisted at least in part by ARs, include the Indo-Pacific lionfish *Pterois volitans* and *Pterois miles* (Dahl et al., 2019), the regal demoiselle *Neopomacentrus cyanomos*, *Tubastrea* spp. cup corals, acorn barnacles, the colonial tunicate *Didemnum perlucidum* (Bieler et al., 2017; Schulze et al., 2020).

The negative impacts of ARs placed on soft sediments can be direct, through the displacement of flora and fauna by their foundations (see sub-section 7.1.1), and indirect, by altering key physical, chemical, and biotic parameters that influence waters and sediments beyond the immediate footprint of the structure (Heery et al., 2017). The mechanisms driving effects from artificial structures include direct smothering of habitats under the AR footprint, habitat degradation, modification of sound and light conditions, hydrodynamic changes, organic enrichment and material fluxes, contamination, and altered biotic interactions (Heery et al., 2017; Shu et al., 2021). A study on bioturbation holes in sediments surrounding shipwrecks on the Reef indicates that the ecological influence of the wrecks on the seabed can extend over an area 10 times that of the wreck itself (Stieglitz, 2013). This “halo” effect is also possible in the pelagic and reef habitats surrounding the AR (Reeds et al., 2018); the propensity for ARs to attract higher predators may increase predation rates on surrounding habitats, including natural reefs (Simon et al., 2011).

ARs have also altered the microtopography and ripple effects of the sediment by affecting local hydrodynamics (Ahmed et al., 2016; Costa et al., 2014), causing localised scour and a coarsening of sediments (Ambrose & Anderson, 1990; Raineault et al., 2013) or an accumulation of fine sediment where water flow is reduced (Zalmon et al., 2014). Microbial processes can also be affected; for example, shipwrecks tend to host unique microbial communities associated with the oxidisation of iron (Price et al., 2020). The effect on surrounding natural habitats of introducing novel microbes is unknown.

ARs that contribute to production may result in local nutrient enrichment (Babcock et al., 2020; Chen & Chen, 2020) from changes to the physical environment and through the waste products of aggregating fish (Layman et al., 2016), which may or may not benefit surrounding ecosystems (Heery et al., 2017). Seagrass beds in oligotrophic environments may benefit from extra organic nutrients (Layman et al., 2013), but in other areas this may lead to oxygen depletion (Rouse et al., 2020) and changes to pH, dissolved oxygen, salinity, chemical oxygen demand, inorganic nitrogen, chlorophyll-a and suspended particulate organic matter in surrounding seawater (Babcock et al., 2020; Chen & Chen, 2020). Additionally, some materials used to construct the ARs (e.g., tires, coal ash, shipwrecks) can leach contaminants into surrounding sediments, which then may bioaccumulate in higher trophic levels (Mohamad et al., 2016; Renzi et al., 2017).

It is plausible that ARs may also change the soundscape of marine habitats, from interrupting the natural movement and sound of, biotic activity within the AR and from increased boat noise as the human use patterns in the general area change to take advantage of the AR. Sound is both useful, in that it can guide adult and larval fish to natural reefs or ARs across soft sediment or pelagic habitats (Simpson et al., 2005; Vermeij et al., 2010), and detrimental, as human noise has been shown to disrupt biological interactions (Holles et al., 2013). How sound may change as a result of AR deployment is currently unknown, but would probably include a combination of the sounds generated by the AR (as opposed to a soft sediment soundscape), and the sounds of motorised vessels using the AR.

Benefits and negative impacts of Fish Aggregating Devices on Ecosystem Health Values

Ecosystem health effects of anchored FADs are likely to include marine debris from lost FADs, the localised increase in productivity, increased recruitment of some fish species, altered connectivity pathways and localised changes in trophic structure. The ecosystem health effects of FADs considered in the literature primarily pertain to the negative impacts of drifting FADs used by industrial tuna fisheries (Dagorn et al., 2012). Even when ecological negative impacts of FADs are discussed, they relate to negative impacts on particular species and populations, rather than the properties of the ecosystem (see sub-section 0). A concern about drifting FADs is that they might create new areas with concentrations of floating objects, beyond natural areas around eddies or fronts where concentrations of natural floating objects already occur. A test of this hypothesis in the Indian Ocean found it not to be true; instead, the properties of drifting FADs mean that they also accumulate in areas where natural drifting objects aggregate (Dagorn et al., 2012). In this sense, anchored FADs may have a greater negative impact than drifting FADs, as they are not entrained by currents and effectively do create new areas with floating objects that did not previously exist.

In the early 1980s, 80 per cent of anchored FADs deployed in Pacific Island countries were lost within the first three years of deployment (Boy & Smith, 1984); approximately 1.6 million FADs were lost in the Mediterranean Sea alone between 1961 and 2017 (Sinopoli et al., 2020). Lost FADs have been known to entangle marine life, smother benthic communities and pollute shorelines (Figure 10). An investigation of marine debris composition on the seabed in Malta's EEZ revealed that about 83 per cent of the total litter was composed of items related to anchored FAD fisheries (Consoli et al., 2020). The European Commission stated that 27 per cent of plastic material in marine waters, globally, is from abandoned, lost or discarded fishing gear, which includes FADs (European Commission 2018).

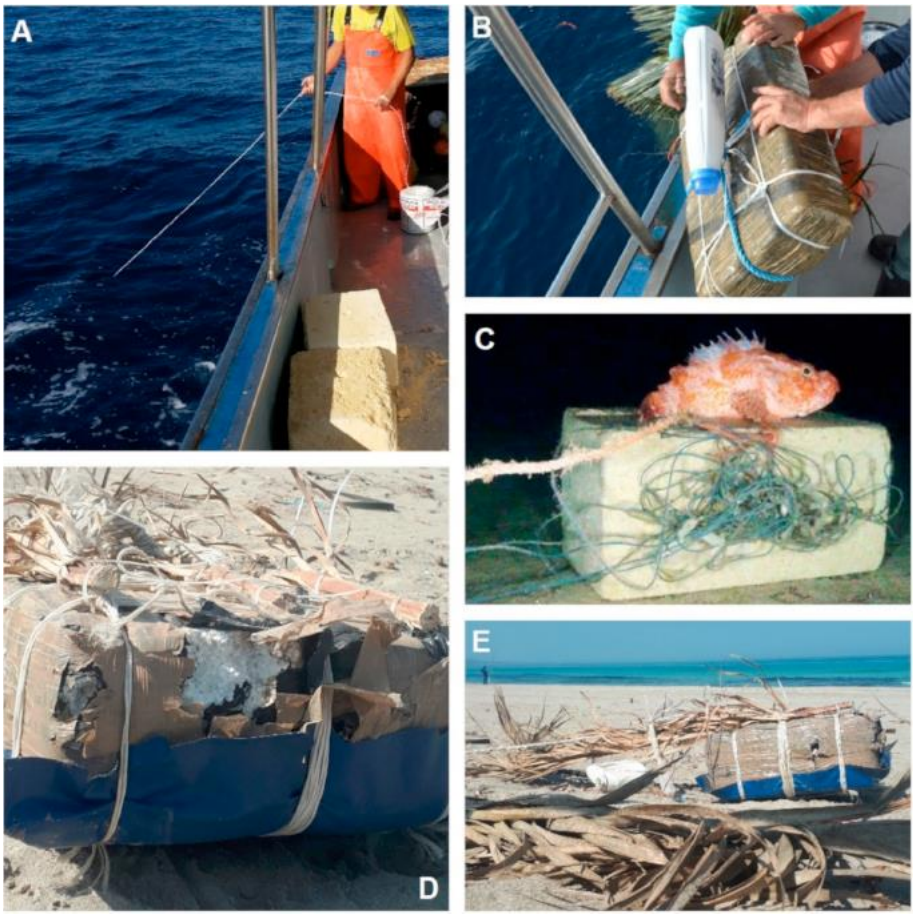

Figure 10 **FAD components and litter: A) polyethylene anchor cables and B) floating structures during their deployment; C) limestone anchor slab with synthetic ropes found in Maltese waters; D) and E) beached floating parts (polystyrene slabs, palm leaves, plastic bottles) found on the Sicilian coast. Reproduced from Sinopoli et al. (2020)**

FADs are deployed into natural pelagic habitats and can disrupt the movements and migrations of highly mobile species, serving as “ecological traps” (but see Doray et al., 2004). Tuna can sense FADs, either through chemotaxic (Dempster & Kingsford, 2003) or auditory processes (Babaran et al., 2008), from between 400 m and 10 km away (Dempster & Kingsford, 2003; Ghazali et al., 2013); each FAD therefore creates an ecological footprint of at least that radius with altered productivity, chemistry and sound. Once around the FAD, tuna trophic structure and feeding behaviour can be altered (Babaran et al., 2009). The feeding success of bigeye tuna (*Thunnus obesus*) and small size classes (<75 cm fork length) of yellowfin tuna (*Thunnus albacares*) was found to be significantly lower around a network of FADs (n was not reported) in Hawai’i, than over a seamount site or at data buoy sites (n=4) in the open ocean (Holland et al., 2003). Importantly, a modelling study indicated that tuna associated with FADs anchored near coral reefs consumed higher proportions of reef prey (Fernandez & Allain, 2010). FADs can serve as nursery structures (Deudero et al., 1999), and when coupled with natural reefs or ARs, the subsea structure can either enhance recruitment to the reefs nearby (Beets, 1989), or entrap recruits, preventing settlement on natural hard substrata (Le et al., 2019) and making the recruits vulnerable to fishing, either as by-catch or, in many developing countries, as part of the catch (Morales-Nin et al., 2000).

7.1.3. Heritage

Summary

AR/FAD	Benefits/negative impacts
	> Provide benefits to the education about historic heritage > Damage existing Indigenous or non-Indigenous cultural heritage values > Divers can cause damage to historic wrecks, degrading their heritage value > Unknown effect of ARs and FADs on Indigenous values; no information in the literature

Aboriginal and Torres Strait Islander peoples have lived in the region and have nurtured a close connection with their land and sea country for tens of thousands of years (Dale et al 2018, GBRMPA 2019a). People of Aboriginal and Torres Strait Islander descent who have spiritual or cultural affiliations with a site or area within the Marine Park or hold native title with that site or area are entitled to undertake customary or traditional activities and are known as Traditional Owners. Despite a history of genocide, dispossession and displacement, remaining cultural knowledge is rich and diverse, and the custodianship of Traditional Owners makes sure the sustainable use of resources through spiritually guided cultural practices (Lyons et al., 2019). There are over 70 Aboriginal and Torres Strait Island Traditional Owner groups with authority for sea country management in the Marine Park (GBRMPA, 2019a). These groups are actively engaged in managing their country through participation in policy and planning programs, including the Traditional Use of Marine Resource Agreement program with the Authority (GBRMPA, 2021d). The Australian Government is also working with a consortium of Indigenous and research organisations to support increased Traditional Owner involvement in implementing the Reef 2050 Long-Term Sustainability Plan and delivery of Traditional Owner aspirations and commitments in the Plan (Dale et al., 2018). Effects of ARs and FADs on Traditional Owner groups and their connection to sea country are unknown.

The role or negative impact of FADs and ARs on the protection of heritage values includes natural, Traditional Owner and historic heritage values (GBRMPA, 2019b). Natural heritage values depend on intact biodiversity and ecosystem function; the effects of FADs and ARs on these elements of marine ecosystems are reviewed in sub-sections 5.2.1 and 5.2.2. In relation to the World Heritage values of the region, the aesthetics and geological formations and processes may also contribute to the region's values (see Section 7.4; Lucas 1997); however, no literature was found which considers the effects of ARs or FADs on the aesthetic quality of marine ecosystems. The Marine Park and its values are central to Traditional Owner cultural practices, observances, customs and lore (GBRMPA, 2019a). The role or negative impact of FADs and ARs on Traditional Owner heritage values were not discussed in the available literature. However, the Reef's Traditional Owners have noted that any interference in their Sea Country could have negative impacts upon their culture and values, and so would require dedicated consultations to determine if such an impact could be avoided (Dale et al., 2018; GBRMPA, 2019d).

The role FADs and ARs may play in the protection of historic heritage can be complex and contradictory. In some cases, ARs are vessels or airplanes that sank accidentally, or during war, and carry inherent historic and cultural value (Mogstad et al., 2020). In such instances, the sunken vessel is an incidental AR and may represent the heritage values that require protection under the GBRMP Act, *Historic Shipwrecks Act 1976* (Australian Government) and/or the *Queensland Heritage Act 1992* (Queensland Government). Protected historic wrecks may be used in ways that interact with other objects of the Marine Park Act in negative (damage to the wreck from recreational fishers or divers) or positive (education and enjoyment provided by the wreck) ways (see also sub-section 7.2.1).

Shipwrecks purposely sunk to attract recreational divers or fish may damage existing Traditional Owner or non-Indigenous cultural heritage values (Giglio et al. 2016). Further, aesthetic qualities that people place on natural habitats that would be affected by the wreck (Giglio et al., 2016). Where shipwrecks are used for recreational diving rather than fishing, education about the history of the wreck and relevant events can be part of the diving experience (Bideci & Cater, 2019; Price, 2011). However, one socioeconomic study on diver experience found that historic ties were not rated highly as a drawcard for visiting shipwrecks (Seaman & Depper, 2019). Drawing divers to historic shipwrecks can cause damage to the wrecks themselves, degrading their historic value (Edney & Spennemann, 2015; Giglio et al., 2016).

7.2. Ecologically Sustainable Use

The other objects of the Marine Park Act are subordinate to the primary object and apply "*so far as is consistent with the main object: …allow ecologically sustainable use of the Great Barrier Reef Region…*". The following four sub-sections review the literature pertinent to the types of sustainable use provided for in the Marine Park Act.

7.2.1. Public enjoyment and appreciation

Summary	
AR/FAD	**Benefits** > ARs and FADs can enhance diver and fisher enjoyment > Shipwrecks can provide access to historic heritage > Public awareness raising about environmental issues
AR/FAD	**Negative impacts** > User conflicts, overcrowding, overuse > User preferences for original shipwrecks or natural reefs > Lack of sensitivity to local and regional recreational demand; ARs and FADs not aligned with user values > Degradation of ARs by users Overfishing erodes public enjoyment

The Marine Park Act allows for public enjoyment and appreciation of the Marine Park, so far as this is conducted in a manner consistent with the primary object. Enjoyment of the region's natural values are closely tied to its aesthetics and natural beauty, part of the outstanding universal value for which it was inscribed into the World Heritage List (Lucas et al., 1997). The effects of ARs and FADs on World Heritage values are covered in Section 7.4. Few studies address the benefits and negative impacts of ARs and FADs on public enjoyment and appreciation, unless they are tied to the socioeconomic values of recreational fishing and diving, which are covered in sub-section 7.2.3.

ARs in the form of shipwrecks are highly valued and popular dive sites around the world (Seaman & Depper, 2019). The risk that divers experience, or the challenge of negotiating the physical and environmental challenges of a shipwreck, is one of the attractive qualities of these ARs (Seaman & Depper, 2019). Hence, recent studies found that divers preferred larger structures (Ditton et al., 2002) and that among ARs, large naval ships (Kirkbride-Smith et al., 2013) and airplanes (Shani et al., 2012) were preferred over smaller structures. Other studies define the experience of diving on shipwrecks in terms of "awe", "mystery" and "unique" (Bideci & Cater, 2019). Other elements that interact with the structure of the AR itself to affect public enjoyment and appreciation are diver experience level, accessibility and depth (Kirkbride-Smith et al., 2013; Shani et al., 2012). For example, shallower and smaller wrecks are preferred by novice divers, while experienced divers tend to prefer deeper and larger wrecks (Kirkbride-Smith et al., 2013; Shani et al., 2012). Wreck divers also specifically tend to prefer sites where penetration of the wreck is permitted (Edney & Spennemann, 2015).

Surveys of divers about their preferences or willingness-to-pay for AR and natural reef attributes found that most chose attributes such as overall biodiversity, fish abundance and diversity and coral abundance and diversity (Ee & Horst, 2019; Polak & Shashar, 2013). This suggests that public enjoyment and appreciation is closely tied to the integrity of the natural heritage, biodiversity and health of the ecosystem (see sub-sections 7.1.1 and 7.1.2), and any negative impacts of ARs or FADs on those values may also affect public enjoyment and appreciation. The aesthetic integrity of visited tropical coral reefs, both natural and artificial, is closely linked to the richness and functioning of the ecosystem in keeping with the aesthetic integrity of places being defined as "*harmonious in terms of the story they tell and their physical features*" (Belhassen et al., 2017). In Eilat, Israel, 35 per cent of recreational diving takes place on ARs; this suggests that they can be effective in capturing divers' interest, which may be partially due to the limited natural reef area available for diving (Tynyakov et al., 2017). Therefore, the study concluded that a well-designed and well-placed AR could contribute to the public appreciation and enjoyment of a place (Kirkbride-Smith et al., 2013), and can reduce diver pressure on natural reefs with otherwise high visitation rates, although diver volume on ARs would also need to be managed (Belhassen et al., 2017). In Queensland, Australia, online reviews by recreational divers typically rate a shipwreck, the SS Yongala, among the top three dive sites off Townsville in the central section of the Reef[2].

As discussed in sub-section 7.2.3, well-managed ARs can significantly contribute to fisher enjoyment through the benefit of higher catches (Chen et al., 2013). Aside from the goal of catching fish, recreational fishing (on both ARs and natural reefs) is also associated with the desire for relaxation, to be close to water, to be outdoors and experience unpolluted natural surroundings, for family recreation, to experience adventure and excitement and to get away from the regular routine (Schuett et al., 2015).

Enjoyment from fishing and diving can be reduced, in part, by overcrowding, which is often a problem at FADs or ARs that are successful in achieving their objectives of aggregating target species (Schuett et al., 2016). Furthermore, if higher fishing effort and catch rates on an AR eventually lead to overfishing followed by lower catches, this element of public enjoyment can also be rapidly eroded.

7.2.2. Public education

Summary	
AR/FAD	**Benefits/negative impacts**
	> Education about to historic heritage > Education about marine ecology > Citizen science involvement > Risk of detracting awareness and understanding from natural reefs

[2] https://divezone.net/diving/townsville, https://www.diveglobal.com/diving/townsville/, http://divescover.com/dive-sites/australia/queensland/townsville

The Marine Park Act allows for public education about and understanding of the Marine Park, so far as this is conducted in a manner consistent with the primary object. No research was found on the use of FADs for the purposes of public education, which is not surprising given the narrow scope of their purpose and use. However, a number of papers suggest that ARs can play a role in training novice divers, educating the public about marine ecosystems, raising awareness about conservation issues and fostering stewardship. Historic shipwrecks may be used to educate divers about historical events and heritage values (Bideci & Cater, 2019), but historic and heritage values would likely not apply to purpose-sunk vessels to create ARs. Some ships have been sunk with the specific goal of serving as sites for environmental education, including about how the vessel was sunk (Cole & Abbs, 2011). In Denmark, an 'underwater laboratory' was established on a shipwreck, with livestream video documenting marine life and research activities from the wreck to the internet, which was then used in schools and accessible to interested members of the public (Seidelin et al., 2018).

In areas with high visitation from recreational divers using scuba (Self-Contained Underwater Breathing Apparatus), ARs that are used for training novice divers take the pressure off natural reefs where substantial damage can occur with high novice-diver volumes (Belhassen et al., 2017). Some AR projects specifically engage community members and citizen scientists with the goal of raising awareness and, through education, generating a sense of stewardship for the environment (Fadli et al., 2012; Florisson et al., 2018).

7.2.3. Recreational, economic and cultural activities

The Marine Park Act allows for recreational, economic and cultural activities within the Marine Park, so far as this is conducted in a manner consistent with the primary object. Literature relevant to this object of the Marine Park Act pertains to commercial, artisanal and recreational fishing on ARs and FADs, and commercial tourism and recreational diving on ARs. In Australia and the USA, ARs and FADs are predominantly deployed as a strategy to enhance local recreational fisheries and tourism, by increasing fishing yield and the number of accessible fishing locations and, in the case of ARs, increasing recreational dive sites (Becker et al., 2019; Folpp & Lowry, 2006; WAMSI, 2020). The socio-economic effects of FADs on recreational fisheries are documented from only a few locations, including Hawai'i (Holland et al., 2000) and Australia (Folpp & Lowry, 2006); benefits and negative impacts are reviewed below.

Although some governments deploy ARs as a means of responding to social and economic expectations to do with coastal ecosystem restoration, recreational fisheries, conflict reduction between user groups and recreational activity development, socioeconomic studies that validate achievement of such purposes of deployment are few (Tessier et al., 2015). A recent AR literature review found that out of 620 studies about ecological and socioeconomic aspects of ARs around the world since 1962, only 49 included socioeconomic research (Lima et al., 2019); the kind of fishing relevant to the situation of the Marine Park was covered by a subset of those. Most of these latter studies were based in the Gulf of Mexico, the Florida Keys and the Mediterranean (Tessier et al., 2015); very few studies were located in tropical or even subtropical continental shelf habitats.

There is very little information on the benefits and negative impacts of ARs and FADs on Traditional Owner cultural activities. The integral connection that Traditional Owners have with the sea country of the Reef is acknowledged and recognised through the Authority's Aboriginal and Torres Strait Islander Heritage Strategy (GBRMPA, 2019a). Protection of Traditional Owner knowledge systems and the conservation and sustainable use of traditional biological resources are central to this. Consultation would be required with the Traditional Owners to further understand how the installation of ARs or FADs may benefit or negative impact the protection of Indigenous knowledge systems and sustainable use of traditional biological resources.

Summary	
AR	**Benefits** > Socioeconomic benefits to recreational divers and associated industries > Socioeconomic benefits to recreational fishers and associated industries > Tourism and ecotourism opportunities, including cultural tourism > Improved catches > Job creation > Restocking of target species and spill-over from protected ARs to subsidise local fisheries
AR	**Negative impacts** > User conflict, overuse > Risk of overfishing or low fishing success > High cost of deployment and maintenance > Inadequate management, poor compliance > Failure to achieve social, economic and cultural objectives; low diversity of users, lack of public acceptance > Damage to AR by users
FAD	**Benefits** > Convenient fishing sites > Increased catch and fishing efficiency > Tourism opportunities (e.g. gamefishing) > Job creation
FAD	**Negative impacts** > User conflict > Overfishing and resource depletion; disproportionate harvest of juveniles > Expensive to deploy, monitor and maintain > FAD loss; short lifespan (~ 2 years) > Gear entanglement, navigation and shipping hazard; interfere with other fisheries > Inadequate management, poor compliance > Unknown bycatch issues > Interaction between FAD placement and environmental parameters (e.g. temperature, currents) can lead to failure to aggregate pelagic fish

Benefits of Artificial Reefs to Recreational, Economic and Cultural Activities

The primary argument in favour of ARs is fisheries enhancement and the recovery of overfished populations (Bortone et al., 2011), followed by tourism benefits by providing dive sites (Chen et al., 2013; Santos et al., 2013), with socio-economic benefits to associated local communities (Adams et al., 2017; Feary et al., 2011). A key stated goal for ARs in this context is also to divert diving and fishing pressure from natural habitats that may be overused or overfished and therefore less productive, to enhance the overall sustainability of local fisheries (Espinoza et al., 2020; Leeworthy et al., 2006).

Whether fishing pressure is reduced on natural reefs following AR deployment is generally unknown, but a study on visitation rates of an AR by divers in the Florida Keys using dive shop logbooks and in-water observations measured reduced diving activity on nearby natural reefs as a result of AR deployment (Leeworthy et al., 2006). A comparison of boat visitation rates at eight reef sites (four ARs and four natural reefs) in

Florida waters found higher visitation rates at ARs, thought to be due to a perception of increased quality of fishing and diving at the AR, or to lack of knowledge of the presence or locations of the natural reefs (Simard et al., 2016). Multiple studies show that the abundance and biomass of target species that are attracted to ARs leads to higher catch on ARs compared with natural reefs over a range of timeframes, especially when stocks on natural reefs were already overfished (Kasim et al., 2013; Santos et al., 2011). This may be because fishers reduce their fishing on natural reefs, which might allow for some stock recovery, or because the stock on the natural reefs is attracted to the ARs, with associated higher fisher success (Pears & Williams, 2005). Some proponents maintain that ARs are necessary for the protection of fisher livelihoods in areas where resources are already overexploited (Espinoza et al., 2020), but this remains largely unverified.

Some studies explore the effectiveness of ARs for restocking purposes, especially for overfished invertebrates (e.g., sea cucumbers), with mixed results (Akeda, 2016; Kim et al., 2011; Rotllant et al., 2015). In the Sea of Marmara, eight different types of ARs that were built for the restocking of lobsters were found to also host a diverse range (6-12) of other invertebrate and fish species; however, these were not compared with natural reefs and it is unclear whether these species recruited to the ARs or were attracted from other habitats (Acarli & Kale, 2020). Some of the literature on the construction of ARs for lobsters shows increased densities of lobsters at the ARs, but there is not enough evidence to demonstrate whether this benefits the lobster population as a whole (reviewed by Spanier et al., 2011).

A large body of work exists examining the effect of ARs on the historically overfished red snapper *Lutjanus campechanus*, with details on growth, reproduction and mortality (reviewed by Cowan et al., 2011). Some studies argue that ARs have increased red snapper stock size, based on a correlation between an increase in catch rates and numbers (tens of thousands) of ARs deployed, and a shift in the geographic distribution of red snapper landings towards areas with high oil and gas platform development (Shipp & Bortone, 2009). However, fisheries management was introduced at a similar time, including catch limits for adults and bycatch reduction measures for juveniles, which likely confounded effects of ARs on stock size (Cowan et al., 2011). More recent papers continue to describe an overfished stock of red snapper in the same area (Gulf of Mexico) (Williams-Grove & Szedlmayer, 2016). Ultimately, ARs do not appear to have resolved the issue of depleted populations, likely due to sustained higher levels of fishing pressure brought about by the accessibility of the ARs (Pears & Williams, 2005).

ARs can be designed to target specific species (Brandt & Jackson, 2013) or users (Ditton et al., 2002); this versatility has both ecological and socioeconomic advantages (Sreekanth et al., 2019). For example, red snapper in the Gulf of Mexico have been shown to use ARs in large numbers, regardless of the mechanism (Schulze et al., 2020), where management intervention for reduced fishing pressure on ARs may have assisted restocking of populations. In Texas, improved knowledge of diver preferences has helped to design ARs that cater to those preferences (Ditton et al., 2002). In India, catch rates of small-scale fishers increased after AR deployment (Sreekanth et al., 2019). Proponents view ARs as having a potentially important role in tourism, fisheries management and biodiversity protection (Brandini, 2014; Oh et al., 2008; Santos et al., 2011). The reduction in illegal trawling with the introduction of ARs, for example, resulted in increased catch rates and habitat protection across just under 300 hectares, positively affecting fishing communities along ~50 km of coastline in Brazil (Brandini, 2014). In Portugal, monitoring of six large ARs covering 45 km^2, and compared with control sites, demonstrated the establishment of a diverse fish assemblage (through both production and attraction) and increased catch rates by traditional fishers over 20 years (Santos et al., 2011). However, the goals of the ARs stated by these studies were not always achieved; an economic valuation study of 1059 divers on Florida natural coral reefs and ARs in the same area found that consumer surplus or net economic value from scuba diving at natural reefs was 70 per cent per trip higher than derived from ARs (Oh et al., 2008).

AR users, including recreational anglers, scuba divers and recreational spearfishers generally have positive perceptions of AR deployment (Tynyakov et al., 2017; WAMSI, 2020); when managed correctly, this positive perception can persist even when multiple groups use the same reef (Tessier et al., 2015). Management strategies for reducing user conflict are often welcomed, including at the design stage, where solutions include the adequate spacing and deployment of multiple AR modules (Espinoza et al., 2020; Sreekanth et al., 2019) or the designation of different ARs for specific activities (Branden et al., 1994).

Negative impacts of Artificial Reefs on Recreational, Economic and Cultural Activities

In Australia, Pears and Williams (2005) suggested that on the Reef, any recreational benefits derived from fishing on ARs are likely to be short-term due to increased fishing pressure. It has been shown that upon deployment of ARs, user pressure often becomes skewed towards those locations, as fishing and diving can be perceived to be better at ARs than natural reefs (Ramos & Santos, 2015; Whitmarsh, 1997). This can lead to overfishing, which negates the gains in fish biomass that ARs are often designed for (Hardiman & Burgin, 2010). Overfished stocks may initially benefit from ARs, but increased fishing pressure and catch efficiency on ARs can lead to very high mortality, even in a fishery with periodic closures (Williams-Grove & Szedlmayer, 2016). Similarly, large numbers of divers can damage the structure of ARs and benthic marine life that may become associated with them, thus diminishing any localised benefits associated with the AR (Giglio et al., 2016).

While many studies demonstrate improved catch rates and catch volumes at ARs, and a positive effect of ARs on recreational diving, other studies show no effect (Koeck et al., 2011). Divers and other tourists still value natural reefs above ARs in many areas (Kirkbride-Smith et al., 2016). An analysis of catch per unit effort of multiple fish and invertebrate species at a $50 million USD AR project in Shandong, China, using matched control and AR sites at three locations, showed no improvement in catch rates when all species were analysed together (Sun et al., 2017). While there were some improvements in the catch rates of the twenty most common reef fish species, the authors were unable to ascertain whether this was due to increased attraction, production or differences in fishing effort (Sun et al., 2017).

Even proponents of ARs to enhance fisheries stress the need for an appropriate design, placement and management (Espinoza et al., 2020). In Australia, size limits, quotas and bag limits apply to ARs as they do to fisheries elsewhere (Branden et al., 1994). ARs themselves are not solutions to poor fisheries management (Cowan et al., 2011); in fact, they are likely to add to the burden of activities and locations that require management in marine ecosystems (see Section 7.3). ARs that attract depleted fish stocks may, in fact, exacerbate the over-exploitation due to the preference of fishers for ARs (Cabral & Primeau, 2015). Poor management can cause user conflicts to arise from overcrowding and from user groups with different objectives (Polovina, 1991a).

Benefits and negative impacts of Fish Aggregating Devices on Recreational, Economic and Cultural Activities

Anchored FADs are used extensively throughout the world by small-scale commercial and artisanal fisheries with the aim to improve livelihoods and food security (Chapman, 2004; Montes et al., 2019) by improving catch rates (Bailey et al., 2012; Beverly et al., 2012; Friedlander et al., 1994), vessel efficiency (Doray & Reynal, 2003), safety at sea (Rohit, 2013), tourism opportunities (Rohit, 2013) and contributing to climate change adaptation of reef-dependent coastal communities (Rohit, 2013). Well-established anchored FAD fisheries operate throughout the Mediterranean (Morales-Nin et al., 2000), south-east Asia (Dickson & Natividad, 2000; Rohit, 2013), various Pacific Island countries (Beverly et al., 2012) and Hawai'i (Holland et al., 2000). However, unregulated fishing around FADs can rapidly erode the benefits of aggregating fish (Beverly et al., 2012); catch diversity also tends to be lower around FADs than around natural reefs (Pinnegar et al., 2019). FAD loss is often listed as one of the risks or costs associated with FADs (Shainee & Leira, 2011); lost FADs can cause environmental negative impacts (Sinopoli et al., 2020) and can be costly to replace (Beverly et al., 2012). In Hawai'i, 10 to 20 FADs out of a total of 52 are replaced each year, and each FAD costs approximately $7500 USD to build and deploy (Holland et al., 2000). The cost of monitoring the state of the FADs, scientific monitoring of the effects of the FADs and maintaining FADs is not reported in the literature.

FAD fisheries have been shown to provide a more certain source of protein in some developing countries, at least in the short term (Beverly et al., 2012). However, empirical evidence of the intended socioeconomic benefits of FADs is extremely rare, as is evidenced through a reduction in inshore fishing and reef fish stock recovery as a result of FAD deployment (see also sub-section 7.1.1). Despite the states goals and concomitant expectations of enhanced catches around FADs, quantitative evidence of fishery benefits is surprisingly rare (Gillett, 2014). The success of fisheries catches around FADs depends to a certain extent on environmental and ecological factors, hydrodynamics, temperature fluctuations and weather patterns, which may or may not be predictable (Doray et al., 2009; Glazier et al., 2009). This means that FAD placement has a strong effect on the success of aggregating fish and therefore enhancing catch rates (see sub-section 5.2.2).

Recreational use of anchored FADs in deep waters where there is no demersal fishing in natural habitats may economically benefit associated industries and local communities (Holland et al., 2000; Samples & Sproul, 1985). In Timor-Leste, a study found improved overall fisheries sustainability through the combined effects of FAD deployment and concurrent closures of some nearshore natural reefs to fishing (Tilley et al., 2019). As discussed in sub-section 7.1.1, evidence of FADs alone meeting objectives of reducing pressure on natural reefs or for stock recovery of overexploited reef fish is rare, although this study implies that FADs may contribute to enabling improved management systems through a multi-faceted approach.

Reports on the failure of FADs to meet the stated objectives of the economic improvement of fisheries are rare (Buckley, 1989; Véras et al., 2020). However, some papers discuss the common problem of user conflict (Polovina, 1991a) and lack of management and regulation. User conflict can be based on user congestion or competition over the stock; in Hawai'i, one commercial fishing vessel effectively removed all the skipjack tuna from around a FAD, leaving recreational anglers with nothing (Polovina, 1991a). Recently deployed sub-surface FADs in south-east Queensland have been met with strong criticism from fisheries representatives, managers and fishers, including established commercial fishing operations, for creating conflict and putting pressure on pelagic fish stocks (Tuna Australia, 2021). Social benefits are thought to be more likely when FADs are managed at a community level, with fisher collectives that are highly effective at managing, monitoring and maintaining local FADs, as occurs in some developing countries (Beverly et al., 2012; Hargiyatno et al., 2018).

In Australia, the NSW government maintains and monitors at least 30 FADs designed to provide fishing opportunities for recreational anglers (Folpp & Lowry, 2006). The catch composition is dominated by dolphinfish, which is also the case in traditional Mediterranean FAD fisheries (Cannizzaro et al., 1999). Fshing success around the NSW FADs was governed by environmental factors such as variations in sea surface temperature (Folpp & Lowry, 2006). This led to seasonal deployments of FADs to coincide with warmer temperatures, which in turn coincides with the migration of targeted pelagic fish species (NSW Government, 2021). There is no information about the negative impacts of fishing on these fish stocks nor their migration, which makes it difficult to ascertain if the apparent long-term sustainability of a FAD-associated fishery, such as the Mediterranean dolphinfish fishery, can be replicated in Australian waters .

Incidentally, oceanographic research buoys are also used by recreational fishers in Australia, as are mooring buoys (see also Jacob, 2003), channel markers and other navigation aids (Dempster, 2005), as well as pipelines and other infrastructure (Schramm et al., 2021). Although these “unintentional FADS” are a separate issue from those designed and deployed specifically for fisheries purposes, their use may set a precedent in a Marine Park context. In the Marine Park, there are over 370 navigational aids and more than 1000 in the region (which includes port areas). Anecdotal evidence indicates intensive use of these structures as FADs in Australia (J. Stevens, recreational fisher, pers. comm.), and published literature exists of their use elsewhere in the world (Holland et al., 2003; Morgan, 2011). Oceanographic research buoys are deployed throughout the Marine Park (Steven et al., 2019); their use by recreational fishers is undocumented and therefore unknown and unmanaged, and the socioeconomic effects of the use of these existing unintentional FADs is unknown.

7.2.4. Research on values of the region

The Marine Park Act provides for research in relation to the natural, social, economic and cultural systems and values of the region, so long as it does not interfere with the first object of the Marine Park Act. FADs and ARs are not often designed and deployed specifically for research purposes, but a number of documents outline the advantages and disadvantages of these structures in contributing to scientific research on other marine ecosystem attributes (Bortone, 2006).

Summary	
AR	**Benefits**
	> Opportunities for reef research and citizen science training
	> Opportunities for research on recreational use
	> Training for novice divers to reduce damage to natural reefs
AR	**Negative impacts**
	> Poor record keeping of AR use
	> Inadequate research objectives and goals; monitoring programs too short to adequately assess achievement of objectives; disconnect between theory and application
	> Lack of socioeconomic research
	> Incomplete understanding of AR negative impacts
	> Illegal fishing confounds research results
	> Lack of applicability to management; unreliable results due to over-reliance on citizen or fisher record-keeping; pseudoreplication issues
FAD	**Benefits**
	> Opportunities for pelagic species research
	> Monitoring of environmental parameters and fishing activities
FAD	**Negative impacts**
	> Insufficient data to fish sustainably

The most obvious research that FADs and ARs can contribute to is that focussed upon the FADs and ARs themselves. Lima et al. (2019) provide a statistical analysis of AR research that also includes FADs, from 1962 to 2018, with analyses by region, field of research, publication types and research methods. Taquet et al. (2013) provided further detail on aspects of FAD research, including the distribution of document types (peer-reviewed articles and reports together accounted for 73 per cent of the literature), time (there was an peak in research in the late 1990s, which declined in the 2000s), FAD type (66 per cent anchored FADs), species (75 percent tuna and pelagic fish) and geographic area (highly varied). Because their structural complexity can be controlled, ARs provide an opportunity to study the relationship between complexity and various aspects of reef ecology (Hackradt et al., 2011). They also provide an opportunity for investigating community succession from its beginnings (Harrison & Rousseau, 2020). FADs can provide opportunities to study the biology of pelagic species that are otherwise too dispersed for effective research (Bach et al., 1998; Mitsunaga et al., 2011; Moreno et al., 2016). Research on the ecology of AR and FAD-associated species, however, may be based on populations occurring outside of their usual habitat and not engaging in typical behaviour, so should be interpreted with caution.

Due to their attractiveness for fishing, research on AR ecology may be confounded by fishing impacts, which may or may not be taken into account; FAD research is often also confounded by interacting environmental parameters such as seasonal changes in temperature (Doray et al., 2009). For example, depth and seasonal temperature changes may interact with FAD placement to be more or less effective at attracting pelagic fishes. The research and monitoring programs conducted on ARs are typically short-term; they may not capture the full scope of ecological development of an AR and consequent positive and negative impacts, and therefore potentially lead to incorrect conclusions (Lima et al., 2019). Studies on ARs can also suffer from pseudoreplication (Bortone, 2006), lack of appropriate controls (Carr & Hixon, 1997) and a disconnect between the objectives of the ARs and the objectives of the research (Bortone, 2006). Finding natural reef control sites for shipwreck ARs and natural pelagic habitat controls for FADs is especially problematic, due to the unique nature of these structures in most locations.

7.3. Management

The Marine Park Act provides for activities that "*encourage engagement in the protection and management of the Great Barrier Reef Region by interested persons and groups, including Queensland and local governments, communities, Indigenous persons, business and industry*". The Authority is responsible for the management of the Marine Park, but partnerships with other tiers of government, Traditional Owners, non-governmental organisations (NGOs), communities, business and industry are an integral part of effective management (GBRMPA, 2019b).

Summary	
AR	**Benefits** > ARs can contribute to conservation and fisheries management in combination with MPAs > Reduce user pressure on natural reefs > Potential for species-specific design and management > Can be used to enhance public environmental awareness and engagement
AR	**Negative impacts** > Poor management; adds to management burden > User conflict > Lack of clear objectives for research and management > Disconnect between AR deployment, conservation goals and fisheries management > ARs detract from conservation of natural habitat

Summary

FAD **Benefits**

> Can contribute to coastal resource management by diverting fishing pressure to pelagic species

> Well-designed monitoring programs can encourage community engagement and stewardship

FAD **Negative impacts**

> Poor management; lack of a clear management plan; lack of compliance and enforcement

> Unclear access rights; weak legislation

> Unclear objectives; management structure disconnected from local community and industry needs

The most likely way in which newly deployed ARs and/or FADs would interact with existing management efforts would be by introducing a new management burden, adding to existing challenges for the management of threats to the region (Pears & Williams, 2005). However, encouraging community participation in the deployment, management and monitoring of ARs and FADs can improve the prospects for effective protection and management; engaging a broad variety of community stakeholders has been shown to enhance AR development and ongoing monitoring and assessment efforts (Seaman et al., 2011). In the Moreton Bay Marine Park, south-east Queensland, ARs were constructed by the Queensland Parks and Wildlife Service (QPWS), together with a working group comprised of representatives from recreational and commercial fishing bodies, the tourism industry, conservation groups and other government departments (Queensland Government, 2021b). The working group contributed to the site selection, structural design, creation and monitoring of the ARs sites, which are managed through a combination of zoning and permits, and the permitted activities at each site are designed to avoid conflict and ensure compatibility.

Management efforts benefit from the increased awareness, participation and stewardship of the public, and ARs may serve as a stepping-stone to improve awareness about the environment in general (WAMSI, 2020). The literature finds that stakeholders for ARs and FADs welcome management of activities around the structures, as there is an appreciation of the need to reduce user conflict and avoid overuse, as these ARs may be purpose-built and positioned to optimise the desires of the community and are therefore likely to be popular (see sub-section 7.2.3). However, the literature does not acknowledge the question of whether this translates to a greater public appreciation or understanding of the natural environment, or whether ARs then contribute to, or detract from, management of natural reefs. Design, consultation, deployment, management and monitoring of FADs and ARs in south-east Queensland could provide some lessons for the Marine Park, although no further information was available during preparation of this literature review.

The introduction of moored FADs and ARs creates a set of novel problems for governance and management (Pittman et al., 2020), extra pressure on compliance and enforcement resources (Delgadillo & Toro, 2018) and the diversion of management resources (Showstack, 2001). Monitoring adds an ongoing, long-term cost; without monitoring of ecological, socio-economic, cultural and management effects, it is difficult to measure benefits or negative impacts of ARs and FADs (Bateman, 2015). Much of the early literature found that older ARs and FADs lack management plans, guidelines and regulations, but this led to a body of literature offering guidelines to assist countries in, at least, the AR construction phase (Fabi & Spagnolo, 2011; Sadusky et al., 2018). Marine management initiatives such as the European Union Water Framework Directive (Fabi et al., 2011), the National Artificial Reef Plan of the USA (NOAA Fisheries, 2019) and Australia's Oceans Policy (Australian Government, 2019) include guidelines about the strategic use of ARs (Lima et al., 2020).

Fisheries management within the Marine Park is yet to be effective for all fisheries; for example, there are no available stock assessments for the target species of the Queensland East Coast Inshore Fin Fish Fishery (ECIFFF), which was recently deemed unsustainable for the purposes of being accredited under the WTO for export trade (McKillop & Wainwright, 2020). Compliance remains an issue for the recreational reef fishery across the Marine Park (Bergseth et al., 2015). Some studies suggest that placing ARs in no-take zones enhances their role as biodiversity hotspots, nursery grounds and the recovery of overfished stocks (Brochier et al., 2015; Claudet & Pelletier, 2004), but there is no shortage of reef habitats within no-take zones in the Marine Park. The examples of ARs and FADs aiding management within the reviewed literature therefore do not appear to be relevant in a Marine Park context.

7.4. World Heritage Obligations

The fourth sub-paragraph (2c) object of the Marine Park Act, so far as it does not interfere with the first object of protecting values of the region, is to "*assist in meeting Australia's international responsibilities in relation to the environment and protection of world heritage (especially Australia's responsibilities under the World Heritage Convention)*". Assessments of the Marine Park's condition and trends consider natural, Indigenous and historic heritage values, and combine national and world natural heritage values (GBRMPA, 2019b). The Marine Park and islands in the Marine Park are part of the World Heritage Area. Recognition of the region's outstanding universal value was based on all four World Heritage natural criteria:

vii. contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance
viii. be outstanding examples representing major stages of Earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features
ix. be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals
x. to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Summary	
AR	**Benefits** > ARs can contribute to meet World Heritage natural criteria > ARs can contribute to conservation in combination with MPAs > Can be used to enhance public environmental awareness and engagement > Can be used in conjunction with other measures for the protection of some threatened species
AR	**Negative impacts** > Can be inconsistent with conservation objectives > Overlap between human users of ARs and threatened species > Diverts resources from more important conservation priorities; detracts from the protection and management of natural habitats

Summary	
FAD	**Negative impacts**
	> Inconsistent with conservation objectives
	> Entanglement of threatened species
	> Changed movement and feeding behaviour of threatened species

The World Heritage criteria broadly overlap with biodiversity and ecosystem health values; the benefits and negative impacts of ARs and FADs reviewed under sub-sections 7.1.1, 7.1.2 and 7.1.3 are therefore also relevant here. The aesthetic values associated with criterion vii is closely tied to the public enjoyment and appreciation of the region; this exceptional beauty relies on the integrity and "naturalness" of the region, and it could be argued that artificial materials and structures are inconsistent with the protection of these values. Protection of these natural attributes forms part of the "higher obligation" that Australia has to protect the entirety and integrity of the natural outstanding universal value because it is a World Heritage Area.

Some AR and FAD research makes specific references to threatened species listed under international agreements and legislation, and which is also relevant to Australia's international responsibilities in relation to environmental protection. ARs and FADs can have potential conservation applications, especially if included in no-take MPAs, by enhancing habitat and food resources for some protected or threatened species. There is evidence that they can assist with the re-establishment of food resources for threatened cetaceans (Mikkelsen et al., 2013), and provide foraging opportunities for marine predators (Altobelli & Szedlmayer, 2020; Burns et al., 2020). They can also play a role in raising public awareness about marine conservation (Fadli et al., 2012) (see Section 7.3). However, there is also concern that using ARs "for conservation" detracts from the protection of natural habitats (Hughes, 2019) and addressing existing fisheries management issues (Uniquest Pty Ltd, 2010), and diverts limited funding away from more serious issues (Showstack, 2001).

There can also be overlap between human use of ARs and FADs and foraging by seabirds (Jaquemet et al., 2004) (Figure 11) and by marine mammals (Wirth & Warren, 2019), or the threat of entanglement for threatened turtles (Barnette, 2017; Blasi et al., 2016; MRAG, 2011) and rays (Clarke, 2013). In the Cook Islands, FADs were associated with the increased bycatch of sharks (Juncker et al., 2006), and although it was unclear which species were affected, 77 per cent of all shark species are listed under one of the threatened categories on the IUCN Red List of Threatened Species. In such cases, ARs and FADs create extra pressure for threatened species (Beverly et al., 2012). Importantly, without adequate management, intensive fishing around FADs can erode the outstanding universal value of the region's ecosystem (Bucaram et al., 2018).

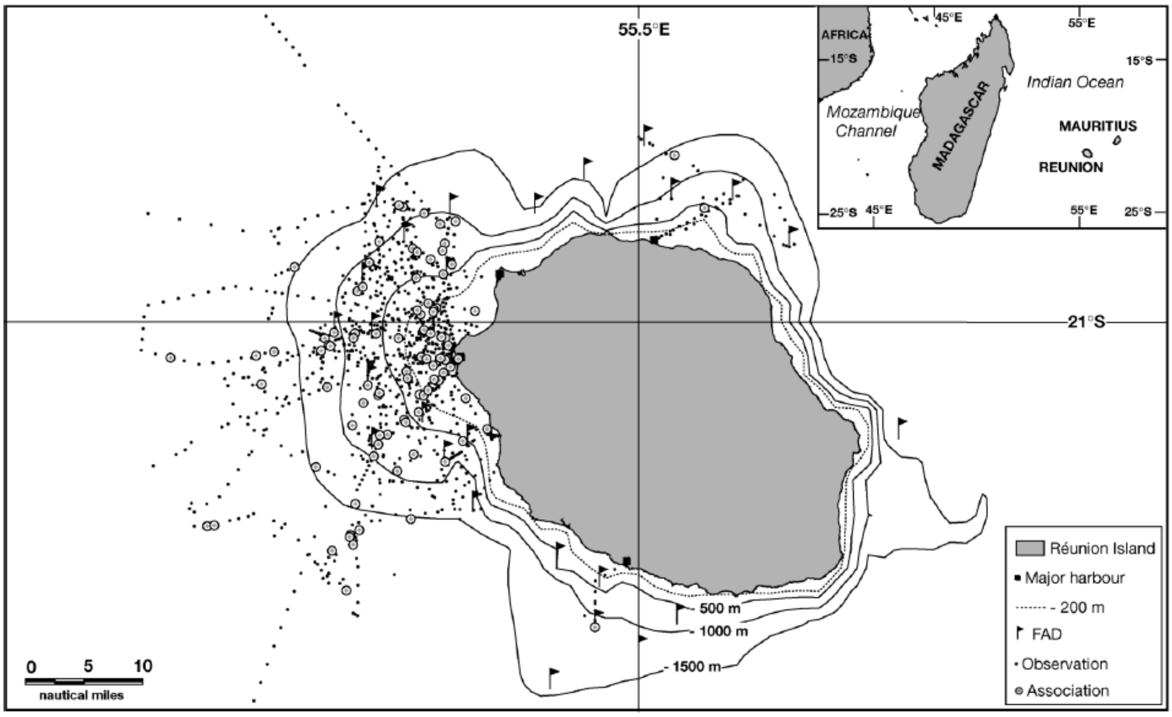

Figure 11 **Locations of seabird observations and associations with subsurface predatory schools of fish, analysed during an Indian Ocean study. Reproduced from Jaquemet et al. (2004).**

8. ENVIRONMENTAL BENEFIT AND NEGATIVE IMPACT RISK ASSESSMENT

Of the 568 articles reviewed here, 226 (40 per cent) stated one or more negative impacts of ARs and or FADs, and 256 (45 per cent) provided information on benefits; 128 (23 per cent) had information on both benefits and negative impacts.

This assessment is presented as a mechanism to summarise the findings of the literature review; each benefit and negative impact is not assigned equal weight. Where the number of benefits is more than the number of negative impacts that were found, it is not assumed that the benefits outweigh the risks, or *vice versa*. In addition, this summary does not reflect whether the benefit or negative impact is supported by extensive evidence in the literature or extremely limited evidence in the literature. Such details are discussed in the body of the literature review, above.

8.1. Risk Assessment Methods

The risk assessment was conducted with the use of a matrix where combinations of likelihood and consequence result in benefit or negative impact ratings of Extreme, High, Moderate and Low (Table 7). Benefits and negative impacts were extracted from the literature and assessed against a scale of the likelihood and consequence of those outcomes in a Marine Park setting. For example, a potential consequence of altering sediment and water quality surrounding an AR may be major in a small and sheltered bay but, given that these effects are documented to be localised, minor consequences are likely in an ecosystem scale of the Marine Park. We also listed the region’s values that would be affected by each benefit or negative impact, and the types of interventions that may be actioned to either optimise the benefits or conversely minimise the negative impacts. The risks were assessed under the assumption that mitigation has not yet been applied.

Table 7 Benefit and Negative Impact risk assessment matrix.

		CONSEQUENCE				
		Insignificant	Minor	Moderate	Major	Significant
Environmental / Heritage		Negligible benefit/impact to biota and ecosystems (less than 1 year). Negligible benefit/impact to cultural features	Minor benefit/impact (up to 1 year) to biota and ecosystems. Minor benefit/impact to cultural features.	Moderate benefit/impact (up to 2 years) to biota & ecosystems. Moderate benefit/impact to cultural features of low significance.	Major benefit/impact (up to 10 years) to biota, ecosystems or environmental ecosystems. Extensive benefits/impacts to cultural features of significance.	Significant benefits/impacts to biota, ecosystems or environmental ecosystems - Benefit/impact persistence >10 years. Benefits/impacts resulting in significant improvement to cultural features of high significance and/or items of National Heritage Value.
Social / Economic		Minor social and economic gains/effects. Negligible benefit/impact	Growth/Inconvenience for social and economic values.	Improvements/impacts to key social/ economic goals	Achievement/non-achievement of social/economic goals	Achievement/non-achievement of social/economic goals and improvement/damage to future plans
LIKELIHOOD	**Almost Certain** Almost certain to occur during the first year of deployment	MOD	HIGH	HIGH	EXTREME	EXTREME
	Likely Frequent in the literature. Likely to occur within two years of deployment	MOD	MOD	HIGH	HIGH	EXTREME
	Possible Common in the literature. May occur within 5 years of deployment	LOW	MOD	MOD	HIGH	HIGH
	Unlikely Few examples in the literature. May occur within 10 to 20 years of deployment	LOW	LOW	MOD	MOD	HIGH
	Rare Few examples in the literature. May occur within 20 to 50 years of deployment	LOW	LOW	MOD	MOD	HIGH

8.2. Assessment of Benefits

Most benefits from the literature were ranked as High or Moderate for a Marine Park setting, primarily due to the high likelihood of occurrence (Table 8). The largest number of benefits in the literature pertain to the effects of ARs and FADs on the first object of the Marine Park Act. The objects of the Marine Park Act relating to sustainable use might be affected in different ways by ARs and FADs: There were few benefits of ARs to public education, a larger number of benefits pertain to public enjoyment and appreciation, and, predictably, a number of benefits relevant to recreational, economic and cultural use. There were also benefits for opportunities to use ARs for research and to assist in management and conservation.

Benefits from FAD deployment, such as the reduction of fishing pressure on coastal or reef resources, which is a ubiquitous aim of FADs throughout the literature, were not substantiated by studies that showed evidence of reduced fishing pressure on reefs. Many of the socioeconomic benefits of FADs listed in the literature, such as improved food security and livelihoods in developing countries, were also not supported by evidence and did not apply to the Marine Park situation. While there were some benefits of FADs for pelagic species research, these benefits were moderate, and found to be mostly inconsistent with management and conservation objectives (Table 8).

Table 8 Detailed assessment of benefits of ARs and FADs, as related to the objects of the GBRMP Act.

Structure	Marine Park Act object	Benefits	Values Profiting					Benefit Rating			Improving Benefits				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
Artificial Reefs	1. Long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region	Adds structural complexity to otherwise barren or degraded habitat	✓					Likely	Moderate	**High**		✓	✓		
		Can be designed to enhance populations of species of interest	✓			▪		Possible	Major	**High**			✓	▪	▪
		Can successfully mimic natural reefs	✓	▪				Possible	Minor	**Moderate**		▪	✓		
		Enhanced primary and/or secondary production	✓	✓				Likely	Major	**High**		✓	✓	✓	✓
		Enhanced biodiversity	✓					Possible	Major	**High**		✓	✓	✓	✓
		Improve connectivity	✓	▪				Possible	Major	**High**		✓	✓	▪	
		Hosts unique communities	✓					Possible	Major	**High**		▪	✓		
		Enhanced fish density and /or biomass	✓	✓				Possible	Major	**High**		✓	✓	✓	✓
		Enhance benthic cover and invertebrates	✓	✓				Likely	Major	**High**		✓	✓	✓	
		Enhance infauna and meiofauna	✓	✓				Possible	Major	**High**		✓	✓	✓	▪
		Increasing ecosystem stability and resilience	▪	✓				Possible	Significant	**High**		✓	✓	✓	✓
		Minimal or no effect on the surrounding seabed		✓				Possible	Insignificant	**Low**		✓	✓	✓	
		Increased benthic recruitment	✓	▪				Possible	Major	**High**		✓	✓		

Structure	Marine Park Act object	Benefits	Values Profiting					Benefit Rating			Improving Benefits				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		Divert user pressure from natural habitats	•	✓				Possible	Moderate	Moderate		✓	✓	✓	
		Provide important ecological functions	•	✓				Possible	Major	High		✓	✓	✓	✓
		Protection of habitat from trawling		✓				Likely	Minor	Moderate			•	✓	
		Reduced pressure on older shipwrecks		•	✓			Possible	Moderate	Moderate			•	✓	
Artificial Reefs	2ai. Sustainable use: public enjoyment and appreciation	Access to historic heritage	•		✓	✓	•	Likely	Major	High	•	✓		•	•
		Diver and fisher enjoyment				✓	•	Likely	Significant	Extreme	✓		•		
		Public awareness raising			✓	✓	•	Possible	Major	High	✓			✓	•
Artificial Reefs	2aii. Sustainable use: public education	Education about to historic heritage			✓	•		Likely	Major	High	✓		•	✓	
		Education about marine ecology				✓		Likely	Major	High	✓		•	✓	
		Citizen science				✓	•	Likely	Moderate	High	✓			✓	•
Artificial Reefs	2aiii. Sustainable use: recreational, economic and cultural activities	Socioeconomic benefits to divers and associated industries				✓	✓	Possible	Significant	High	✓	✓	✓	✓	✓
		Tourism and ecotourism opportunities	•			✓	✓	Possible	Significant	High	✓	✓	✓	✓	•
		Socioeconomic benefits to recreational fishers and associated industries				✓	✓	Possible	Significant	High	✓	✓	✓	✓	✓

Structure	Marine Park Act object	Benefits	Values Profiting					Benefit Rating			Improving Benefits				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		Improved catches	·			✓	·	Possible	Moderate	Moderate		✓	✓	✓	✓
		Job creation				·	✓	Possible	Significant	High	·	✓	✓	✓	
		Spill over effects from protected ARs subsidise local fisheries				·	✓	Unlikely	Minor	Low	·			✓	
		Re-stocking of target species	✓	✓		✓	✓	Possible	Significant	High		·	✓	✓	·
Artificial Reefs	2aiv. Sustainable use: research	Opportunity for research about reef ecology				✓	✓	Possible	Moderate	Moderate	✓	✓	✓	✓	
		Training for novice divers				✓	✓	Possible	Moderate	Moderate	✓	✓	✓	·	
		Opportunity for research on recreational use				✓	✓	Likely	Major	High	·			✓	
		Training for citizen scientists	·			✓	✓	Possible	Moderate	Moderate	✓			✓	
Artificial Reefs	2b. Encourage protection and management	Effective conservation in combination with Marine Park authorities	✓	✓	✓	✓	✓	Possible	Minor	Moderate	✓			✓	
		Positive public perception and support for management				✓	·	Likely	Major	High	✓			✓	
		Reduce user pressure on natural reefs	✓	✓		✓	·	Possible	Major	High		✓	✓	✓	✓
		Assist with sustainable fisheries management	✓			·	✓	Possible	Significant	High	·	✓	✓	✓	✓
		Increased awareness and engagement of citizens	·			✓	·	Possible	Major	High	✓	·	·	✓	

Structure	Marine Park Act object	Benefits	Values Profiting					Benefit Rating			Improving Benefits				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		Potential species-specific design and management	✓	✓		✓	✓	Possible	Major	**High**	·	✓	✓	✓	✓
Artificial Reefs	2c. Meeting Australia's international responsibilities	Effective conservation in combination with Marine Park authorities	✓	✓		·	·	Possible	Minor	**Moderate**	✓			✓	
		Increased awareness and engagement of citizens	·			✓		Possible	Minor	**Moderate**	✓			✓	
		Promising for protection of some endangered species	✓					Possible	Significant	**High**	·	✓	✓	✓	
Fish Aggregating Devices	1. Long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region	Enhanced production	✓	✓				Likely	Major	**High**		✓	✓	✓	✓
		Nursery structures; enhanced recruitment to nearby reefs	✓	✓				Possible	Major	**High**		✓	✓	✓	·
		Increased density and biomass of fish	✓					Likely	Major	**High**		✓	✓	✓	✓
		Reduced pressure on coastal ecosystems	✓	✓				Possible	Significant	**High**		✓	✓	✓	
Fish Aggregating Devices	2ai. Sustainable use: public enjoyment and appreciation	Convenient fishing sites				✓	·	Likely	Major	**High**		✓	✓	✓	✓
Fish Aggregating Devices	2aiii. Sustainable use: recreational, economic and cultural activities	Convenient fishing sites				✓	·	Almost Certain	Minor	**High**	✓	✓		·	·
		Increased catch and efficiency				✓	·	Likely	Moderate	**High**		✓	✓	✓	✓
		Tourism opportunities				✓	✓	Possible	Major	**High**	✓	✓	✓	✓	✓

Structure	Marine Park Act object	Benefits	Values Profiting					Benefit Rating			Improving Benefits				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
Fish Aggregating Devices	2aiv. Sustainable use: research	Opportunity for pelagic species research	✓			✓	✓	Possible	Moderate	**Moderate**				✓	
		Allows monitoring of environment and fishing activities	✓			✓	·	Likely	Major	**High**				✓	
Fish Aggregating Devices	2b. Encourage protection and management	Contributes to coastal resource management	✓	✓			✓	Possible	Major	**High**	✓	✓	✓	✓	✓
		Community engagement and stewardship	·			✓	·	Likely	Major	**High**	✓			✓	
Fish Aggregating Devices	2c. Meeting Australia's international responsibilities		·											·	
			·								·	·	·	·	
			·									·	·	·	

8.3. Assessment of negative impacts

Most negative impacts gleaned from the literature were ranked as High or Moderate for a Marine Park setting, primarily due to the high likelihood of occurrence (Table 9). The largest number of risks in the literature pertain to the effects of ARs and FADs on the first object of the Marine Park Act; ARs and FADs present a large number of negative impacts to the protection of values of the region (Table 9). The most certain effects were the aggregation and disproportionate fishing risk to juveniles of FADs, the risk of poor management and the general lack of data to make sure that fishing at FADs is sustainable. Moderate negative impacts were often classified as such because of their relatively small scale (e.g., the localised effects of fish fitness or behaviour) relative to the scale of the Reef.

The number of negative impacts of FADs outweighed the number of potential benefits for almost every object of the Marine Park Act. In relation to the primary object of the Marine Park Act, the literature offered ample evidence of the potential for FADs to attract fish from a wider area, increasing the risk of overfishing, as well as a number of examples of the increased vulnerability of juveniles and the pervasive problem of FAD loss. This is compounded with the lack of information that would be needed to fish sustainably around FADs. Surprisingly, the literature also offered a large number of negative impacts for the socioeconomic effects of FADs on the recreational, economic and cultural use of the Reef. The expense of FAD deployment, their short lifespan, user conflicts, safety issues for smaller vessels travelling offshore and interference with other fisheries are issues that are highly relevant to the Marine Park. FADs are considered inconsistent with conservation objectives; FADs deployed directly outside MPA boundaries were found to interfere with MPA protection in the Galapagos islands (Bucaram et al., 2018).

Table 9 Detailed assessment of Negative Impacts of ARs and FADs, as related to the objects of the GBRMP Act.

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
Artificial Reefs	1. Long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region	Lack of evidence for production, more evidence for attraction	✓					Likely	Moderate	**High**		✓	✓		
		Risk of overfishing; unlikely to benefit heavily exploited or overfished species without extra management; AR effect undermined by fishing pressure	✓					Likely	Major	**High**				✓	✓
		Alter the composition of sedimentary habitats and species assemblages	✓	✓				Almost certain	Minor	**High**		✓	✓		
		ARs are not surrogates for natural reefs	✓	✓				Likely	Moderate	**High**			✓		
		Alter fish communities on nearby reefs	✓					Possible	Major	**High**		✓			
		Benthic and pelagic 'ecological halo' or 'footprint' of the AR can	✓	✓				Possible	Major	**High**		✓	✓	✓	

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		be up to 15 times the area of the actual reef													
		Can divert fish arriving from inshore nursery habitats from settling on natural reefs	✓					Possible	Moderate	**Moderate**		✓			
		Alter sediment and water quality		✓				Possible	Minor	**Moderate**			✓	✓	
		Conservation benefits only at small scales	✓					Almost certain	Insignificant	**Moderate**			✓		
		Corridors or steppingstones for invasive species	✓	✓				Possible	Major	**High**				✓	✓
		Direct effects of AR construction on footprint and nearby natural habitats	✓	✓				Almost certain	Moderate	**High**		✓	✓	✓	
		Barriers to the movement of organisms, material and energy		✓				Unlikely	Major	**Moderate**		✓	✓		
		Habitat fragmentation		✓				Possible	Minor	**Moderate**		✓	✓		

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		Lower fitness of fish on ARs	✓					Possible	Minor	**Moderate**			✓	✓	
		Increased catch rates of juveniles and small individuals	✓					Possible	Major	**High**				✓	✓
		Nutrient enrichment		✓				Possible	Moderate	**Moderate**			✓	✓	
		Chemical contamination		✓				Possible	Moderate	**Moderate**			✓	✓	
		Modifications to fish behaviour	✓					Possible	Minor	**Moderate**			✓		
		Fails to achieve biological objectives	✓					Unlikely	Major	**Moderate**		✓	✓		
		Weathering of AR can cause loss of organisms	✓					Rare	Major	**Moderate**			✓		
		Alter microbial communities and processes		✓				Rare	Minor	**Low**		✓	✓		
		Diverts funding from more important environmental actions; distract from	✓	✓				Likely	Major	**High**	✓			✓	

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		conservation of natural habitats													
Artificial Reefs	2ai. Sustainable use: public enjoyment and appreciation	User conflicts and overuse	✓			✓	✓	Likely	Significant	Extreme	✓			✓	✓
		User preferences for original shipwrecks or natural reefs				✓	✓	Possible	Minor	Moderate	✓		✓		
		Lack of sensitivity to local and regional recreational demand				✓	✓	Possible	Minor	Moderate	✓			✓	✓
		Low diversity of users				✓		Possible	Insignificant	Low	✓	✓	✓		
		Degradation of AR by users	✓	·	·		✓	Possible	Major	High				✓	✓
		AR not aligned with user values				✓	✓	Possible	Major	High	✓				
Artificial Reefs	2aii. Sustainable use: public education	Lack of technology and capacity				✓		Unlikely	Insignificant	Low	✓		✓		
		User conflicts				✓	·	Possible	Minor	Moderate	✓			✓	✓
Artificial Reefs	2aiii. Sustainable use: recreational, economic and cultural activities	User conflicts				✓	✓	Possible	Major	High	✓			✓	✓
		Overuse; overfishing	✓				✓	Likely	Major	High				✓	✓

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		High cost of deployment and maintenance					✓	Likely	Moderate	**High**			✓	✓	
		Inadequate management	✓			✓	✓	Unlikely	Major	**Moderate**				✓	
		Fails to achieve economic, cultural or social objectives				✓	✓	Unlikely	Major	**Moderate**	✓		✓		
		AR not aligned with user needs and preferences				✓	✓	Possible	Major	**High**	✓				
		Damage to AR by users	✓				✓	Possible	Major	**High**				✓	✓
		Low diversity of users				✓		Possible	Insignificant	**Low**	✓				
		Poor compliance	✓				✓	Possible	Major	**High**				✓	✓
		Low fishing success					✓	Possible	Moderate	**Moderate**		✓	✓		
		Lack of public acceptance of AR				✓		Unlikely	Moderate	**Moderate**	✓				
Artificial Reefs	2aiv. Sustainable use: research	Inadequate research objectives and goals					✓	Unlikely	Minor	**Low**				✓	
		Poor record keeping of AR use					✓	Possible	Moderate	**Moderate**				✓	

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		Lack of socioeconomic research				✓	✓	Possible	Moderate	**Moderate**	✓			✓	
		Monitoring programs too short or inadequate to assess achievement of objectives	✓				✓	Likely	Major	**High**				✓	
		Incomplete understanding about AR negative impacts	✓			✓	✓	Possible	Major	**High**	✓			✓	
		Disconnect between theory vs. application	✓			✓	✓	Unlikely	Moderate	**Moderate**	✓			✓	
		Illegal fishing confounds research results				✓		Possible	Major	**High**				✓	✓
		Monitoring done by fishers and citizens does not provide reliable data				✓		Likely	Moderate	**High**				✓	
		Pseudoreplication, standardisation and lack of applicability to management				✓		Possible	Moderate	**Moderate**				✓	

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
Artificial Reefs	2b. Encourage protection and management	Lack of clear objectives for research or management	✓			✓	✓	Possible	Major	**High**				✓	
		User conflicts				✓	✓	Possible	Major	**High**	✓			✓	
		Poor management	✓			✓	✓	Likely	Significant	**Extreme**				✓	
		Lack of public acceptance of AR				✓		Unlikely	Moderate	**Moderate**	✓				
		Fails to achieve stated objectives	✓			✓	✓	Unlikely	Major	**Moderate**	✓	✓	✓	✓	
		Disconnect between AR deployment, conservation goals and fisheries management	✓			✓	✓	Unlikely	Moderate	**Moderate**	✓			✓	
		ARs detract from conservation of natural habitat	✓					Possible	Major	**High**	✓	✓	·	✓	
Artificial Reefs	2c. Meeting Australia's international responsibilities	Disconnect between different relevant authorities	✓			✓	✓	Unlikely	Moderate	**Moderate**	✓			✓	
		Can be inconsistent with conservation objectives	✓					Possible	Major	**High**	✓			✓	

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		Overlap between human users and threatened fauna	✓					Likely	Major	**High**	✓			✓	
		Diverts funding from more important environmental actions	✓					Possible	Major	**High**	✓			✓	
		ARs detract from conservation of natural habitat	✓					Possible	Major	**High**	✓	✓		✓	
		Disconnect between AR and Marine Park authorities	✓			✓	✓	Unlikely	Moderate	**Moderate**	✓			✓	
		Increased predation risk for turtle hatchlings; sea turtle entrapment and entanglement	✓					Possible	Major	**High**	✓	✓	✓	✓	
Fish Aggregating Devices	1. Long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region	Attraction and aggregation of pelagic fish from other habitats	✓					Almost certain	Major	**Extreme**		✓	✓		
		Assist range shifts	✓	✓				Possible	Major	**High**		✓	✓		
		Increased vulnerability of juveniles	✓					Almost certain	Major	**Extreme**				✓	✓

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		Change in fish feeding behaviour	✓	✓				Likely	Moderate	**High**		✓	✓		
		Fad loss, Ghost fishing; pollution; marine debris	✓	✓			✓	Likely	Major	**High**			✓	✓	
		Increased risk of overfishing	✓	✓			·	Likely	Major	**High**				✓	✓
		Species become dependent on the FADs	✓	✓				Possible	Moderate	**Moderate**		✓	✓	✓	
		Disrupt pelagic species movement and migration, "ecological trap"	✓	✓				Likely	Major	**High**		✓	✓	✓	
		Unknown bycatch issues	✓	✓				Unlikely	Moderate	**Moderate**				✓	✓
		May attract but not aggregate tunas					✓	Unlikely	Moderate	**Moderate**		✓	✓	✓	
		Entanglement of marine fauna	✓					Possible	Moderate	**Moderate**	✓	✓	✓	✓	
		Gear entanglement, navigation and shipping hazards					✓	Possible	Major	**High**	✓	✓	✓	✓	

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
Fish Aggregating Devices	2ai. Sustainable use: public enjoyment and appreciation	User conflict; overcrowding; safety issues				✓	✓	Likely	Significant	**Extreme**				✓	✓
Fish Aggregating Devices	2aiii. Sustainable use: recreational, economic and cultural activities	User conflict				✓	✓	Possible	Major	**High**	✓			✓	✓
		Environmental parameters can interfere with FAD function					✓	Possible	Moderate	**Moderate**		✓	✓		
		Expensive to deploy, monitor and maintain					✓	Likely	Moderate	**High**			✓	✓	
		FAD loss	✓	✓			✓	Likely	Major	**High**			✓	✓	
		Gear entanglement, navigation and shipping hazards					✓	Possible	Major	**High**	✓	✓	✓	✓	
		Overfishing and resource depletion	✓	✓				Likely	Major	**High**				✓	✓
		Poor compliance	✓				✓	Possible	Major	**High**					✓
		Unknown bycatch issues	✓	✓				Unlikely	Moderate	**Moderate**				✓	✓

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		May attract but not aggregate tunas					✓	Unlikely	Moderate	**Moderate**		✓	✓	✓	
		Disproportionate harvest of juveniles	✓					Almost certain	Major	**Extreme**				✓	✓
		Lower catch diversity means higher sensitivity to climate change	✓				✓	Possible	Moderate	**Moderate**			✓	✓	
		Fails to achieve stated objectives				✓	✓	Unlikely	Major	**Moderate**	✓	✓	✓		
		Compromise other fisheries				✓	✓	Possible	Major	**High**	✓	✓	✓	✓	
Fish Aggregating Devices	2aiv. Sustainable use: research	Insufficient data to fish sustainably					✓	Almost certain	Major	**Extreme**				✓	
Fish Aggregating Devices	2b. Encourage protection and management	Lack of compliance and enforcement	✓				✓	Possible	Major	**High**				✓	✓
		Lack of a clear management plan	✓				✓	Possible	Major	**High**				✓	
		Unclear access rights				✓	✓	Possible	Major	**High**				✓	
		Weak legislation				✓	✓	Possible	Major	**High**				✓	
		Unclear objectives				✓	✓	Possible	Major	**High**	✓			✓	

Structure	Marine Park Act object	Negative impacts	Values affected					Risk Rating			Mitigations				
			Biodiversity	Ecosystem Health	Heritage	Social	Economic	Likelihood	Consequence	Risk	Consultation	Placement	Design	Management	Compliance
		Management structure disconnected from local needs				✓	✓	Possible	Major	**High**	✓			✓	
Fish Aggregating Devices	2c. Meeting Australia's international responsibilities	Overuse of FADs interfere with MPA objectives	✓					Likely	Major	**High**				✓	
		Entanglement and bycatch of threatened species	✓					Possible	Major	**High**	•	✓	✓	✓	
		Changed movement and feeding behaviour of threatened species	✓					Possible	Major	**High**		✓	✓	✓	

8.4. Benefit and Negative impact Assessment Discussion

The benefits and negative impacts of ARs were often social and economic as well as ecological; he effects of FADs appear to be more straightforward and can be grouped into ecological negative impacts, with low ecological benefits, socioeconomic benefits and socioeconomic negative impacts. The largest number of benefits and negative impacts in the literature pertain to the effects of ARs and FADs on the first object of the Marine Park Act; ARs and FADs present a large number of potential negative impacts to the region's values (Table 9), but also offer potential benefits (Table 8).

The life history of some of the target species potentially attracted to ARs or FADs for recreational fishing in a Marine Park may influence the assessment of benefits and negative impacts. For example, evidence suggests that FADs set in southern Queensland and NSW waters primarily attract dolphinfish or mahi mahi (*Coryphaena hippurus*), a species thought to be highly resilient to fishing, as it has a population doubling time of less than 15 months (Froese et al., 2017). This species is also likely to be attracted to FADs in the region (Dr. J. Lowe, fisheries scientist and recreational fisher, pers. comm.).

Precedents for the management of ARs in the Marine Park exist in the context of historic or accidental shipwrecks (e.g. the SS Yongala). Measures to prevent negative impacts on heritage and biodiversity values of the wrecks also enhance the social and economic benefits through recreational diving. The Marine Park wrecks used for recreational diving and/or historic heritage protection have no-take protection status, which reduces user conflict, damage to the shipwrecks themselves and the risk of overfishing species attracted from elsewhere. This model can be embedded, if needed, within a more formal management and governance of ARs or FADs, including the funding of the extra management requirements through permits[3]. On the other hand, there is also a risk that approval of one or two FADs/ARs on the Reef can set a precedent for more, leading to a cumulative deployment process. The literature clearly warns against the unplanned deployment of multiple artificial structures resulting in ocean sprawl (see sub-section 7.1.2) (Bishop et al., 2017). Inadequate management was classified as extreme risk (See sub-section 7.3); ARs and FADs in the Marine Park would almost certainly add to the management burden in a system where there are still existing management challenges to overcome.

Management is the key tool to optimising benefits and preventing or mitigating negative impacts of ARs or FADs. The mitigation measures for many of the risks discussed in the literature can be classified into five key components, which include:

1. consultation (see Section 6.2),
2. design,
3. placement (see Chapter 5),
4. management (including effective fisheries management), monitoring (for both structural integrity and ecosystem negative impacts), and
5. compliance (see Chapter 9).

For example, fish size and bag limits associated with FAD catches can substantially reduce the risk of overfishing juveniles. Optimising the potential benefits of ARs and FADs is possible through a transparent process of stakeholder consultation and participatory planning. User conflict can be avoided through, for example, spatial

[3] https://www.gbrmpa.gov.au/access-and-use/responsible-reef-practices/maritime-heritage-sites

management which allocates specific activities (e.g., diving or fishing, but not both) to individual ARs or FADs, or through a licensing system. Some of these mitigating factors are already in place where FADs are deployed in Australian waters, and a recent socioeconomic analysis suggests that user groups (especially fishers and divers) perceive artificial structures to have a positive effect on the management of marine resources (WAMSI, 2020). The reason for this is unclear; perhaps the tangible, physical structure of an AR is viewed as a visible management action. However, how this might flow on to greater awareness of management and conservation of the natural environment more generally is also unclear.

One approach that may be useful to support assessment of a proposal to install ARs or FADs may be a Net Environmental Benefits Analysis (NEBA). This is an analytical approach to balance the benefits, negative impacts and trade-offs associated with competing alternatives within each of the five key components. For example, competing alternatives of an AR installation may include options for what stakeholders to consult with, the optimal design, where to place the AR, the use for the AR and requirement for construction and operational management plans or monitoring, and the approach for measuring compliance. The NEBA is a systematic process incorporating the region’s values as environmental metrics which are assessed using risk quantification. The process is currently used for evaluating decisions for decommissioning offshore oil and gas infrastructure, which incidentally includes options for retaining the structure for AR habitat. Whilst a specific template would need to be prepared for the Authority, the framework of the NEBA process is already well defined. The primary aim of a NEBA assessment is to compare alternative options for the ability to maximise environmental, social and economic benefits while managing risks.

9. REGULATION AND GOVERNANCE

9.1. State and Federal Regulatory Approvals and Management

9.1.1. Great Barrier Reef Marine Park Authority

Prior to the recent Interim Policy position of the Authority that no FADs or ARs are to be deployed in the Marine Park, any proposal to install and operate an AR in the Marine Park would have been considered with regards to a guideline and required permission from the Authority. The definition of an AR within this now-revoked guideline included provision for deployment of FADs. The permission system of the Authority provides a transparent, consistent and contemporary approach to evaluate individual project proposals against achievement of the objects of the Marine Park Act. Permits are granted by the Authority and the Queensland Department of Environment and Science for activities in the Marine Parks through a joint permission system. The permission system regulates activities that require permission or accreditation under Australian and Queensland Government acts, regulations and the Zoning Plan.

The permit application process may require stakeholder consultation, placement, design, preparation of Environmental Management and Operational Plans, management of public access issues and appointment of a technical advisory panel. Therefore, the mitigations and improvements for protecting and achieving the objects of the Marine Park Act are reviewed on a case-by-case basis to evaluate the specific benefits and negative impacts of each project proposal.

Depending on the scale and location of an AR project proposal, an AR may also need to be considered under the Sea Dumping Act. The Authority also works closely with the Queensland Department of Environment and Science (DES) to ensure such assessments and permitting processes are integrated.

To date, one FAD (which lasted three weeks before becoming unmoored and lost in 2007 (Fernandes pers.comm.)) and no ARs have been permitted in the region.

9.1.2. Sea Dumping Act

The Sea Dumping Act aims to minimise pollution threats by:

- prohibiting ocean disposal of waste considered too harmful to be released in the marine environment.
- regulating permitted waste disposal to make sure environmental negative impacts are minimised.

This applies to dumping of or dumping from vessels, aircraft and platforms, as well as ARs as defined by the Sea Dumping Act (see Section 4.2). The Authority administers the Sea Dumping Act within the Park on behalf of the Department of Agriculture, Water and the Environment (the Department).

9.1.3. Environment Protection and Biodiversity Conservation (EPBC) Act

Where an AR or FAD deployment is likely to impact on matters of national environmental significance (e.g., Marine Park or region, threatened species), approval under the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) is required.

9.1.4. Department of Environment and Science

Queensland has an integrated development application, assessment and decision-making system which it operates jointly with the Authority, as discussed above.

Other federal or state legislation may also be applicable to FADs or ARs.

9.2. Literature Review of Regulation and Governance

In the USA, where there is one of the longest-standing programs of ARs for recreational fisheries, a policy was developed as early as 1985 – the National Artificial Reef Plan (NOAA Fisheries, 2019). However, by the mid-1990s there was still a disconnect between the national plan and state-level management systems and policies (Murray, 1994). One of the ways in which fishing around ARs has been regulated in USA waters is with Special Management Zones, which usually restrict the types of fishing gear permitted (Hooper et al., 2014). Elsewhere, the ecological performance of ARs and FADs has been maximised by prohibiting all extractive use; the fisheries benefit of these ARs is associated with the spill-over of fish from the ARs or FADs into fished zones (Addis et al., 2016; Cabral et al., 2014).

In the eastern Caribbean, FADs are governed in three different ways, depending on the location: private-individual, community-based, and top-down. An analysis of the benefits and trade-off of these three types of governance found that community-based and top-down governance scenarios reduced conflict, but also reduced incentives to develop and maintain the FADs. The private-individual governance scenario increased conflict, but also improved incentives for monitoring FADs. However, this scenario had no impact on incentives for maintaining and deploying FADs (Pittman et al., 2020). The Marine Park may benefit most from the model used by the NSW Government, where FADs are managed by a working group of government departments and stakeholder groups (NSW Government, 2021). In fact, a partnership model is already used across the Marine Park to manage other aspects of marine park use (GBRMPA, 2021b). However, information on management or monitoring of existing FADs in Queensland or other Australian States was unavailable.

Pittman et al. (2020) suggested that the best social and ecological outcomes may be achieved when stakeholders and community groups are given the opportunity to develop policies make decisions and be involved in the logistics of deployment, management, maintenance and monitoring, and government maintains the responsibility of ensuring compliance, as occurs in some parts of the Eastern Caribbean. The review of the relevant literature also suggests that, as is evident in other regions, any ARs or FADs that may be used within the Marine Park would not benefit from a one-size-fits-all, top-down approach (Ostrom et al., 2007). There is already a functioning system of guidelines and permitting conditions for recreational and commercial activities within the Marine Park; these, if necessary, can be tailored to or updated for ARs and FADs (Pears & Williams, 2005). Strategies such as restricted access, limited effort, or segregation of users in space and time have been shown to work elsewhere (Polovina, 1991b).

Together with development of a policy, management plans for FADs and ARs can also be prepared as a collaborative effort (Sadusky et al., 2018). Management plans or systems are mandated by the Food and Agriculture Organization (FAO) for FADs and ARs used commercially, with less direction given by FAO for those used for recreational purposes (FAO, 2011). Australia has a number of examples for the development of management plans for FADs, including by the NSW and Western Australian state governments (NSW Government, 2021; Recfishwest, 2021); unfortunately, information on the success or otherwise of the implementation of these plans was unavailable. At the national level, the Game Fishing Association of Australia also has a Code of Conduct for FAD fishing (Game Fishing Association Australia, 2021). One of the factors that can improve the success of managing ARs and FADs is the development of quantitative and measurable goals (Murray, 1994) and may include measures such as permits, seasonal deployment or temporary closures (MRAG, 2011). Explicit quantitative goals may be biological, social or economic, these goals can give rise to performance indicators to be measured by monitoring programs (Becker et al., 2018).

More generally, the Authority is moving towards a more risk-based approach to management whereby the limited management resources of the agencies is being better aligned toward addressing the highest risks to the Marine Park (GBRMPA, 2019c, 2020). The literature reviewed indicates that effective consultation about, assessment, monitoring, management and reporting of ARs/FADs requires significant resources which would have to be diverted from other, current management priorities (Showstack, 2001).

10. KNOWLEDGE GAPS AND NEXT STEPS

This literature review on ARs and FADs, undertaken specifically to highlight benefits and negative impacts to the values of the region, covers a broad range of information pertinent to the benefits and negative impacts of FADs and ARs. However, there are significant knowledge gaps associated with all the benefits and negative impacts. Unfortunately, there is a general lack of information on MPAs similar to the Marine Park where ARs and/or FADs are deployed or prohibited that could inform the likelihood of different scenarios for the Marine Park. The same lack of guidance is applicable to World Heritage Areas. Further research would assist in better answering the following key questions:

- What are the changes to natural reefs caused by movement of species from them to ARs or FADs, and how are these changes best measured?
- Which species are most likely to be negatively impacted by ARs and FADs as bycatch, or by becoming entangled?
- What are the species most likely to be attracted to ARs and FADs in the Marine Park, and how sustainable would it be to catch them?
- What is the optimal distance of an AR or FAD from a natural reef in the Reef for its negative impacts on natural reef communities to be negligible?
- How much fishing is already occurring on the Reef around moored floating objects or other artificial installations? What species are predominantly caught?
- How much recreational diving is already occurring within the Reef at artificial subsea structures (i.e. shipwrecks, underwater art) compared to the natural reef?
- How do physical factors (e.g. currents, sediments, soundscapes) change with AR or FAD deployment?
- How would the deployment of ARs or FADs change patterns of fishing effort, and at what spatial scales?
- What are the benefits and negative impacts of ARs and FADs on Indigenous values?
- What are the social and economic benefits and negative impacts on other stakeholders using the environment within the region (e.g. commercial fishing industry, tourism)?

Additionally, there are still substantial gaps in knowledge on the basic biology and ecology of assemblages that develop on ARs and FADs.

Some of these questions can be answered by conducting modelling or experimental work (e.g. where ARs or FADs are constructed and deployed for the purpose of research and then removed). At the scale of the Marine Park, monitoring the distribution of fishing effort, catch rates and composition would need to take place across a whole region before and after AR or FAD deployment, including with appropriate and adequate numbers of controls, to deliver answers at an appropriate scale. This needs to include both biophysical and socioeconomic monitoring on an ongoing basis.

The usefulness of the benefits and negative impact assessment developed here could be maximised through a stakeholder consultation process to determine stakeholder knowledge and perceptions about individual benefits and negative impacts in a real-world Marine Park context. Inviting the assessment of experts and stakeholders with local knowledge and experience in a workshop format similar to that employed by the Outlook Reporting process (GBRMPA, 2019b) could be a logical next step towards contextualising the findings from the global literature to the local situation.

11. CONCLUSION

The benefits and negative negative impacts of ARs and FADs on values of the region, and their effects on achieving the objects of the Marine Park Act, are primarily ecological (affecting biodiversity and ecosystem health values) and relevant to the primary object of the Marine Park Act (environment, biodiversity and heritage protection). The greater versatility of ARs compared to FADs may lend itself to a larger variety of available mitigation measures to diminish risks while retaining potential benefits. There is a large number of high and moderate level risks of ARs for the achievement of the primary object of the Marine Park Act, but a similar number of high and moderate level benefits. This is not the case for FADs, where only a small number of high-level benefits were found in the literature, against a larger number of extreme, high and medium level risks. In the context of the region, it is worth noting that the balance of benefits and risks should not be read as a “numbers game”; that is, even one of the risks could be serious enough to negate any number of benefits. The other object of the Marine Park Act, for which there were multiple relevant benefits and risks, applies “so far as is consistent with the main object” of the Act, and pertain to recreational, educational, economic, research and cultural activities.

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Appendix A TERMS OF REFERENCE

Fish Aggregation Device and Artificial Reef Literature Review

Terms of Reference

Background

The Great Barrier Reef Marine Park Authority (GBRMPA) has noted heightened interest in the possibility of deploying anchored Fish Aggregation Devices (FADs) in the Marine Park.

As the GBRMPA is also subject to *the Environment Protection (Sea Dumping) Act 1981* (the Sea Dumping Act), the definition of artificial reef, in the Sea Dumping Act, is also pertinent as it includes FADs. In this Act:

"artificial reef means a structure or formation placed on the seabed:

- *for the purpose of increasing or concentrating populations of marine plants and animals; or*
- *for the purpose of being used in human recreational activities.*

and includes anything prescribed by the regulations to be an artificial reef for the purposes of this definition, but does not include anything prescribed by the regulations not to be an artificial reef for the purposes of this definition."

The GBRMPA does not have a policy position on FADs or artificial reefs.

An interim moratorium on FADs and artificial reefs was put in place by the Board of the GBRMPA on 28th October 2020 whilst a policy position is developed.

Scope of work

- A national and global literature review is required to inform the development of GBRMPA's policy position on anchored FADs and artificial reefs.
- The literature review must:
- include review of all available peer-reviewed and non-peer reviewed literature;
- carefully consider (and reference), in all instances, the definition of artificial reefs/FADs used in any documents cited;
- assess the pros and cons of artificial reefs and FADs against the objectives of the Marine Park Act which are as follows:
    - The main object of the Marine Park Act is to provide for the long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region.
    - The other objects of the Marine Park Act are to do the following, so far as is consistent with the main object:
        - allow ecologically sustainable use of the Great Barrier Reef Region for purposes including the following:
- public enjoyment and appreciation;

- (ii) public education about and understanding of the Region;
- (iii) recreational, economic and cultural activities;
- (iv) research in relation to the natural, social, economic and cultural systems and value of the Great Barrier Reef Region;
    - encourage engagement in the protection and management of the Great Barrier Reef Region by interested persons and groups, including Queensland and local governments, communities, Indigenous persons, business and industry;
    - assist in meeting Australia's international responsibilities in relation to the environment and protection of the world heritage (especially Australia's responsibilities under the World Heritage Convention).
- The environment, biodiversity and heritage values of the Marine Park, referenced in the Marine Park Act, should be taken to include all the environment, biodiversity and heritage values as listed in the 2019 Great Barrier Reef Outlook Report.
- The literature review must analyse and evaluate the identified pros and cons of FADs and artificial reefs with especial reference to their potential deployment, uses and impacts within the GBRMP, given the objectives as outlined above.
- All statements of fact in the literature review must cite the source.
- All sources of information must be included in a reference list, with hotlinks to original documents if possible.
- The literature must include an Executive Summary which summarises, and provides an evaluation of, the pros and cons of artificial reefs and FADs in the Marine Park.
- The successful applicant may be required to also follow guidance within GBRMPA's Reports – Guidelines for Consultants when developing and writing the report.

Appendix B DEFINITIONS

List of definitions for FADs and ARs identified in the literature

Structure	Human use included	Definition	References
AR	No	A man-made underwater structure designed to protect, enhance, or restore components of marine ecosystems	Espinoza et al. (2020)
AR	No	A submerged structure intentionally placed on the seabed that mimics characteristics of natural reefs	Firth et al. (2016)
AR	No	A submerged structure placed on the substratum (seabed) deliberately, to mimic some characteristics of a natural reef	Baine, M. (2001); Hackradt et al. (2011)
AR	No	All kinds of structures deliberately submerged to the sea floor in order to imitate some features of natural reefs	Demirhan et al. (2020)
AR	No	Approved structures that have intentionally been placed or constructed for the purpose of enhancing benthic relief	Harrison and Rousseau (2020)
AR	No	Are deployed in coastal waters to mimic certain characteristics of natural rocky habitats	Shin et al. (2014)
AR	No	Artificial underwater structures which are usually built to protect or enhance marine biodiversity, including commercial species, in areas with an otherwise featureless sea bed	Tsiamis et al. (2020)
AR	No	Formed by submerged structures that have been accidentally or deliberately sunk in aquatic environments	Amaral et al. (2010)
AR	No	Human-made structures installed in aquatic habitats that serve as a substrate and/or shelter for organisms	Lima et al. (2019)
AR	No	Human-made structures that are placed on coastal seabeds to mimic some characteristics of a natural reef and to thereby rehabilitate coastal habitats	Chen et al. (2019)
AR	No	Human-made structures, sometimes with established coral colonies or fragments attached, intended to mimic natural reefs and enhance habitat availability for corals and reef-associated invertebrates and fish	Higgins et al. (2019)
AR	No	Man-made habitats placed on the bottom of waters and are usually made from heaps of materials such as used tires, cement or concrete molds and bamboo	Setiadeswan et al. (2019)

Structure	Human use included	Definition	References
AR	No	Man-made structures deliberately deployed in the marine environment to mimic the characteristics of a natural reef, and to serve as shelter, a source of food, and breeding grounds for fish and other organisms in the absence of a natural hard substratum	Magro et al. (2017)
AR	No	Man-made structures designed to enhance fish populations and mitigate habitat loss by mimicking the biota and structural features of live-bottom natural reefs	Altizer (2013)
AR	No	Man-made structures located underwater that replicate certain characteristics of a natural reef	Bideci and Cater (2019)
AR	No	Man-made structures placed underwater to mimic some characteristics of natural reefs	Belhassen et al. (2017)
AR	No	Man-made submerged structures that are deliberately placed on the sea bed	Targusi et al. (2013)
AR	No	Man-made, underwater structure, typically built for the purpose of promoting marine life in areas of generally featureless bottom	Sreekanth et al. (2019)
AR	No	Manmade structures deployed on sea bottoms with the primary purpose of protecting coastal habitats and increasing biotic resources by aggregating marine species and preventing trawling	Ponti et al. (2015)
AR	No	Manmade structures that are placed on the seabed deliberately to mimic some characteristics of a natural reef	Liu et al. (2011)
AR	No	Solid structures immersed directly and arranged on the seabed, without anchorage in the subsoil	Cazalet and Salvat (2011)
AR	No	Structures constructed at sea to attract and concentrate fish and to potentially improve and rehabilitate coastal ecosystems	Lee et al. (2018)
AR	No	Structures immersed in aquatic environments (especially marine ones) that provide fauna with shelter, hard substrates, food and nursery areas.	Lira et al. (2010)
AR	No	Structures intentionally deployed on the seafloor to influence biological or physical processes	Jiang et al. (2016)
AR	No	Structures purposely placed on the substrate that mimic characteristics of natural structural habitat and concentrate populations of marine flora and fauna	Bateman (2015)
AR	No	Structures purposely submerged in the sea floor to mimic some features of natural reefs1 and increase the concentration of nutrients, thereby increasing local primary productivity, which can, in turn, cause an increase in the abundance of many typical species from rocky environments	Costa et al. (2014)

Structure	Human use included	Definition	References
AR	No	Structures that are placed on the substratum deliberately to create new three-dimensional structure, therefore interrupting the negative feedback loop and giving corals the chance to settle	Ee and Horst (2019)
AR	No	Submerged objects placed on the seabed to mimic some natural reefs	Kantavichai et al. (2019)
AR	No	Submerged structures (e.g. ships, tires, steel frames, boulders) placed on the seafloor deliberately, to mimic attributes of a natural habitat	Logan and Lowe (2018)
AR	No	Submerged structures deliberately or accidentally placed on the substratum to imitate some of the characteristics of natural reefs	Coelho et al. (2012)
AR	No	Submerged structures placed in the aquatic environment where these would not naturally occur, to mimic some characteristics of natural reefs	Boerseth (2016)
AR	No	Submerged structures placed on the substratum (seabed) deliberately, to mimic some characteristics of a natural reef	Cresson et al. (2014)
AR	No	Underwater, man-made structures that affect the local biological community	Tynyakov et al. (2017)
AR	Yes	A man-made structure, mostly in hard materials like concrete & ceramic in different shapes and designs so as to suit the required purposes and aims to serve various needs ranging from conservation, production, protection, mitigation, adverse impact reduction, reconstruction of natural habitats and ecosystems, sometimes serving more than one purpose	Kasim (2017)
AR	Yes	A structure of natural or human origin deployed purposefully on the seafloor to influence physical, biological, or socio-economic processes related to living marine resources	Glarou et al. (2020)
AR	Yes	A structure that is installed near the shoreline to create space for spawning and inhabitation of marine life and provide a hiding place for small fish, for the purpose of ensuring aquatic resources of onshore fisheries	Muñoz-Pérez (2008)
AR	Yes	A structure which is constructed or placed in waters covered under this title for the purpose of enhancing fishery resources and commercial and recreational fishing opportunities	Hornbeck (2017)
AR	Yes	A submerged structure deliberately placed on the seafloor to mimic some functions of a natural reef such as protection, regeneration, concentration and/or enhancing population of living marine resources	Callaway (2018)
AR	Yes	Anthropogenic objects that have traditionally been deployed on the seabed to influence physical, biological or socio-economic processes related to living marine resources	Shani et al. (2012)

Structure	Human use included	Definition	References
AR	Yes	Anthropogenic structures that are deliberately or accidentally submerged, and often alter local habitat by providing vertical relief and a hard substratum where typically none previously existed	Bieler et al. (2017)
AR	Yes	Any material or matter deliberately placed in an area of the marine environment where that structure does not exist under natural circumstances for the purpose of protecting, regenerating, concentrating or increasing populations of living marine resources, or for enhanced recreational use of the area	Claudet and Pelletier (2004)
AR	Yes	Any material purposefully placed in the marine environment to influence physical, biological, or socio-economic processes related to living marine resources	Sutton and Bushnell (2007)
AR	Yes	Any submerged structures placed on substratum to mimic some characteristics of anatural reef, often to augment fishery yields.	Layman et al. (2016)
AR	Yes	Artificial (concrete, reinforced concrete, coal ash) objects that are deployed on sandy, muddy or sandy and muddy sea beds to create a diversification element on the flat and original habitat and to enhance the fishery resources of ecosystems	Giansante et al. (2010)
AR	Yes	Artificial objects intentionally deployed on the seabed to affect the physical, biological or socio-economic processes of marine resources	Zhang et al. (2020)
AR	Yes	Human-made structures that can mimic some characteristics of natural structures. Intentionally deployed for many purposes, such as enhancing fisheries and tourism as well as surfing and diving.	Florisson (2015)
AR	Yes	Human-made structures, employed worldwide for recreation, fisheries enhancement, research, and conservation	Bulger et al. (2019)
AR	Yes	Man-made substrates that are deliberately submerged and placed on the seafloor to reproduce the structure and functioning of a natural marine ecosystem, so that it can be used by the local community for a variety of purposes such as hook-and-line fishing and underwater tourism	Brandini (2014)
AR	Yes	Man-made underwater structures that promote marine life and enhance fish stocks	Chen et al. (2013)
AR	Yes	Manmade structure that may mimic some of the characteristics of a natural reef. One or more objects of natural origin deposited purposefully onto the seafloor to influence physical, biological or socioeconomic processes related to living marine resources	Mohamad et al. (2016)

Structure	Human use included	Definition	References
AR	Yes	Natural and man-made objects deployed on the seafloor deliberately used for multiple processes related to living marine resources	Franco Melendez et al. (2015)
AR	Yes	Objects deployed to influence aquatic resources	Bortone et al. (1997)
AR	Yes	One or more objects of natural or human origin deployed purposefully on the sea-floor to influence physical, biological or socioeconomic processes related to living marine resources	Genzano et al. (2011); Manoulian et al. (2011); Pascaline et al. (2011); Kheawwongjan and Kim (2012); Florisson et al. (2018)
AR	Yes	Structures deployed on the sea floor, often with the objective of enhancing fisheries	Scott et al. (2015)
AR	Yes	Structures placed intentionally on the sea bed with the aim of imitating the function of a natural reef, i.e. protection, regeneration, concentration or growth of marine resources.	Toledo et al. (2020)
AR	Yes	Structures purposely sunk to create habitats for marine life and infrastructure for unique diving experiences	Seaman and Depper (2019)
AR	Yes	To throw cement and concrete into the sea to create artificial bank for aquatic organisms so as to recover and reproduce fishery resources	Fang et al. (2013)
FAD	No	A man-made object used to attract ocean-going pelagic fish such as marlin, tuna and mahi-mahi	Schraader (2013)
FAD	No	Anchored or drifting objects that are placed in the ocean to attract fish	Rohit (2013); SPC (2012)
FAD	No	Any man-made or partly man-made floating device, whether anchored or not, intended for the purpose of aggregating fish, and includes any natural floating object on which a device has been placed to facilitate its location.	Annandale and Atherton (2013)
FAD	No	Any object or group of objects, of any size, that has or has not been deployed, that is living or non-living, including but not limited to buoys, floats, netting, webbing, plastics, bamboo, logs and whale sharks floating on or near the surface of the water that fish may associate with	MRAG (2011)
FAD	No	Any structure or device of permanent, semipermanent or temporary nature made from any material and used to lure or aggregate fish.	Ahmad et al. (2004)

Structure	Human use included	Definition	References
FAD	No	Any type of method, object or construction that facilitates the aggregation and attraction of fish for capture, and that when put in water, algae starts to accumulate itself to attract small fishes and feeds on them and smaller fishes attracts bigger fishes.	Aguilar (1989)
FAD	No	Any type of structure deployed on the water surface or just below the surface in order to attract pelagic fish species	Özgül (2015)
FAD	No	Buoys designed specifically to aggregate pelagic fishes	Brill et al. (1999)
FAD	No	Floating platforms in the open sea, moored to the seabed that fish are naturally attracted to (fish tend to congregate around any floating object in the marine environment).	Pinnegar et al. (2019)
FAD	No	Floating structures called fish aggregating devices (FADs) for attracting and concentrating pelagic fish	Robert et al. (2013)
FAD	No	Man-made drifting or anchored buoys or rafts that attract and aggregate fish and other marine organisms.	Beverly et al. (2012)
FAD	No	Man-made structures which facilitate attraction and aggregation of fish	Rajeswari (2012)
FAD	No	Manmade structures that float on or just below the surface of the ocean	Montes et al. (2019)
FAD	No	Permanent, semi-permanent, or temporary structures made from any material and used to attract fish	Blasi et al. (2016)
FAD	No	Positively buoyant structures that aggregate marine species	Florisson et al. (2018)
FAD	No	Structures deployed specifically to concentrate fishes	Dempster (2005)
FAD	Yes	A moored or free-floating device designed to attract and/or aggregate fish, generally to provide recreational fishing opportunities	NSW Government (2015)
FAD	Yes	An anchored or drifting object that is placed in the ocean to attract fish; an infrastructure that facilitates the capture of pelagic fish	Sharp (2014)
FAD	Yes	Any floating construction that is installed at sea in order to attract and aggregate fish for harvest	Shainee and Leira (2011)
FAD	Yes	Any method, object or construction used for the purpose of facilitating the harvesting of fish by attracting and thus aggregating them	Rosdi and Syed (2018)

Structure	Human use included	Definition	References
FAD	Yes	Attract and aggregate free schooling tuna and small pelagics over a limited area, making fishing more successful	Cabral et al. (2014)
FAD	Yes	Fish aggregating devices applied worldwide over the centuries to increase fish catch	Sinopoli et al. (2007)
FAD	Yes	Fishing devices that concentrate pelagic fish (e.g. tuna) in one location to make them easier to catch	Albert et al. (2015)
FAD	Yes	Floating objects deployed to concentrate target species or bait fishes and improve the catch for artisanal, sport, or commercial fisheries	Nelson (2003)
FAD	Yes	Human-made structures anchored to the ocean floor with fish attraction material on or near the surface designed to effectively create a resource patch	Alvard et al. (2015)
FAD	Yes	Humanmade objects deployed at sea to concentrate pelagic fish in an area for capture	Amos et al. (2014)
FAD	Yes	Man-made floating structures moored in oceanic water with the primary function of aggregating large numbers of pelagic fish in the hope of improving catch rates	Folpp and Lowry (2006)
FAD	Yes	Man-made structures set to float or anchored at a desired location in the sea to aggregate fish thus rendering their capture easier and may vary in shape and size, and can be either anchored or drifting	Mzingirwa et al. (2016)
FAD	Yes	Structures floating at the surface of the ocean placed by fishers to increase fishing oppor-tunities and specifically attract and capture both pelagic juvenile and adult fishes, such as tropical tuna including skipjack Katsuwonus pelamis, yellowfin Thunnus albacares and bigeye Thunnus obesus	Castro et al. (2020)

Appendix C SUMMARY BENEFIT AND NEGATIVE IMPACT TABLE

Structure	GBRMP Act object	Level	Benefit	Negative Impact
Artificial Reefs	1. Long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region	High	Adds structural complexity on top of soft seabed habitat	Lack of evidence for production, more evidence for attraction
			Can be designed to enhance populations of species of interest	Risk of overfishing; unlikely to benefit heavily exploited or overfished species without extra management; AR effect undermined by fishing pressure
			Enhanced primary and/or secondary production	Alter the composition of natural sedimentary habitats and species assemblages
			Enhancement of preferred above-seabed biodiversity	ARs are not surrogates for natural reefs; “enhanced” biodiversity replaces existing natural habitats
			Improve connectivity	Alter fish communities on nearby reefs
			Hosts unique communities	Benthic and pelagic ‘ecological halo’ or ‘footprint’ of the AR can be up to 15 times the area of the actual AR
			Enhanced fish density and /or biomass	Corridors or stepping-stones for invasive species
			Enhance benthic cover and invertebrates	Direct effects of AR construction on footprint and nearby natural habitats
			Enhance above-seabed infauna and meiofauna	Increased catch rates of juveniles and small individuals

Structure	GBRMP Act object	Level	Benefit	Negative Impact
			Increasing natural ecosystem stability and resilience	Diverts funding from more important environmental actions; distract from conservation of natural habitats
			Increased benthic recruitment	The benthic community created will not duplicate but rather replace natural communities.
			Provide important ecological functions	ARs also replace soft seabed communities and their natural functions.
		Moderate	Can successfully mimic aspects of natural reefs	Can divert fish arriving from inshore nursery habitats from settling on natural reefs
			Divert user pressure from natural habitats	Alter sediment and water quality
			Protection of habitat from trawling	Conservation benefits only at small scales
			Reduced pressure on older shipwrecks	Barriers to the movement of organisms, material and energy
				Habitat fragmentation
				Lower fitness of fish on ARs
				Nutrient enrichment
				Chemical contamination
				Modifications to fish behaviour
				Fails to achieve biological objectives
				Weathering of AR can cause loss of organisms

Structure	GBRMP Act object	Level	Benefit	Negative Impact
		Low	Minimal or no effect on the more distant surrounding seabed	Alter microbial communities and processes
Artificial Reefs	2ai. Sustainable use: public enjoyment and appreciation	Extreme	Diver and fisher enjoyment	User conflict Overuse
		High	Access to historic heritage Public awareness raising	Degradation of AR by users AR not aligned with user values
		Moderate		User preferences for accidental, historic shipwrecks or natural reefs Lack of sensitivity to local and regional recreational demand
		Low		Low diversity of users
Artificial Reefs	2aii. Sustainable use: public education	High	Education about to historic heritage Education about marine ecology Citizen science	 Potential to misunderstand AR as a "solution" to damage that occurs to natural environments Potential that citizen science can be misunderstood as a "solution" to damage that occurs to marine environments.
		Moderate		User conflicts
		Low		Lack of technology and capacity
Artificial Reefs	2aiii. Sustainable use: recreational, economic and cultural activities	Extreme		Inadequate management
		High	Socioeconomic benefits to divers and associated industries	User conflicts

Structure	GBRMP Act object	Level	Benefit	Negative Impact
			Tourism and ecotourism opportunities	Overuse; overfishing
			Socioeconomic benefits to recreational fishers and associated industries	High cost of deployment and maintenance
			Job creation	AR not aligned with user needs and preferences
			Re-stocking of target species	Damage to AR by users
				Poor compliance
		Moderate	Improved catches	Fails to achieve economic, cultural or social objectives
				Low fishing success
				Lack of public acceptance of AR
		Low	Spillover effects from protected ARs subsidise local fisheries	Low diversity of users
Artificial Reefs	2aiv. Sustainable use: research	High	Opportunity for research on recreational use on ARs	Monitoring programs too short or inadequate to assess achievement of objectives
				Incomplete understanding about AR negative impacts
				Illegal fishing confounds research results
				Monitoring done by fishers and citizens does not provide reliable data
		Moderate	Opportunity for research about reef ecology	Poor record keeping of AR use
			Training for novice divers	Lack of socioeconomic research

Structure	GBRMP Act object	Level	Benefit	Negative Impact
			Training for citizen scientists	Disconnect between theory vs. application
				Pseudoreplication, standardisation and lack of applicability to management
		Low		Inadequate research objectives and goals
Artificial Reefs	2b. Encourage protection and management	High	Positive public perception and support for management	Lack of clear objectives for research or management
			Reduce user pressure on natural reefs	User conflicts
			Assist with sustainable fisheries management	Poor management
			Increased awareness and engagement of citizens	ARs detract from conservation of natural habitat
			Potential species-specific design and management	ARs seen as a solution to natural habitat degradation
		Moderate	Effective conservation in combination with Marine Park authorities	Lack of public acceptance of AR
				Fails to achieve stated objectives
				Disconnect between AR deployment, conservation goals and fisheries management
				Disconnect between different relevant authorities
Artificial Reefs	2c. Meeting Australia's international responsibilities	High	Promising for protection of some endangered species	Can be inconsistent with conservation objectives

Structure	GBRMP Act object	Level	Benefit	Negative Impact
				Overlap between human users and threatened fauna Diverts funding from more important environmental actions ARs detract from conservation of natural habitat Increased predation risk for turtle hatchlings; sea turtle entrapment and entanglement
		Moderate	Effective conservation in combination with Marine Park management Increased awareness and engagement of citizens	Disconnect between AR and Marine Park management
Fish Aggregating Devices	1. Long term protection and conservation of the environment, biodiversity and heritage values of the Great Barrier Reef Region	Extreme		Attraction and aggregation of pelagic fish from other habitats Increased vulnerability of juveniles
		High	Enhanced production Nursery structures; enhanced recruitment to nearby reefs Concentrates density and biomass of fish Reduced pressure on coastal ecosystems	Assist range shifts Change in fish feeding behaviour FAD loss, ghost fishing; pollution; marine debris Increased risk of overfishing Disrupt pelagic species movement and migration, "ecological trap" Gear entanglement,

Structure	GBRMP Act object	Level	Benefit	Negative Impact
				navigation and shipping hazards
		Moderate		Species become dependent on the FADs
				Unknown bycatch issues
				May attract but not aggregate tunas
				Entanglement of marine fauna
Fish Aggregating Devices	2ai. Sustainable use: public enjoyment and appreciation	High	Convenient fishing sites	User conflict
				Overcrowding
				Safety issues
Fish Aggregating Devices	2aiii. Sustainable use: recreational, economic and cultural activities	Extreme		Disproportionate harvest of juveniles
				User conflict
		High	Convenient fishing sites	Expensive to deploy, monitor and maintain
			Increased catch and efficiency	FAD loss
			Tourism opportunities	Gear entanglement
				Navigation and shipping hazards
				Overfishing and resource depletion
				Poor compliance
		Moderate		Unknown bycatch issues
				May attract but not aggregate tunas
				Environmental parameters can interfere with FAD function
				Lower catch diversity means higher sensitivity to climate change
				Fails to achieve stated objectives

Structure	GBRMP Act object	Level	Benefit	Negative Impact
Fish Aggregating Devices	2aiv. Sustainable use: research	Extreme		Insufficient data to fish sustainably
		High	Allows monitoring of environment and fishing activities	
		Moderate	Opportunity for pelagic species research	
Fish Aggregating Devices	2b. Encourage protection and management	High	Contributes to coastal resource management	Lack of compliance and enforcement
			Community engagement and stewardship	Lack of a clear management plan
				Unclear access rights
				Weak legislation
				Unclear objectives
				Management structure disconnected from local needs
Fish Aggregating Devices	2c. Meeting Australia's international responsibilities	High		Overuse of FADs interferes with meeting WHA obligations
				Entanglement and bycatch of threatened species
				Changed movement and feeding behaviour of threatened species