Habitat Enhancement Structures in Western Australia

The applications, needs, costs, benefits and cost-effective monitoring methods

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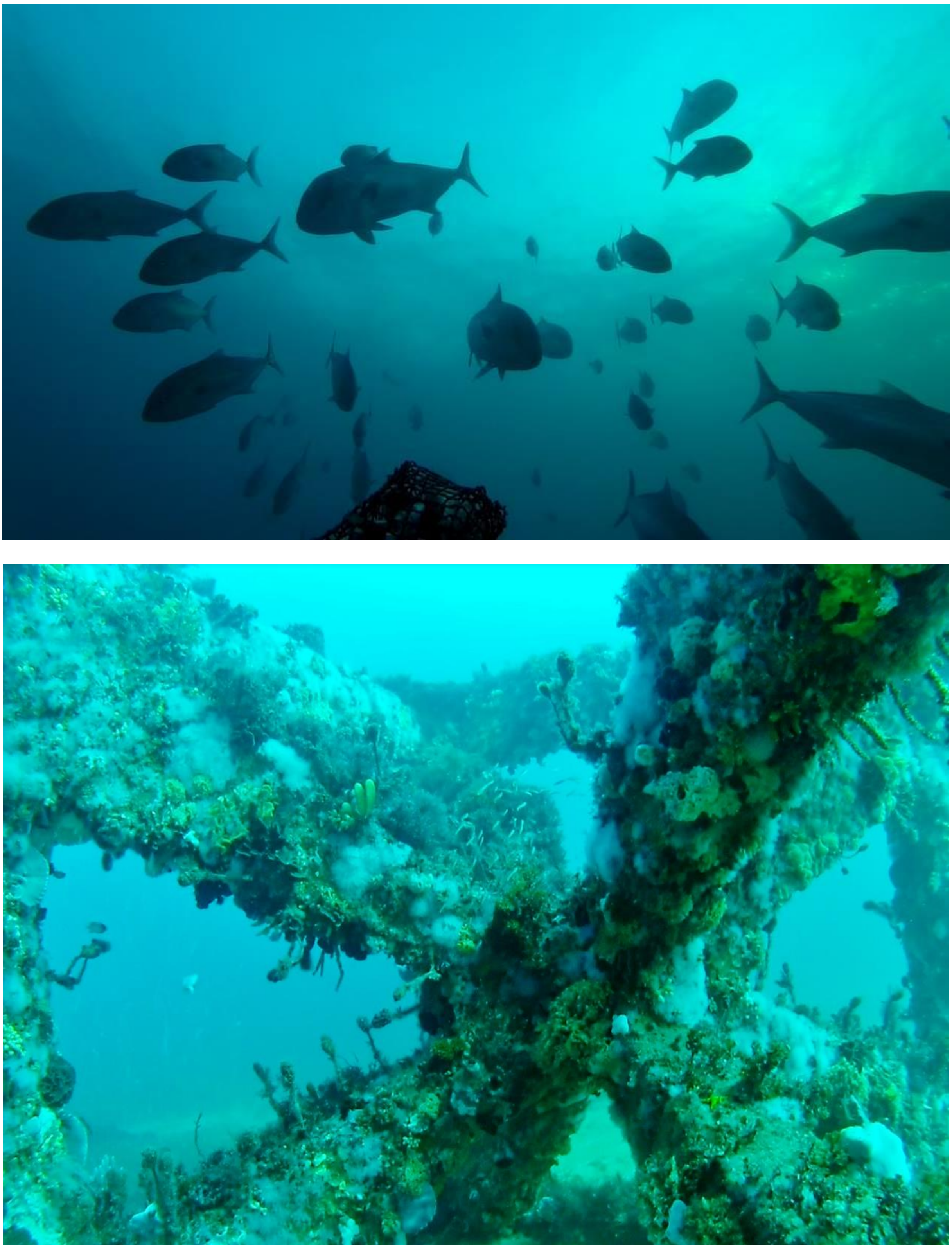
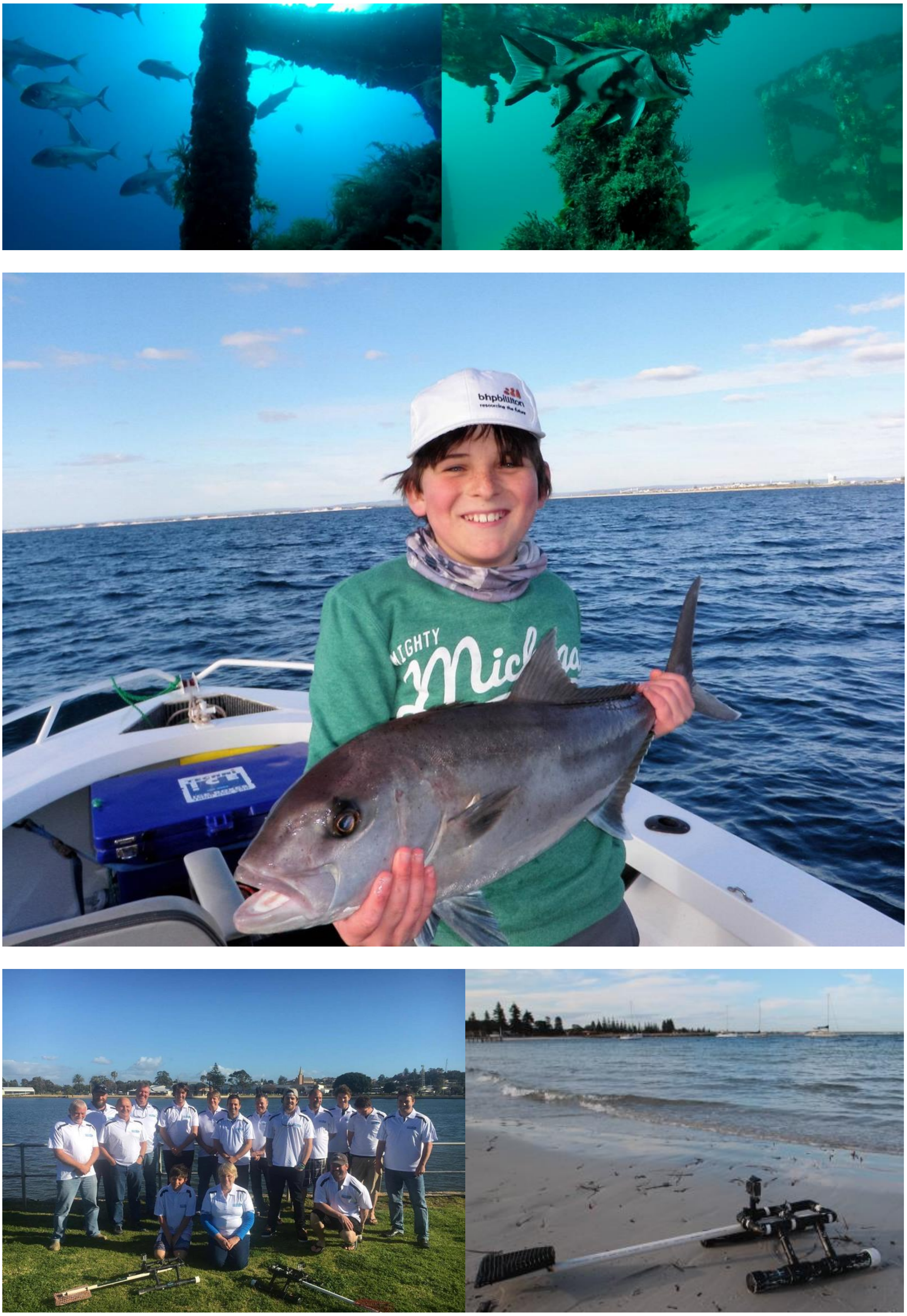


Photographs: School of Samson fish (*Seriola hippos*) chasing a Baited Remote Underwater Video system (BRUVs) on the Dunsborough Artificial Reef (Top) and the growth of sessile organisms on the Bunbury Artificial Reef (Bottom) after four years of ecological development.



Photographs: Samson fish (*S.hippos*, Top Left) and longsnout boarfish (*Pentaceropsis recurvirostris*, Top Right) at the Bunbury Artificial Reef. Max Moore with a samson fish (*S.hippos*) caught on the South West Artificial Reefs (Middle). The Bunbury Reef Vision Team (Bottom Left) and one of the custom designed Baited Remote Underwater Video systems ready for deployment in Esperance (Bottom Right).

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The application, needs, costs and benefits of Habitat Enhancement Structures in Western Australia and cost-effective monitoring methods

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Abbreviations

BRUVs – Baited Remote Underwater Video system

DIDSON - Dual-frequency IDentification SON

DOV – Diver Operated Video

DPIRD – Department of Primary Industries and Regional Development

FADs – Fish Aggregation Devices

GIS – Geographic Information Systems

GPS – Global Positioning System

HES – Habitat Enhancement Structure

LWD – Large Woody Debris

LAR – Living Artificial Reef

Max-N - Maximum number of individuals of a species observed

MOP – Materials of Opportunity

OGA – Ocean Grown Abalone Limited

RAPs – Research Angler Program

RFIF – Recreational Fishing Initiatives Fund

TOW-V – TOWed Video systems

Executive Summary

This report investigated the application, needs, costs, monitoring methods and benefits of Habitat Enhancement Structure(s) (HES) in Western Australia (WA). The project designed, validated and established a world first monitoring method using recreational fishers to survey artificial reefs with Baited Remote Underwater Video system (BRUVs). It also produced a guide to assist industry, researchers, managers and the community with the HES development process.

Peer-reviewed and grey literature on HES from around the world was reviewed and used to evaluate the benefits for recreational and commercial fisheries, aquaculture industries and the environment. Consultation was undertaken with stakeholders and beneficiaries, particularly within the seafood industry to identify the most effective HES designs, application and locations, however, this had limited uptake by the commercial fishing sector in WA. Various monitoring methods were explored through a desktop study to evaluate cost-effectiveness, and some of the more feasible options the subject of physical trials. All of the investigated aspects of HES were then combined into the HES guide for business, industry and community groups that have a desire to invest in HES developments.

Monitoring methods were tested on the South West Artificial Reef Trial (*i.e.* the Dunsborough and Bunbury Artificial Reefs) in Geographe Bay from October 2015 – 2017. During this period the range of community-based monitoring methods tested included logbooks, manual and automatic observation posts, benthic mapping, and Baited Remote Underwater Video (BRUV). Each of these methods involved members of the public playing a role in collecting data. The BRUV component of Reef Vision was determined to be extremely effective and has gone on to become the primary monitoring method now being expanded to other HES developments state-wide.

The HES guide is a tool that provides direction to a range of stakeholders and decision makers looking to undertake new HES projects. It has been promoted around WA and Australia and has already been an essential component in the development of five HES installations that will be deployed 2018 – 2020. The guide provides a background to the different types of HES, considerations for HES development (including purpose, target species, stakeholder engagement, approvals, design, location, configuration, cost/benefit analysis and many more) and the seven-step habitat enhancement process designed in this project which includes purpose, constraints mapping, finalisation of reef site, consultation, approvals, installation (procurement, construction and deployment) and post-deployment activities (monitoring, reporting and extension).

Background

Over the last two decades, HES have grown in popularity around Australia because of their proven functionality. Deployments of HES have been increasing in WA, with over 120,000m^2 of artificial reef area (with purpose-built habitat installed) and over seven million dollars invested in recreational fishing artificial reefs 2013-2017. While these reefs have been deployed for the purpose of enhancing recreational fishing opportunities, there is also a large potential application for commercial fisheries, aquaculture, environmental organisations and community groups. Given the opportunities these types of developments present, there is a need to develop clear pathways and guidance for groups who aim to install and monitor HES projects.

The cost prohibitive nature of professional scientific monitoring could potentially make HES projects unfeasible. The development of cost-effective monitoring using local communities, and the provision of a HES guide will give these projects the best chance of achieving their desired outcomes. With the rate of installations increasing, there is a need to create expertise in the field and develop local capacity.

Objectives

The objectives of this project were to:

1. Identify what HES are currently available throughout the world and what benefits each type may have for recreational and commercial fishing, as well as identifying the benefits for aquaculture and the environment.

2. Identify how various HES designs might provide benefit to the WA seafood sector and community and determine applications and locations for the most effective return on investments.

3. Determine cost-effective methods to monitor HES developments using easily available materials and data collection by community and industry groups.

4. Investigate cost-effective reef, site selection, approvals, construction, deployment and monitoring strategies for business, industry and community groups wanting to invest in HES.

Methodology

- Objective 1: To identify the various types of HES available from around the world, and what benefits and draw-back each provides, several literature reviews were undertaken. These studies collated the citations of over 3,500 articles and processed a vast amount of national and international information on HES.

- Objective 2: Consultation occurred with industry, community and government to determine where and how HES types could provide the best return on investment in WA. Historical uses of HES in the WA commercial sector were reviewed and international HES practises were assessed for application in WA commercial fisheries.

- Objective 3: To increase this return on investment, cost-effective monitoring methods were trialled 2015 – 2017 on the South West Artificial Reef Trial in Geographe Bay to meet the third aim. Over 50 volunteers were recruited and trialled different techniques and methods including BRUVs, observation posts, logbooks and mapping to collect social and ecological data.

- Objective 4: All of this information was reviewed and collated from the above three aims to create the HES guide in the fourth objective. The guide was developed in further workshops with other groups.

Results

- Objective 1: Literature reviews identified the main types of HES from Australia and around the world including artificial reefs, Fish Aggregation Devices, and Living Artificial Reefs (including the addition of woody debris, shellfish reefs and translocation of seagrass or coral species).

- Objective 2: Consultation with industry found that there was little knowledge of HES developments in WA in the early stages of the project, except for abalone ranching on concrete artificial reefs in Augusta. Discussions with other sectors did reveal a high level of engagement and interest in future possibilities irrespective of the knowledge gaps. Consultation occurred with a range of groups which assisted in the completion of the other outcomes of this project, particularly the production of the HES guide.

- Objective 3: The most effective monitoring method tested was the BRUV component of Reef Vision, which, is still ongoing with eighty-four species now recorded on the Bunbury and Dunsborough artificial reefs. While the manual observation post and mapping activities were somewhat effective, the automated observation station and logbooks were not found to be effective under the circumstances tested due to the complex technology and minimal engagement with volunteers.

- Objective 4: Information from all aspects of the project was compiled to create an easy-to-follow guide, a twenty-four-page document which outlines the background, considerations and process for HES developments. The HES guide has been promoted locally, nationally and internationally and has already played a large role to assist in several HES developments. A shorter four-page pamphlet was also produced.

Implications

- This project filled knowledge gaps associated with HES designs, configurations, installation methods and monitoring techniques and particularly the development process.

- The guide will assist industry, community and government groups that aim to deploy HES is a valuable tool that will increase the social, ecological and economic success of future HES developments.

- Cost-effective monitoring trials resulted in the establishment of Reef Vision. The BRUV component of this citizen science program was extremely successful in providing cost-effective data collection and fostering community involvement and ownership. This world first technique using BRUVs deployed by recreational fishers for monitoring can be used on HES to improve cost-efficiencies.

- The project has developed capacity within the recreational fishing sector through a significant increase in expertise related to all aspects of HES projects.

Recommendations

Habitat Enhancement Structure Development

- Any community or industry group that aims to deploy an artificial reef should consider using the HES guide. The guide not only outlines the types and benefits of HES, but also describes the process for a HES development from an idea, right through to post deployment extension activities.

- The purpose of a HES installation should be clearly defined and accepted by stakeholders and all regulators prior to any other considerations in the process. A cost-benefit analysis should be undertaken to ensure that the anticipated ecological, social and economic benefits of a HES project outweigh the investment in infrastructure and subsequent monitoring.

- Concrete, steel/metal and integrated reefs have been the most effective globally and should be deployed over materials of opportunity in future HES deployments.

- When deploying Fish Aggregation Devices, consideration needs to be given to depth, prevailing currents and distribution of the target species to ensure they are effective.

- Consultation needs to include ***informing*** affected stakeholders (such as local shires, community groups, tackle stores and dive shops) and ***consulting*** with regulators and approval providers (such as environmental regulators, Commonwealth and State/Territory Governments, port authorities and the navy). Local, state and national approval processes need to followed.

- Cost of long-term effective monitoring of HES (particularly structural) should be included in the initial funding amount for an installation.

- Habitat Enhancement Structure developments should include a communications and extension plan for the project to inform and engage the community with relation to the location, purpose and performance of the installation. This assists in creating ownership, fostering stewardship, managing expectations and growing community wide support for future projects.

Habitat Enhancement Structure Monitoring

- The use of citizen science or community monitoring is a cost-effective method to collect a large amount of spatial and temporal data on HES installations. It also engages the community and has various social benefits such as improved scientific literacy, community involvement, project ownership and stewardship of aquatic resources.

- BRUVs with small action cameras were found to be the most cost-effective method to collect footage of installations by volunteers. The units should be cheap, durable, compact and easy to use by the volunteer.

- Clear, concise and consistent instructions and simplified monitoring protocols will decrease volunteer attrition rates as well as spatial and temporal biases. This increases the accuracy and quality of the footage.

- Volunteer management can be optimised by adequate and consistent communication and engagement with the volunteers.

- Positive engagement will increase volunteer attendance and interest, fostering stewardship and ownership of the reefs for the volunteers and local community.

Keywords

Artificial Reefs, Baited Remote Underwater Video system, citizen science, Fish Aggregation Devices, fish faunal assemblage, Habitat Enhancement Structures, monitoring, Reef Vision.

Awards

- Best oral presentation at the 11th Conference for Artificial Reefs and Related Aquatic Habitats in Malaysia, 2017 (James Florisson).

- Third place in Western Australian branch of Australian Marine Science Association Honours Prize Night Presentations 2016 (James Florisson).

- Third place in Western Australian branch of Australian Marine Science Association Honours Prize Night Presentations 2017 (Tim Walker).

Introduction

Habitat Enhancement Structures (HES) are purpose-built structures or materials, strategically positioned in an aquatic environment, for the purpose of creating, restoring or enhancing a habitat for fish, fishing and recreational activities in general (Department of Fisheries, 2012). These structures create new habitat and provide services in an aquatic environment such as the provision of food, colonising surfaces and shelter for marine organisms (Baine, 2001; Svane and Peterson, 2001; Sutton and Bushnell, 2007; Diplock, 2011) and, in turn, provide a source of recreation and/or income to end users (Brock, 1994; Gallaway *et al*, 2009; Cole and Abbs, 2012). Habitat Enhancement Structures also boost economies through the creation of jobs, utilisation and tourism (Adams *et al*, 2006 and Gallaway *et al*, 2009). Habitat Enhancement Structures, and the benefits they provide, will continue to develop and evolve in the future around WA, Australia and the world providing benefits to the community, individual end users, aquatic organisms and the environment.

Habitat Enhancement Structures can be broadly categorised into artificial reefs, Fish Aggregation Devices (FADs) and living artificial reefs (restoration or enhancement of shellfish, seagrass, coral etc). An artificial reef is any man-made or altered material placed into an aquatic environment to mimic certain characteristics of a natural reef, by creating additional habitat, food sources and colonising surfaces as well as varying hydrological effects such as current, temperature and shade availability (Sherman *et al*, 2002; Diplock, 2011). Artificial reefs vary greatly in type, structure, purpose and function. Examples of these reefs include species specific reefs (such as abalone, sea cucumber, lobster and octopus reefs), large metal structures, (up to 35m high deployed in Japan and Korea) aimed at facilitating the propagation of pelagic species, and a range of different concrete structures deployed all over South East Asia, Europe and the United States designed to create varying habitats for a myriad of different species (Ino, 1974; Barnabe and Barnabe-Quet, 2000; Jiansan and Jiaxin, 2001; Jiaxin, 2003; Spanier *et al,* 2011; Ula *et al,* 2011; Tessier *et al,* 2015).

Globally, HES have an extensive history. In the Mediterranean, fishers accumulated ballast stones to enhance fishing grounds between tuna seasons in Sicily, and Greek temple stones were disposed during harbour construction creating reefs as early as 3,000BC (Riggio *et al*, 2000). Indigenous cultures have used reefs to harvest aquatic food supplies for thousands of years, including Australian aboriginals using reefs as far back as 2,000BC (Carstairs, 1988; Kerr, 1992). These early reefs, however, have mainly been constructed using materials of opportunity such as woody debris including bamboo, rocks and rubble and sunken vessels (such as ancient fishing boats). In 1952, the Japanese Government started to subsidise artificial reefs, triggering a huge phase of reef development. Japan now have over 130 different reef module designs targeting an array of different species such as oysters, octopus, squid, algae, abalone, sea urchins and demersal and pelagic fish (such as Carangidae) (Thierry, 1988; Polovina and Sakai 1989; Barnabe and Barnabe-Quet, 2000; Surman 2015). Since the subsidy scheme, Japan, Korea, Philippines and Taiwan have been at the forefront of artificial reef and FAD development to increase commercial fishing harvests.

Habitat Enhancement Structures have been deployed in more than 50 countries around the world for many different purposes including snorkelling, SCUBA, surfing, energy production, eco-tourism, erosion mitigation, aquaculture, research, infrastructure and conservation (Brock, 1994; Baine, 2001; Diplock, 2010; Ng *et al*, 2014). However, in the majority of cases HES are used for the enhancement of commercial, recreational and artisanal fisheries. The first purpose-built artificial reef in Australia was deployed in QLD in 1971 and was closely followed by a reef installed in Western Australia also in 1971 to study Western Rock Lobster (Chittleborough, 1973; Pollard, 1989). While there were many reefs deployed using materials of opportunity in the earlier period, the next known purpose-built reef with modules designed to target specific species in WA, was undertaken by Ocean Grown Abalone (OGA) in 2011. OGA deployed 10 different module designs off the coast of Augusta as an abalone ranching trial. These different modules remain *in-situ* and are used for the production of abalone (Melville-Smith *et al*, 2013).

As of 2015, at least 120 artificial reefs have been deployed in Australian waters, with the vast majority being constructed for the purpose of enhancing recreational fishing (Bateman *et al*, 2015). These reef structures have been built out of a range of materials, such as reinforced concrete or limestone, plastics and fibreglass, steel, ceramics, polypropylene and other recycled and repurposed materials (also known as materials of opportunity), although the most common and recommended materials to use for artificial reefs are reinforced concrete and/or steel.

Western Australia has been at the forefront of recent HES development in Australia, with large investment from both industry and the community. The first purpose-built artificial reefs used to enhance recreational fishing in WA were deployed in April 2013. These artificial reefs each comprised of thirty 10 tonne concrete modules arranged in clusters of five and were deployed off the coasts of Bunbury and Dunsborough in 17 and 27m depth, respectively (Florisson *et al*, 2018). The modules were specifically designed to promote upwelling by driving nutrients up the water column, provide shelter and food sources and to increase variation in hydrological and environmental effects to increase habitat such as vertical profile and habitat complexity, light and temperature.

Since 2012, over seven million dollars had been invested into purpose-built HES for recreational fishing in WA alone, with four reefs having been deployed (habitat spread over 120,000m^2), with three more artificial reefs and a state-wide FADs project recently receiving funding. Installed reefs include concrete reefs off the coasts of Dunsborough, Bunbury and Mandurah, as well as two steel 'Fish Towers™' south of Rottnest Island. Industry has also deployed over 5000 modules (10,000 planned) for abalone sea ranching in Augusta and is expanding further, as well as trialling modules at sites near Esperance.

Habitat Enhancement Structures are continually evolving in terms of their structure, function and purpose in Australia and around the globe, with innovative new prototypes and methods ever increasing the efficiencies and services that HES provide. While interest and deployment of purpose-built HES has expanded, it's imperative that developments are purpose driven and that design, configuration, type, approvals, construction, installation and monitoring are all carefully planned and considered (Baine, 2001; Becker *et al*, 2018; Florisson *et al*, 2018).

Given the rapid increase and interest in HES developments in WA and Australia, there is a need for a better understanding of the current technology and methodologies available and how they could best be applied. There is also a need to create a set of tools to gain a better understanding of regulations, facilitate cost-effective deployment and monitoring, assess infrastructure and ensure social, ecological and economic benefits are provided. Thus, this project aims to assist industry and the community in determining the optimum HES designs, configurations, site selection, deployment methods and post installation monitoring and extension techniques (for specific objectives see Table 1).

Objectives

Table 1: Project objectives and relative chapters.

Number	Objective	Chapter
1	Identify what HES are currently available throughout the world and what benefits each type may have for recreational and commercial fishing as well as identifying the benefits for aquaculture and the environment.	1
2	Identify how various HES design might provide benefit to the WA seafood sector and community and determine applications and locations for the most effective return on investments.	1, 2
3	Determine cost-effective methods to monitor HES developments using easily available materials and data collection by community and industry groups.	3
4	Investigate cost-effective reef, site selection, approvals, construction, deployment and monitoring strategies for business, industry and community groups wanting to invest in HES.	4

Chapter One: Habitat Enhancement Structure Types from around the World

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Figure 1: One of 140 one tonne concrete cubes deployed in three sites around Koh Tao, Thailand by the Department of Marine and Coastal Resources and the Prince of Songkla University. Photo Andreas Fiskeseth.

Foreword

This chapter addresses objective one by identifying what Habitat Enhancement Structures (HES) are currently available throughout the world and what benefits each type provide for a range of purposes, including recreational and commercial fishing. To best understand the various types of HES and their benefits, several comprehensive literature reviews were undertaken. The first review included a bibliographic analysis to decipher what research had already been completed on HES. This was followed by a review of HES types and history in Australia. Finally, a global review of HES design, application and deployment was undertaken. Habitat Enhancement Structure types were classified according to size, construction material, function, depth, hydrological conditions, cost-effectiveness, installation techniques, target species, purpose and benefactors locally, nationally and internationally.

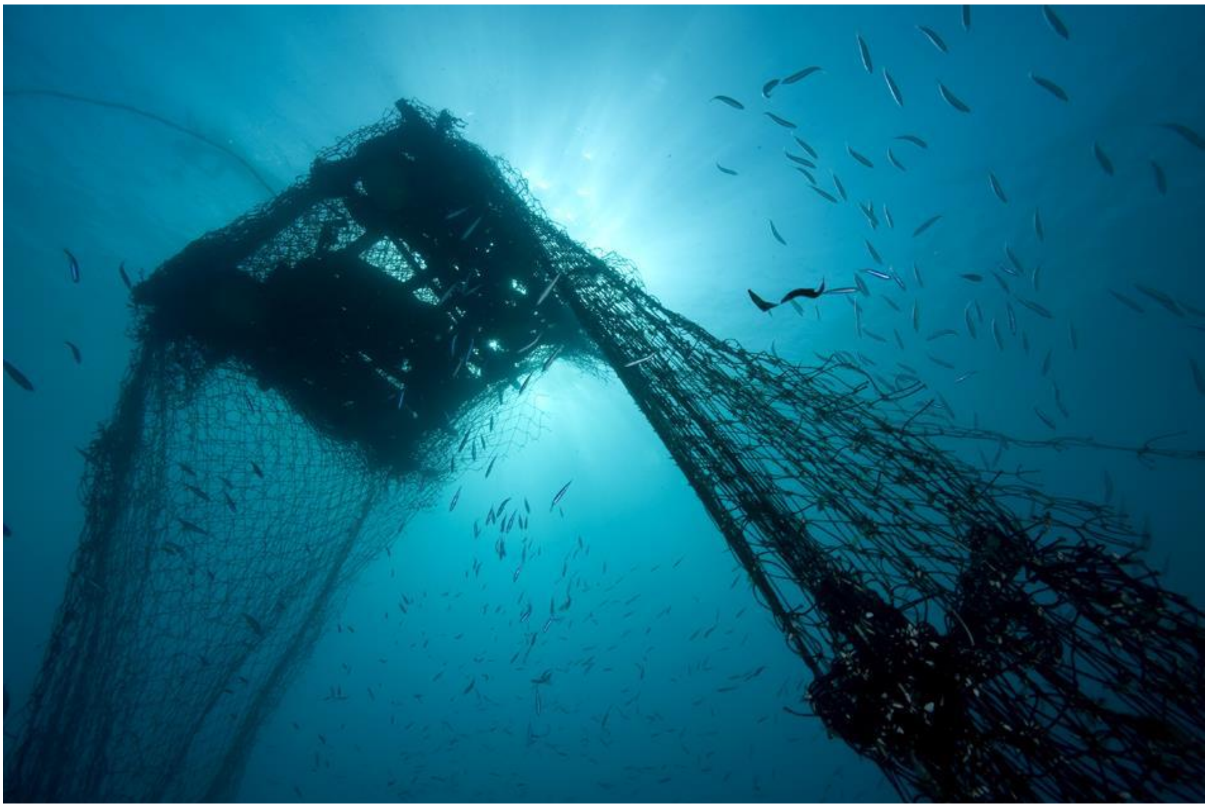

Figure 2: A fish aggregation device deployed in the Aldabra atoll (Seychelles). Photo Thomas Peschak.

Summary

Habitat Enhancement Structures (HES) have been used for over 3,000 years for a range of purposes and have been deployed in over 50 countries around the world. A literature search of the Scopus and Web of Science databases was conducted using the terms ‘habitat enhancement structure’, ‘artificial reef’ and ‘fish aggregation device’ and >3,500 citations that employed these terms were exported and the citations presented. Bibliographic analyses indicated that among these three terms, artificial reef was the most widely used in the literature comprising ~76% of all references. The fact that this term is the most widely used reflects the fact that it was first used in 1968 and thus well before fish aggregation device (1975) and habitat enhancement structure (1982). The use of all terms, and particularly that for fish aggregation device, has increased markedly post 2000, reflecting the increased levels of interest and research in this field. Researchers from the USA were the most prolific publishers, together with those from Australia, UK and, to a lesser extent, France and Canada. In fact, more than 96% of all documents found in the two databases were written in English, which may explain the relatively low contribution by researchers from Japan, China and South Korea, all of which have long histories of research and development in this area. In terms of the research areas, the majority of documents were focused on the biology and ecology of faunal communities. In contrast, documents focusing on the design of these structures and of their social and economic implications received little attention.

Although the first modern habitat enhancement structure was deployed in Australian waters in 1965, the total count of artificial reefs stood at 121 in 2015. The prevalence of such structures varies between states, with relatively large numbers in Victoria (VIC) (28), South Australia (SA) (26), Queensland (QLD) (22) and New South Wales (NSW) (21), with lower numbers in Western Australia (WA) (11), Northern Territory (NT) (9) and Tasmania (TAS) (4). Unsurprisingly, the highest concentrations of artificial reefs are found close to major cities and/or within sheltered bays, such as the Gulf of St Vincent (SA) and Moreton Bay (QLD). The rates of deployment of these structures have changed overtime, with the trends also differing among states, however, it is relevant that 29 of the 121 reefs (24%) have been deployed since 2010 reflecting a change in government policy and demand from particular public sectors. To date, 65% of artificial reefs in Australia are composed from materials of opportunity (*i.e.* cheap and easily accessible waste items), with decommissioned steel vessels and used tyres the most commonly employed constituents. However, there has been a clear shift in materials used to construct artificial reefs in Australia over the 50 years. For example, most reefs constructed between 1965 and 1978, were comprised of used tyres, with this material of opportunity being used less frequently compared to scuttled steel vessels between 1982 and 1994. Whereas, since 2001 almost all the artificial reefs deployed around the country were constructed from purpose-built pre-fabricated concrete and steel modules. While artificial reefs in countries such as Japan and South Korea have been deployed to enhance commercial fisheries and most of those in France used to prevent illegal trawling, the vast majority of reefs in Australia were deployed for recreational activities. Thus, 96 of the 121 artificial reefs were constructed for the primary purpose of enhancing fishing activities, with a further 19 and 2 designed to facilitate SCUBA diver and generate waves for surfers, respectively.

Recently, as a result primarily from overfishing pressures, some nations have implemented regulated and systematic installation of HES to increase the availability of both recreational and commercial fishes. In the past 40 years, millions of cubic metres of artificial reefs have been installed. A wide variety of materials and designs have been utilised with a shift recently (due to community concerns) from materials of convenience (*i.e.* tyres, building rubble, cars, ships, telegraph poles) to purpose designed and built structures. In Japan at least 130 different reef modules have been designed with favoured construction materials including concrete and steel. The purposes of artificial reefs are manyfold: Principally they are used to enhance fisheries for either commercial or more recently recreational purposes; reefs also are playing an increasingly important role in tourism associated with recreational diving. However, the construction of artificial reefs around the globe adhere to a few

main outcomes; preservation or protection of coastline, enhancement of fisheries, conservation of marine flora and fauna or prevention of trawling in sensitive areas.

The literature indicates several consistent requirements in the design and deployment of artificial reefs. These include the use of stable materials, non – toxic material, complexity of structure rugosity (roughness of surface) and the provision of shelter, refuge, settlement areas and feeding areas all increase the biodiversity of and therefore success of HES. Much has been written of whether such structures actually increase fish production, or merely act as attraction device thereby making fish extraction easier for users. The careful design and implementation of guidelines for any artificial reefs can lead to a well- balanced design that incorporates all biotic trophic levels thereby increasing feeding opportunities not only for predatory fishes but for grazing animals. The use of artificial reefs is generally an expensive process – however the socio-economic benefits of a well-designed reefal system will in the longer term, contribute to the community.

Bibliographic Analyses of Scientific Literature on Habitat Enhancement Structures

Introduction

Habitat Enhancement Structures (HES) are thought to have been employed for at least 3,000 years to help increase catches of target fish species (Riggio, 2000), with the first documented creation of a dedicated artificial reef in Japan in 1795 using a sunken vessel. After elevated catches of fish were recorded during the next summer, hundreds more artificial reefs were developed over the next 10 years using scuttled vessels and other materials of opportunity (Ino, 1974). Such was the success of these structures that, by 1930, the Japanese Government began subsidising the research and development of artificial reefs and designing purpose-built structures in 1952 (Thierry 1988, Grove *et al*., 1994). Regulations stipulating that only those HES which pass stringent design protocols to ensure longevity were passed and, as of 2000, there were 6,400 HES sites in Japanese waters, which cumulatively covered an area of ~20 million m^3 (1,800 km^2) (Sheehy, 1982; Barnabe and Barnabe-Quet, 2000).

During the last 60 years there has been a marked increase in the number of HES around the world, with more than 50 countries having deployed these structures (Fabi *et al*., 2011). For example, there is approximately 1 million m3 of artificial reef habitat in the USA along, with over 1,500 artificial reefs in Florida alone (Barnabe and Barnabe-Quet, 2000; Sutton and Bushnell, 2007) and South Korea has invested almost AU$1 billion in HES over the last 40 years, creating 2,070 km^2 of artificial reef habitat (DoF, 2010).

Despite the success of HES around the world, the first artificial reef was not deployed in Australian waters until 1965 and, to date, only 121 reefs have been constructed using the wide range of available materials (both materials of opportunity and purpose-built modules; Bateman *et al*., 2015). However, the use of HES in Australia is gaining popularity, with 29 reefs comprising such structures (*i.e.* 24% of all Australian artificial reefs) being deployed since 2010 and with many more in the planning process. Moreover, a policy shift by the WA Government towards facilitating the deployment of HES has created the need to understand what peer-reviewed research has been conducted on HES and where the work has taken place.

In light of the above, the aim of this bibliographic study was to search major databases of scientific publications for publications that used key words relating to HES and i) describe broad trends in the usage of these terms in the scientific literature and ii) compile a reference lists of documents using these terms that can be used by scientists and managers to find relevant information quickly and easily.

Materials and Methods

Habitat Enhancement Structures (HES) comprise a wide range of structures and materials placed deliberately in the aquatic environment. As this term is designed to encompass a range of structures, including artificial reefs and Fish Aggregation Devices (FADs) each of the above three terms was used in content analysis. Scientific publications containing any of these terms in either the title, abstract or list of keywords were identified using search functions in two large databases of scientific documents, namely Scopus and Web of Science (WoS). Scopus (http://www.scopus.com/) contains 22,000 documents (55 million records) dating back to 1966 and Web of Science (http://wokinfo.com/) contains more than 50,000 books, 12,000 journals and 160,000 conference proceedings (90 million records). These databases were employed in this study because unlike some others, *e.g.* Google Scholar, they are able to analyses and export large quantities of bibliographic information, including the citations for each document (year or publication, type of document, journal title), location and institution of the lead author, research area and language.

Trends in the bibliographic data for year of publication, location and research area were calculated and graphed using Microsoft Excel. The resultant bibliographic information, together with the abstract for each publication, from each database was exported, combined and used to create a separate Endnote library for i) habitat enhancement structure, ii) artificial reef and iii) fish aggregation device. Duplicate records were identified by the Endnote X7.4 and deleted, visual analyses were also employed to delete records that were similar and highly likely to be recorded of the same publication, but whose character strings for each field were not identical *e.g.* Smith, A.B versus Alan B. Smith. A reference list for each of the libraries has been published in this report. Note that, while the individual publications recorded have been reported in a consistent 'output' style, the information in the records has not been altered to correct any errors *e.g.* erroneous capitals and incorrect use of italics.

Results and Discussion

The total number of documents recorded in the Scopus and WoS databases using any one of the terms HES, artificial reefs or FADs was 2,475 and 2,541, respectively. Of those documents, 83% were journal articles and 13% conference proceedings, while the remainder were book, trade publications and reports. Among the three terms, artificial reefs (*i.e.* 1,896 and 1,949 in Scopus and WoS, respectively) was the most recorded, compared to 390 and 370, respectively for HES and 189 and 222, respectively, for FADs.

While the first document containing the phrase 'artificial reefs' was published in 1968, it was not until 1975 and 1982, respectively, that the terms FADs and HES were employed in the scientific literature. The use of all terms, and particularly FADs, has increased markedly post 2000. As implied above, for each search term, the number of documents published per year has tended to progressively increase each year after the date in which that term was first used (Figure 3). There are, however, noticeable peaks in the number of documents produced in particular years, most notably in the case of artificial reefs (Figure 3, bottom). These peak years, *i.e.* 1985, 1989, 1994 and 2002, coincided with international conferences on artificial habitats and reefs and thus special issues of the Bulletin of Marine Science and ICES Journal of Marine Science were published comprising papers presented at those meetings. This also explains why these two journals ranked first and third in terms of the highest number of papers on artificial reefs (*i.e.* 185 and 68, respectively; data not shown).

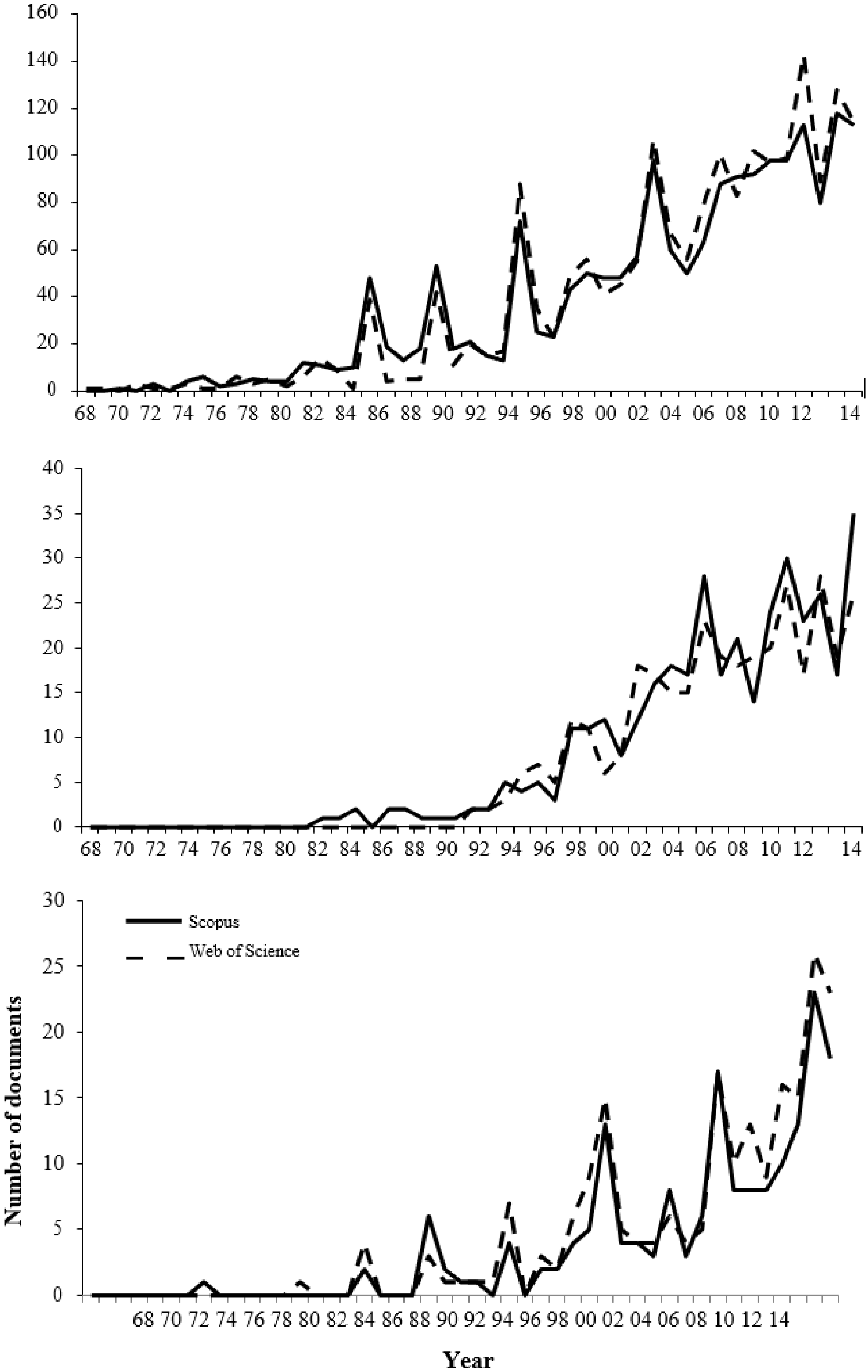

Figure 3: Number of documents listed in the Scopus and Web of Science databases in each year using the words; fish aggregating device (top), habitat enhancement structure (middle) and artificial reef (bottom).

The lead authors of much of the research on artificial reefs (*i.e.* 25 and 35% in Scopus and WoS, respectively) and HES (38 and 45%) and, to a lesser extent, FADs (17 and 18%) were based in the USA (Table 2). Australian authors have been productive in each of the three areas, producing the second highest number of documents on artificial reefs and fifth and sixth on HES and FADs, respectively. The relatively small number of documents produced by workers from several Asian countries with a strong history in habitat enhancement *e.g.* Japan, China and South Korea (Table 2) may reflect the fact that both Scopus and WoS predominately search databases containing records of documents written in English and thus undoubtedly would have underestimated the contribution made by research workers from these countries. For example, 1,800 of the 1,896 artificial reefs documents found by Scopus were written in English, with only 26 and 14 written in Chinese and Japanese, respectively and the same was true for HES (387 out of 390) and FADs (183 out of 192). These trends are mirrored by the work of Baine (2001) who reviewed 249 abstracts from six volumes of published papers on global artificial reef research (usually those associated with special editions of journals following international conferences) and found that although acknowledged as a world leader in artificial reef research, particularly in terms of HES design, only 29 of the 249 papers (12%) were written by Japanese authors.

Table 2: The percentage contribution made by research workers in different countries to documents with Artificial Reefs (AR), Habitat Enhancement Structure (HES) or Fish Aggregating Devices (FADs) in the title, abstract and/or keywords. Countries making a large contribution (>~5%) are highlighted in grey. Note that for brevity, only the countries that produced the ten greatest percentage contributions for each keyword in each database have been included in the Table.

	AR		HES		FAD	
Database	Scopus	WoS	Scopus	WoS	Scopus	WoS
Number of documents	1,896	1,949	390	370	189	222
Country						
Australia	***10.34***	***11.65***	***3.30***	***4.87***	***4.36***	***4.67***
Belgium					2.01	
Brazil	2.77					
Canada		3.28	5.49	8.92		
China	3.94		2.42			
Finland			2.20	3.51		
France	2.72	4.46	2.86		21.14	19.51
Germany	3.14		2.20			
Ireland				2.97		
Israel		3.59				
Italy	3.78	5.70	2.86	4.05	5.03	4.67
Japan	5.70	5.64	3.52	5.14	3.69	4.40
Netherlands				2.97		
Philippines					2.01	2.20
Portugal		3.23				
Reunion Island						2.20
Seychelles					8.39	7.14
South Africa					2.35	2.20
Spain	2.82	3.18		2.97	7.05	6.87
United Kingdom	6.29	4.87	9.67	12.16		
USA	25.20	35.40	38.02	44.87	16.78	18.68
Other	***33.30***	***18.98***	***27.47***	***7.57***	***27.18***	***27.47***

While the geographic distribution of documents was similar for artificial reefs and HES, *i.e.* mainly produced by workers from USA, UK, Australia and Japan, the countries responsible for much of the research into FADs differed. Specifically, many of the 'FADs documents' were produced by workers from France (principally the Institut de Recherche pour le Développement and the Institut Francais de Recherche pour l'Exploitation de la Mer rather than Universities), Italy, the Seychelles and Spain. Interestingly, researchers from Canada produced more documents in the HES area than all other countries except the USA and UK, but rarely published on artificial reefs or FADs. Such a trend likely reflects the fact their research has focused on habitat modifications that enhancing salmonid fisheries in freshwater rivers and lakes.

In terms of the research areas of documents on artificial reefs, HES and FADs, the majority were focused on the biology and ecology of faunal communities (Figure 4). For example, between 8 and 32% of the documents that used each term were classified as belonging to Marine & Freshwater Biology or Environmental Science areas. The percentage contribution of documents in the Fisheries area varied among terms, representing 8 and 11% for HES and artificial reefs, respectively, but 30% for FADs. This presumably reflects the fact that FADs are usually employed for the sole purpose of attracting fish, rather than the often multipurpose nature of artificial reefs and HES. Documents focusing on the Engineering of artificial reefs, HES and FADs made up only a small proportion of the total number of documents (<~4%). Little attention was also given to the social and economic research.

While, at a broad level, the percentage contribution of documents produced on artificial reefs and HES were similar, there were a few subtle differences. For example, documents on Oceanography were far more prevalent in artificial reefs than HES (17 versus 6%, respectively) whereas the reverse was true for Biodiversity Conservation (<1 versus 5%, respectively), which again reflects the purpose of the structures. Thus, while artificial reef may have been deployed for a number of reasons, some of which do not relate to fisheries or faunal communities, these structures may be deployed to protect eroding coastlines and/or create favourable surfing conditions.

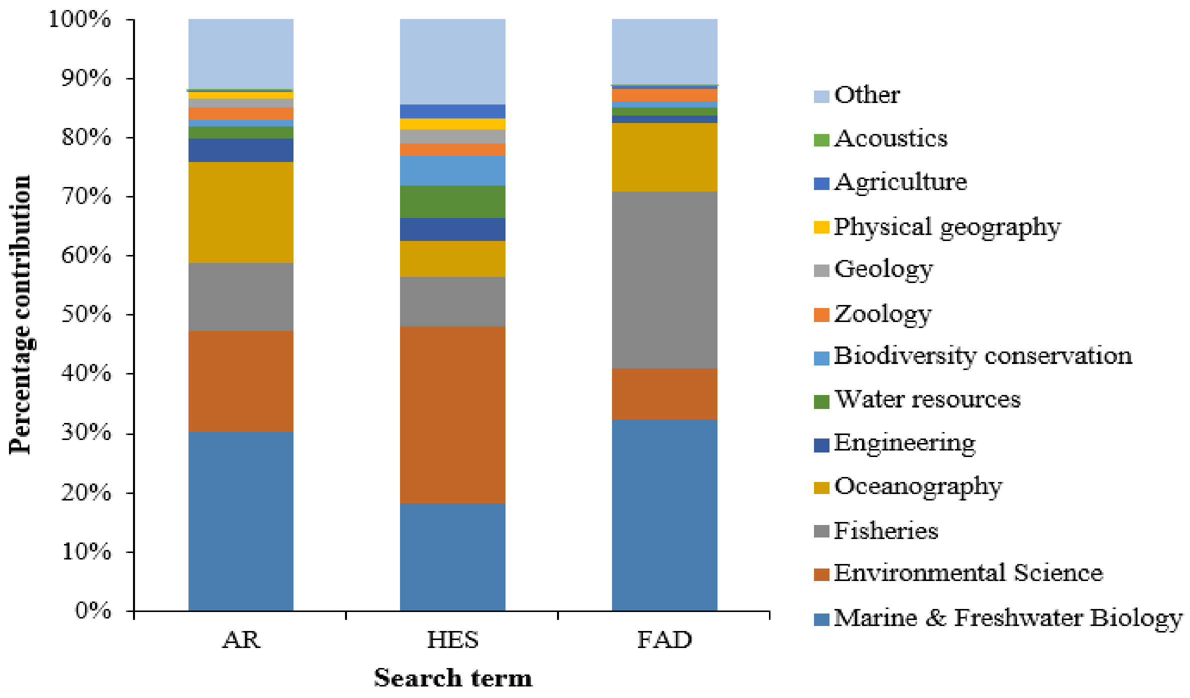

Figure 4: Stacked histogram of the percentage contribution of documents in the various field of research categories used by Web of Science. Note, for clarity only fields making a sufficiently large contribution were included as categories. The contributions made by those 68 other fields were combined into the 'Other' category.

Trends in Artificial Reef Construction, Design and Management in Australia

Introduction

There has and will always be a need for food and the realisation that placing objects into waterbodies attracted fish, and other potential food sources, resulted in the creation the first Habitat Enhancement Structures (HES). In the Mediterranean Sea, the use of such structures dates back 3,000 years, with the disposal of ancient Greek temple stones during harbour construction (Riggio *et al*., 2000). Furthermore, Sicilian tuna fishermen cut ballast stones free from their nets at the end of the fishing season, which, over time, provided fish habitat and thus stocks for the fishermen to exploit (Riggio *et al*., 2000). In Australia, however, there is archaeological evidence that indigenous groups employed artificial reefs much earlier from about 2,000BC to 200 years ago to grow both marine and freshwater food (Carstairs 1988), with some of those structures still present in some south-western Australian estuaries today (Dix and Meagher, 1976; Dortch, 1997).

Initially HES were used to attract fishes for commercial exploitation and, such was the success of these structures that, by 1930, the Japanese Government was subsidising the development of artificial reefs (Thierry, 1988). The earliest reefs were made from natural, locally abundant materials, such as rocks, logs and bamboo, referred to as "Materials of Opportunity" (Harris, 1995; Harris *et al*., 1996). By 1954, Japan had established a national program to undertake research and development on HES and specifically purpose-built designs (Nakamae, 1991; Grove *et al*., 1994; Jensen, 2002; Bortone *et al*., 2011). The increase in functionally and range of purpose-built designs led to the realisation that HES could not only increase commercial fishery yields, but could also enhance recreational fisheries and provide opportunities for aquaculture and sea ranching (Nakamae, 1991; Grove *et al*., 1994; Fabi and Fiorentini, 1996) and tourism, particularly SCUBA diving (Branden *et al*., 1994). Moreover, these structures could aid in species conservation (Pickering *et al*., 1999; Claudet and Pelletier, 2004), the provision of additional specific types of habitat (Spanier and Almog-Shtayer, 1992), illegal fishing mitigation (Ramos-Esplá *et al*., 2000), habitat restoration (Clark and Edwards, 1994) and habitat protection (Jensen, 2002).

Despite the proliferation of HES around the world, the first modern artificial reef was not deployed in Australian waters until 1965 (Kerr, 1992). Since then more reefs have been deployed and reviews undertaken by Pollard and Matthews (1985), Kerr (1992), Branden *et al*. (1994) and Coutin (2001) have provided information on trends in early reef developments. However, unlike countries like Japan and South Korea, which deploy specifically designed pre-fabricated HES, as of 2001, the majority of artificial reefs within Australia were still made up of material of opportunity such as tyres (37%) or ships (22%) with only a small portion made from concrete (6%; Coutin, 2001). In recent times, states such as NSW and WA have developed policy statements and guidelines on the design, location and use, environmental impacts and monitoring (Department of Fisheries WA, 2012; NSW Government, 2015). Moreover, a number of artificial reef programs have been developed, aimed at improving the quality and management of artificial reefs and which have resulted in the deployment of numerous HES (Department of Fisheries WA, 2015; Fisheries VIC, 2015; NSW Department of Primary Industries, 2015).

In light of the above, the aim of this study is to undertake a literature search to identify trends in artificial reef construction within Australia, since the deployment of the first artificial reef in 1965 to the present day. The chapter considers where and when artificial reefs were deployed, what the reefs were constructed from, and their primary purpose. It identifies trends in artificial reef design, location and purpose, and assesses how these patterns have changed over the past 50 years.

Materials and Methods

This work builds directly on to earlier analyses of artificial reefs in Australia conducted by Pollard & Matthews (1985), Kerr (1992), Branden *et al*., (1994) and Coutin (2001). It thus combines the data presented in those documents with those obtained during contemporary literature searches. These searches were conducted in search engines (*e.g.* Google and Google Scholar) and documents indexed in scientific databases (*e.g.* Scopus and Web of Science). Keywords employed as search terms included artificial reefs and habitat enhancement structures, with additional words such as Australia and the names of the various states and territories. Once a habitat enhancement structure was detected in the literature, information for the following metrics, *i.e.* location, year of deployment, materials of construction, primary purpose and builder/funder were obtained and stored in a database.

To allow comparison of different reefs in different spatial locations (states and territories) and over time, the information was condensed into several broad categories. For example, the materials of construction were categorised as either being 'Materials of Opportunity' (MOP) or 'purpose-built' and then subdivided further based on the material (see Table 3). Similarly, the data for the reef purpose and the builder/funder for that structure were also categorised.

Note that the literature search was limited to purposely-placed benthic artificial reefs and thus both accidental shipwrecks or floating Fish Aggregation Devices (FAD) have been excluded from this meta-analysis.

Table 3: Classification and description of materials used in the construction of artificial reefs. Photographs of each of the various types of artificial reefs are provided in Figures 5 and 6.

Materials of Opportunity (MOP)	
Category	**Description**
Tyres	Used vehicles tyres of any size (Figure 5).
Steel vessels	Steel hulled ships and other steel vessels that have been purposely scuttled for the creation of an artificial reef (Figure 5).
Rubble	Quarry rock and concrete rubble/waste (Figure 5).
Mixed MOP	Combination of two or more MOP at a single reef.

Purpose-built	
Category	**Description**
Concrete modules	Concrete modules of any size built specifically for use in the construction of an artificial reef *e.g.* concrete Fish Boxes™ and Reef Balls™ (Figure 6).
Steel modules	Steel modules of any size built specifically for use in the construction of an artificial reef, *e.g.* steel Fish Caves™ (Figure 6).
Geotextile bags	Geotextile bags, which can be filled with material such as sand, that have been specifically designed for use in artificial reef construction (Figure 6).
Mixed	Mixture of materials of opportunity and purpose-built modules at a single reef. Generally, this occurs when a reef is added to over multiple years.

Figure 5: Examples of artificial reefs constructed from various materials of opportunity (see Table 3).

Osborne Tyre Reef, USA. Photos from http://fishwrecked.com/forum/reef-or and http://www.projectbaseline.org/gulfstream/

Deploying a rubble reef, USA.

Photo from http://www.mymanatee.org/

Tiwi Pearl, part of the Harry Atkinson artificial reef in Queensland

Photos from http://www.nprsr.qld.gov.au/parks/moreton-bay/zoning/trial_artificial_reef_program.html

Figure 6: Examples of various purpose-built artificial reefs (see Table 3).

Concrete fish boxes made by Hae Joo. Boxes are 4 m^3 and weigh 14.4 T.

Photos from http://haejoo.com.au/qld-moreton-bay-artificial-reef-program/ and http://www.nprsr.qld.gov.au/parks/moreton-bay/zoning/trial_artificial_reef_program.html

Reef Ball
Photos from http://www.reefball.org

Steel fish cave made by Hae Joo, 11m tall & 14.4 T.
Photos from http://haejoo.com.au/qld-moreton-bay-artificial-reef-program/ and https://www.youtube.com/watch?v=63xSeBSoGx0

Geotextile bag.
Photos from http://www.elcorock.com/ and https://secure.ifai.com/geo/articles/0610_up1_reef.html

Results and Discussion

In 2015, 121 artificial reefs were found in this study to have been deployed in Australian waters (Figure 7). While artificial reefs were present in each state and territory with a coastline (*i.e.* excluding the ACT), the numbers recorded in each location differed markedly. For example, relatively large numbers of artificial reefs were found in VIC (28), SA (26), QLD (22) and NSW (21), while lower numbers are present in WA (11), NT (9) and TAS (4). Unsurprisingly, the highest densities of artificial reefs are found close to major cities and/or within sheltered bays, such as the Gulf of St Vincent and Moreton Bay. In contrast, remote coastlines, such as those in the Kimberley in WA and the Great Australian Bight, do not contain artificial reefs and there is only one in the Gulf of Carpentaria.

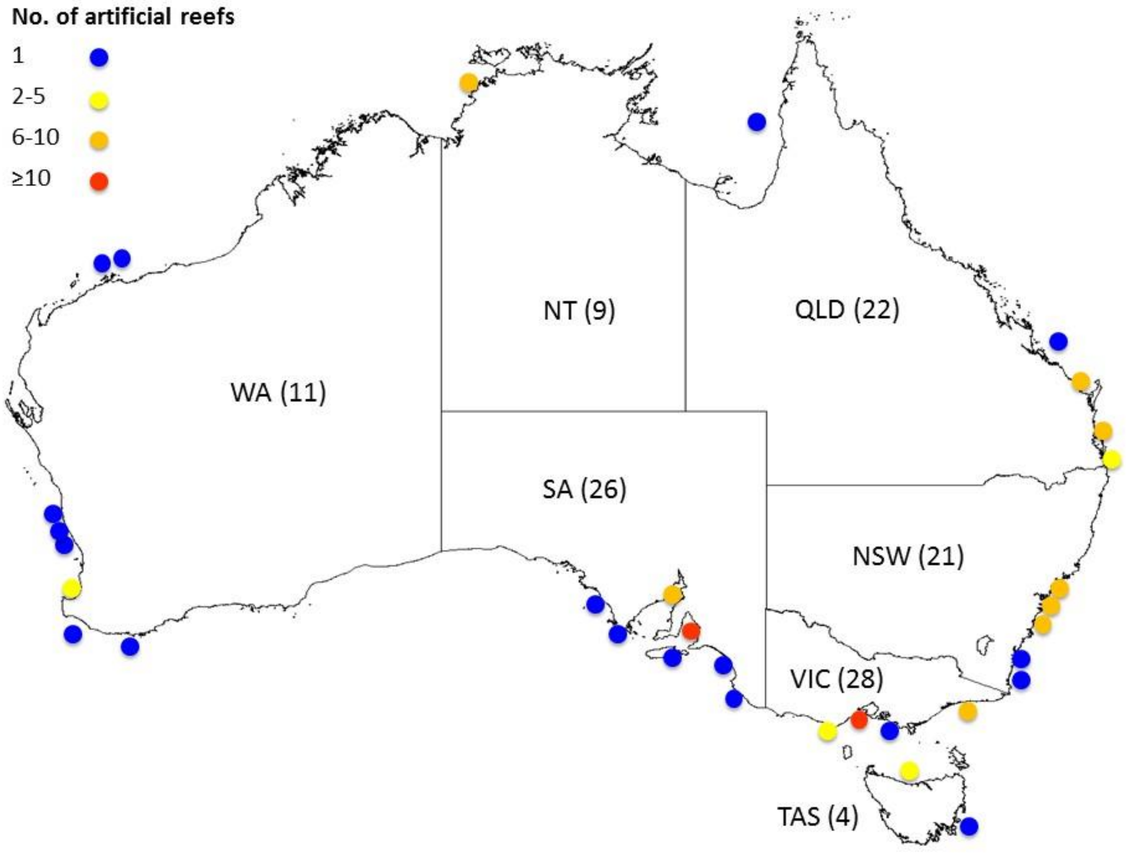

Figure 7: Geographical distribution of artificial reefs in Australian waters. Colour coding reflects the number of artificial reefs in a given area. The numbers of artificial reefs in the waters of each state and territory are given in brackets after the name of that state/territory.

Currently, 65% of artificial reefs in Australia are composed from MOP (see Table 3 for a definition). Indeed, for some locations, such as SA and the NT, all artificial reefs deployed to date have been constructed from MOP (Figure 8). Victoria is the only location where the proportion of purpose-built reefs is greater than those constructed from MOP, although the ratio between these two 'types' is almost equal in QLD.

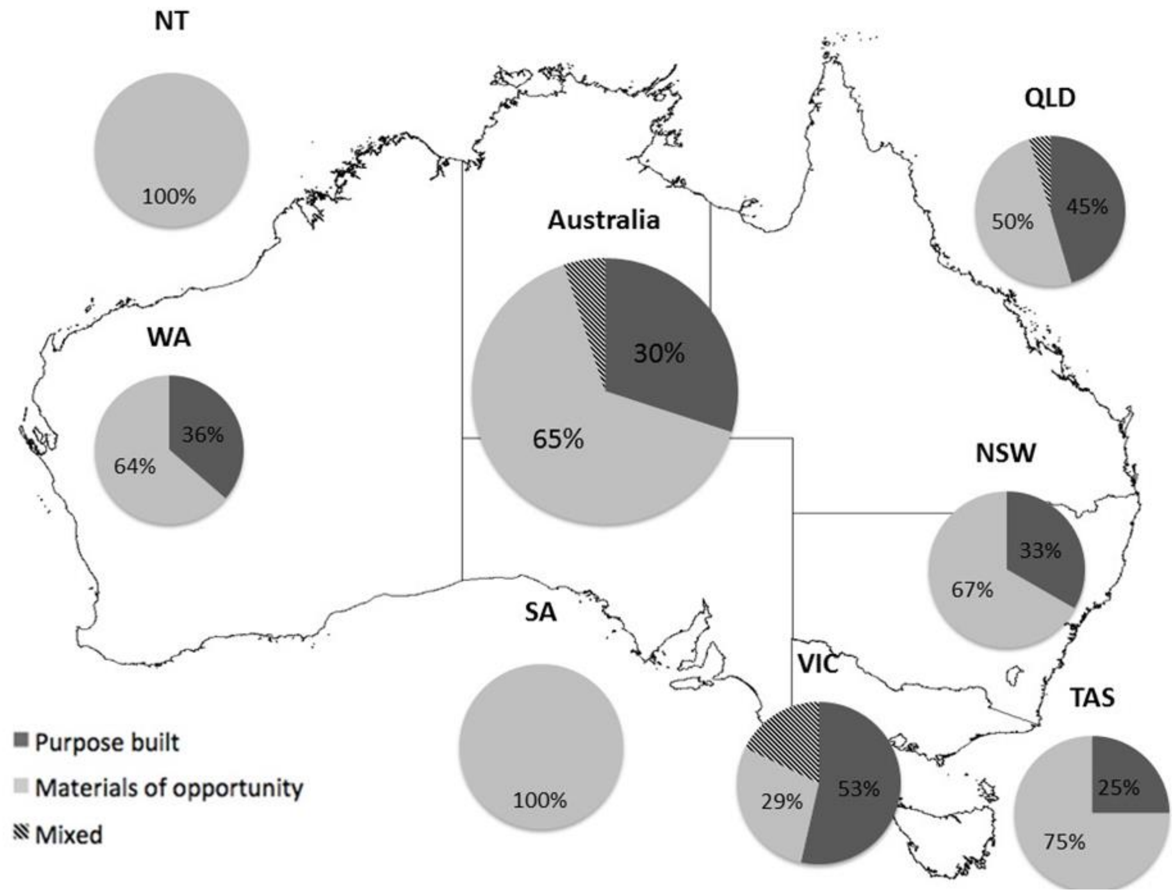

Figure 8: The contribution of artificial reefs constructed from purpose-built material, MOP or both broad types of material to the total number of artificial reefs in each state and territory and to Australia as a whole.

Among the purpose-built artificial reefs in Australia, the vast majority (34 out of 43) are constructed from concrete modules, with only two and one reefs comprising steel modules and geotextile bags, respectively (Figure 9). The constituency of reefs constructed from MOP was more diverse and included scuttled steel vessels (32), such as old warships, used tyres (28) and mixed materials (13). While rubble has been used, it has only been so sparingly, with only five reefs constructed from this MOP.

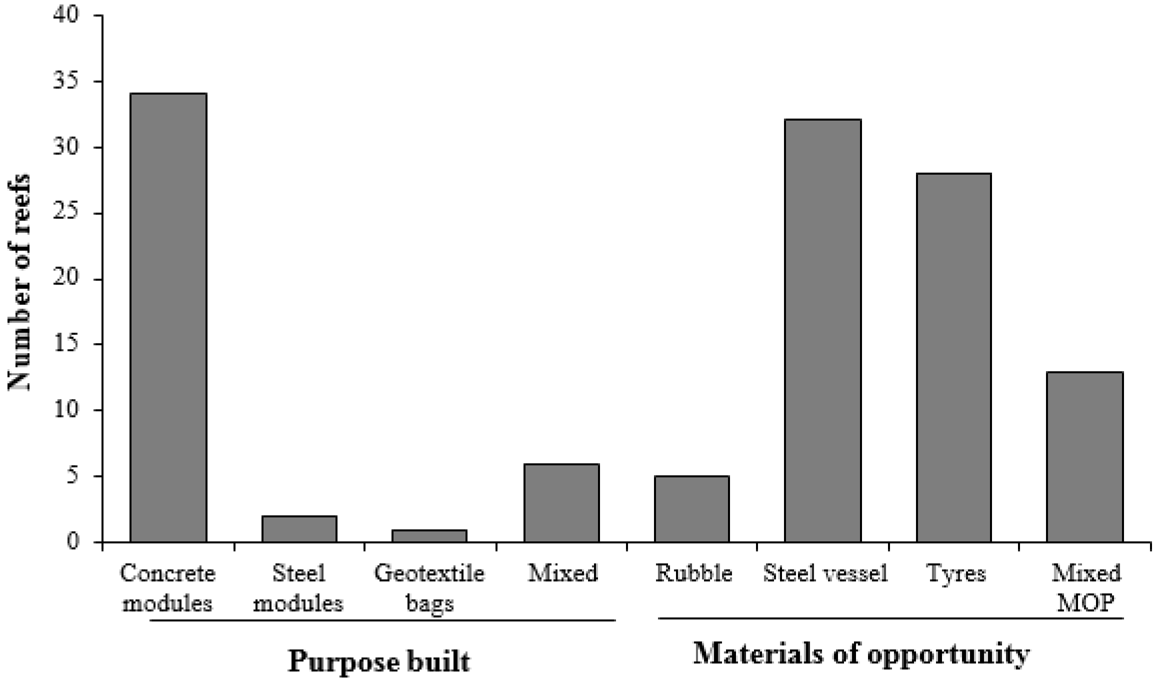

Figure 9: The number of artificial reefs in Australia constructed from different materials.

Since the first artificial reef was deployed in VIC in 1965, another 120 reefs have been constructed (Figure 10). In each of almost all the last 50 years at least one artificial reef has been deployed, with a relatively large number of reefs (2-8) being deployed in some periods, *i.e.* 1968-1973, 1982-1991 and 2009-2015. While the construction of artificial reefs in some states, such as VIC, NSW and WA, was spread out across the last 50 years, in SA and the NT construction occurred in distinct periods (Figure 10). In the case of SA deployment occurred almost exclusively between 1969 and 1973 and between 1983 and 1991, whereas construction in the NT occurred between 1982 and 1991. The activity in SA was mainly focused around deploying tyre reefs for recreational fishers led by recreational fishing clubs and the state fisheries department following the results of initial tyre reef trials and the first placement of a tyre reef in Grange in 1970 (Pollard, 1989). Construction of reefs in the NT in the 1980s was typified by the use of steel vessels. This activity was the result of the increasing popularity in the fishing of wrecks left from the bombing of Darwin and Cyclone Tracy, by recreational fishers for species such as black jewfish (Julius, 2018). Due to the success of these structures in holding recreational target species, local recreational fishing groups with government assistance scuttled derelict vessels to create additional artificial reefs.

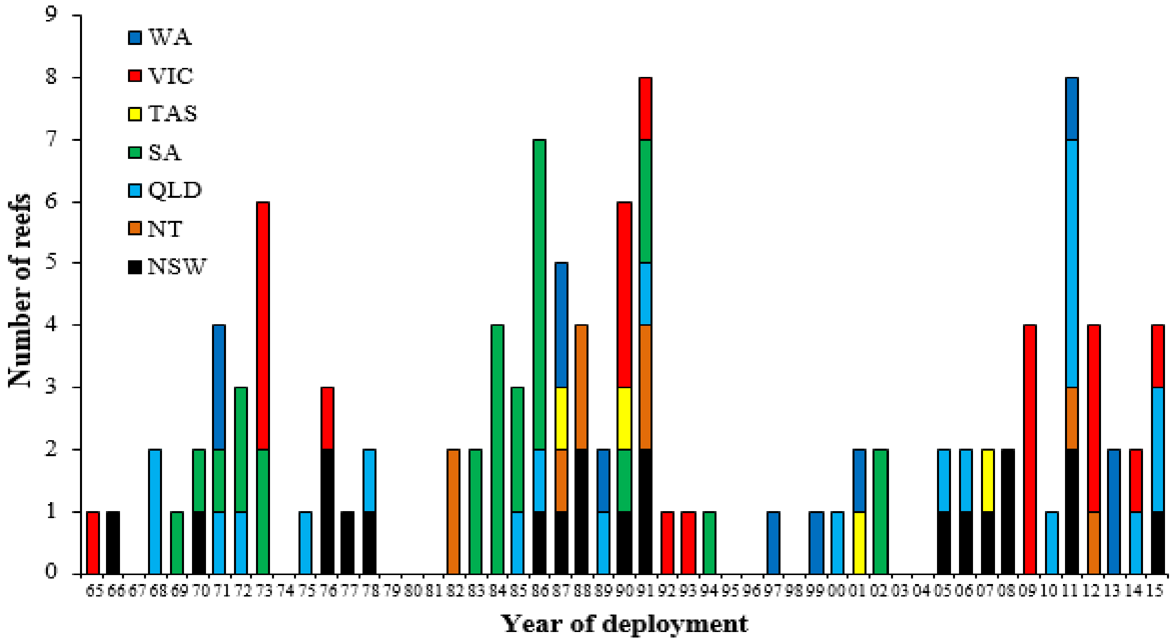

Figure 10: The number of artificial reefs deployed between 1965 and 2015, and the state or territory in which they were deployed.

The materials used to construct the various artificial reefs found in Australian waters differ among states and territories (Figure 11). Tyres, for example, are the primary constituent of artificial reefs in SA, representing 18 out of 26 reefs, but were not used to construct any of the artificial reefs in the NT or TAS and only comprised a limited number of reefs in VIC, QLD and WA. Instead, these last three states employed a mixture of reef materials, most notably concrete modules and steel vessels.

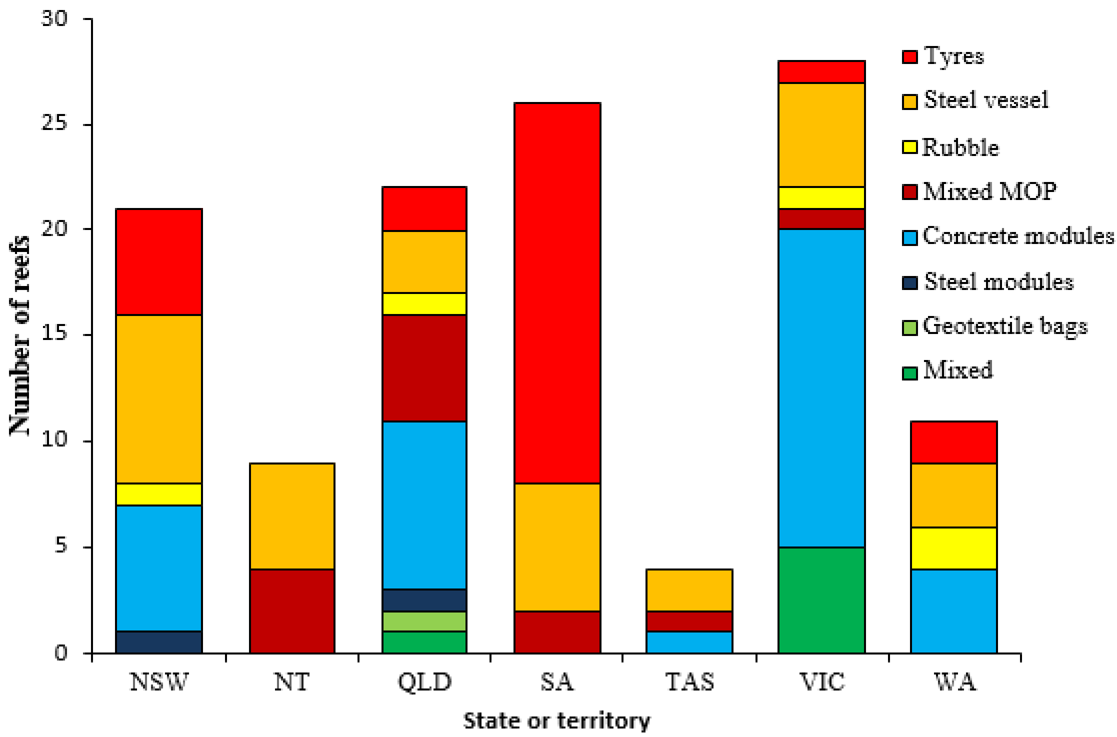

Figure 11: The number of artificial reefs in each state and territory and the materials used to construct them.

There has been a clear shift in materials used to construct artificial reefs in Australia over the 50 years. The ‘early’ reefs (*i.e.* 1965-1978) were most commonly constructed from MOP predominantly used tyres (Figure 12). The trend of using MOP also extended into the ‘middle’ period (*i.e.* 1982-1994). During these years the relative proportion of reefs constructed from tyres decreased, albeit they were still heavily used, and there was a switch to primarily the sinking of steel vessels. As with the early period, very few purpose-built reefs were deployed, however, this changed in the ‘modern’ period (*i.e.* 2001- 2015), where the majority of reefs were constructed from purpose-built concrete and steel modules (Figure 12).

In terms of the individual materials used to construct artificial reefs, tyres were widely used from 1966 through to 1991. This likely reflects the availability of this material and the view that utilising this material as a HES constituted recycling, which would also benefit fish and invertebrate communities. However, in many cases around the world, tyre reefs have broken up with tyre(s) moving across the sea floor destroying habitat and/or washing ashore after storms (Skoloff, 2007; Ferrer, 2015). These environmental impacts led France to commence removal of 25,000 tyres in the Mediterranean in 2015, while in Florida US$3.4 million is spent annually in an effort to remove the tyres that wash up from a nearby reef (Ferrer, 2015).

From the mid-1970s onwards, steel vessels became a popular construction material, with the first steel vessel being sunk to form a reef in 1976. This material continues to be used, with the last reef of this type deployed in Australian waters in 2011 (HMAS Adelaide). These types of reef are popular with SCUBA divers and provide tourism opportunities and, as such, have been funded by diving clubs. For example, Ex-HMAS Brisbane has generated revenue of AU$18 million since its scuttling four years ago off the Sunshine Coast (Sundstrom, 2015) and Ex-HMAS Adelaide, after costing AU$5.8 million to prepare and deploy in 2011, currently generates an estimated AU$4.5 million of dive revenue per year (Cole and Abbs, 2012). Due to legalisation, such as the London Convention on the prevention of marine pollution by dumping of wastes and other material, and state, national and international guidelines pertaining to the construction and deployment of artificial reefs, the methods for deploying them has changed significantly since the 1970s. Thus, there are now more stringent clean up and safety requirements for scuttling of decommission vessels as HES (see Worley Parsons, 2009 for information pertaining to the preparation and environmental considerations for the sinking of Ex-HMAS Adelaide as a SCUBA diving reef).

Although the first reef built from purpose-built concrete modules was deployed in Australian waters in 1971, it was not until the 2000s, and particularly post 2010, that this type of material was been widely used. Today it constitutes the dominant construction for contemporary artificial reefs and is more widely used than other purpose-built materials, such as steel modules and geotextile bags. Such a trend reflects the awareness of the artificial reef technology (*e.g.* Department of Fisheries WA, 2010), the research and development of state policies on HES and artificial reefs (*e.g.* Department of Fisheries WA, 2012; NSW Government, 2015) and the availability of funds collected through recreational fishing licences fees. As such, it is not surprisingly that the majority of these reefs have been deployed to improve recreational fishing experiences.

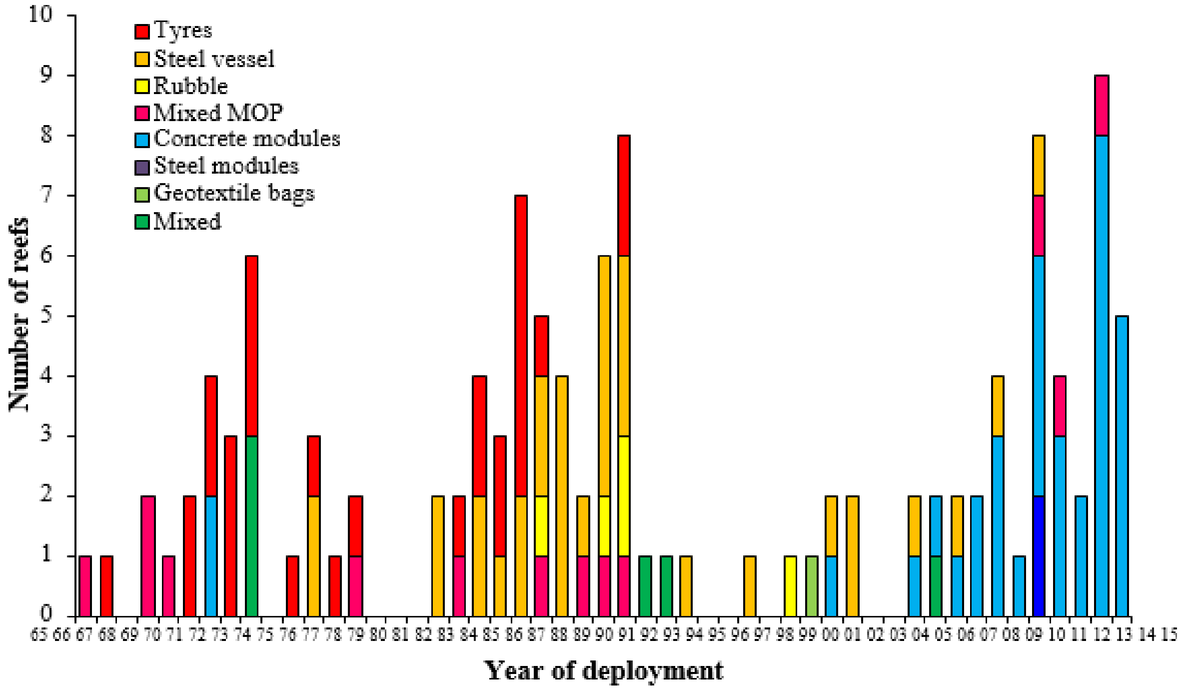

Figure 12: The number of artificial reefs deployed in each year between 1965 and 2015 and the materials used to construct them.

The vast majority of artificial reefs currently deployed in Australian waters (*i.e.* 96 out of 121) have been constructed for the primary purpose of enhancing fishing activities (Figure 13). While these structures have been deployed by a wide range of organisations, including community groups, fishing and diving clubs, most were installed by state (or territory) fisheries departments. The next most common purpose for artificial reef deployment was for SCUBA divers, with 19 such reefs present in Australia. Many of these were organised by diving clubs themselves or state fishery departments. Small numbers of reefs were also deployed by scientists and industrial partners for research (4) and two reefs where also deployed for surfing purposes.

The provision of artificial reefs in Australia, for recreational purposes mirrors that of the USA, where most of the reefs are utilised for recreational fishing and SCUBA diving (Boshnack *et al*., 1991; Kerr 1992; Grossman *et al*., 1997; Lukens *et al*., 2004). However, this is in marked contrast to Japan and South Korea where such structures have the sole purpose to enhance commercial finfish and invertebrates catches (Thierry 1988; Kim *et al*., 1994). Trends of artificial reef usage are different again in Europe where, in France, many HES designs are based upon the principle of a weighty structure/base with devices for snagging nets and 80% of the reefs are deployed to prevent illegal trawling of sensitive seagrass beds and other fish nursery habitats (Charbonnel *et al*., 2011; Tessier *et al*., 2015).

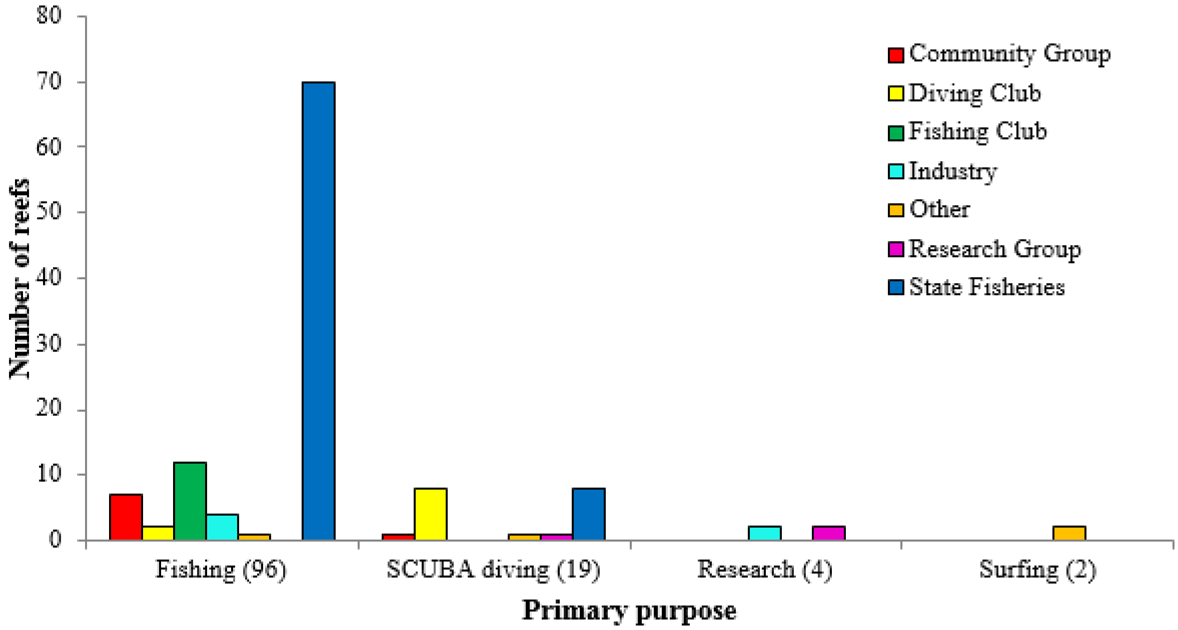

Figure 13: Histogram on the number of artificial reefs categorised by their primary purpose (noting that many have multiple purposes) and the group that deployed the reef. The number in parentheses on the x axis refers to the total count of artificial reefs constructed for that primary purpose.

Conclusion

Whilst Australia's artificial reef developments have previously been behind those of other countries, the past 10 years has seen a surge in interest in the use of modern purpose-built artificial reefs (Pitcher and Seaman, 2000; Coutin, 2001; Diplock, 2010). These purpose-built reef modules offer significant benefits over MOPs, and the availability of additional funds through recreational fishing licence fees has been successfully used in NSW, VIC, and WA to fund artificial reef programs and reduce pressure on natural reefs and could potentially be utilised by other states in the future. As the vast majority of Australia's artificial reefs have been deployed primarily for the purpose of enhancing recreational fishing, reefs have been deployed close to major cities and generally within popular fishing regions. Although this makes the reefs easily accessible, it also creates the potential for overfishing of target species. Future research should also aim to incorporate the socio-economic impacts of these structures and factors, such as reef visitation levels and catch rates, which have not been discussed in detail within this review. With the number of artificial reefs in Australia set to increase over the coming years, dedicated management and monitoring of these structures is essential (Carr and Hixon, 1997; Pickering and Whitmarsh, 1997).

Chapter Appendix

Table 4: Each of the 121 artificial reefs in Australian waters identified during this study and its location, year of deployment, construction materials, primary purpose, who it was deployed by and a reference for the source information. Reefs ordered chronically within each state/territory. NSW = New South Wales; NT = Northern Territory; QLD = Queensland; SA = South Australia; TAS= Tasmania; VIC = Victoria and WA = Western Australia.

Reef #	State	Year	Depth (m)	Specific construction materials	Materials	Purpose	Deployed by	Reference
1	NSW	1966	8	250 tyres	Tyres	Research	Research Group	Kerr 1992
2	NSW	1970	10	4,660 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
3	NSW	1976	25		Tyres	Fishing	Diving Club	Kerr 1992
4	NSW	1976	45	Sydney Harbour Ferry and 11 other vessels	Steel vessel	Fishing	State Fisheries	Kerr 1992
5	NSW	1977	25		Tyres	Diving	State Fisheries	Kerr 1992
6	NSW	1978	12		Tyres	Fishing	State Fisheries	Kerr 1992
7	NSW	1986	33		Steel vessel	Fishing	State Fisheries	Kerr 1992
8	NSW	1987	20		Steel vessel	Fishing	Community Group	Kerr 1992
9	NSW	1988	20		Steel vessel	Fishing	Community Group	Kerr 1992
10	NSW	1988	20		Steel vessel	Fishing	Community Group	Kerr 1992
11	NSW	1990	200		Steel vessel	Fishing	Other	Kerr 1992
12	NSW	1991	45		Rubble	Diving	Other	Kerr 1992
13	NSW	1991	30		Steel vessel	Diving	Research Group	Kerr 1992
14	NSW	2005	5	Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
15	NSW	2006	10	180 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
16	NSW	2007	2	210 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
17	NSW	2008	8	400 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
18	NSW	2008	8	400 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
19	NSW	2011	38	Fish Cave, 12 by 15 metres in length, has two 12 metre high masts and is anchored at each corner by a chain and a 60 tonne concrete block	Steel modules	Fishing	State Fisheries	State Fisheries
20	NSW	2011	32	Navy ship	Steel vessel	Diving	State Fisheries	State Fisheries
21	NSW	2015	30	20 concrete modules	Concrete modules	Fishing	State Fisheries	State Fisheries
22	NT	1982	12		Steel vessel	Fishing	Fishing Club	Kerr 1992
23	NT	1982	16		Steel vessel	Fishing	Fishing Club	Kerr 1992
24	NT	1987	25		Mixed MOP	Fishing	State Fisheries	NT Fisheries
25	NT	1988	18		Steel vessel	Diving	Diving Club	Kerr 1992
26	NT	1988	20		Steel vessel	Fishing	State Fisheries	Kerr 1992
27	NT	1991	13		Steel vessel	Fishing	Fishing Club	Kerr 1992

Reef #	State	Year	Depth (m)	Specific construction materials	Materials	Purpose	Deployed by	Reference
28	NT	1991	20		Mixed MOP	Diving	State Fisheries	Kerr 1992
29	NT	2011	15	Steel vessels, concrete	Mixed MOP	Fishing	State Fisheries	State Fisheries
30	NT	2012		Steel vessels, concrete	Mixed MOP	Fishing	State Fisheries	State Fisheries
31	QLD	1968	18	Car bodies, tyres, concrete rubble	Mixed MOP	Fishing	Fishing Club	Kerr 1992
32	QLD	1968	20	Car bodies, tyres, concrete rubble	Mixed MOP	Research	Research Group	Kerr 1992
33	QLD	1971	5	28 Concrete modules	Concrete modules	Fishing	State Fisheries	Kerr 1992
34	QLD	1972	5	Concrete shelters	Tyres	Fishing	State Fisheries	Kerr 1992
35	QLD	1975	3	Tyres	Tyres	Fishing	Fishing Club	Kerr 1992
36	QLD	1978	9		Mixed MOP	Fishing	Community Group	Kerr 1992
37	QLD	1985	22	Steel vessel	Steel vessel	Fishing	Industry	Kerr 1992
38	QLD	1986	66	Steel vessel	Steel vessel	Fishing	State Fisheries	Kerr 1992
39	QLD	1989	9	Car bodies	Mixed MOP	Fishing	Community Group	Kerr 1992
40	QLD	1991	5	Concrete pipes and rubble	Rubble	Fishing	Community Group	Kerr 1992
41	QLD	2000	5	Geotextile bags filled with sand	Geotextile bags	Surfing	Other	State Fisheries
42	QLD	2005	28	Former warship	Steel vessel	Diving	State Fisheries	State Fisheries
43	QLD	2006	15	Steel vessels and concrete pipes, some concrete and steel modules	Mixed	Diving	State Fisheries	State Fisheries
44	QLD	2010	10	117 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
45	QLD	2011	15	78 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
46	QLD	2011	14	25 Fish Boxes	Concrete modules	Fishing	State Fisheries	State Fisheries
47	QLD	2011	22	20 Fish Boxes	Concrete modules	Fishing	State Fisheries	State Fisheries
48	QLD	2011	35	3 Steel Fish Caves	Steel modules	Fishing	State Fisheries	State Fisheries
49	QLD	2014	21	1975-2014	Mixed MOP	Fishing	State Fisheries	State Fisheries
50	QLD	2015	16	30 reef temple modules	Concrete modules	Fishing	State Fisheries	State Fisheries
51	QLD	2015	10	30 reef temple modules	Concrete modules	Fishing	State Fisheries	State Fisheries
52	QLD	2015		6 cluster of concrete modules	Concrete modules	Fishing	State Fisheries	State Fisheries
53	SA	1969	10	Car bodies	Mixed MOP	Fishing	Fishing Club	Kerr 1992
54	SA	1970	10	15000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
55	SA	1971	10	5000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
56	SA	1972	8	2000 tyres	Tyres	Fishing	Fishing Club	Kerr 1992
57	SA	1972		Vessels and tyres	Tyres	Fishing	State Fisheries	Kerr 1992
58	SA	1973	10	Tyres	Tyres	Fishing	Fishing Club	Kerr 1992
59	SA	1973	18	25000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
60	SA	1983	15	50 tonnes of tyres, 10 tonnes of concrete pipes	Mixed MOP	Fishing	Fishing Club	Kerr 1992

Reef #	State	Year	Depth (m)	Specific construction materials	Materials	Purpose	Deployed by	Reference
61	SA	1983		14,000 tyres	Tyres	Fishing	Fishing Club	Kerr 1992
62	SA	1984	10	1,000 tyres	Tyres	Fishing	Fishing Club	Kerr 1992
63	SA	1984	20		Steel vessel	Fishing	State Fisheries	Kerr 1992
64	SA	1984	20		Steel vessel	Fishing	State Fisheries	Kerr 1992
65	SA	1984	18	Tyres	Tyres	Fishing	State Fisheries	Kerr 1992
66	SA	1985	18	Tyres	Tyres	Fishing	State Fisheries	Kerr 1992
67	SA	1985	20	Tyres	Tyres	Fishing	State Fisheries	Kerr 1992
68	SA	1986	18	Tyres	Tyres	Fishing	State Fisheries	Kerr 1992
69	SA	1986	18	1,200 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
70	SA	1986	18	400 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
71	SA	1986	18	1,000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
72	SA	1986	18	1,000 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
73	SA	1990	15		Steel vessel	Fishing	Fishing Club	Kerr 1992
74	SA	1991	9		Tyres	Fishing	State Fisheries	Kerr 1992
75	SA	1991	15		Tyres	Fishing	State Fisheries	Kerr 1992
76	SA	1994	20		Steel vessel	Diving	Diving Club	http://www.adfha.net/adelaide_menu.htm
77	SA	2002	20	Fishing boat	Steel vessel	Diving	Diving Club	State Fisheries
78	SA	2002	30	Navy ship	Steel vessel	Diving	State Fisheries	State Fisheries
79	TAS	1987	25		Steel vessel	Fishing	Industry	Kerr 1992
80	TAS	1990	17	Loading facility	Mixed MOP	Fishing	Industry	Kerr 1992
81	TAS	2001	20	50 Reef Balls	Concrete modules	Fishing	Diving Club	State Fisheries
82	TAS	2007	27	55 m hopper barge	Steel vessel	Fishing	State Fisheries	State Fisheries
83	VIC	1965	20	440 tonnes of concrete pipes and two vessels	Mixed MOP	Fishing	State Fisheries	Kerr 1992
84	VIC	1973	10	2000 tyres	Tyres	Diving	Diving Club	Kerr 1992
85	VIC	1973	10	Quary rock, steel frames, cube modules and tyres	Mixed	Fishing	State Fisheries	Kerr 1992
86	VIC	1973	10	Quary rock, steel frames, cube modules and tyres	Mixed	Fishing	State Fisheries	Kerr 1992
87	VIC	1973	10	Quary rock, steel frames, cube modules and tyres	Mixed	Fishing	State Fisheries	Kerr 1992
88	VIC	1976	20	74 m bucket dredge	Steel vessel	Fishing	State Fisheries	Kerr 1992
89	VIC	1990	12		Steel vessel	Diving	Diving Club	Kerr 1992
90	VIC	1990	24		Steel vessel	Diving	Diving Club	Kerr 1992
91	VIC	1990	20		Rubble	Research	Industry	Kerr 1992
92	VIC	1991	22		Steel vessel	Diving	Diving Club	Kerr 1992
93	VIC	1992	20	150 tetrahedron shaped units with a base of 9 tyres (3 x 3) bound together with industrial straps that were fastened with stainless steel crimps	Mixed	Fishing	State Fisheries	Coutin 2001

Reef #	State	Year	Depth (m)	Specific construction materials	Materials	Purpose	Deployed by	Reference
94	VIC	1993	20	150 tetrahedron shaped units with a base of 9 tyres (3 x 3) bound together with industrial straps that were fastened with stainless steel crimps	Mixed	Fishing	State Fisheries	Coutin 2001
95	VIC	2009	11	100 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
96	VIC	2009	11	100 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
97	VIC	2009	11	100 Reef Balls	Concrete modules	Fishing	State Fisheries	State Fisheries
98	VIC	2009	28	Navy ship	Steel vessel	Diving	State Fisheries	State Fisheries
99	VIC	2012	4	99 concrete dome modules	Concrete modules	Fishing	State Fisheries	State Fisheries
100	VIC	2012	4	99 concrete dome modules	Concrete modules	Fishing	State Fisheries	State Fisheries
101	VIC	2012	4	99 concrete dome modules	Concrete modules	Fishing	State Fisheries	State Fisheries
102	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
103	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
104	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
105	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
106	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
107	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
108	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
109	VIC	2014	5	Reef Balls, 8 small reefs all together, made from 15 modules	Concrete modules	Fishing	State Fisheries	State Fisheries
110	VIC	2015	25	25 Fish Box modules	Concrete modules	Fishing	State Fisheries	State Fisheries
111	WA	1971	4.5	8 concrete module reefs	Concrete modules	Fishing	State Fisheries	Kerr 1992
112	WA	1971		80 tyres	Tyres	Fishing	State Fisheries	Kerr 1992
113	WA	1987	20		Tyres	Fishing	Community Group	Kerr 1992
114	WA	1987	20		Rubble	Fishing	Industry	Kerr 1992
115	WA	1989	50		Steel vessel	Diving	Diving Club	Kerr 1992
116	WA	1997	30	Navy ship	Steel vessel	Diving	Community Group	State Fisheries
117	WA	1999	4	Rock	Rubble	Surfing	Other	State Fisheries
118	WA	2001	35	Navy ship	Steel vessel	Diving	State Fisheries	State Fisheries
119	WA	2011	19	700 concrete units	Concrete modules	Research	Industry	State Fisheries
120	WA	2013	27	30 ten-tonne concrete modules	Concrete modules	Fishing	State Fisheries	State Fisheries
121	WA	2013	17	30 ten-tonne concrete modules	Concrete modules	Fishing	State Fisheries	State Fisheries

Habitat Enhancement Structures (HES): A Review of Design, Application and Deployment

Introduction

Habitat Enhancement Structures (HES) encompass a wide range of structures and materials placed deliberately in the aquatic environment for various purposes, but usually associated with increasing fishing success. More widely referred to as artificial reefs, HES have been crudely defined as the development of any productive habitat in an otherwise unproductive location (Brock, 1985). However, this has been further refined by the European Artificial Reef Research Network (EARRN) as *"submerged structures placed on the substratum (seabed) deliberately, to mimic some characteristics of a natural reef"* (Jensen 1998; Baine, 2001). However, to incorporate a broader range of uses, Sutton and Bushnell, 2007 defined HES as *"one or more objects of natural or human origin deployed purposefully on the seafloor to influence physical, biological or socioeconomic processes related to living marine resources"*.

HES come in many forms, ranging from waste or surplus materials to sophisticated, specifically designed pre-fabricated units ranging from old car tyres, shopping trolleys, building rubble and decommissioned oil and gas infrastructure, to plastic reinforced concrete or moulded ceramic reef modules. Similarly, the purposes and acceptance of HES and their construction material has evolved from one of the creation of fish habitat through the disposal of waste materials to the development of artificial reef modules capable of mimicking natural ecosystems. The aim of this study was to review the types and uses of HES both within Australia and around the world with the aim of providing an overview and guide that may aid in the decision process when developing the concept of a new HES or AR.

The History of Habitat Enhancement Structures

Indigenous cultures have used artificial reefs for thousands of years to harvest both marine and freshwater food supplies (Kerr, 1992). In the Mediterranean, ancient tuna fishermen from Sicily cut ballast stones free from their nets, the accumulation of these ballast stones provided fish habitat for the fishermen to exploit between tuna seasons, and eventually they added to the sites with wrecks. Similarly, the disposal of ancient Greek temple stones during harbour construction created new artificial reefs about 3000BC (Riggio, 2000).

Elsewhere, particularly Japan, ad hoc use of artificial fishing reefs constructed of trees, rocks and sand-filled straw sacks were commonly used in the 17th century (Sato, 1985). However, specific documented creation of an artificial reef in Japan occurred in 1795 when a local fisherman noted elevated fish catches over a sunken vessel. When the vessel deteriorated, the local fishing community constructed gabion baskets of bamboo and rocks in an effort to replicate the effects of the vessel. Elevated catches were recorded during the next summer, and hundreds more such reefs were developed over the next 10 years (Ino, 1974).

Japan became the first nation to systematically develop HES for increased fisheries production. By 1930, the Japanese Government was subsidising the development of artificial reefs through the ministry of Agriculture and Forestry, and by 1954 regulation on the design and placement of HES was in place (Thierry, 1988).

HES or artificial reef development has increased rapidly in the past 40 years. The United States of America, Taiwan, Korea and Europe started developing artificial reefs programs in the early 1960's and the first Australian artificial reefs were placed in 1965 (Sheehy, 1982; Kerr, 1992; Kim *et al*., 1994). However, unlike Japan, most other countries initially constructed artificial reefs with waste materials, or Materials of Opportunity (MOP), such as tyres, car bodies, culvert pipes and building rubble. Led by Japan and the USA, by the 1980's most HES were being constructed of pre-fabricated concrete. Today more than 50 countries have deployed HES (Frijlink, 2012).

Types of Habitat Enhancement Structures – Materials.

Habitat Enhancement Structures fall into two main categories of construction, those constructed from MOP and those that are purpose-built to task. The types of construction material utilised since HES became more widespread has evolved in line with both experience and environmental, community and design concerns. More recently however, materials have become more sophisticated as tolerance for waste materials declines. Manufactured reef modules can range in shape, size, function and materials, with most constructed of reinforced concrete often stabilised to provide a neutral surface.

Materials of Opportunity

Early HES were principally constructed of readily available materials that could be used to create bulk whilst at the same time disposing of unwanted waste material. Common materials used to generate many reefs worldwide included tyres (Downing *et al*., 1985; Campos and Gamboa, 1989; Kerr, 1992; Ferrer, 2015; Tessier et al., 2015), car bodies (Fitzhardinge and Bailey-Brock 1989; Kerr, 1992; Barnabe *et al*., 2000; Brown, 2014), concrete rubble (Kerr, 1992) and vessels (dos Santos, 2012; MMCS, 2012) and discarded oil and gas platforms (Jorgensen *et al*., 2002). However, a myriad of materials has been utilised to create reefs either for recreational fishing or diving and range from shopping trolleys (QLD Govt. 2015), trolley cars (Lukens *et al*., 2004; Urbina, 2008), tanks, armoured personnel carriers, drones and aircraft (Lukens *et al*., 2004), white goods (Brown, 2014) and telegraph poles (Chuang *et al*., 2008).

Whilst some MOP such as scuttled vessels have proved successful both environmentally and socio-economically (Brock 1994; Cole and Abbs, 2012), others have provided both important lessons in the design and application of HES in the marine environment. For example, environmental concern of the impacts that tyres may have on the marine environment has led France to commence removal of 25, 000 tyres in the Mediterranean. Part of the issue for materials such as car tyres is that whilst readily available, they may leach toxins in to the environment (Collins *et al*., 2002), move across the sea floor destroying habitat (Sherman and Spieler, 2006; Ferrer, 2015) and are not suitable substrate for many benthic species due to the flexibility of the rubber (Fitzharding, 1989, Barnabe *et al*., 2000). Tyre reefs in many cases have broken up and washed ashore after storms, or weighted tyres have fragmented, depositing rubber fragments onto beaches (Skoloff, 2007; Ferrer, 2015).

In Florida, at Osborne Reef, nearly two million tyres were dumped at sea in a community effort to create an artificial reef (Figure 14). After the reef broke up and dispersed, and tyres repeatedly washed ashore, the state government decided to remove the reef. Currently the government contributes US$3.4 million annually in an effort to remove the tyres. It is estimated that there are 200 reefs worldwide constructed of tyres with at least 20 million m^3 of artificial reef (Ferrer, 2015).

It is beyond the scope of this study to detail each type of HES created by MOP. However, it does appear that the costs associated with this type of habitat creation in the marine environment presents long-term socio-economic issues, including costs to local, state or federal government in clean-ups, damage and loss of marine habitat or leaching of material into the sea.

Figure 14: Recycled car tyres at Osborne Reef, Florida. The reef has broken up and dispersed (Lukens *et al.*, 2004).

Whilst scuttled vessels must also be cleaned and prepared extensively prior to deployment, it appears that the costs involved may be offset by increased annual returns, especially from tourism-based activities, and especially diving (Brock, 1994; dos Santos, 2012). In Hawaii, a vessel that cost $US1 million to prepare and scuttle currently generates revenues in excess of $8 million a year for three operators, including an annual profit (after costs) of $1.3 million (Brock, 1994). The scenario is similar in Australia. The HMAS Brisbane has generated revenue of $AUD18 million since its scuttling four years ago (Sundstrom, 2015). The HMAS Adelaide after costing $AUD5.8 million to prepare and deploy, currently generates an estimated $AUD4.5 million of dive revenue per year (Cole and Abbs, 2012).

Some often overlooked environmental impacts from MOP are entrapment. Fish and sea turtles are known to have died as a result of disorientation in newly deployed vessels and aircraft in the USA due to inadequate planning and escape hatches (Lukens *et al.*, 2004).

The convenience and availability of many MOP no longer exists. International Marine Pollution laws prohibit dumping of certain products at sea, requiring the cleaning and removal of hydrocarbons from car bodies prior to deployment. Scrap materials previously available to be used as MOPs for artificial reef projects are often recycled. For example, tyre recycling rates in the USA have increased from 10-70% in the past 15 years (Lukens *et al.*, 2004). Yip (1998) listed the longevity and suitability of MOP for artificial reefs and concluded that many materials do not last as long as previously expected (Table 5).

Table 5: Materials used for construction of artificial reefs, degradation lifespan and suitability for use as an artificial reef (adapted from Yip, 1998 and Brown, 2014).

Type	Life time (years)	Recommended
Cars and buses	<8	No, they are subject to corrosion
Wooden materials	<1-6	No, they collapse even sooner from wave surge and destruction by marine borers
Household appliances	<6	No, polluting
Tyres	Indefinite	No, difficult to keep in place
Concrete/rock rubble	Indefinite	Yes, but transport costs excessive
Boxcars	2-14	Debateable, breakup quickly
Subway cars	25-30	Yes
Tanks	>30	Yes, but preparation expensive
Aircraft	>15	Yes, but preparation expensive
Vessels (Navy ships, barges, ferry's)	>30	Yes, preparation expensive

Purpose-built

The goals or objectives of many HES are to increase the productivity of specific target fishes, principally fish with intrinsic commercial or recreational value. The effectiveness of HES increasing productivity of any particular target species largely depends upon the design of the reef structure to be used (Pickering and Whitmarsh, 1997).

The development of pre-fabricated reef structures or HES has largely been driven by a renewed focus upon clear HES objectives and target species. The need to design HES that target particular species has been extensively developed in Japan, where over 130 different reef module designs targeting particular species have been constructed since 1952 (Thierry, 1988; Polovina and Sakai, 1989). Many authors have agreed that to achieve the desired objectives from the installation of an HES, integrating specific biological requirements of target species with engineering components will often lead to a more successful outcome (Sheehy, 1982; Sato, 1985; Seaman *et al*., 1989; Seaman, 2008; Guner *et al*., 2009; Diplock, 2010; Fabi *et al*., 2011; Koeck *et al*., 2014).

Japan has been at the forefront of the development of pre-fabricated HES, with reef modules specifically designed for increasing the production of pelagic and demersal fisheries, abalone (Okamoto, 2002), sea cucumber, sea urchin, octopus (Polovina and Sakai, 1989), marine algae culture, oysters and squid (Barnabe and Barnabe-Quet, 2000). Extensive biological and engineering studies conducted by the Japanese, reflected in specifically designed reef material, allow for greater certainty that the reef will stay in place and provide the proper conditions for the particular species desired (Stone, 1982; Thierry, 1988).

In Japan, Korea, Taiwan and some states of the USA there are various government regulations stipulating the types of materials as well as the design and durability of new HES (Thierry, 1988; Murray, 1994; Chuang *et al*., 2008; Diplock, 2010; Lindberg and Seaman, 2011).

Purpose-built HES take many forms, and may be constructed of;

- Reinforced concrete or limestone
- Plastic injected concrete
- Fibre reinforced plastic
- Steel
- Ceramics
- Polypropylene (artificial seagrass)
- Geotextile bags
- Recycled shells
- Electrical current $CaCO_3$ deposition
- Recycled nylon fishing line
- Waste bivalve shells in cages or bags

Some HES may utilise a combination of the above materials in a composite design. For example, the Shell Nurse utilises discarded oyster or scallop shells embedded within a steel framework creating a "nursery-like" HES that recruits spawning invertebrates up to 80 times faster than standard concrete (JF Group, 2008). Each material or composite has its benefits to allow the exact fabrication and manufacture of the engineered designs.

To date the most practicable material found to meet the growing requirements of HES is high strength marine-grade concrete. The advantages of concrete are that it can be manufactured in a wide range of shapes and sizes to suit specific requirements of individual reefs, and that they are non-toxic, pH balanced and may be altered to provide more suitable surface textures to encourage benthic settlement (Baine, 2001; Lukens *et al*., 2004; Perkol-Finkel and Sella, 2014). An added benefit is that the material is universal and easily applied by community groups in developing countries wishing to utilise designs such as Reef Balls™ (Reef Balls, 2015). The Reef Ball Foundation estimates Reef Ball™ life expectancy to be 500 years or more. Steel, however, is used in pre-fabricated units for high-profile type reefs where weight precludes the use or transportation of concrete equivalents.

Government-set manufacturing standards in Japan have allowed the development of far more sophisticated, longer-lasting designed HES. Japanese Government approved designed units must meet specific criteria, including durability/stability (minimum of 30 years' service, ability to withstand handling/placement rigors, resistant to burial/movement); safety (non-toxic, handling safety); functionality/biological effectiveness (proven and tested record of fish aggregation, attraction/production of targeted species, creation of desired habitat, biotic diversity); and economy (Grove and Sonu, 1985).

Geographical Evolution of Habitat Enhancement Structures

Habitat Enhancement Structures, in the form of artificial reefs, have been utilised for many centuries. However, more recently many countries have adopted a regulated approach to installing HES, and consequently there is an increase in the sophistication of design and deployment of these structures, which then equates to more effective uses of materials and a more productive output. The development of HES has occurred principally in regions where fisheries production is paramount – either economically or socially. Hence it is no surprise that Japan leads in both the deployment and design in HES in the world, followed closely by Taiwan, Korea and the USA. The following sections outline the history of the use of HES in each of these regions.

Japan

Habitat Enhancement Structures have been installed in Japan for several hundred years. The first records date to 1650 however regular use of intensive bamboo structures 1789-1801 was initiated after artisanal fishers noticed increased fish catches over old wrecks (Ino, 1974). Fishers had placed over 2,000 cubic feet of stones creating two reefs. Fish catches where larger than expected for 4-5 years after deployment. By 1906, the first disused naval vessel was scuttled deliberately as an artificial reef. In 1930 the Japanese Ministry for Agriculture and Forestry had commenced subsidizing the construction of artificial reefs (Ino, 1974). Since 1952, construction has intensified with estimates that the Japanese Government invests billions of dollars into enhancing fishing in both shallow and deep waters (Stone, 1982). Japan is almost unique in that its HES are developed to enhance not only finfish, but also commercial algae, lobsters, sea cucumbers, octopus and sea urchins.

The first generation of prefabricated artificial reef units were deployed in 1950, and were simple concrete cubes/boxes with windows (voids) which could be stacked to increase the height of reefs. By 1954, the Japanese Government had regulations stipulating that only designed units could be deployed, and more recently that pre-fabricated units or reefs must pass stringent design protocols of longevity (Sheehy, 1982). There are 6400 HES sites and approximately 20 million m^3 (1800 km^2) of artificial reefs in Japan (Barnabe and Barnabe-Quet, 2000).

United States of America

The first use of reefs in the USA were small log huts (1.2m x 1.2m) immersed to attract table fish in Carolina during the 1830's (Lukens *et al*., 2004). Most artificial reefs in the USA were comprised of rocks, logs, ships or tyres, using waste material disposal as a secondary objective of the use of artificial reefs (Sheehy, 1982). However, the cost-effectiveness of such materials (it was cheaper to dispose of such materials in land fill) and inherent issues with tyres scouring bottom, and dislodging and becoming washed onto beaches, prompted both California and Florida to ban their use (Lukens *et al*., 2004). Since the 1980's, artificial reef development has been led by Japanese inspired design. A set of three study reefs as early as 1960 compared four materials, including street cars, vehicles, building rubble and prefabricated Japanese modules – the results found that both streetcars and vehicles lasted only 3-4 years whilst the rubble and prefab units lasted greater than 15 years (Sheehy, 1982). In the USA, approximately 1 million m^3 of reef exists, much of this along the Florida coastline where over 1500 artificial reefs have been deployed (Barnabe and Barnabe-Quet, 2000; Sutton and Bushnell, 2007).

Philippines

Thousands of small reef modules have been deployed as part of aid programs sponsored by the federal government, and through Japanese and USA aid programs. Between 1977 and 1995, an estimated 70,541 reef modules were deployed, each module comprising either bamboo pyramids, clusters of four tyres, or a single concrete block (Munro and Balgos, 1995).

Since 1991, 174 artificial reefs have been deployed in 75 sites in Negros Oriental, Central Visayas, Philippines (Munro and Balgos, 1995). It was estimated that the annual harvest from these artificial reefs is 3.0 kg.m^2 which can be about 150 times higher than the yield from natural coral reefs. In this area, and elsewhere in the Philippines, artificial reefs are popular because they attract a great abundance of fish and enable fishers to reduce fishing effort. However, it appears that they can contribute severely to overfishing if the catches exceed the maximum potential new production (Waltemath and Schirm, 1995).

Korea

The government started subsidising and coordinating the placement of artificial reefs in 1971 using prefabricated concrete structures, which by 2011 had become a $55 million a year project (Kim *et al*., 1994; DoF, 2010). Approximately $885 million has been spent on developing the South Korean artificial reef program over the past 40 years (DoF, 2010). The total area of artificial reefs now installed exceeds 207,000 ha.

The South Korean Government applies a strict approvals process which takes 2 - 3 years. During the approvals process, each design is assessed on the basis of cost, economic efficiency and quality. A HES design has to demonstrate to be the equivalent or greater at generating productivity and effectiveness than any surrounding natural reef systems.

There are two basic types of HES deployed in South Korea, reinforced concrete structures designed for shellfish, crustacean and seaweed cultivation in shallow waters and larger concrete or steel structures used for finfish production in deeper waters (Kim *et al*., 1994; DoF, 2010).

Taiwan

The first reef sets were small 1m^3 concrete blocks installed in 1957 (Chuang *et al*., 2008). Whilst a more recent participant in artificial reefs, the Taiwan Government commenced a coordinated approach in 1974 (Sheehy, 1982; Chuang *et al.*, 2008) as part of their national fishery policy. By 1996 reefs designed to promote abalone, lobsters and fish had been installed using a variety of materials including fly ash, tyres, ships and concrete (Lin and Wang, 2006). By 2008, an estimated 88 artificial reef sites containing 180,000 modules and creating 2.2 million m^3 of reef had been deployed (Chuang *et al.*, 2008).

Europe

The first reefs are thought to have been deployed 3000 years ago when fishing nets were left amongst boulders to enhance fish catches in the next season (Riggio *et al*., 2000). In the last 40 years HES development has increased rapidly. For example, in France, up until the 1980's there were 30,000m^3 of reefs installed compared to at least 90,000 m^3 at 33 sites presently. Europe, unlike other locations, has developed prefabricated modules to restrict illegal trawling and protect adjacent habitats (Fabi *et al*., 2011).

The design of many European artificial reefs has experimented with a wide variety of forms of modules. These include Bonna (4x6m rectangular concrete matrixes), Alveolar Pyramids (2.5x2.5x2.9m concrete/steel pyramids), Comin (2.3x2.3m soccer ball like concrete frames), various cubic reefs (hollow cube concrete with various windows), Fakir electric piles (7 concrete pillars 1.6m on a concrete base), Floating ropes suspended in a cube frame 6x6m, the very strange prefabricated Kheops (concrete modules) and Thalame (Igloo-like concrete structures 1x3m) (Tessier *et al*., 2015, Figure 15).

In addition, several structures have been deployed specifically to prevent trawling to protect habitats. These include concrete Tripods, Negris (three large columns on concrete base), Fakir electric piles and hexapods constructed of electricity poles (Tessier *et al*., 2015). The designs are based upon weighty structures with devices for snagging nets, thereby providing a disincentive to illegal trawling in the region. Often, they are deployed in sets, and adjacent sensitive seagrass beds (Charbonnel *et al*., 2011; Tessier *et al*., 2015).

The French no longer utilise MOP, and have moved to prefabricated and designed structures almost exclusively manufactured from concrete. In addition, over the past ten years most HES have been planned, designed and subjected to environmental impact assessments and monitoring, with few negative impacts now being observed.

Eighty percent (80%) of reefs in France have the primary objective of protecting artisanal fisheries, but also the protection of habitat from illegal trawling. Habitat Enhancement Structure modules must be stable and have design attributes to provide suitable habitat for a variety of organisms, not just fish. The European use of ‘Reef Villages’ is extensive, where reefs systems are composed of a designed arrangement containing different reef modules with connectivity between each area (Fabi *et al*., 2011; Tessier *et al*., 2015). This type of reef increases the structural complexity overall in order to suit a larger variety of organisms in a sustainable manner.

In contrast to both the USA and Australia, over half of the artificial reefs in France prohibit fishing, anchoring, dredging, trawling and diving.

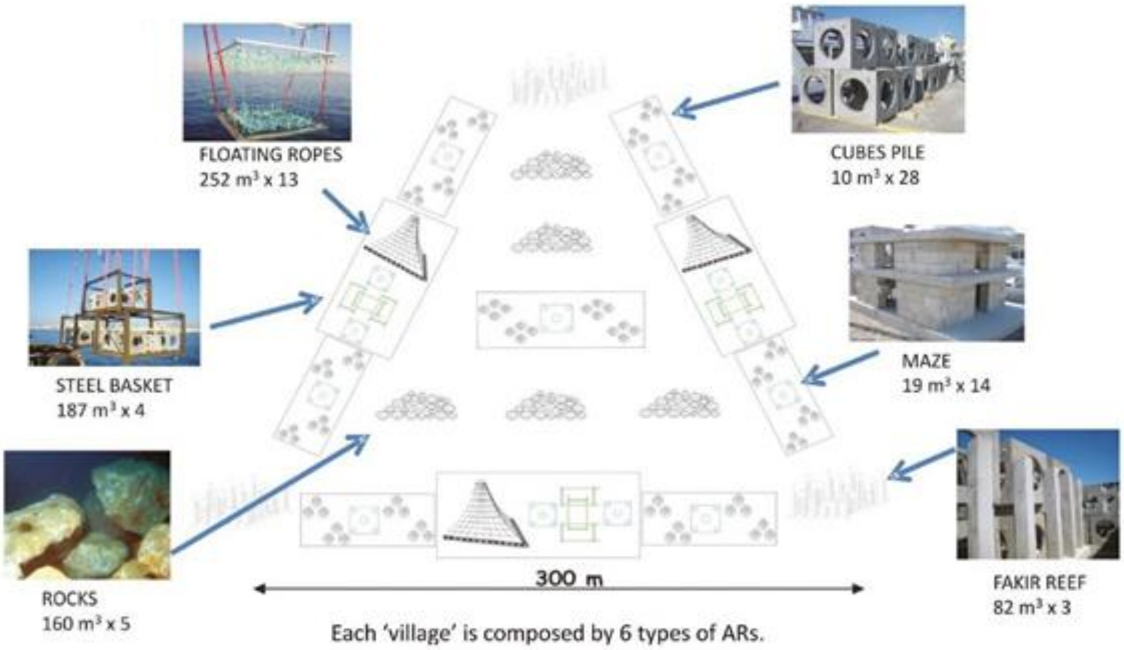

Figure 15: The European example; a ‘Reef Village’ in the French Mediterranean (Tessier *et al*., 2015).

Australia

In Australia, aboriginals utilised artificial reefs as far back as 2000BC (Carstairs, 1988 in Kerr, 1992). Non-indigenous development of artificial reefs in Australia did not commence until the 1960’s. Of the 72 reefs reviewed in Kerr (1992), 29 were constructed of recycled car tyres and 22 of vessels. Interestingly, at the same time that Japan was heavily regulating the use of artificial reefs and had moved away from ad hoc materials, Australia continued to deploy tyre-based reefs. Similarly, by 1982 several North American states had banned the use of tyres due to pollution concerns (Sheehy, 1982) and in the Mediterranean France have begun to remove tyre reefs (Ferrer, 2015).

More recent artificial reefs include several surfing reefs (Rocks-Cable Stations and Geotextile - Narrowneck Reef, Frijlink, 2012), several Reef Ball-based reefs in QLD (Moreton Bay) and NSW (Botany Bay), and several large-scale prefabricated concrete Fish Box^{TM} (Haejoo Pty Ltd, Geographe Bay, W.A. – DoF, 2013) and steel Fish Cave^{TM} (Haejoo Pty Ltd) units (Sydney, NSW – Frijlink, 2012). Unlike European and Asian HES, Australian installations are primarily focussed upon recreational activities such as fishing or diving, rather than artisanal or commercial fisheries.

The Benefits and Purposes of Habitat Enhancement Structures

Habitat Enhancement Structures may be defined by their functionality according to the outcomes that each HES aims to achieve. Originally HES, principally in the form of artificial reefs composed of MOP (tyres- *i.e.* Philippines, Munro and Balgos, 1995) or of more durable pre-fabricated concrete structures (*e.g.* Japan, Korea - Thierry, 1988; Kim *et al*., 1994), had the sole purpose to enhance commercial finfish catches. In contrast, during the early development of HES in the USA and Australia, extensive use of waste tyres, vehicles (cars, buses, railway carriages, tanks) or building rubble was primarily aimed to increase benefits for recreational fishers and SCUBA divers (Boshnack *et al*., 1991; Kerr. 1992; Grossman *et al*., 1997; Lukens *et al*., 2004).

More recently, HES take many physical forms, ranging from small, plastic artificial seagrass units (100 cm^2) to massive rock breakwaters (1000's m^3) (Virnstein and Curran, 1986; Bartholomew, 2002; Dyson, 2009). There may be physical (coastal processes, coastal defence) biological (conservation, enhancement, protection) or socio-economic (recreational fishing, surfing and diving) factors in determining both the siting and structural attributes of HES. They may be designed to mitigate for loss of fish habitat during the construction of marinas (Davis, 1984), to rehabilitate or stabilise habitat for fish and dolphins (Mikkelsen *et al*., 2013), to attract or encourage commercial fish species (Nakamura, 1985), to protect sensitive marine areas from trawling (Tessier *et al*., 2015), to develop a commercial tourism industry (Brock, 1994), to prevent coastal erosion (Kliucininkaite and Ahrendt, 2011) for surfing (Tomlinson *et al*., 2007) or habitat rehabilitation after coral mining (Clark and Edwards, 1994).

The broad primary purposes of HES may be categorised as;

- Conservation
- Recreation
- Restoration
- Prevention
- Attraction

This list can be expanded to include specific purposes of HES;

- Restoration of habitat- rehabilitate habitat perceived to have been impacted by some process (*i.e.* trawling, fishing, storms).
- Creation of protection zones – install HES to create a barrier to entry to an area.
- Reduce fishing on stock
- Prevention of trawling – install HES to prevent fishing trawlers damaging habitat.
- Control of erosion – install HES to deflect waves, accrete sand, and protect coasts.
- Creation of breakwaters- shelter harbours dissipates waves.
- Increase fishery catches- attraction of commercial fish species to artificial reefs.
- Create spawning grounds-creation of designed micro niches suitable for breeding.
- Create recreational fishing grounds- utilisation of artificial reefs targeting favoured table fish species.
- Create diving areas - design of aesthetically pleasing structures or vessels to attract marine life.
- For scientific research- experimental assessment of HES.
- For mariculture – Designed HES for abalone, oyster, lobster culture.

Habitat Enhancement Structures in Japan have been almost exclusively designed to enhance commercial fisheries production. There are numerous designs of structures that have been approved by the government, ranging from small-scale modules developed for abalone (Cultivar Base; Kaiyo Doboku, 2010), octopus (Octopus Home; Kaiyo Doboku, 2010), and Shell Nurses (JF Group, 2008) to promote the spawning of and settlement of fish and cephalopods. Rectangular, modular low-profile concrete units have been developed to encourage algal growth (Kanakura Block Reef; JAFRA, 2011), which in turn enhances production of crustaceans, molluscs and fishes. In contrast, large, multi-faceted steel or concrete, high-profile reefs have been specifically designed to provide habitat for benthic fishes but also create upwelling and favourable current profiles for pelagic fishes (*i.e.* the 30m tall Uni-tower Series, the triangular JUMBO Reef, or the pyramidal Truss Reef, JAFRA, 2011). A large range of cubic concrete modules are also produced which may be arranged together if necessary (*i.e.* the Tetra Reef TR3, Fish Paradise Reef, JAFRA, 2011) which are very similar to the Haejoo designed Fish Box™ reef module deployed recently in WA (DoF, 2013).

The Norwegian-designed SeaCult Habitat (SeaCult AS, 2015), comprises a central concrete cylinder filled with stones and surrounded by numerous polyethylene pipes creating fish habitat and seabed stability. This unit provides 300m^2 of growing surfaces and the equivalent of 100 tonnes of rock in a unit weighing only 7.5 tonnes (SeaCult AS, 2015). At a much smaller scale, Diplock (2011) reviewed numerous structures and construction techniques designed to retrofit microhabitat for fishes along defensive structures (such as riverside rock revetments), below pontoons or jetties in marinas or anchored between jetty pylons or secured to pylons. One particular module called FishHab are made from recycled plastic (including old fishing line), which provides a durable and environmentally friendly structure. The prefabricated slats join together to form crate-like modules of 1.2m^2 that provide additional fish habitat (Barwick *et al*., 2004).

Reef Balls™ (Figure 16) are one of the most extensively utilised designed HES, with over 500,000 deployed. The designs range from 3kg-5,000kg, and can be manufactured on site using moulds provided by the Reef Ball foundation (Lennon, 2003; Reef Balls 2015). They are comprised of a rough-textured hollow concrete dome with numerous holes.

Figure 16: Reef Balls™ deployed in the marine environment.

In WA, there has been a range of different purpose-built modules deployed to date. These modules include a range of different sizes, shapes and voids, creating complex habitat and influencing productivity to enhance recreational fishing. All modules have been constructed out of concrete reinforced with fibre or steel. Ninety-two modules (for the enhancement of recreational fisheries) have been deployed since February 2017, with an additional 286 planned to be deployed before July 2019. Five different purpose-built artificial reef modules designs (including concrete and steel) have been used for the purpose of recreational fishing in WA, built by two organisations, Haejoo and Subcon (Figures 17-19).

Figure 17: Haejoos 'Fishbox'™ modules (Recfishwest).

Figure 18: Subcon concrete modules used to date, the Reef Dome™ (left), Abitat™ (middle) and Apollo™ (right) modules (Recfishwest).

Figure 19: Reef Pyramid™ (left) and Fish Towers™ (right), steel modules constructed and deployed by Subcon (Recfishwest).

Habitat Enhancement Structure Design and Construction

Prior to the adoption of Japanese-inspired designed structures, many artificial reefs deployed from the 1960's to the 1980's considered only the availability of cheap materials and a site to dump them. More recently, HES design focussed on structural integrity and stability (Bohnsack *et al*., 1994; Brickhill *et al*., 2005). However, current consensus is that the design process must consider an array of factors in order to better meet the objectives of any HES (Barnabe and Barnabe-Quet, 2000; Spieler *et al*., 2001; Baine and Side, 2003; Chuang *et al*., 2008; Dyson, 2009; Kliucininkaite and Ahrendt, 2011). The architecture of any HES should consider biological, physical factors and socio-economic and engineering concerns during the design stage (Figure 20). Thorough assessment and community stakeholder consultation will increase the likelihood of a successful outcome.

Reef Design and Complexity

Many authors have reviewed the influence upon HES design and its effectiveness at meeting the reefs objectives. For example, in Europe, and particularly in Spain and France, some reef designs are predominately aimed at reducing the levels of illegal trawling in shallow waters in order to protect important fisheries nursery grounds of *Posidonia oceanica* (Bombace, 1989; Barnabe *et al*., 2000; Charbonnel and Bachet, 2010; Fabi *et al*., 2011). Such designs utilise heavy, concrete-based structures with protuberances that may catch or destroy nets. In Malaysia, the use of Reef Balls™ was in part to reduce bycatch of turtles by trawlers, which reduced from 100 to 20 pa (Bali, 2004). These reefs are less effective at providing new habitat complexity for colonisation by different species, however provide both protection (from trawlers) at the same time as providing habitat for fishes.

As many HES and artificial reefs are focused upon the enhancement or recovery of commercially or recreationally important fishes, their design is orientated to this end. Of the 72 artificial reefs reviewed by Kerr (1992), 61 (85%) were placed to enhance fisheries. Most of these reefs were constructed of tyres, and had little habitat complexity. However, more recently, HES have multiple objectives that must be met. An assessment of the importance of the structural complexity of HES was undertaken in 2007 at a new 'village' style HES placed in shallow water offshore of Marseille, France (Rouanet *et al*., 2015). The relationship between habitat complexity and species diversity has been demonstrated (Rilov and Benayahu, 1998; Moura *et al*., 2007; Charbonnel *et al*., 2011; Diplock, 2011; Perkel-Finkel and Sella, 2011; Le Direach *et al*., 2015). Spieler *et al*. (2001) review of artificial reefs concluded that there is a long list of design attributes, *i.e.* tructure, texture, colour, substrate composition, leaching toxins, chemistry (*i.e.* wettability), that should be considered before construction. Design elements such as vertical profiles and shelter to reduce predation and increase settlement as well as increase diversity will all impact upon the numbers and diversity of species attracted to any structure, and ultimately to its overriding ecological success.

Biological Considerations

The design of any HES must include careful assessment of the biological attributes of the target species or community, as well as the existing environment. Milon (1989) summarised the biological objectives of HES as:

- Attraction effects - the recruitment and concentration of species from an existing stock
- Productivity effects - an increase in the number and density of habitat-limited species due to greater food resources, reproductive habitat, and/or protection from predators
- Diversity effects - the attraction or development of new species in particular areas

One of the central arguments surrounding HES is whether they simply aggregate fish from surrounding waters or other natural reefs (a FAD effect) or whether they actually contribute to the production of target species and biomass in a potentially resource-limited ecosystem. Many authors have discussed the ability of HES, particularly artificial reefs to attract fishes, and particularly pelagic fishes (Koeck *et al*., 2014; Powers *et al*., 2003; Bohnsack, 1989; Polovina, 1989; Grossman *et al*., 1997; Pitcher and Seaman, 2000; Brickhill *et al*., 2005). In fact, the potential for increased catches of fish encouraged the early development of the first artificial reefs by the Japanese artisanal fishers in the 1700's (Ino, 1974). Newly placed HES are often rapidly colonised by adult and juvenile fishes, and are often characterised by higher diversity and biomass when compared to adjacent natural reef systems (Bohnsack *et al*., 1994; Charbonnel *et al*., 2002; Gratwicke and Speight, 2005; Willis *et al*., 2005; Folpp *et al*., 2011). However, there is scant data on the whether HES actually contribute to the production of biomass.

Pickering and Whitmarsh (1997) outlined four main pathways for increase in production;

- Increase in growth through prey availability at the HES
- Reduction in mortality through refuges provided by the HES
- Increase in recruitment of larval/juveniles by provision of suitable settlement habitat
- Reduction of harvesting pressure on adjacent natural reefs

Very few papers have been able to demonstrate recruitment of fishes through production, although Feigernbaun *et al*. (1989) recorded spawning and recruitment of juvenile fish at a reef in Chesapeake Bay effectively demonstrating production within that site. In a study based on assessing the production versus attraction debate, Cresson *et al*. (2014) assessed trophic relationships on the largest artificial reef installed offshore of Marseille, France. Their results found two pathways, one based on the consumption of organic matter of pelagic origin and the benthic pathway based on local production. The reef system at Marseille was shown to increase the amount of organic matter produced which in turn led to an increase in secondary biomass production, perhaps representing that artificial reef can enhance the biomass of commercial fishes outside of the influence of attraction (Cresson *et al*., 2014).

Habitat Enhancement Structures may represent an effective management tool by increasing fish productivity at the HES whilst redirecting potentially harmful human activities away from natural reefs (Ambrose and Swarbrick, 1989; Osenberg *et al*., 2002). However, most studies on artificial reefs have focused monitoring at the HES rather than on nearby natural reefs or habitats. Osenberg *et al*. (2002) argues that whilst artificial reefs and HES present apparently attractive cure-alls for declining recreational fish takes, or increased recreational fishing effort, the risks are that HES may simply redistribute fishes away from natural habitats to the HES, and if exposed to fishing effort, increased catch rates (which are perceived as successful outcomes for HES) may actually lead to longer term declines in fish stocks (Bohnsack, 1989; Milon, 1989; Brock, 1994).

Attraction versus Production

It is widely accepted that many fish species rapidly colonise HES within the first months of deployment (Charbonnel *et al*., 2002; Terashima *et al*., 2007; Cresson *et al*., 2014). However, does attraction and production interact through density dependence (the provision of new habitat) or simply redistribute existing fishes? Some argue that it is possible that attraction of adults and juveniles (particularly of benthic species) away from natural reefs reduces the density of these species at those reefs, thereby providing settlement opportunities for larval fishes (Wilson *et al*., 2001; Osenberg *et al*., 2002). However, these arguments suggest that HES present similar attributes to existing habitat, when many HES are installed over sea beds largely devoid of reefs.

In summary, the attraction debate suggests that net production will not increase but that fish will aggregate towards either the natural reef or artificial reef depending upon the quality of the two habitats, thus if the HES installed presents as preferred habitat, recruitment to the HES will be seen as a reduction in the density of the same species at nearby natural reefs. The production debate argues that any neighbouring natural reefs will be unaffected by HES, as larval fishes that could not settle or recruit on existing reefs due to competition for space, could do so at the HES, thereby increasing production (Polovina and Sakai, 1989; Osenberg *et al*., 2002).

Brock (1994) suggests that artificial reefs may aggregate the last remaining fishes in a local population and make them more vulnerable to exploitation from fishing, contributing to their decline or collapse from fishing. Similarly, Milon (1989) suggests that developing HES in support of commercial fishery may lead to a reduction in catches through congestion at sites, gear loss, fish take exceeding production or recruitment rates leading to declining returns to the fishery. This argument can equally be applied to HES development to encourage recreational fishing.

When assessing the objectives of any HES, Milon (1989) suggests considering several key factors;

- What is/are the target species?
- What are the expected harvest levels?
- What potential impacts can be expected to background stocks?
- What expected impacts are there on any non-users of the proposed HES?

Prior to the deployment or design of any such structure, planners of HES should consider the levels of activity of potential users in the area before the HES are installed. This can then be assessed compared to post deployment activity levels and an assessment of cost-benefits be made. Coupled with this, during the consultation and through to the design stage, the focus user groups or stakeholders should be consulted to determine what the preferred target species are and design the HES to enhance the availability of these species.

In Hong Kong, Wilson *et al*. (2002) found that whilst the artificial reef installed had rapid recruitment of both adult fish and settlement of small fry, careful management of fishing effort would be required for the artificial reef to be successful in improving habitat, physically preventing bottom trawling, and enhancing nursery areas.

Biological or ecological requirements to be considered prior to the design of any HES include:

- What species are being targeted?
- What are the habitat requirements of target species (pelagic/benthic, temperature, visibility)?
- What are the food requirements?
- What are the shelter requirements (refuges, surfaces, lighting)?
- What is the life-history traits of the target species?
- Seasonality (timing of larval settlement of prey or habitat species *i.e.* weed, coral, crustaceans)

Life History

All life forms that potentially may be targeted for any HES exhibit vastly different life history traits. For example, pelagic fishes are likely to be attracted to high-profile reefs that generate favourable water currents, whereas demersal species will be more dependent upon the structure and configuration of a HES. Incorporating micro habitats within a high-profile reef may help attract both, and in some areas artificial reefs are comprised of networks of different structures designed for different target species (Barnabe and Barnabe-Quet, 2000; Tessier *et al*., 2015).

Seasonality

There are seasonal differences in the distribution and abundance of larvae of marine fauna and in the presence of mobile adult pelagic species. The sequence of larval settlement upon new HES may impact upon the later colonisation of higher trophic levels (Spieler *et al*., 2001) impacting upon target species. Assessing seasonal trends at the chosen site may facilitate recruitment to the HES.

Shelter and Habitat

Different species require different depth, light and temperature regimes, with some requiring shadowed areas for shelter. Some coral species recruit best to vertical surfaces, and others like gorgonia require dark overhangs. Similarly, the complexity of the habitat and the range of shelter provided will ultimately determine what species of demersal fishes are able to successfully recruit to the HES.

Physical Characteristics

The physical attributes of a HES that will contribute to its design and function include;

- Surface texture, colour and chemistry
- Reef profile
- Shelter and shading
- Reef size and configuration
- Stability
- Substrate
- Hydrodynamics (currents, waves, tides)

Benthic assemblages (algae and invertebrates) are more abundant and diverse on textured surfaces, and texture increases the diversity of grazing fish. The impact of this upon the ability of different species to colonise a HES will impact upon larger, predatory species of fishes that are often the target of recreational fishers (Spieler *et al*., 2001). As concrete is able to be manipulated to produce a desirable rugosity, and with the addition of micro silica can have a neutral pH, it has a prominent role in design of HES (Frijlink, 2012; Reef Ball, 2015).

Once a HES is immersed, it's surface will rapidly acquire a biofilm. Studies have demonstrated that the type of biofilm will influence the succession of epibiota, and in turn influence higher trophic levels, including fishes (Fitzhardinge and Bailey-Brock, 1989). Incorporating design features that include the provision of shelter or refuges of different types will also influence settlement onto a HES. Some fish species prefer blind-ended holes, others open-ended void spaces that are shaded. A variety of void spaces or refuges will influence the ability of both small fishes or different life-stages of fishes to settle on a HES. One study observed that increases in large void spaces reduced the number of smaller fish species likely due to predation pressure (Hixon and Beets, 1989). Habitat complexity too increases diversity and biomass in fishes on HES. For example, Baine (2001), Charbonnel *et al*. (2002) and Sherman *et al*. (2002) found that increasing the number of small void spaces by adding concrete blocks into Reef Balls™ provided increased habitat for small fishes, crustaceans and other taxa. This appeared to have the added benefit of providing prey for larger fishes that used the reef. These physical attributes provide a feed-back loop into the engineering considerations for HES during the development stage and will likely influence the end design.

Engineering Characteristics

Engineering considerations for HES include attributes of the structure, quality of the construction material as well as the attributes included in the design to facilitate recruitment (Dyson, 2009). Depending upon the purpose of the HES, engineering considerations will vary. For example, a HES with the sole purpose of attracting fish for fishers will not need to consider any visual or aesthetic qualities like one that is designed for both attracting fishers and recreational divers.

The most important attributes (apart from those design elements discussed above), are to provide an economical structure that is readily manufactured and transported to site that will also remain *in situ* without impacting the environment under a range of sea conditions. Thus, it is essential that a design will not subside or sink into the substrate (Chuang *et al*., 2008), or be dispersed by storm events like tyre reefs or aircraft reefs (Lukens *et al*., 2004; Ferrer, 2015).

Hydrodynamic features of the site also influence the construction and design, with many reef modules currently in use designed to produce upwelling effects to encourage fish attraction (JF Group, 2008; Kaiyo Doboku, 2010; JAFRA, 2011).

Figure 20 (following page) shows a flow diagram illustrating the factors influencing HES design. A combination of biological and physical characteristics of the site and target species along with engineering and socio-economic concerns will determine the siting, size and type of HES deployed.

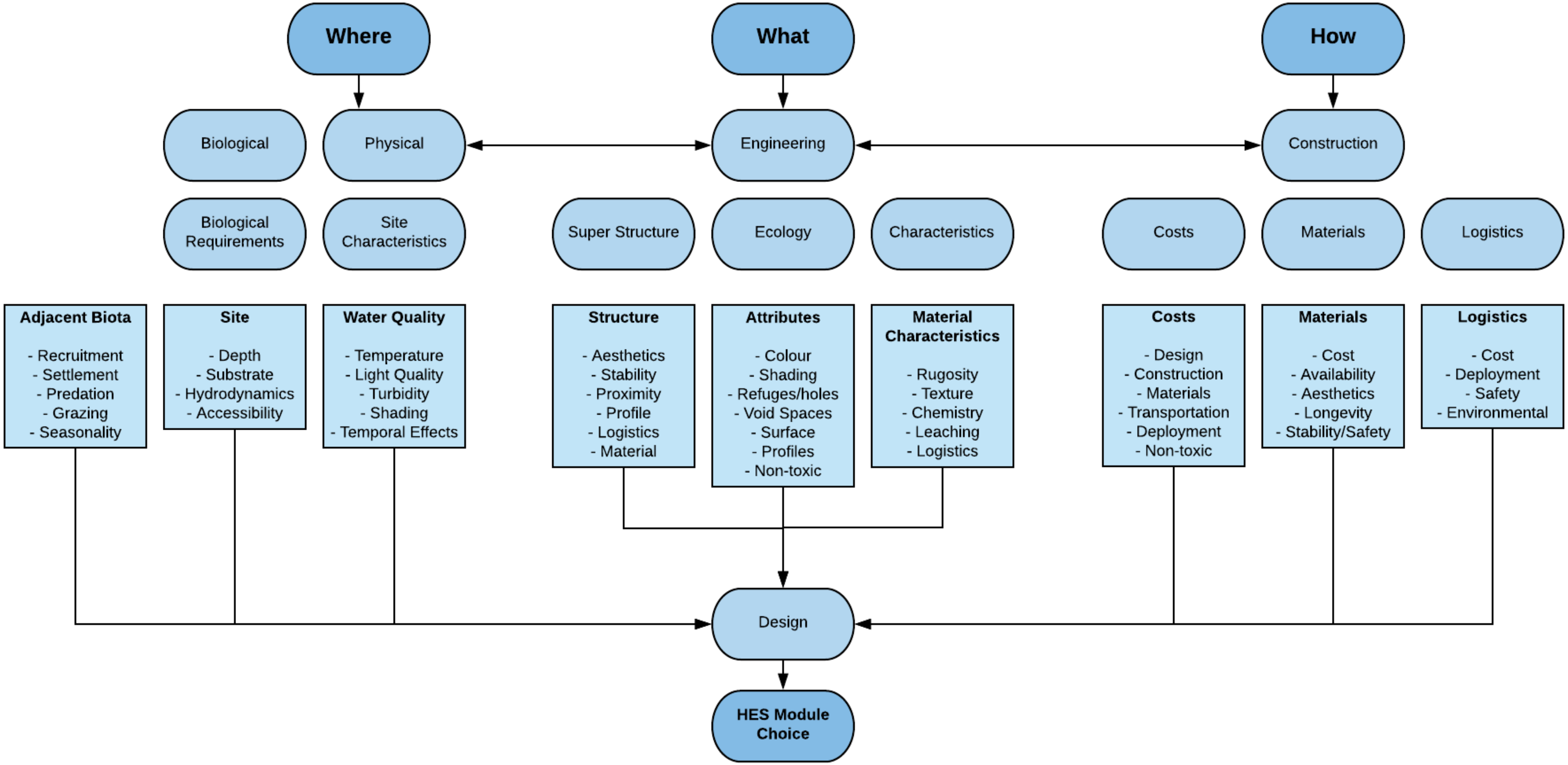

Figure 20: Diagram illustrating the factors influencing HES design. A combination of biological and physical characteristics of the site and target species along with engineering and socio-economic concerns will determine the siting, size and type of HES deployed.

The Design and Management Process

In Baine's (2001) extensive review of 249 reefs, over half failed to adequately meet the objectives originally set out for each HES. Most of the issues encountered revolved around poor planning and management in the early stages (1960-1980's outside of Japan) of the deployment of artificial reefs. Issues arose through;

- Poor site selection
- Size, stability and structure of HES
- Cost of the development
- Poor monitoring
- Illegal fishing/take
- Impacts of local climatic factors

Baine also found that there was no single approach to managing a HES, but that it was dependent upon historical, social, economic and political factors unique to the site and objectives, all of which benefit from extensive planning and stakeholder consultation. Of the most critical factors to be considered during the process of managing HES are socio-economics, economic evaluation, potential assessment of conflict, location of the HES, and design.

Need/Objectives/Goals

Before the development of any HES the need to identify the objectives to be fulfilled by any installation needs to be established (Dyson, 2009). Is the HES necessary and the most appropriate solution for the objectives and goals set?

As discussed above, there are many reasons or demands for HES and/or artificial reefs. The development of HES in the form of artificial reefs in Australia has primary focussed upon the demand created from recreational fishing or diving groups (Kerr, 1992). However, when considering any HES, the managers of such deployments must consider the implications of production or aggregation of various species on existing management policies (Guner *et al*., 2009), as well as a complex array of reef variables in order to produce the most cost-effective outcome for the user group being targeted.

Site Identification

Perhaps the most significant contributor to the failure of HES is poor site selection (Baine, 2001; Lowry *et al*., 2010). Selection of an appropriate site must consider ecological characteristics as well as physical and social-economic factors.

Site selection must consider areas with appropriate sea bed characteristics to deploy a HES (Figure 20) whilst at the same time considering the proximity of suitable sites for end users of the HES. Folpp and Lowry (2013) recommend the development of constraints mapping, where limiting factors such as user conflict, environmental constraints or engineering constraints pose potential limitations on the potential location for any HES. Constraints mapping was used extensively in Bahrain to select suitable sites for artificial reefs (Edwards and Arora, 2013).

Farina-Franco *et al*. (2013) considered the following aspects to increase the success of a new mussel reef;

- Targeted species historically known from the area populations historically existed
- Sea bed characteristics are adequate for the proposed HES
- Natural recruitment is likely to occur
- Hydrodynamics of the site suitable for biological and engineering considerations
- It is protected from human activities

Each of these factors is equally important for any target taxa, although there may be some community resistance to limiting access to potential HES.

Material Selection

The development of modern HES has moved away from the use of materials of opportunity that were often utilised in the past. The increased cost of utilising purpose-built structures is likely to be more cost-effective as designed HES may be:

- Engineered to suit specific objectives such as target specific species, user groups and fishing gear
- Manufactured to suit a chosen location in terms of depth, oceanographic conditions and substratum type
- Designed to maximise the duration, durability and compatibility of the structure to avoid problems associated with material toxicity
- Considered to yield comparatively greater cost-benefits than the use of materials of opportunity
- Improved ability to assess reef performance against set objectives

Reef Design – Layout

The structure and layout or site plan of any HES will determine the effectiveness of the HES to meet its objectives as well as the type and diversity of species utilising the HES (Folpp and Lowry, 2013). The principal factors have been discussed above, but include biological (habitat availability, habitat complexity, refuge availability, texture), physical (reef profile, module layout, size stability and strength) and socio-economic (community use, economic benefits, social benefits to perceived end user groups or stakeholders).

Environmental Impact Assessment

Prior to the deployment of any reef, once a design has been agreed upon through the above processes and community consultation has taken place, an Environmental Impact Assessment (EIA) should be undertaken. An EIA will assess the impacts to the existing environment (*e.g.* scouring around structures from changes to existing habitat and communities), as well as social impacts to the community including existing user groups such as commercial or recreational fishers.

Evaluation of Effectiveness/Monitoring

The success of any HES can only be assessed through a managed monitoring program designed with the original objectives in mind. This is covered more broadly in Chapter Three.

Examples of Habitat Enhancement Structures

Concrete

The most practicable artificial reef material is high strength marine-grade concrete. Concrete reefs are advantageous as purpose-built reefs because concrete moulds can be altered to create a huge range of different sized reef modules with different shapes, voids and structures. They are also pH balanced, non-toxic, built with universal material that is easily applied by a range of different groups from Industry to community and can provide more suitable surface textures to promote benthic settlement (Baine, 2001; Lukens *et al.,* 2004; Perkolfinkel and Sella, 2014).

There are many different concrete module designs that are used all over the globe. Designs vary for different environments, depths and for different species and are always changing in shape, size, and weight as well as internal and external surface sizes. In Japan and Korea, commercial fishers and aquaculturists harvest artificial reefs that are specifically used for sea cucumbers, abalone, shellfish, squid, octopus, lobsters and finfish. Although most concrete artificial reefs in Australia are utilised by the recreational sector to enhance finfish fisheries, reefs are used in the South West of WA to sea ranch abalone and there are trials in TAS for lobster reefs.

Although used for a suite of different marine organisms, most concrete artificial reefs worldwide and in Australia are deployed to enhance finfish fisheries. Variation in module design allows reefs to mimic different natural reef profiles and varying habitat complexity. Knowing the target species desired for the reef will greatly aid in design choice with respect to environmental conditions. Larger modules with larger openings and high vertical profile would better suit large cods and groupers as well as pelagic species as they can swim through the modules, while smaller modules with lots of habitat complexity may favour cryptic species and concentrate higher numbers of smaller fish. Many reefs mix differently shaped and sized modules to have a larger species abundance and diversity and to resemble natural substrate.

The different concrete artificial reef modules already deployed in WA have been a huge success with fish and human communities alike. These reefs are also utilised by large amounts of anglers, particularly in holiday periods catching big numbers of Samson Fish, Pink Snapper and Flathead. The Mandurah Artificial Reef recorded 21 different species in only five months since deployment and fishers have been catching Pink Snapper, School Sharks, Flathead and Flounder on these reefs.

Artificial reefs consisting of concrete modules have not just been successful for the enhancement of recreational fisheries in WA, but have also been great innovations in other sectors. The Jurien Bay Artificial Reef snorkelling and dive trail has been a massive draw card with tourists and residents' alike visiting the trail and contributing to the local economy and has had 51 species identified on the reef. The Coogee Maritime Trail will also be a drawcard for tourists and residents being consisted of 33 concrete modules as well as two art sculptures and the Omeo shipwreck which dates back to 1905. Modules have also been used in abalone farming in WA.

Metal/Steel

Metal materials play a large role in artificial reef components around the world. Many MOP such as military vehicles, cars, carriages, white goods and sunken vessels are all constructed of various metals. Inshore and offshore infrastructure such as oil rigs, ports, beacons, windfarms, jetties and wharfs also have subsurface metal components that support an array of colonising organisms and ecological communities that utilise the structures. Metal is also used with other materials in the various constructed components in artificial reefs. For example, many concrete artificial reefs are ferroconcrete structures meaning they are built with concrete internally reinforced with steel, usually rebar (also known as reinforcing bar or reinforcement steel).

Steel components are also sometimes built into concrete modules to create baitfish aggregation areas or as reinforcement bars to act as an anti-fishing reefs to stop trawling in some countries. Metal slag is also used in the construction of some artificial reefs. Slag is produced once a desired metal has been smelted or separated from its ore and is a glass like by-product. The slag is a waste product; however, it can be used to produce concrete for artificial reefs, particularly steel and blast furnace slag (Huang *et al.*, 2016). Biorock® reefs and similar electrodeposition reefs also use welded conductive metal frames constructed of rebar or steel mesh as artificial reefs (Biorock.org). Additionally, metal is also used in many rock and shell reefs as gabions or cages. This allows more efficient transport and installation of these reefs and stops contents such as limestone rock or oyster shells dispersing, forming mounds or being washed away from water movement such as tides, storm surges, wave energy and strong currents. In some cases, steel gabions are purposely designed to corrode with time giving the reef enough time to establish.

While metal is an important component in many different types of artificial reefs, this section will focus on large purpose-built metal artificial reefs that are mainly composed of steel and/or cast iron. Along with concrete, welded steel is the preferred material for artificial reef construction (Diplock, 2011).

These reefs are generally larger than concrete modules and are deployed in smaller numbers. The structures have a large amount of surface area and vertical profile with structures as tall as 35m deployed in Japan. The large vertical profile allows substantial amounts of habitat in different areas of the water column benefitting benthic or bottom dwelling species, epi-benthic species and free ranging pelagic species. Many of these reefs are specifically designed to congregate smaller baitfish. This is done by providing a large surface area in which colonising organisms such as macro algae are a source of food for smaller invertebrates which are then a food source for baitfish.

Metal panels protruding from the structures create upwelling, again providing food sources and the steel lattice like structure also provides shelter and safe areas for the baitfish to congregate. A recent study on the Sydney Offshore Artificial Reef found that the reef provided enough habitat and refuge to support around 130kg of Mado on the reef that fuels fish production by feeding on zooplankton supply (Champion *et al.*, 2015).

Steel also has a differing colonising community than concrete, with some species such as marine borers showing preference for concrete over steel until the steel has corroded. However, other species such as corals can prefer metal, with a study in Hawaii reporting the highest coral recruitment to be on metal over concrete (Fitzhardinge, 1989). Large-scale metal artificial reefs are generally used for commercial fish production units in Japan and Korea, though are used for recreational fisheries enhancement elsewhere.

Concrete versus Metal/Steel

Table 6: The advantages and disadvantages of the two most recommended and common HES materials (adapted from: London Convention and Protocol/UNEP, 2009; FRA-SEAFDEC, 2010; FAO, 2015).

Material	Advantages	Disadvantages
Concrete	• Compatible with the marine environment. • Durable, stable and readily available. • Readily formed into any shape for the deployment of prefabricated units. • Provides adequate surfaces and habitats for the settlement and growth of organisms, which in turn provide a substrate, food and places of refuge for other invertebrates and fish. • Universal and easily applied by community groups.	• Concrete's weight, which necessitates the use of heavy equipment to manipulate it. This increases the land and marine transport costs. • The deployment of large concrete blocks or prefabricated units requires the use of heavy sea equipment, which is not only costly but also dangerous. • The weight on concrete increases the possibility of it sinking into the marine sediments.
Metal/Steel	• Steel is easy to work, can be made in accordance to specific environments and species. • Steel is high strength, has a stable quality and is durable. • Possibility of developing large prefabricated units of very high relief and unmatched complexity. • Steel is free from harmful material and quickly colonised by organism and thus produces effects fast.	• Reduced design life in shallow or highly oxygenated water bodies (*i.e.* rough exposed coastlines). • High relief of large singular modules may cause stability issues requiring increased anchoring considerations of units resulting in increased reef costs. • Unit size may need specialised or large-scale deployment equipment which will increase project costs.

Fish Aggregation Devices

The purpose of a Fish Aggregation Device (FADs) is to enhance fisheries. For recreational fishing, this can be achieved by creating new fishing opportunities, boosting fishing experience and diversifying types of fishing and methods. Fishing FADs may also decrease pressure on other surrounding fishing areas. For commercial fisheries, FADs enhance catch and Catch Per Unit Effort (CPUE) through concentrating schooling pelagic species as well as individual predators and bycatch for harvest. For aquaculture, FADs may be used to collect broodstock such as Yellowtail Kingfish, or collecting juvenile fish such as Southern Bluefin Tuna for sea ranching.

FADs are broadly categorised into three main groups: surface, subsurface or mid-water and drifting and can consist of many different materials. Drifting FADs consist of any drifting material not attached to substrate. There can be natural drifting FADs such as macro-algal clumps, palm fronds or logs, accidental man-made drifting FADs such as lost equipment or material from shipping or purpose-built man-made drifting FADs. Purpose-built drifting FADs are primarily used by commercial fisheries and feature GPS locators and sonar allowing them to be tracked and allowing fishers to detect fish numbers congregating around the FAD (Castro *et al.*, 2002; Bateman, 2015). FADs aggregate fish by providing baitfish with protection from predators, which increases the amount of target species such as tuna aiming to prey on the sheltering baitfish. FADs are also thought to aggregate fish by creating a source of food (colonising surface), by increasing the survivability of eggs and juvenile species and by fish schooling behaviour.

Due to the environmental consequences of drifting FADs and Commonwealth restrictions on FAD use for purse seine fisheries, drifting FADs will not be considered further in this document. Both sub-surface and surface FADs remain in the same location as they are moored to an anchoring mechanism on the sea floor. Both these FADs can be made in a variety of different materials depending on costs, availability and environmental regulations in different areas. Designs can vary from a simple spherical buoy to a solid fibre reinforced plastic complex shaped float. Floats are attached to chain and/or rope joined to an anchor mechanism and can feature additional mesh and flashers on the rope to aggregate larger numbers of fish species. Anchoring mechanisms can vary from materials of opportunity to custom cast concrete blocks or purposely fabricated anchor systems, depending on logistical and regulatory restrictions. The anchor and attachment mechanisms must be able to keep the float attached throughout all weather events for the given life of the FAD.

The biggest loss of FADs in WA is due to ship collisions and extreme weather events. The subsurface FAD therefore provides a further benefit in being suspended much deeper below the water surface. Current Recfishwest Subsurface FADs are 20m below the sea surface. Depending on the skill level of fishers, subsurface FADs may be harder to locate without an indicator on the surface.

Subsurface and surface FADs are currently only deployed in the Perth metropolitan area, although there have been recreational trials in Kalbarri, Cervantes and Jurien Bay, while commercial FADs have been historically used around the state. There is currently plans for a state-wide FAD project in WA (similar to those in the eastern states), funded through the Recreational Fishing Initiatives Fund which will see a large number of FADs deployed in regional areas in the near future.

Ceramic-based Reef Modules

Several relatively small sized, low-profile reef modules have been produced in using a ceramic-based material. EcoReef (Ecoreef, 2015) and Alex Goad's Modular Artificial Reef Structure (MARS – Goad, 2015) use novel, small-scale interlocking ceramic modules to create HES (Figure 21). The benefit of both the MARS and EcoReefs are that the modules are made from ceramic, an ideal material because it is pH neutral, non-toxic and chemically inert in seawater. The modules function to create suitable settlement or transplanting options for coral reefs and other epibenthos, as well as creating matrices of interlocking interstitial spaces suitable to a range of marine fauna. Ecoreefs have been utilised to rehabilitate reef areas damaged by dynamite fishing in the Caribbean (Pappagallo, 2012). Cost-benefits of Ecoreef is that it is estimated that the cost per organism settled was estimated at $2 compared with tyre reefs at $32.

Figure 21: MARS (left) and Ecoreef ceramic modules (right).

Geotextile

Geotextiles are often constructed as large sausages or bags that may be deployed and filled *in situ* with local materials such as sand. Large geotextile reefs are beneficial as they are relatively easy to deploy, utilise local sand as fill, and if used as recreational reefs, provide a soft substrate to reduce potential injury from users.

Several multi-purpose reefs have been established using geotextiles. Two, one at Narrowneck Reef QLD, and another in India were both designed to act as coastal protection reefs to reduce erosion of the shoreline, but also as recreational surfing reefs. In both cases, the deployment has proven very successful in terms of coastal erosion prevention, and somewhat successful at providing regular surf breaks (Jackson *et al*., 2007; Tomlinson *et al*., 2007). The Narrowneck (QLD), Boscombe (UK), Kovalam (India) and Mount (NZ) reefs have all experienced extensive colonisation by epifauna. In the case of the Narrowneck Reef, its role as a multi-function reef includes dive trails and as a popular fishing spot. Both the fishing and diving activities do not conflict with the reefs surfing role as a large swell precludes the former activities (Kurian, 1995; Edwards and Smith, 2005).

There have been few reefs developed principally for surfing, however nearly all suffer from cost blowouts. The Boscombe Artificial Reef in Bournemouth, UK cost nearly £3 million and currently does not produce any surf, due to poor planning and knowledge gaps (Bloxham, 2010). A surfing reef installed in California as compensation for the loss of surfing amenity through the construction of a nearby rock groyne by Chevron, resulted in poor surf conditions largely due to poor planning and the size of geotextile bags deployed. The bags were removed in 2008 after 24 years (Fontaine, 2008). A successful surfing reef, designed by ASR Limited at Mount Maunganui in New Zealand, utilised long geotextile bags in an A frame shape. The project has been successful in meeting its prime objective as a surfing reef (http://www.asrltd.com/media/project- pdf/mount-maunganui.pdf). Similarly, at Kovalam, India, a multi-purpose reef was designed to direct the region's powerful waves to break offshore, thereby minimizing the erosive effects of those waves on the beach. The outcomes included rapid restoration of the beach width as well as a consistent surfing reef, again constructed of geotextile sand-filled bags.

Rigs-to-Reefs (Decommissioned Oil and Gas Infrastructure)

Decommissioned offshore oil and gas production platforms (rigs) are known to attract large and diverse fish communities (Seaman *et al*., 1989; Love *et al*., 1994; Rooker *et al*., 1997). Rigs-to-Reefs (RTR) are the practice of converting decommissioned offshore rigs platforms so that it can continue to support marine life as an artificial reef. Through this decommissioning process, the oil well is capped and the upper 25m of the platform is towed, toppled in place, or removed. The platform structure is removed at the expense of the oil company, leaving the remaining structure in place so that is can continue to support marine life. The oil company then donates the underwater platform to the state to manage as an artificial reef. (Twomey 2010; Rig2Reef 2015). Ajemian *et al*. (2015) surveyed 15 artificial reefs in the Gulf of Mexico ranging from vessels to cut-off oil rigs. Their findings were that ambient water depth influenced fish assemblages, and that vertical structures situated in 50m of water were best suited for both fisheries enhancement and recreational diving opportunities. They also observed that a reefed platform deck provided more productive material for fish communities, although environmental considerations could preclude leaving rig decks in place due to the risk of hydrocarbons.

Shell/Shell Bags

Several artificial reefs utilise waste bivalve shells as either a part of a composite reef unit (see ShellNurse) or as stand-alone material for a low-profile reef. Bivalve shells incorporated into concrete or steel structures assist in the settlement of algae and other epibenthos (Nestlerode *et al*., 2007; JF Group, 2008; Fariñas-Franco *et al*., 2013). In Ireland, several experimental artificial reefs constructed of 16 tonnes of bagged scallops were very successful at re-establishing the existing benthic community (Fariñas-Franco *et al*., 2013).

Rock and Rubble

Natural quarried rocks or rubble from construction have been widely used to create HES. Aggregations of rocks were used in the 17th century in Japan to encourage kelp growth (Nakame, 1991), and ballast rocks from tuna nets were known to be functional fish attracting reefs in the Mediterranean (Riggio *et al.*, 2000). Large rock seawalls, revetments and breakwaters are regularly used as coastal defensive structures and are also known to provide large surface areas and refuge spaces between rocks that encourage fish settlement (Bohnsack and Sutherland, 1985; Lukens *et al*., 2004; Bulleri and Chapman, 2010). Pastor *et al*. (2013) reported that one coastal defence structure in the south of France had juvenile fish densities 30-109 times greater than adjacent natural habitats. A Californian study comparing reef substrates found that whilst prefabricated concrete shelters were more successful in attracting fish, quarried rocks were the material of choice due the availability, cost and ease of handling and deployment when compared to other materials (Turner *et al*., 1969). However, the use of quarried rock and associated transport and deployment costs must be shown to be significantly more cost-effective than purpose-built designed concrete structures.

Recently, Mikkelsen *et al*. (2013) reported on a project where 100,000 tonnes of boulders quarried from a harbour area were redeployed to create a stable reef system to prevent further erosion, create cavernous rock areas and restore the original vertical profile of the reef. The key target was to re-establish habitat for commercially important species such as Atlantic cod (*Gadus morhua*) and Atlantic lobster (*Homarus gammarus*) and increase the use of the area by porpoises. The project was successful, increasing the frequency of porpoises feeding in the area over time.

Electrodeposition

Electrodeposition uses a low-voltage current to encourage the deposition of calcium carbonate (aragonite) on the cathode to produce a biorock very similar in composition to natural coral skeletal material (Hilbertz, 1977; Goreau, 2012). The use of creating coral reefs utilising electrolysis has proven to be successful in providing a stable substrate for transplanting coral nubbins and encouraging epibenthos growth (van Treek and Schumacher, 1998). In experiments conducted in Corsica, within 2 months of deployment approximately 5-10mm of aragonite was deposited upon the experimental mesh. Elsewhere it was found that corals and other benthic organisms spontaneously settle upon the produced substrate (Schumacher and Schillak, 1994). The advantages to the system were found to be:

- Little alien material is required
- Not necessary to transport large amounts of material
- Can create any shape of foundation by bending cathode
- Substrate produced is like natural coral rock
- Materials can be recycled

Many projects are currently using the process in Indonesia (Goreau, 2014), where power supplies are fed directly to developing reef areas close to shore. While the process is limited due to the nature of the power supply, the survival of transplanted coral and the speed of growth onto the substrate are far greater than on conventional substrates.

Artificial Seagrass

Artificial seagrass has been used extensively in seagrass community research, as the artificial beds can be placed next to natural meadows and easily sampled without damaging the natural seagrass (Virnstein and Curran, 1986; Bartholomew, 2002). Artificial seagrass has also been widely used as a soft engineering method to protect shorelines from erosion and as an alternative habitat for various marine organisms (Shahbudin *et al*,. 2011). Artificial seagrass beds can be made from a range of materials and customized to mimic the target seagrass species.

Studies by Virnstein and Curran (1986) on artificial seagrass made from green polypropylene ribbons designed to mimic *Thalassia testudinum* (Turtle Grass) showed extremely rapid colonisation by seagrass-associated epifauna. The colonisation of artificial seagrass by epifauna was remarkably quick, with experiments showing peaks in abundance and species diversity after just 4-8 days. The growth of bacterial or diatom film on the seagrass blades was very rapid with evidence of colonisation within hours of deployment (Virnstein and Curran, 1986). In another experiment, Shahbudin *et al*. (2011) constructed seagrass beds of $3m^2$ with seagrass manufactured from rubber. They recorded over 490 fishes around the installed modules, illustrating the effectiveness of artificial seagrasses as a habitat and refuge.

Most artificial seagrass beds are small, and thus susceptible to being displaced by storm events. However, the inclusion of seagrass habitat adjacent to larger HES perhaps as part of a multi-functional HES habitat could significantly increase the diversity of fauna.

Assessment of Existing Habitat Enhancement Structures

Scales for each category assessed with enough data are cumulative, that is the higher the score the less effective or attractive the HES is perceived to be based on the materials used, deployment techniques, outcomes achieved and impacts to the environment. Every care has been made when compiling this data, however it must be understood that there are overlaps between categories. Three categories were able to be scored:

• Cost
• Success
• Materials used

Cost

An arbitrary cost scale was assigned to standardise information from numerous sources where often no cost is documented. Costs include the acquisition of materials (MOP, purpose-built, community manufactured), transport (terrestrial and marine), deployment platform (small vessel, large barge, large barge with crane) and labour source (volunteer groups, government agencies, private contractors). After considering the range of published costs for particular projects (see Appendix 1), a scale was developed where 1 = cheapest known method of installing reef, and 10 = most expensive documented reef (approx. seven million Euros).

Table 7: Cost scales assigned to each HES reviewed.

	Scale	Description
Inexpensive	1	Very inexpensive, use of recycled or natural materials of opportunity, volunteer groups, simple deployment.
	2	Medium sized volunteer-driven reefs using MOP, very small research reefs.
	3	Large volunteer driven MOP reefs, small-scale HES modules (*i.e.* FishHab modules) under jetties, or Reef Ball type projects in developing countries.
Moderately Expensive	4	Small-scale designed HES or larger-scale Reef Ball type project in developing countries.
	5	Small –medium scale designed HES (*i.e.* Reef Balls^{TM}), commercial construction, government funded or small vessels.
	6	Medium scale designed HES (composite reefs) funded by government.
Expensive	7	Designed HES or MOP (*i.e.* tanks, trams, aircraft or oil rigs) cleaned and modified for deployment, deployed via barge with crane.
	8	Sophisticate designed or quarried rock on a medium to large-scale government run with barge and crane.
	9	Sophisticated design, med-large scale HES or large ex-military vessels, cleaned & deployed with contract labour and barges with cranes.
	10	Sophisticated design, large-scale HES deployed with contract labour and large barges and cranes.

Success

The success of any HES is whether it meets the original objectives set for the HES. In many early cases of artificial reefs using materials of opportunity there is little evidence of whether a reef was successful or not. In these cases, a neutral value is assigned. Success scores are based on a scale outlined in Chuang *et al*. (2008).

Table 8: Matrix used to evaluate reef performance of case studies.

	Scale	Reef Performance
Successful	1	The reef has successfully met all of its objectives. There are no social or ecological concerns; research is acceptable and conclusive; the management is considered very well so it does not require any change.
	2	The reef has succeeded in meeting its objectives. It also shows positive effects over the local environment or sea users. Research is fair enough and conclusive and has good management but still needs improvement.
	3	The reef has only succeeded in meeting its objectives with limited success. Beneficial effects are recognizable. Research is fair enough to determine their performance; management has been good but needed to be improved.
Neutral	4	The reef has had an inappropriate location, but it exhibits some achievement of objectives and also other beneficial effects in terms of the local environment or sea users. Some research has been done but is poor and not conclusive.
Unsuccessful	5	The reef's performance in terms of its objectives is inconclusive. Some positive aspects are identifiable but the overall success of the reef is indeterminable. The reef has had poor management.
	6	The reef has had an inappropriate location; It does not exhibit any achievement of objectives nor any effect in terms of the local environment or sea users; poor or none research has been done.
	7	The reef has failed in its objectives and has negatively impacted the local environment or sea users.

Materials

A scale based upon the material used has been assigned to each reef based upon aesthetics and environmental attributes for each material. Therefore, purpose-built designs score better (lower score) than materials of opportunity. Some MOP score better than others (*e.g.* waste quarry stones score better than used tyres).

Table 9: Scale of HES materials based upon aesthetics and environmental attributes.

Scale	Material
1	Purpose-built – Ceramic modules
2	Purpose-built – Plastic/rubber seagrass modules or waste shell reefs
3	Purpose-built – Pre-fabricated concrete modules
4	Purpose-built – Steel frames, geotextile bags, composite reefs
5	Materials of Opportunity – Waste quarry rock
6	Materials of Opportunity – Building rubble, concrete rubble
7	Materials of Opportunity – Ships (stripped and cleaned)
8	Materials of Opportunity – Dismantled oil platforms
9	Materials of Opportunity – Car bodies, white goods
10	Materials of Opportunity - Tyres

Table 10: Average rankings of the main materials utilised in HES as summarised.

HES Types	Type	N	Material	Cost	Success	Total
Purpose-built - Bagged Shell	B	1	2.0	4.0	2.0	8.0
Purpose-built - Concrete	C	48	3.2	5.0	3.3	11.4
Purpose-built - Geotextile	G	5	4.0	7.6	4.4	16.0
Purpose-built - Mixed	MPB	22	3.8	6.1	2.9	12.8
Purpose-built - Steel	I	1	4.0	9.0	4.0	17.0
Purpose-built - Rocks	R	8	5.5	6.0	3.4	14.9
Purpose-built - Seagrass	SG	2	2.0	1.0	2.0	5.0
Purpose-built - Natural	N	1	1	1	2	4
Total		**88**	**3.5**	**5.4**	**3.2**	**12.1**
Material of Opportunity - Mixed	MW	23	8.8	3.4	3.5	15.7
Material of Opportunity - Oil Rigs	O	13	8.0	7.0	3.0	18.0
Material of Opportunity - Vessels	S	51	6.1	4.6	3.1	13.8
Material of Opportunity - Tyres	T	35	10.0	2.8	3.6	16.4
Material of Opportunity - Vehicles	V	14	8.1	5.5	4.1	17.6
Total		**136**	**7.9**	**4.2**	**3.4**	**15.6**
		224				

The results of assessing 224 HES from around the world are presented in Table 10 above. In general, purpose-built HES performed better than those using materials of opportunity in all categories except cost. MOP were on average ranked as 4.2 for costs (this would be lower if we excluded disused oil rigs, the preparation of oil rigs is considerably more expensive than the acquiring of waste materials) compared with 5.4 for purpose-built HES. However, purpose-built HES outperformed MOP HES in both material ranks and success. Material utilised in the construction of purpose-built HES are invariably higher quality, designed for purpose and constructed of non-toxic materials. MOP generally still have some risk of being toxic, or polluting the environment through degradation. Whilst there is little difference in the rank success of both HES types, this is largely due to the paucity of data assessing the ability of HES to meet their original objectives in full or in part. Appendix 1 has an extensive assessment of the 224 reefs, but of these 94 (41.9%) do not include any qualitative or quantitative assessment of the success of the deployment.

Also missing from the assessment of HES, are results of the deployment on HES in Japan. Whilst there are numerous brochures and some references to Japanese development of artificial reefs and HES, none contained detailed descriptions of deployed reefs. A heat-map (Table 11) is presented showing a colour-coded scaling of the various characteristics of each type of HES reviewed. Codes were assigned based upon scores as outlined in the above tables, where the more desirable HES for a particular factor will be bright green, a mid-range HES will be pale blue and a highly undesirable HES will be bright red.

Table 11: Heat-map highlighting the various characteristics of HES, their effectiveness and applicability.

	Site			Fishing			Tourism			Environmental			Cost			Legislative		
HES	Estuarine	Nearshore	Offshore	Commercial	Recreational	Aquaculture	Surfing	Diving	Ecotourism	Pollution	Sediment	Anti-trawl	Design	Materials	Deployment	Maintainance	Materials	Permits
Materials of Opportunity																		
Tyres	Unsuitable	Very Unsuitable	Very Unsuitable	Unsuitable	Unsuitable	Very Unsuitable	Very Unsuitable	Very Unsuitable	Very Unsuitable	Very Unsuitable	Very Unsuitable	Very Unsuitable	Very Suitable	Very Suitable	Suitable	Very Unsuitable	Very Unsuitable	Very Unsuitable
Vessels	Unsuitable	Suitable	Very Suitable	Neutral	Suitable	Neutral	Very Unsuitable	Very Suitable	Suitable	Neutral	Neutral	Very Suitable	Suitable	Neutral	Very Unsuitable	Neutral	Unsuitable	Unsuitable
Oil and Gas Rigs	Very Unsuitable	Very Unsuitable	Suitable	Suitable	Very Suitable	Unsuitable	Very Unsuitable	Very Suitable	Suitable	Very Unsuitable	Very Unsuitable	Very Suitable	Neutral	Very Unsuitable	Very Unsuitable	Suitable	Very Unsuitable	Unsuitable
Vehicles	Very Unsuitable	Unsuitable	Suitable	Neutral	Suitable	Neutral	Very Unsuitable	Suitable	Unsuitable	Neutral	Neutral	Very Suitable	Very Suitable	Unsuitable	Unsuitable	Unsuitable	Very Unsuitable	Very Unsuitable
Building Rubble	Neutral	Neutral	Neutral	Suitable	Suitable	Neutral	Unsuitable	Neutral	Unsuitable	Neutral	Suitable	Very Suitable	Very Suitable	Suitable	Unsuitable	Very Suitable	Unsuitable	Very Unsuitable
Quarried Rock	Very Suitable	Very Suitable	Very Suitable	Suitable	Suitable	Suitable	Suitable	Neutral	Unsuitable	Suitable	Suitable	Very Suitable	Suitable	Suitable	Unsuitable	Very Suitable	Neutral	Suitable
Purpose-built Structures																		
Ceramic Modules	Suitable	Very Suitable	Neutral	Neutral	Suitable	Suitable	Very Unsuitable	Very Suitable	Very Suitable	Suitable	Neutral	Unsuitable	Very Unsuitable	Unsuitable	Very Suitable	Very Suitable	Very Suitable	Suitable
Recycled Plastic Modules	Suitable	Suitable	Neutral	Suitable	Very Suitable	Suitable	Very Unsuitable	Neutral	Neutral	Suitable	Neutral	Unsuitable	Unsuitable	Neutral	Very Suitable	Suitable	Very Suitable	Suitable
Low Profile Concrete Modules	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Unsuitable	Suitable	Suitable	Very Suitable	Very Suitable	Suitable	Unsuitable	Neutral	Unsuitable	Suitable	Very Suitable	Neutral
High Profile Concrete Modules	Unsuitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Unsuitable	Very Suitable	Suitable	Very Suitable	Suitable	Very Suitable	Very Unsuitable	Unsuitable	Unsuitable	Suitable	Suitable	Neutral
Steel/Concrete Modules	Unsuitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Suitable	Very Unsuitable	Suitable	Suitable	Very Suitable	Suitable	Very Suitable	Very Unsuitable	Very Unsuitable	Very Unsuitable	Neutral	Suitable	Neutral
High Profile Steel Structures	Very Unsuitable	Suitable	Very Suitable	Very Suitable	Very Suitable	Suitable	Very Unsuitable	Very Suitable	Very Suitable	Very Suitable	Neutral	Very Suitable	Very Unsuitable	Very Unsuitable	Very Unsuitable	Neutral	Suitable	Unsuitable
Multi-purpose multi module	Unsuitable	Suitable	Very Suitable	Very Suitable	Very Suitable	Suitable	Very Unsuitable	Suitable	Suitable	Very Suitable	Very Suitable	Very Suitable	Very Unsuitable	Unsuitable	Very Unsuitable	Neutral	Suitable	Neutral
Geotextiles	Suitable	Very Suitable	Suitable	Unsuitable	Suitable	Unsuitable	Very Suitable	Neutral	Neutral	Very Suitable	Very Suitable	Very Unsuitable	Unsuitable	Unsuitable	Very Unsuitable	Unsuitable	Suitable	Neutral
FAD	Unsuitable	Suitable	Very Suitable	Very Suitable	Very Suitable	Unsuitable	Very Unsuitable	Very Suitable	Neutral	Neutral	Unsuitable	Very Unsuitable	Neutral	Suitable	Very Suitable	Suitable	Suitable	Suitable
Electrodeposition	Very Suitable	Very Suitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Very Unsuitable	Neutral	Neutral	Neutral	Neutral	Very Unsuitable	Unsuitable	Suitable	Suitable	Unsuitable	Neutral	Neutral
Artificial Seagrass	Very Suitable	Very Suitable	Very Unsuitable	Unsuitable	Neutral	Neutral	Very Unsuitable	Neutral	Neutral	Neutral	Very Suitable	Very Unsuitable	Unsuitable	Suitable	Very Suitable	Suitable	Suitable	Suitable

Key: The likelihood that HES will be suitable for a particular suite of situations.

Very Suitable	Suitable	Neutral	Unsuitable	Very Unsuitable

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Please note: Due to the size (126 pages), the references for the bibliographic study are not included. If you would like a copy of these references, please contact james@recfishwest.org.au.

Chapter Two: Habitat Enhancement Structure Application in the Western Australian Seafood Sector

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Figure 22: Harvesting Greenlip Abalone (*Haliotis laevigata*) from concrete artificial reef modules at the abalone ranch in Augusta, Western Australia (Sourced from Ocean Grown Abalone).

Foreword

To identify how various Habitat Enhancement Structure(s) (HES) designs may provide benefit to the WA seafood sector and community, consultation was undertaken with a range of different organisations and stakeholders. Consultation with most sectors was successful and findings contributed to the other chapters in this report. However, consultation with the WA seafood sector indicated that HES are a somewhat low priority or have low direct commercial relevance to industry outside a very few operators, particularly abalone ranching. As such, this chapter briefly examines the existing and historic uses of HES in the commercial sector in WA as well as potential uses in developed fisheries (if the returns justified the investment). With relatively low interest within the commercial sector, and lack of historical and current use in WA, this chapter has been minimised with the project instead emphasising on the other objectives.

Habitat Enhancement Structure Benefits for the WA Seafood Sector

Consultation with the WA seafood sector and community began in 2015 with various organisations (see below list). The purpose of the consultation was to identify potential direct and indirect benefits HES may provide in the future. This included constraints mapping and investigating other competing needs of the general marine environment, as well as the possible localised benefits of HES. This activity assisted in determining applications and potential locations where HES would provide the best social benefits, cost-effectively. Investigations into potential benefits of HES focussed on purpose, design type, previous successes and future opportunities.

Consulted groups:

- Environmental sector
- Artificial reef designers and manufacturers
- Marina developers
- Government agencies
- Tourism operators
- Local community groups
- Conservation groups
- Fishing clubs
- University researchers
- Peak bodies
- Reference groups
- Ecological consultancies
- Abalone ranchers
- Tackle stores
- Hatcheries

Consultation with most sectors and organisations was successfully undertaken, and learnings were applied in the construction of the HES Guide (Chapter 4). Consultation protocols were developed for HES developments throughout WA during the reporting period, to ensure HES benefits were optimised in relation to deployment purposes to ensure the best value for investment. These consultation protocols were also incorporated into community and regulator consultation, constraints mapping, site selection, design and the approvals process.

Consultation with the WA seafood sector demonstrated that members had little understanding or appreciation for the ecological benefits and a direct commercial relevance to the industry. It was noted that, specifically in the early stages of the project, very little was known about the science and successes of HES - particularly around design, productivity and function other than what was reported in mainstream media. To date, HES uptake by the WA seafood industry has been minimal with the exception of abalone ranching operations using purpose designed concrete modules on the south coast of WA. Discussions with these organisations failed to identify HES opportunities and direct applicability to the seafood industry in WA. This consultation occurred in the first phase of this project (2014/15). Thus, it’s a recommendation of this project that the WA seafood sector is re-engaged in HES discussions as the science, design and a better understanding of possible applications for the use of HES in commercial fisheries has increased and developed during the timeframe in WA, Australia and globally.

Existing Application in WA Commercial Fisheries

The first trial of HES for commercial fisheries in WA took place in 1971-1972. Concrete modules were deployed and seeded with tagged Western Rock Lobster (*Panulirus Cygnus*) by the CSIRO Division of Fisheries, offshore of Cliff Head, however when resurveyed there were no lobster present (Chittleborough, 1973; Pollard, 1989). The previous example was the only found HES trial on this species of lobster and it was unsuccessful. However, this could be due to location, design, predation, fishing pressure and seasonality. Other lobster species of the same family (Palinuridae) have been successfully harvested from specially designed artificial reefs to great effect, particularly in Mexico, Cuba and Japan (Spanier *et al*, 2011). Concrete modules designed for lobsters may be placed in areas with sparse natural habitat to create new lobster fishing areas, even if low relief. Habitat Enhancement Structures will need to have niches, crevices and complexity to reduce natural mortality of rock lobster during the day, to increase overall abundance.

The first known use of Fish Aggregation Devices (FADs) for commercial fisheries in WA occurred between Esperance and Hopetoun in 1980-1981 with three FADs being deployed between 120-200m deep (Pollard, 1989). Southern Bluefin, Bigeye and Skipjack tunas, as well as sharks were caught using the poling method on the FADs, with these structures contributing to at least 34% of the total tuna catch in the area (Starling, 1983; Pollard, 1989). Further FADs were then trialled in the same area and also in Albany, Cape Naturaliste, Cape Leeuwin and Exmouth Gulf with varying levels of success.

The most successful commercial use of HES to date has been on abalone. Abalone is a prized seafood delicacy and is farmed and harvested in the wild around the world. The aquaculture of abalone has increased since farms first began in the 1950s and 1960s in Japan and China with 5,357 tonne harvested in legal wild capture fisheries and 160,080 tonne farmed around the world in 2017/18 (compared to 19,720 tonne and 50 tonne respectively in 1970) (Cook, 2016; 2018). There have been many studies into the potential use of HES for abalone in Australia and around the world (Hirose *et al*, 2002; James *et al*, 2007; Tang *et al*, 2015). Some of this research was also funded through the FRDC (Adams, 2013) resulting in the first successful harvested use of HES (ranching) for abalone in Australia.

Ranching involves stocking juvenile abalone on an artificial substrate. Interestingly, abalone ranching in Japan has actually used as a tool to recover stocks, with abalone being stocked on natural and artificial reefs, with fishers only being able to harvest those specimens that were found on artificial reefs (Tanaka, 1988). Abalone ranching in the South West of WA has proven that HES are extremely beneficial in abalone fisheries and aquaculture. HES enhance abalone fisheries by providing crevices and complex habitat to reduce mortality through predation, trap drift algae, and increase food sources through the growth of algae on the structure and to create a colonising surface for the recruitment of future stocks. Reefs can be used for ranching seeded abalone species as well as wild harvest any abalone naturally recruited to reefs.

Reef modules in Augusta were first trialled in 2011 with the original modules still *in situ*. There are now 10,000 modules deployed in Augusta, with 400 deployed in Esperance and pending results of these trial another 5,000 to be deployed in Esperance. Each module will be able to yield an average of 60 abalone at 130mm or 20kg per module per year once modules are in a steady state (*pers.comm*. OGA, 2017). With a beach price of AUD$43.81 (for wild caught) per kilogram for 2015/16 (Gaughan and Santoro, 2018) in WA, there is a clear economic benefit for operators and local economies. There are also benefits to the environment and community with relaxed pressure on wild stocks, large amounts of finfish recruitment recorded on the ranches and accessibility for recreational fishers to capture finfish on these reefs.

There has also been research into the use of HES in the aquaculture process of some crustaceans in WA. In the concurrent FRDC project (2015/028), project managers are trialling the use of HES in enhancing marron stocks (mainly for recreational and aquaculture purposes). Two main types of HES are being trialled, large brick structures and smaller 'Nursery Hide Habitats' (Figure 23). The use of brick structures is hoped to drive natural productivity by actively promoting diatom and zooplankton growth as well as reduce predation (not yet measured). The use of the 'nursery hide habitats' is to provide for natural and stocked juvenile marron from birds and fish, particularly Redfin Perch.

Figure 23: 'Nursey Hide Habitats'(left) and brick structures (right) being developed (FRDC 2015/028) in WA to enhance marron stocks.

Potential Application in WA Commercial Fisheries

The commercial applications of HES were researched from around the world (Chapter One) to assist in growing state-based capacity and capability. To investigate whether HES may benefit the WA seafood sector (by developing and enhancing current commercial fisheries and potential aquaculture practises), a heat map was produced looking at how suitable HES are to the current 32 developed commercial fisheries in WA. It determined that 29 of 32 *i.e.* 90% could potentially use some form of HES to enhance their fishery. However, there needs to be further research done in the future to investigate whether some of these HES developments in developed fisheries would be worth the investment.

It should be noted that this heat map was based off preliminary results and literature reviews on global applications of HES. This is an indicative heatmap only. Cost-benefit analyses and further research should be undertaken as the costs of implementing some enhancement structures (while benefiting stock) may not necessarily increase yields or income. For example, sea cucumbers are ranched on a range of different HES designs (Figure 24) in China and South East Asia. Habitat Enhancement Structures protect broodstock and their larvae against the predators, increase the availability of natural feed like benthic algae and accumulating organic debris and improve the habitat for aestivation (dormancy) and hibernation (Jiansan and Jiaxin, 2001; Jiaxin, 2003). As such, the Beche-de-mer/sea cucumber is listed in the following chart below as being suitable for HES use. However, the 2016 harvest for the fishery in the Northern Bioregion of WA was only 93 tonnes contributing to less than AUD$1 million to the Gross Value of Product (Gaughan and Santoro, 2018). Thus, this fishery may not benefit due to the cost of HES without fishery expansion, which is dependent on external drivers such as abundance, accessibility and market value.

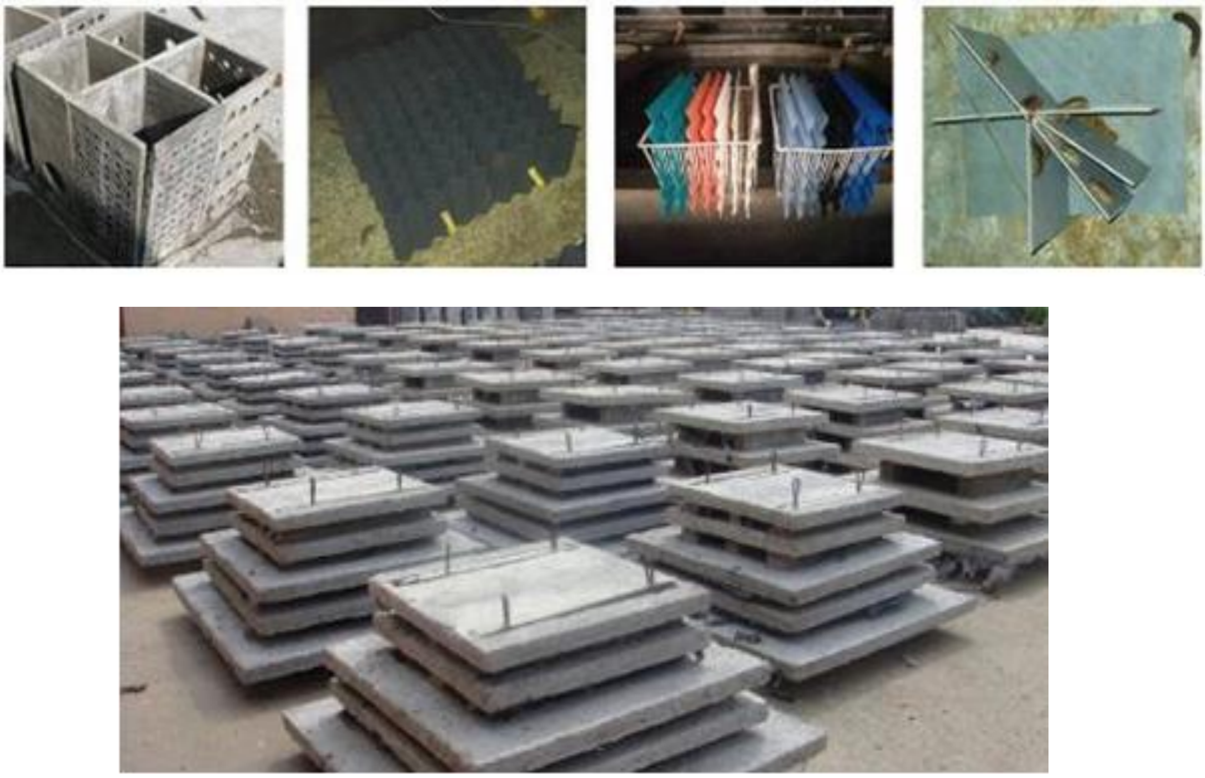

Figure 24: Different artificial reef modules for sea cucumbers (images: Qiang Xu and Chenggang Lin). Could these be utilised in Australia?

Table 12: Suitability of HES to current developed commercial fisheries in WA. Colour gradient indicates effectiveness.

#	Fishery	HES Type	Purpose
1	West Coast Rock Lobster Fishery	Artificial Reefs	There has been varying success with Western Rock Lobster (*Panulirus cygnus*) enhancement by artificial reefs in WA, however more research is needed. Other species of the family Palinuridae (Spiny Lobsters) fisheries are enhanced around the world. Mexico, Cuba and Japan have been using artificial reefs for commercial fishing since the 1950s (Bortone *et al*, 2001). Niches, crevices and complex habitats are created on artificial reefs to reduce natural mortality of lobster during the day to increase overall abundance. Artificial reef design also assists with harvesting. Artificial Seaweed Collectors are used to measure puerulus settlement of P. *cygnus* in Western Australia.
2	Roe's Abalone Fishery	Artificial Reefs	While extremely site dependant, other species of abalone have successful been cultured and harvested by seeding spat on artificial reefs in Western Australia. Roe Abalone (*Haliotis roei*) can be found up to 5m deep so could potentially be seeded on shallow water artificial reef systems. The reefs would enhance the fishery by providing crevices and complex habitat to reduce mortality through predation, increase food sources through the growth of algae on the structure and create a colonising surface for recruitment of future stocks.
3	Abrolhos Islands and Mid West, South West Trawl Managed Fisheries and South Coast Trawl Fishery	None	This fishery mainly targets Saucer Scallops (*Amusium balloti*). While this species can be enhanced by stocking (Scoones and McGowan, 2002), since its preferred habitat is sand, habitat enhancement would likely not benefit this fishery. Grow-out cages may stop natural predation of stocked species, though this will not be included in this project. A marginal component of this fisheries targets prawns, this may be enhanced through prawn fishery enhancement methods below.
4	West Coast Blue Swimmer Crab Fishery	Artificial Seagrass, Seagrass Translocation or Rehabilitation	Crustacean abundance is increased and natural mortality decreased by the presence of seagrass (or seagrass like habitat), particularly in certain life stages. This habitat can provide food sources, shelter and act as a nursery.
5	West Coast Nearshore and Estuarine Finfish Resources	Artificial Reefs	Artificial reefs can enhance the fishery by increasing the abundance and types of finfish species, this has been used to rebuild and enhance fisheries around the world (Bortone *et al,* 2011). The reefs achieve this by increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Florisson, 2015).
6	West Coast Purse Seine Fishery	FADs and Artificial Reefs	This fishery could be greatly enhanced by the use of FADs. However, it is Illegal to commercially purse seine around FADs in Australia. Artificial reefs could be used to create upwellings to concentrate these species, however it would have to be on a large scale to benefit this fishery which would not be cost effective.
7	West Coast Demersal Scalefish Resource	Artificial Reefs	Artificial reefs can enhance the fishery by increasing the abundance and types of finfish species, this has been used to rebuild and enhance fisheries around the world (Bortone *et al,* 2011). The reefs achieve this by increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Florisson, 2015). 3 out of 5 indicator species are commonly observed on the South West Artificial Reef Trial.
8	Octopus Fishery Status	Artificial Reefs	Octopus fisheries are can be enhanced by artificial reefs as octopuses are heavily habitat dependant. Artificial reefs can provide prey and shelter for these species and artificial reefs designed for the purpose of octopus nests have been successful in Turkey (Ula *et al*, 2011). *Octopus tetricus*has been observed on the South West Artificial Reef Trial in WA.
9	Shark Bay Prawn and Scallop Managed Fisheries	Artificial Seagrass, Seagrass Translocation or Rehabilitation (Prawns)	Crustacean abundance is increased and natural mortality decreased by the presence of seagrass (or seagrass like habitat), particularly in certain life stages. This habitat can provide food sources, shelter and act as a nursery.
10	Exmouth Gulf Prawn Managed Fishery	Artificial Seagrass, Seagrass Translocation or Rehabilitation	Crustacean abundance is increased and natural mortality decreased by the presence of seagrass (or seagrass like habitat), particularly in certain life stages. This habitat can provide food sources, shelter and act as a nursery.
11	West Coast Deep Sea Crustacean Managed Fishery	None	There is limited information on the habitat preferences and biology of the deep water crabs involved in this study. Given they are mostly caught on mud-like sediment on the edge of the continental shelf, it's unlikely habitat enhancement structures could feasibly enhance this fishery.
12	Gascoyne Demersal Scalefish Fishery	Artificial Reefs	Artificial reefs can enhance the fishery by increasing the abundance and types of finfish species, particularly demersal species that favour medium to high profile reef. This has been used to rebuild and enhance fisheries around the world (Bortone *et al,* 2011). The reefs achieve this by increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Florisson, 2015).

13	Inner Shark Bay Scalefish Fishery	Artificial Reefs	Artificial reefs can enhance the fishery by increasing the abundance and types of finfish species, this has been used to rebuild and enhance fisheries around the world (Bortone *et al,* 2011). The reefs achieve this by increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Florisson, 2015).
14	Shark Bay Blue Swimmer Crab Fishery	Artificial Seagrass, Seagrass Translocation or Rehabilitation	Crustacean abundance is increased and natural mortality decreased by the presence of seagrass (or seagrass like habitat), particularly in certain life stages. This habitat can provide food sources, shelter and act as a nursery.
15	North Coast Prawn Managed Fisheries	Artificial Seagrass, Seagrass Translocation or Rehabilitation	Crustacean abundance is increased and natural mortality decreased by the presence of seagrass (or seagrass like habitat), particularly in certain life stages. This habitat can provide food sources, shelter and act as a nursery.
16	North Coast Nearshore and Estuarine Fishery	Artificial Reefs, Habitat Restoration and Enhancement, Mangrove Translocation/Rehabilitation	Artificial reefs can enhance the fishery by increasing the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Florisson, 2015). However, since the main species caught in this fisheries are Threadfin Salmon and Barramundi, this fishery may be further improved by other types of habitat enhancement. Habitat translocation and restoration including mangroves would increase nurseries and habitat for these species, as well as increase food sources.
17	North Coast Demersal Fisheries	Artificial Reefs	Artificial reefs can enhance the fishery by increasing the abundance and types of finfish species, particularly demersal species that favour medium to high profile reef. This has been used to rebuild and enhance fisheries around the world (Bortone et al, 2011). The reefs achieve this by increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Florisson, 2015).
18	Mackerel Managed Fishery	FADs and Artificial Reefs	Pelagic mackerel species are known to hunt around natural and artificial reefs systems as well as target baitfish schooling around FADs, thus HES could increase mackerel abundance to enhance this fishery. Mackerel have anecdotaly been observed and caught on and around FADs and Artificial Reefs in Western Australia.
19	Pearl Oyster Managed Fishery	Artificial or Shellfish Reef	This species may be enhanced by introducing and seeding hard structure to bare areas of sea floor. However, with current harvesting techniques, seeding these species onto hard artificial substrate would be less efficient.
20	Beche-de-mer Fishery	Artificial Reefs	Beche-de-mer are ranched in China and South East Asia. Artificial Reefs can protect broodstock and their larvae against the predators, increase the availability of natural feed like benthic algae and accumulating organic debris and improve the habitat for aestivation and hibernation (Jiansan and Jiaxin, 2001 and Jiaxin, 2003).
21	North Coast Crab Fishery	Artificial Seagrass, Seagrass or Mangrove Translocation/Rehabilitation	Crustacean abundance is increased and natural mortality decreased by the presence of mangrove and/or seagrass (or seagrass like habitat), particularly in certain life stages. This habitat can provide food sources, shelter and act as a nursery.
22	South Coast Crustacean Fisheries	Artificial Reefs (Rock Lobster)	This fishery harvests deep sea crab and rock lobster. Artificial reefs effects on the crabs would be minimal, however, artificial reefs are known to support various life history stages of rock lobster (Coutin, 2001). Internationally artificial reefs are also used to protect migrating lobsters from predators and the success of the reef is governed by the niche sizes (Svane and Peterson, 2001). More than 60% of this fishery's catch is Southern Rock Lobster (*Jasus edwardsii*), there are currently artificial reef trials for this species in Tasmania.
23	Greenlip/Brownlip Abalone Fishery	Artificial Reefs	Greenlip Abalone (*Haliotis laevigata*) is currently being ranched on artificial reefs off Augusta in Western Australia. The technique is proving successful and is expanding. There is many opportunities for this fishery to be improved by Habitat Enhancement Structures.
24	South Coast Nearshore and Estuarine Finfish Resources	Artificial Reefs, Habitat Restoration and Enhancement,	Artificial reefs can enhance the fishery by increasing the abundance and types of finfish species. The reefs achieve this by increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Florisson, 2015). Abundances of species harvested in this fishery could also be increased by seagrass restoration/translocation.
25	South Coast Purse Seine Fishery	FADs and Artificial Reefs	This fishery could be greatly enhanced by the use of FADs. However, it is Illegal to commercially purse seine around FADs in Australia. Artificial reefs could be used to create upwellings to concentrate these species, however it would have to be on a large scale to benefit this fishery which would not be cost effective.

26	Temperate Demersal Gillnet and Demersal Longline Fisheries	Artificial Reefs	Artificial reefs can enhance the fishery by increasing the abundance and types of finfish species, particularly demersal species that favour medium to high profile reef. This has been used to rebuild and enhance fisheries around the world (Bortone *et al,* 2011). The reefs achieve this by increase the abundance and diversity of marine life within an area by creating additional shelter, food sources and a colonising surface for marine organisms (Florisson, 2015).
27	Lake Argyle Silver Cobbler Fishery	Artificial Reefs, Habitat Restoration and Enhancement,	Habitat Restoration/Enhancement through adding woody debris, replant bank riparian vegetation, restructuring course flow, fish ladders/ways (Bain et al 1988, Nicol et al 2004 and Baumgartner et al 2010). Artificial reefs could also potentially be used in this fishery.
28	Licensed South-West Recreational Freshwater Angling Fishery	Artificial Reefs, Habitat Restoration and Enhancement	Habitat Restoration/Enhancement through adding woody debris, replant bank riparian vegetation, restructuring course flow, fish ladders/ways (Bain *et al* 1988, Nicol *et al* 2004 and Baumgartner *et al* 2010). Artificial Reef and/or woody debris would be largely beneficial in dams with little to no current benthic habitat.
29	Licensed Recreational Marron Fishery	Habitat Restoration and Enhancement	Habitat enhancement through a range of materials can improve a marron fishery. Marron are found to utilise many types of new habitat (rapidly in aquatic systems with minimal habitat), at different parts of its life history depending on habitat complexity, the habitat also decreased rates of teleost predation on Marron (Molony and Bird, 2005).
30	Marine Aquarium Fish Managed Fishery	Artificial Reef	This fishery could be enhanced by artificial reefs providing food, shelter and a colonising surface for marine organisms (Florisson, 2015). This fishery could benefit by large amounts of small shallow artificial reef modules producing new assemblages of these fish feeding on colonising sessile biota and microfauna such as copepods and annelids.
31	Specimen Shell Managed Fishery	Artificial Reef	Depending on the biology of different species of specimen shells, they could potentially be seeded onto artificial reefs in the future.
32	Hermit Crab Fishery	Mangrove Restoration and Enhancement	This fishery harvests a terrestrial species of hermit crab (*Coenobita variabilis*). The fishery maybe enhanced through mangrove restoration, though this may have little effect. As this is not a true aquatic species it will not be included in this project.

Unlikely HES Use	Potentially HES Use	Suitable HES Use

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Chapter Three: Effective Community Monitoring Methods for Habitat Enhancement Structures

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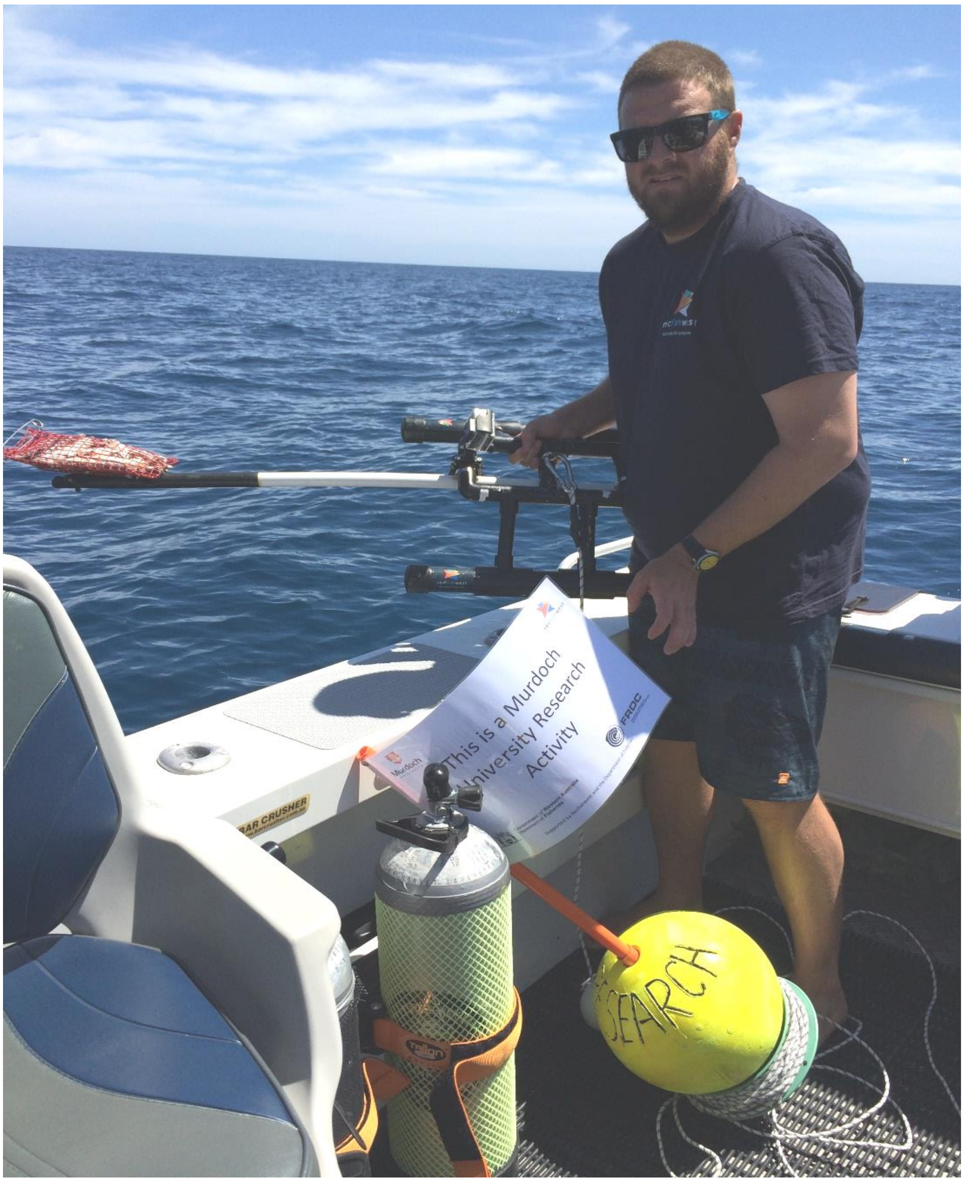


Figure 25: Reef Vision volunteer deploying a Baited Remote Underwater Video system.

Foreword

Chapter Three explores the testing and development of different Habitat Enhancement Structure(s) (HES) monitoring techniques to determine effective methods using easily available materials. It also highlights the use of the community in data collection in the form of citizen science. Physical trials of HES monitoring methods were undertaken on the Dunsborough and Bunbury artificial reefs in the South West of Western Australia (WA). Logbooks, manual and automatic observation posts, mapping and Baited Remote Underwater Video systems (BRUVs) were all tested and further developed through a community research program entitled Reef Vision. Other techniques which were identified as having a considerable amount of literature on their usage were analysed through various 'desktop studies'. The success of one particular monitoring techniques, the use of BRUVs, far exceeded expectation in the community commitment, social values and quality of data obtained. As such, the second half of this chapter provides a proof of concept study on this world first monitoring method using citizen scientists to deploy BRUVs on artificial reefs. The second section of this chapter has since been peer reviewed and is now available in the Journal of Fisheries Research (Florisson *et al*, 2018).

Figure 26: Bunbury Reef Vision volunteers with BRUVs.

Summary

There has been a marked increase in the number of artificial reefs being deployed around the world, many of which are designed to increase catches of recreationally-targeted fish species. As artificial reef deployments should be accompanied by clear and measurable goals and subsequent environmental impact monitoring and performance evaluation, there is a need to develop cost-effective monitoring programs.

To develop effective community-based monitoring methods, five specific techniques were trialled on the Bunbury and Dunsborough artificial reefs in Geographe Bay, south-western Australia. These reefs were chosen as they were close to shore, had high levels of usage, in a populous area, and had several years to socially and ecologically establish since they were deployed in 2013. To create an 'entity' and provide the community with ownership over the project (and thus increase engagement and decrease volunteer attrition), the trials were encapsulated under one citizen science research program entitled 'Reef Vision'. In the program five different techniques were trialled including Baited Remote Underwater Video systems (BRUVs), logbooks, mapping, manual observation posts and automatic observation posts. The techniques were tested and collected data was analysed. The BRUVs were the most effective method with high community value and quality spatial and temporal data being collected. The manual observation post was the next most effective method followed by mapping the artificial reef area. The automatic observation post and logbooks were ineffective in this trial, however the study was limited by time and technology, and similar methods have been since successful elsewhere. The high level of success in the BRUVs trial led to a further investigation into their applicability as a HES monitoring method.

The second component of this chapter provides proof of concept for a citizen science approach to monitoring the fish faunas of artificial reefs using BRUVs. Recreational fishers were recruited to collect video samples using baited remote underwater video systems and submit the resultant footage for analysis and interpretation by professional scientists. The volunteers were able to collect enough data of sufficient quality to monitor the artificial reefs. Data were extracted from the footage and used in robust univariate and multivariate analyses, which determined that a soak time of 45 minutes was sufficient to capture 95% of the number of species, abundance, diversity and community composition of the fish fauna. The potential for these data to detect differences in the characteristics of the fish fauna between reefs and seasons was also investigated and confirmed. With the continuing deployment of artificial reefs around the world, the use of similar cost-effective citizen science monitoring approaches can help determine the effectiveness these structures in achieving their aims and goals and provide valuable data for researchers, managers and decision makers. Projects such as Reef Vision can also benefit volunteers and communities by enhancing social values, creating ownership over research projects and fostering stewardship of aquatic resources.

Introduction

Habitat Enhancement Structure(s) (HES) are monitored all over the world for a range of purposes, however the overarching reason for monitoring is to ensuring there are no adverse environmental outcomes from the HES. Monitoring of HES in Australia can be generally classified as measuring impacts on the ecosystem, structural integrity and stability, and the level of use by targeted end users. While monitoring objectives and needs vary globally, there are clear monitoring requirements in Australia associated with HES approvals process. The fundamental legislation covering the deployment of HES in Australia is the Commonwealth *Environment Protection (Sea Dumping) Act 1981*. Each state or territory also have their respective environmental protection legislation that may apply depending on the HES type and location.

Most state and territory governments in Australia manage the entire HES process from funding through to approvals and managing tenders to design construct and deploy the structures and post deployment monitoring. In WA however, a different model is employed. The WA Government while providing base funding, encourages the leveraging of funding to get the best value from each proposed reef. Under this model, government takes a more 'hands-off approach' allowing the recreational fishing sector, led by Recfishwest, to develop and deliver HES projects throughout the State. This has proven successful with more recent HES projects securing leveraged funding from the resources sector.

In its assessment of applications to install artificial reefs under the *Environmental Protection (Sea Dumping) Act 1981*, the Commonwealth has indicated that is unlikely to provide approval to non-government organisations due to liability concerns over the life of the artificial reef. To continue to allow community driven artificial reef proposals, the WA Government has developed a policy of taking ownership and liability for artificial reefs once they are deployed. To ensure that due diligence is carried out before the State Government accepts that ownership and liability, proponents are required to obtain approval under the State Governments *Fish Resources Management Act 1994* (FRMA). The WA Government, in consultation with key stakeholders produced Fisheries Management Paper No. 256 "Policy on Habitat Enhancement Structures in Western Australia" to assist proponent applications and to provide guidance on assessment of those applications. The outcome of this process is that when HES projects are approved under the FRMA, and successfully deployed, ownership and liability of the HES moves to the State Government. The FRMA will soon be replaced by the *Aquatic Resources Management Act (ARMA) 2016* in WA. Under the ARMA the process will be followed guided by the habitat enhancement structures policy.

Under the *Environmental Protection (Sea Dumping) Act 1981* a rigorous and comprehensive proposal assessment has to be completed. This includes an environmental monitoring plan that evaluates the structure and its effects on the surrounding ecosystems. The structural integrity, design, materials, surrounding environment, target species, usage and effort and outcomes must all be considered during design and site selection to ensure that HES objectives are met while minimising risks as set out in the policy.

There are many different types of monitoring that are used to inform ecosystem-based management approaches to help conserve biodiversity and functioning (Christensen *et al*, 1996) and these can be broadly categorised into extractive or non-extractive monitoring approaches. One of the most frequently employed method of non-extractive monitoring in the marine environment involves the use of underwater video systems. The use of underwater video systems for research in the marine environment has become increasingly popular since it was first employed in the 1950s (Brock, 1954). There are many reasons for this popularity including: the limited amount of damage done to the surrounding habitat and target organisms, the fact that footage can be permanently archived and replayed/reused and the increasing quality of the footage and decreasing purchasing costs of the equipment (Willis *et al*, 2000; Tessier *et al*, 2005; Mallet and Pelletier, 2014). Underwater video systems vary in structure and purpose, and can be categorised into four main groups, *i.e.*) Baited

Remote Underwater Video systems (BRUVs), ii) Remote Underwater Video systems (RUVs), iii) Diver Operated Video systems (DOVs) and iv) Towed Video (TOWV). Other types of non-extractive monitoring techniques that could also be utilised on HES can include, but are not limited to: photo quadrats, settlement tiles, surveys, observations, environmental DNA (eDNA), Remotely Operated underwater Vehicle (ROVs) (ROVs can collect underwater video, however, are not limited to this method of sampling), logbooks, mapping, tagging and acoustic research.

Ongoing monitoring can be expensive and time-consuming if conducted through regulatory organisations or consulting companies employing professional scientists (Conrad and Hilchey, 2011). The effectiveness of monitoring by regulatory organisations have decreased in some countries due to cutbacks in funding and staffing, however the monitoring data is still needed for decision-making processes (Conrad and Daoust, 2008; Conrad and Hilchey, 2011), given HES are generally deployed for the purposes of community recreation. One mechanism to reduce costs, would be to use citizen science to collect monitoring data.

In recent years, there has been a marked increase in the use of members of the general public to assist in scientific research (Silverton, 2009; Baltais, 2013; Lambert, 2014). This type of approach is called 'citizen science' (Kruger and Shannon, 2000). Citizen science potentially provides a cost-effective method for data collection and monitoring, as well as a range of other benefits, although there are also some potentially significant limitations (Silverton, 2009; Dickinson *et al*, 2010; Rotman *et al*, 2012; Baltais, 2013). Citizen science has the ability to reduce funding and labour costs to research organisations and increase general cost-efficiency, whilst also providing social benefits to volunteers and the opportunity for the collection of spatially and temporally large data sets and samples (Dickinson *et al*, 2010; Tulloch *et al*, 2013; Wilson and Godinho, 2013).

Citizen science was used to trial different techniques to determine cost-effective methods to monitor HES developments using easily available materials and data collection by community and industry groups. To investigate the effectiveness of these methods there were two main aims of the study: i) to investigate the effectiveness of community-based techniques, and ii) test and develop monitoring methods. These aims were achieved by physically testing five different techniques on the Bunbury and Dunsborough artificial reefs in the South West of WA. These monitoring methods were each trialled with the first section of this chapter detailing the methods, results and impacts of each of these techniques. Additionally, literature was also reviewed on other monitoring methods not included on the physical trials. The second section of this chapter uses a more concentrated scientific approach to explore the most effective method that was trialled on the artificial reefs.

Community Monitoring Trials

To determine cost-effective methods to monitor HES developments, a range of monitoring methods were tested, developed and reviewed. To firstly understand various existing monitoring techniques, several monitoring studies were undertaken. This provided an insight into monitoring types, purposes, strengths, limitations and costs. Recfishwest in consultation with Ecotone Consulting, Murdoch University researchers and community members, developed a Monitoring Matrix in 2014, which helped identify novel and cost-effective monitoring methods which were considered valuable, and therefore worth further investigation (Figure 27). The matrix included biological, ecological, social, environmental and structural methods and included specific techniques such as acoustic recording, sonar and side-scan mapping, visual observation, log books, underwater video, and radar.

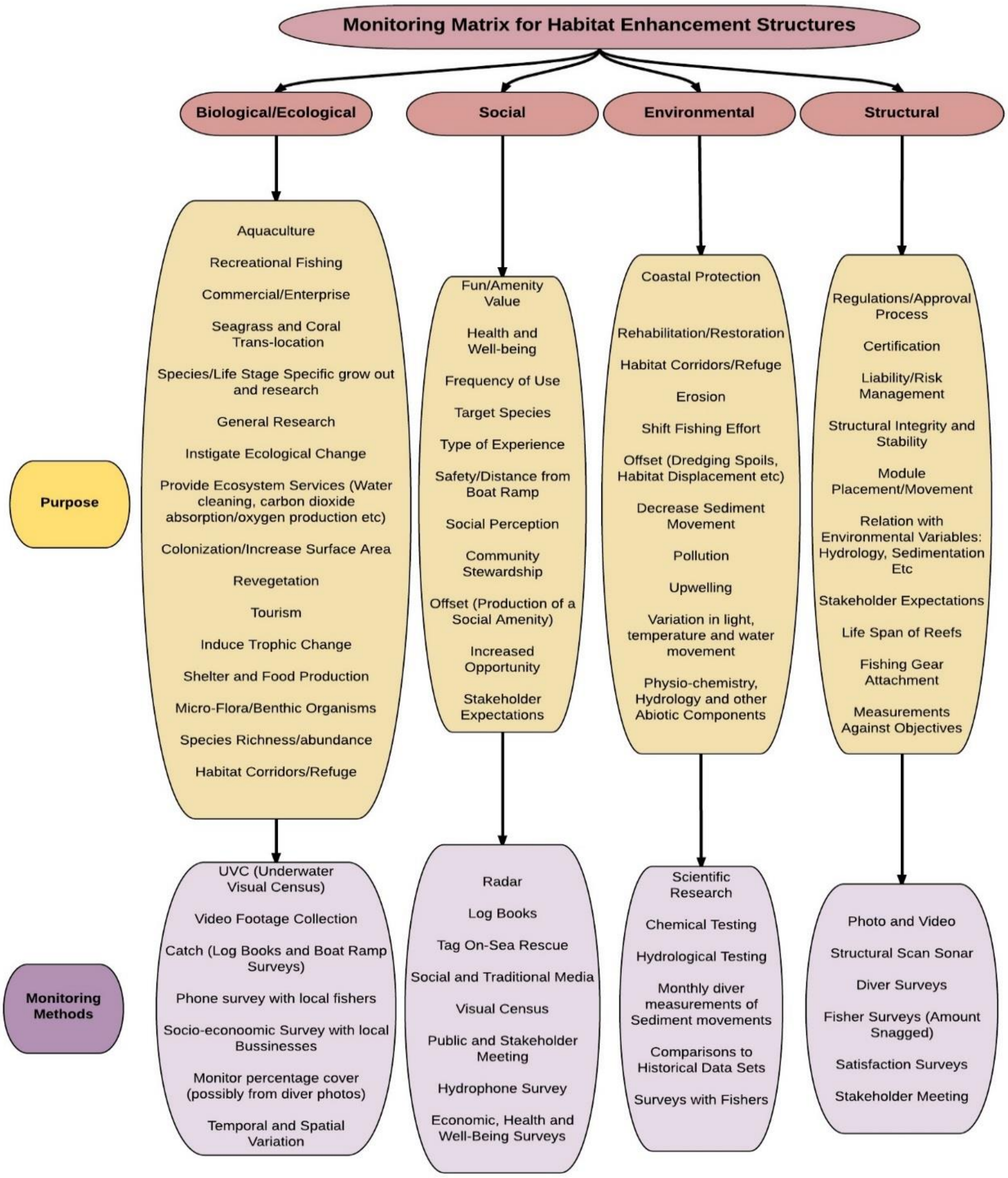


Figure 27: Monitoring Matrix for HES.

Several forms of community monitoring were tested and developed on the South West Artificial Reef Trial in Geographe Bay, WA. To consolidate efforts, promote the project and to increase participant ownership of the project, the various monitoring techniques were amalgamated into one program called Reef Vision. Reef Vision is a citizen science program and involves monitoring social and biological/ecological utilisation of the reef through observation posts, logbooks and underwater monitoring using BRUVs. The ability to monitor structural stability was also explored through the use of side-scan sonar.

The South West Artificial Reef Trial (Figure 28 for locations) was used as a sample site to test community monitoring techniques to evaluate their potential applicability to future HES developments in WA. These sites consist of two artificial reefs off the coasts of Bunbury and Dunsborough in Geographe Bay, WA. Each reef was constructed using 30 purpose-built, 3m^3 10 tonne reinforced concrete modules in cluster formations to increase habitats.

The reefs were deployed in April 2013 and were funded by recreational fishing license fees and the State Government for the purpose of enhancing fishing opportunities, particularly for target species such as Pink Snapper (*Chrysophrys auratus*), Samson Fish (*Seriola hippos*) and Trevally (*Pseudocaranx sp.*). The time since deployment, site characteristics, current legislative requirements for monitoring in WA, their proximity to towns and cities and the environmental conditions of Geographe Bay have made these artificial reefs a suitable site to test the effectiveness of different community monitoring methods on HES.

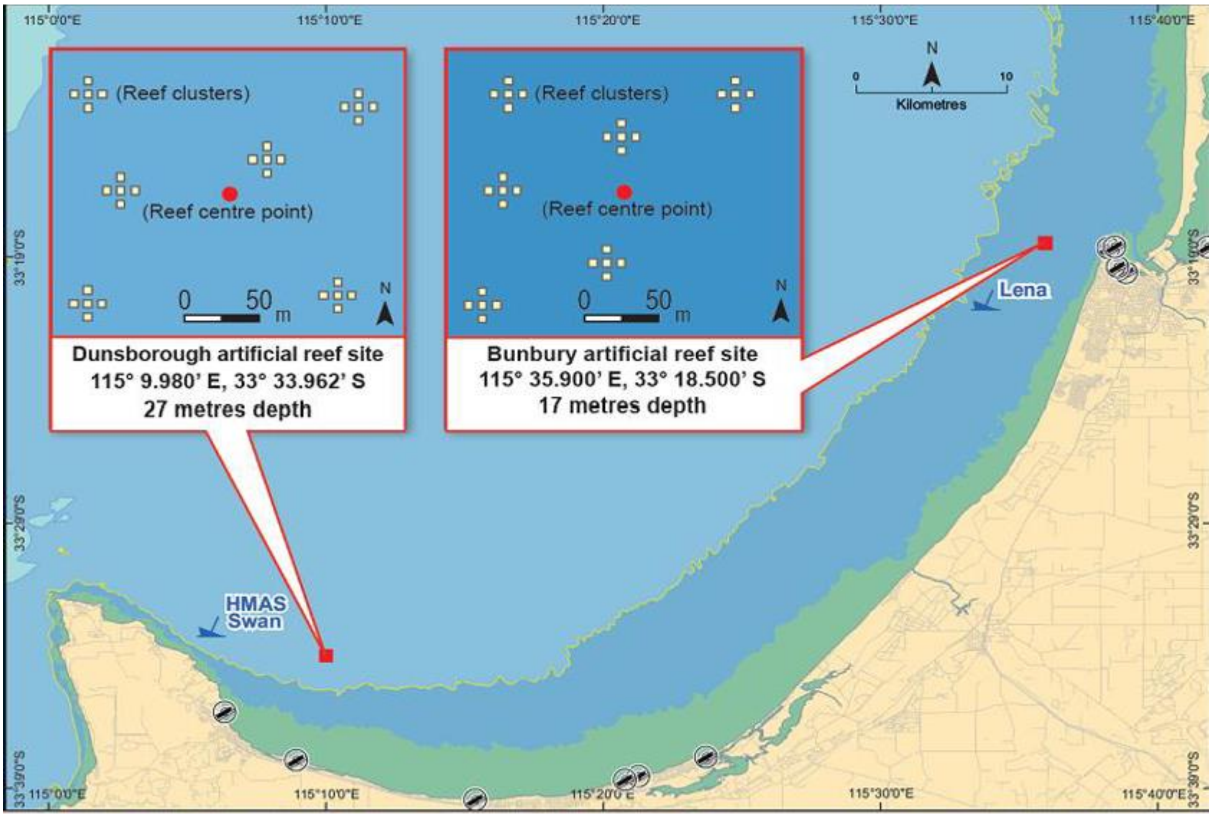


Figure 28: The South West Artificial Reefs, the location of monitoring for Reef Vision (Image courtesy of the Department of Fisheries WA).

To best manage community volunteers and techniques, the 'Reef Vision' citizen science program was created; one overarching program for all monitoring methods (Figure 29). Reef Vision tested BRUVs, logbooks, manual and automatic observation posts and mapping. Reef Vision also provided volunteers and the fishing community with a set of social values which assisted in reducing volunteer attrition. These values included increased scientific literacy, provision of a communication network for volunteers, provided a high level of engagement, and two-way dissemination of information. This increased volunteers', and the overall community's, ownership and stewardship of the project, artificial reefs and marine environment.

Figure 29: The Reef Vision logo which was designed for the project with the aim to create a community owned and valued 'entity' for the project.

Logbooks

Thirty volunteers that commonly fished in the Geographe Bay area were given recreational angling logbooks to monitor their catches on the artificial reefs. Logbooks can monitor HES by collecting data on catch effort, level of use by fishers and ecological monitoring by presence/absence of recreational target species caught on the reef. Volunteers were recruited using a pamphlet displayed at tackle stores and through local fishing groups on Facebook. An advertisement was also displayed in the local newspapers. Additional volunteers were also recruited through social media and through community presentations in the South West of WA on artificial reefs.

To increase cost-efficiency, enhance partnerships and to utilise existing information and services, the Reef Vision logbook program joined an existing logbook program run by the WA Department of Fisheries, called the Research Angler Program (RAPs) (Figures 30; 31). Fishers were asked to record specific artificial reef information in the comments field on the log sheets. Recreational Fishing Logbooks are successfully used as a research and monitoring tool all over the world for the majority of aquatic systems and habitats including artificial reefs (Stephens and MacCall, 2004; Leeworthy *et al*, 2006; Bastardie *et al*, 2010).

The RAPs data assists in analysing trends and fluctuations in the abundance of species, faunal composition, size, growth rates, age of maturity and many other parameters that can help establish whether species or habitats are under pressure and current management arrangements are adequate. The Department of Fisheries uses logbooks to record details of catches, species, numbers, length and health on release which is used to help monitor fish abundance and diversity as indicators of fish and ecosystem health. In addition to this, fishers on the artificial reefs were asked to record location specific catch data such as species and size, to assist with the ecological monitoring of the artificial reefs. The number of boats fishing the reef was also to be recorded to monitor social use of the HES.

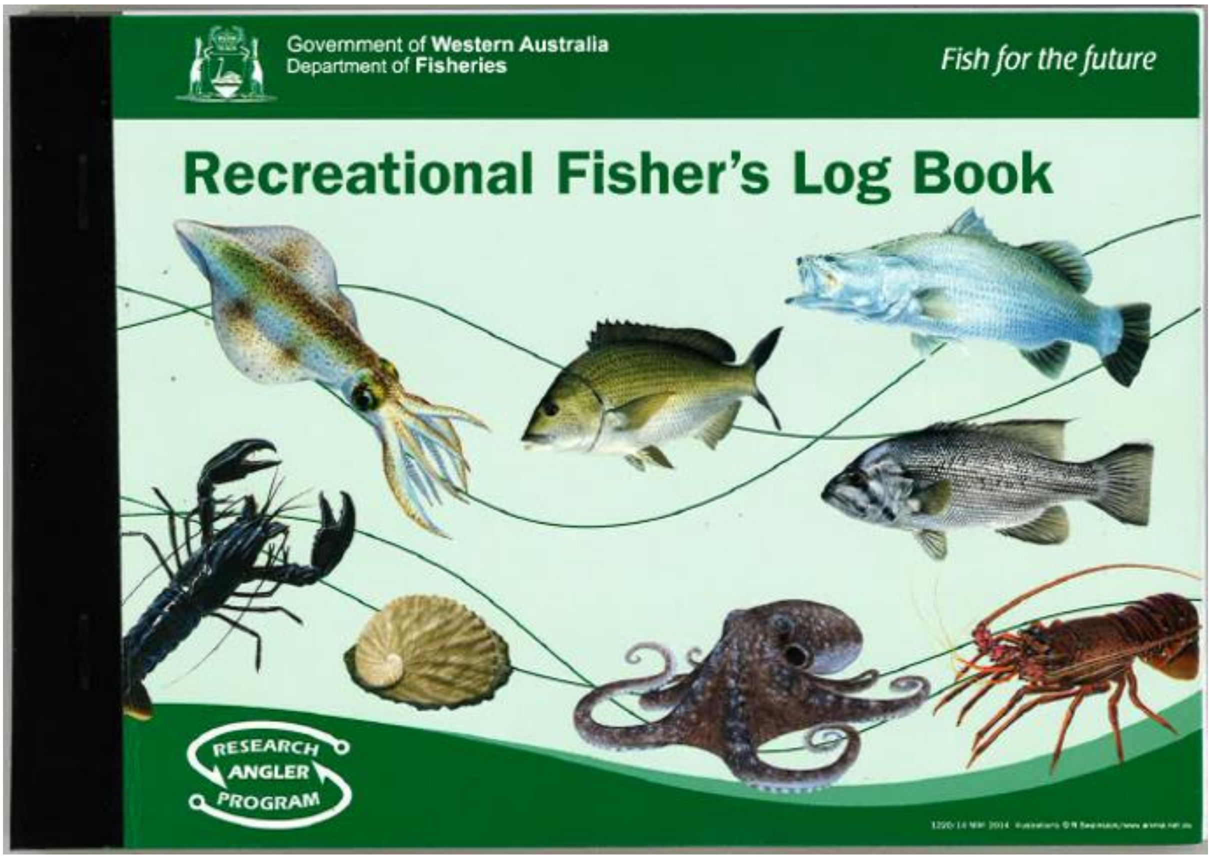
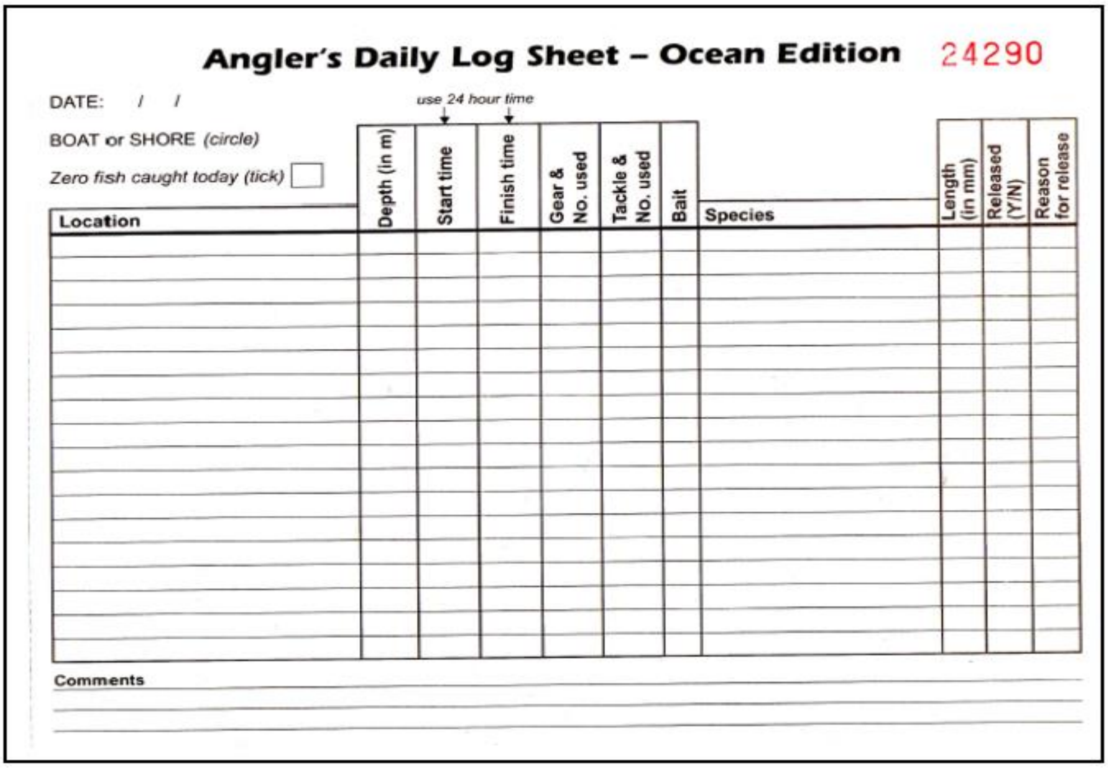


Figure 30: The Department of Fisheries Research Angler Program logbook.



Angler's Daily Log Sheet – Ocean Edition 24290

DATE: / /

BOAT or SHORE *(circle)*

Zero fish caught today (tick) ☐

use 24 hour time

Location	Depth (in m)	Start time	Finish time	Gear & No. used	Tackle & No. used	Bait	Species	Length (in mm)	Released (Y/N)	Reason for release

Comments

Figure 31: The metadata and catch data recorded in the Research Angler Program logbook, included the comments field in which social data on artificial reef utilisation will be collected.

The Reef Vision Logbook trial however, was not effective. Although logbooks are usually a successful data collection technique, the Reef Vision Logbook trial was ineffective with no logbooks returned to the Department of Fisheries Research Angler Program within the 6month testing period. Feedback (including quotes) from participants demonstrated a number of potential causes to why the logbooks were ineffective including:

- Complexity of logbook format was unnecessary for the needs of artificial reef monitoring and thus were not 'user-friendly' for volunteers …"The complex nature of the logbook makes a hobby become a responsibility or a task"…
- The potential length of time it takes to receive the feedback and results on research conducted from completing the logbook (if the logbook was completed).
- Fear of losing fishing access because of fisheries management alterations due to results of data collected as well as fear of giving away information on 'secret' fishing spots.
- Don't want to record catch information when fishing was below average quality (ashamed).
- Don't see the value in reporting non-target species.

Although this trial yielded no discernible data, it has provided value in further developing artificial reef monitoring using logbooks. This was achieved through establishing a set of recommendations which could be considered when using logbooks for monitoring artificial reefs in the future, supported by feedback from fishers who took part in the trial. Recommendations include:

- Digitalizing the logbook format … "A simple smartphone app-based logbook would be much easier to use, it could also provide personal results such as the amount of a species caught or hours fished, it would be simpler and much more popular meaning more information could be collected" …
- Reduce the complexity by limiting data collection fields.
- Minimize different research variables to focus on specific data collection type (such as biological monitoring through the presence/absence or recreationally important species).
- Increase the usability for end users.
- Extend the temporal range for the project.

The Reef Vision logbook trial was shown to be an ineffective artificial reef monitoring technique. Of the original 30 volunteers, 10 individuals left the program due to personal reasons, mainly including difficulties with boats, work and leaving the area and the other volunteers did not submit any data. This trial had a limited number of volunteers that were asked to collect information over a short period. However, volunteers did collect limited catch and social information on recording sheets for the BRUV component of Reef Vision (separate trial). Logbooks used by Reef Vision BRUV volunteers measured boat visitation between October 2015 and October 2016. Volunteers counted 177 boats on the reef in 113 hours averaging out to 1.2 boats fishing the Dunsborough Artificial Reef and 1.7 boats fishing the Bunbury Artificial Reef per hour. Figure 32 shows a summary of data collected through logbooks on boat usage on the South est artificial reefs. This demonstrates that by varying the format, information can be collected by using logbooks on the artificial reefs, particularly in relation to social usage of the structures.

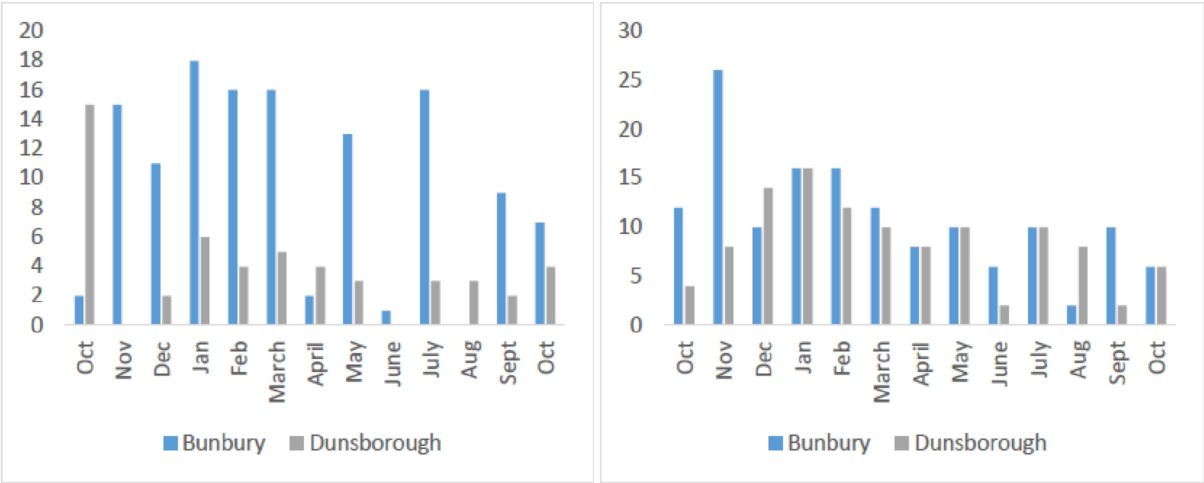


Figure 32: Total boats observed between Oct 15 and Oct 16 (left) and total number of observations on the reefs between Oct 15 and Oct 16 (right).

Manual Observation Station

To quantify visitation by boaters as well as trial the ability of community-based social monitoring, a manual long-range observation post was established to study the Bunbury Artificial Reef. A well engaged volunteer was recruited through the already established Reef Vision network following citizen science recommendations by Florisson (2015). The volunteer had to be particularly engaged as the study required observation of the reefs three times daily over a medium temporal scale of 24 days. It was also imperative that they reside in a building high enough above sea level to optimize the viewing range. Due to the success of the initial trial, this was then repeated the following year.

The selected volunteer's residency is approximately 4km south-west of the Bunbury Artificial Reef and 24m above sea level. The objectives were met by logging observations of boats on the artificial reefs. Observations were taken by viewing the artificial reef on a spotting scope, a 'Redfield Rampage 20-60x60mm' on a tripod that allowed a high level of stability. The scope has 20-60x magnification and has a field of view of 34.7 – 15.5m at 1000m. This spotting scope was also user friendly and allowed the user to focus, and record boats at the distance of the artificial reef (approximately 4km) from the current observation post. The WA Easter School holidays (7/4/2016-30/4/2016) were chosen to record the vessels and this was repeated on the same dates, the following year. These times were chosen for the observation period so that the data collected could:

- Assist in future socio-economic analysis of the artificial reefs from tourism.
- Compare future visitation between the Bunbury, Dunsborough and future reefs.
- Compare results against observations from a baseline data set from a normal weekly period to see the social effects of the holiday period on the reefs.

The reefs are in a four-hectare area, so to improve accuracy, the scope was set by zooming in on a boat anchored at the centre point of the reef. The boat was in contact with the person setting up the scope. Once the boat was in the centre of the field of view, it travelled to the extremities of the artificial reef area perimeter, to ensure the north-east, north-west and south-west clusters are also included in the field of view (Figure 33). This activity ensured the entire artificial area was observed. Once the scope was calibrated, the feet of the scope were taped to the floor then traced with chalk. All screws on the tripod were locked and taped and the power selector ring and focus adjustments were taped, as precautionary measures in case the observation post is accidently bumped or moved.

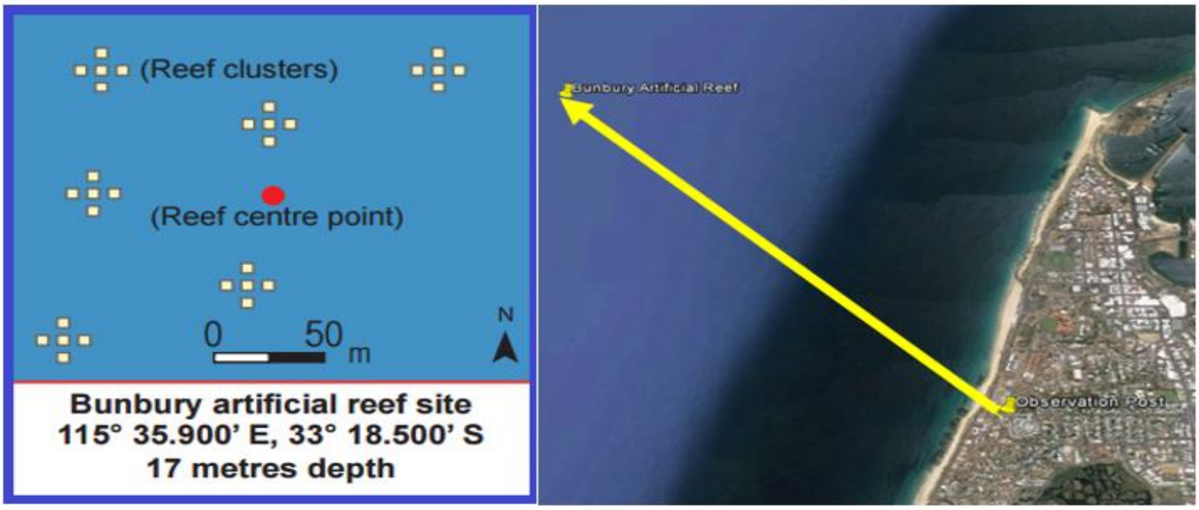


Figure 33: The Bunbury Artificial Reef site including the viewing direction of the observation post.

Boat visitation was recorded three times a day at the times of 7am, 10:30am and 2pm. These times were decided after consultation with local fishers for the fishing times (strong winds in the afternoon in the location at that time of year restrict temporal effort). At the time of recording, the volunteer counted the number of observable boats in the field of view, then repeated the count five minutes later. The lowest count of boats in the two observations was recorded for that time period to provide a conservative number by mitigating any boats that were travelling through the area. Results were then recorded.

These results were analysed to look at temporal variation in usage, including time of the day and day of the week. During 2016 and 2017 the observations station monitored use of the reef over a 46-day period with 138 individual counts taking place. This identified at least 58 different boat usages of the reef. While 130 boats were counted on the reef in total, only the largest count for the day was included in this analysis to remove the chance of any repeat counts of boats fishing the reef at multiple times during the same day. This information could potentially be paired with surveys to perform socio-economic analyses of artificial reefs. An example of how the information can be used is seen on the following Table 13 and Figure 34.

Table 13: Total counts of vessels using the Bunbury Artificial Reef, from the Bunbury Observation Station.

Year	Total Boats Counted	Minimum Unique Boat Usages
2016	83	33
2017	47	25
Total	**130**	**58**

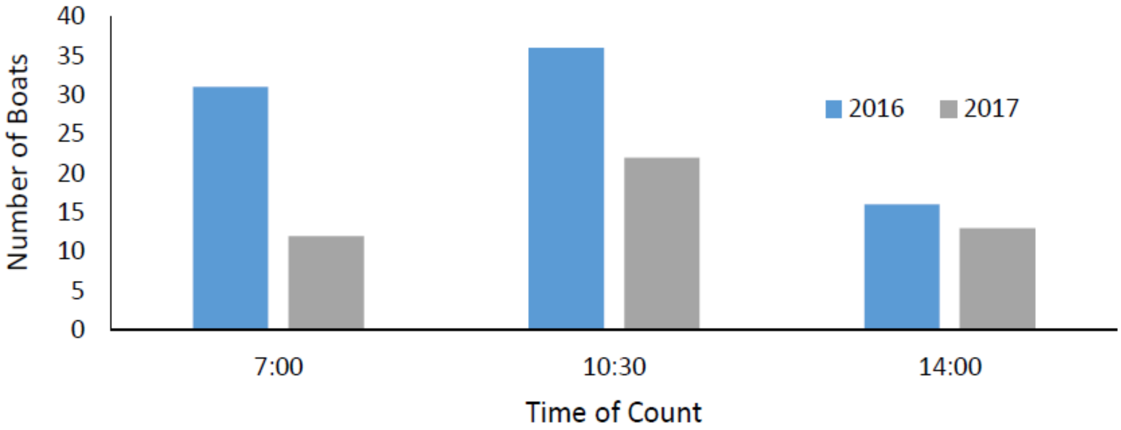


Figure 34: Number of boats recorded on the Bunbury Artificial Reef from the observation station during 2016 and 2017 sampling regimes.

This technique was identified as an effective method for monitoring HES, requiring minimal volunteer effort, technology and simple methodology needed to create a large and practical dataset on HES social usage that could be applied to various research applications. The method is not restricted to a stationary position, but similar techniques could involve counts by regular ocean uses such as fisheries compliance, commercial fishers, ferries, pleasure craft, sea rescue, spotter planes, fishing charters and others.

Automatic Observation Station

To gather information on usage on the Dunsborough Artificial Reef, an automatic observation station was set up at the Quindalup Sea Rescue building due to its height above sea level. Evidenced based long-range photographic recording techniques were reviewed and tested, focusing on utilising affordable, off-the-shelf visual surveillance equipment suitable to capture time lapse images at predetermined intervals. A GoPro Hero4 'Silver' camera was fitted to a Redfield 'Rampage' 20-60x60mm Spotting Scope using PhoneSkope lenses adaptors (Figure 35). A programmable CamDo Time Lapse Intervalometer was then attached via the camera serial port, recording and data transfer was with Micro-SD cards. To use the CamDo programmable scheduler, the GoPro HERO4 camera required a firmware modification downloaded from the company's website which allowed some of the factory settings to be over-ridden. Power supply was provided with a mini USB cable and generic 5V – 230-250V power pack. Equipment utilised for the study can be seen in the following Table 14.

Table 14: Materials utilised in the automatic observation station for determining usage of the Dunsborough Artificial Reef.

GoPro Hero4 'Silver'	C3113112 - 5851473
Redfield 'Rampage' 20-60x60mm Spotting Scope	(Part number 67600)
CamDo Solutions Time Lapse Intervalometer	PS-004 Programmable Scheduler (180104)
PhoneSkope - GoPro Hero 4/3+ Adapter Plate	PS- AP 22387
PhoneC3 Optic Adapter	(Part number C3-054-A)
USB Cable - 10 foot mini-USB male	(USB-10FT 180063)
USB 5V /230-250v power pack	Generic

With co-operation from members of the Quindalup Volunteer Sea Rescue, the long-range camera was installed in an elevated observation post within the club rooms which had clear line of sight over the area above the artificial reef cluster. Focusing the camera's field of view was achieved by volunteers positioning a rescue boat directly about the centre modules (Figure 35). The programmable scheduler was set to take three pictures, one minute apart at four predetermined times during the day- 7.00am, 10.30am, 12.00pm and 3.30pm. Photographic analysis would be conducted manually, where all boats in the image would be counted and time of the day noted. This monitoring method was ineffective.

Figure 35: GoPro Hero4 Camera attached via lens adaptors to a Redfield 'Rampage' 20-60x60mm Spotting Scope. The CamDo Time Lapse Intervalometer can been seen 'piggy backed' onto the camera which was programmed to take three pictures, one minute apart.

Figure 36: Image of boat centrally situated above Dunsborough Artificial Reef viewed through Redfield 'Rampage' 20-60x60mm Spotting Scope at approximately eight kilometres from Quindalup Sea Rescue elevated observation post.

Although a small data set was available close to the cessation of the study, the trial failed due to the complexity and lack of synchronicity between involved technological components and the timing and amount of data produced for analyses. It is anticipated by project managers that the main difficulties were caused in the initial phases of establishing a functioning automatic observation post. However, since the trial other research with similar equipment (such as Wood *et al*, 2016) have been completed and shown that this technique may provide important HES monitoring data in the future. This method may also be applicable to other research areas, particularly as optical technology and automation continues to develop and evolve.

Mapping

Mapping technology was tested as a monitoring method to look at the potential effects of artificial reef modules on substrate, as well as to assess the structural integrity and position of modules. Hydrographic and Bathymetric surveys are commonly used as a method to monitor changes to the substrate and analyse aquatic vegetation, sedimentation and other important water quality characteristics over time. Investigators examined cloud-based software and GIS automation based Social Mapping technologies that were available, which helped identify underwater areas using High-Resolution bottom composition sonar imaging and vegetation mapping. This powerful cloud-based software processes soundings, creates reports and layered maps from community generated sonar data logs. These data can help chart and analyse trends of sedimentary sand drifts, vegetation changes and is used as a spatial analysis (Polygon) tools. Each sonar log that is uploaded also automatically records weather, temperature and barometric-pressure readings taken while the user is on the water.

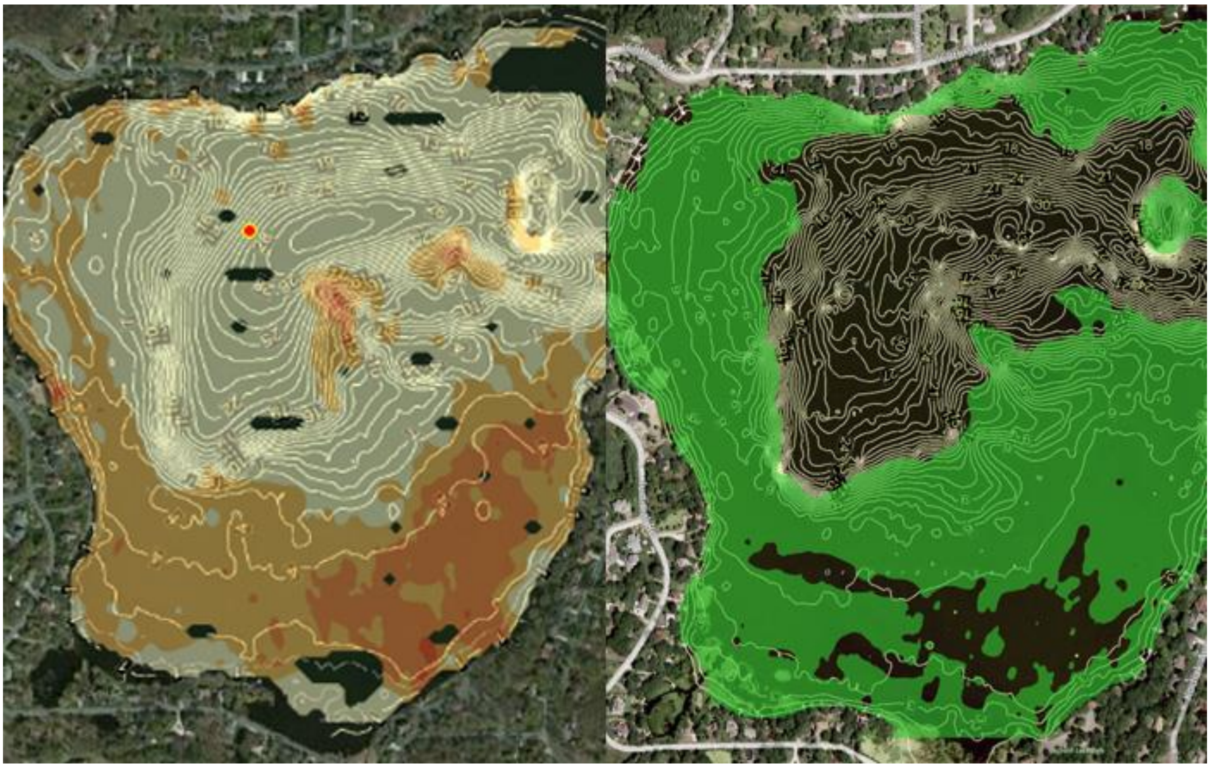


Figure 37: Examples of bottom hardness (left) and vegetation (right). Maps were generated using Insight Genesis (http://www.gofreemarine.com/insight-genesis).

Sophisticated Global Positioning Systems (GPS) coupled with extremely accurate High Definition (HD) multi-frequency sonar data loggers are now affordable and readily available to boat owners. These onboard systems continually measure and log physical environmental information such as water temperature, depth and substrate hardness at regular intervals for each location. This information can be stored for future reference by the user. This monitoring method was trialled as there has been a large increase of advanced and cost-effective sounding equipment amongst the fishing and diving, and boating community. This could assist in habitat mapping used in HES site selection, measuring sessile organism growth and variation in sedimentation to create an effective monitoring method. Manufacturers and other third-party providers support these ‘fish finder’s’ with the ability to export and upload these large data files to be processed into detailed aquatic vegetation and substrate maps. These bathymetric maps can then be shared and compared online via open source or subscription software. Over time these social maps can be compared for physical changes in both the artificial reef positions and the immediate surrounding areas. Movement or changes in localized sedimentation around the HES can be documented. Density and distribution of sedentary seagrasses could for example be measured by community groups.

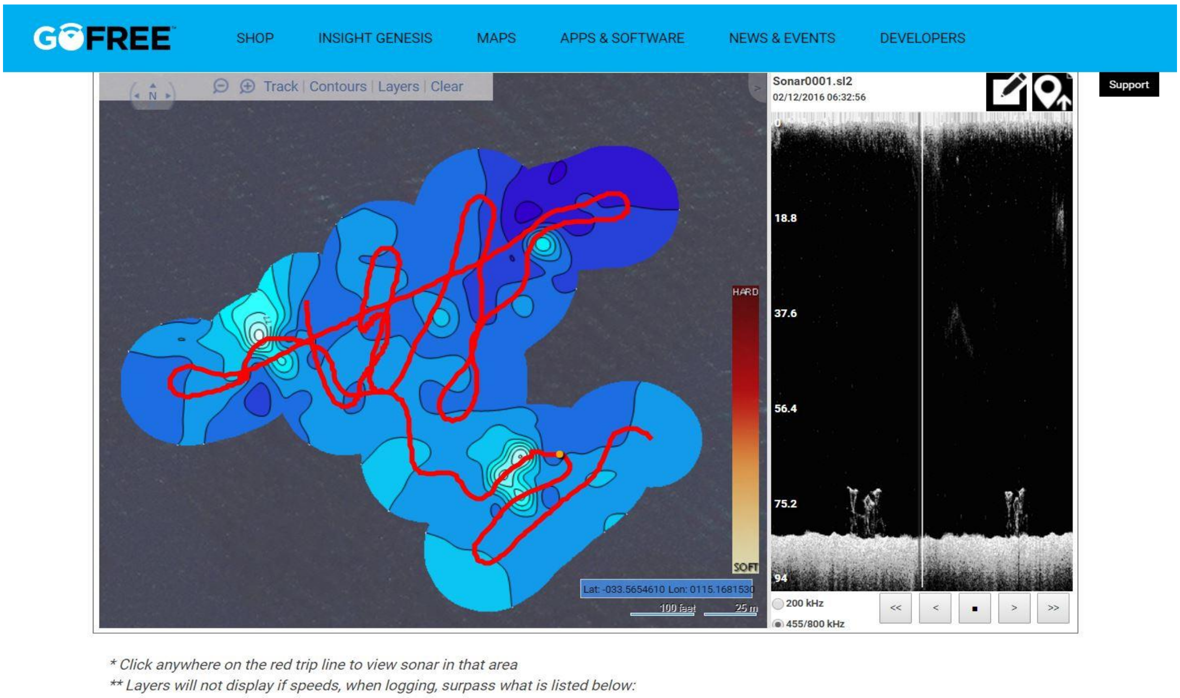


Figure 38: Sounder mapping details of Dunsborough Artificial Reef (note modules on right).

Volunteers from the Dunsborough Reef Vision program provided sonar and structure-scan logging data files using Lowrance HDS Gen3 chart plotters. Analysis of these files were provided via Insight Genesis® GoFree subscription software to time-scale map any structural changes to the reef modules (an example of this can be seen in Figure 38). This was found to be a potentially effective monitoring method. Fishers already involved in the BRUV component provided data through their sounder storage cards of the depth and hardness of the substrate around the HES sites. This can be used to compare sediment shifts and biomass growth both spatially and temporally. The applicability of this method is continually increasing with improved data sharing and storage services, and cost and technological abilities of modern sounders, and chart plotters.

Baited Remote Underwater Video

The final monitoring technique that was tested on the South West Artificial Reef Trial involved the use of BRUVs. Twelve volunteers were supplied with specialised BRUVs and asked to deploy the cameras for at least one hour on their allocated artificial reef (either Bunbury or Dunsborough) to collect footage of the fish assemblages. They were also asked to collect observations and social information such as the number of other boats using the reefs.

The BRUV component of Reef Vision was successful beyond expectation. Since the Reef Vision BRUV trial commenced in 2015, over 250 hours of footage has been collected identifying over 80 species on the South West Artificial Reefs. Not only did the volunteers collect a large amount of high quality spatial and temporal data, but it also created real community ownership over the project and a set of social benefits to volunteers. Local businesses invested resources into the research and the project had a large amount of adoption by volunteers, media and the community.

Due to the unexpected quality of social and ecological data collected and the community values associated with the project, the BRUV component of Reef Vision was further investigated and is incorporated in the second half of this chapter. This further investigation undertook a heightened scientific approach to provide a proof of concept around the monitoring technique. Reef Vision using BRUVs has now been expanded to three other artificial reefs in WA and is being trialled on Oyster Reefs in WA and Victoria. The methodology has been requested by interested parties nationally and internationally and the study has been presented in Canada, South East Asia and in Australia. It has been accepted as an effective monitoring technique by the Commonwealth Department of Environment and Energy as well as the academic world.

Desktop Studies

Community monitoring methods were also analysed in ‘desktop studies’ due to the large amount of existing literature on these methods. Since these methods had already been trialled in different studies around the world, project managers decided to not conduct physical trials on the South West Artificial Reefs, instead opting to perform desktop studies. These studies were undertaken by researchers from Murdoch University. Differing variations of monitoring methods were analysed (Tables 15; 16) to evaluate the effectiveness of the technique. A heat map of the effectiveness of each monitoring method against a variety of criteria is provided on the following page, to assess the efficiency of these community monitoring methods is included below. For more information on these different monitoring methods, particularly strengths, limitations and application, please see theses by Florisson (2015) and Walker (2016).

Table 15: Monitoring methods and variations evaluated in the desktop studies.

Categories of fauna and their monitoring methods	Variations
Sessile/sedentary fauna	
Settlement tiles	Direct attachment Raised racks
Visual quadrats	Transect Random
Photo quadrats	Transect Random Photo Point monitoring
Mobile fauna	
Stationary visual census	Nested sampling
Rapid visual technique	
DIDSON acoustic survey	
Sessile/sedentary and mobile fauna	
Visual transects	Point intercept Line intercept
Video transects	
Manta tow	
Towed video	Seabed tow Mid-water tow Towed diver video
Remotely operated underwater video	Linked Autonomous
Environmental DNA analysis	
Extractive methods	Fish trap Trawls Icthyocides Hook and line
Fisher surveys	Onsite surveys Offsite surveys

Table 16: Heat map of the effectiveness of each monitoring method against a variety of criteria (adapted from Walker, 2016) Note: TOWV=Towed Video, ROVs=Remotely Operated Underwater Video and E-DNA=Environmental DNA analysis.

	Artificial Reef Type			Scale			Data	Evaluative Criteria					
	Shallow	Deep	Artificial Seagrass	Broad	Medium	Fine	Quantitative	Deployment	Species Diversity Accuracy	Abundance Accuracy	Precision	Time	Cost
Sessile/Sedentary Fauna													
Settlement Tiles	Very Effective	Neutral	Effective	Very Ineffective	Neutral	Very Effective	Very Effective	Neutral	Effective	Very Effective	Very Effective	Ineffective	Ineffective
Visual Quadrat	Very Effective	Very Ineffective	Very Effective	Very Ineffective	Neutral	Very Effective	Very Effective	Effective	Very Effective	Very Effective	Effective	Neutral	Ineffective
Photo Quadrat	Very Effective	Very Ineffective	Very Effective	Very Ineffective	Neutral	Very Effective	Very Effective	Very Effective	Neutral	Neutral	Effective	Neutral	Ineffective
Transect	Effective	Very Ineffective	Neutral	Very Ineffective	Very Effective	Very Ineffective	Very Effective	Effective	Ineffective	Ineffective	Neutral	Ineffective	Neutral
Video Transect	Effective	Very Ineffective	Effective	Very Ineffective	Very Effective	Very Ineffective	Very Effective	Effective	Neutral	Neutral	Neutral	Ineffective	Ineffective
Manta Tow	Very Effective	Very Ineffective	Very Effective	Very Effective	Neutral	Very Ineffective	Neutral	Effective	Neutral	Neutral	Effective	Effective	Effective
TOWV	Very Effective	Very Effective	Very Effective	Very Effective	Effective	Very Ineffective	Very Effective	Effective	Effective	Effective	Effective	Effective	Neutral
ROVs	Very Effective	Very Effective	Effective	Neutral	Very Effective	Neutral	Effective	Very Effective	Effective	Effective	Effective	Neutral	Effective
E-DNA	Very Effective	Very Effective	Very Effective	Very Effective	Ineffective	Very Ineffective	Very Ineffective	Very Effective	Very Effective	Very Ineffective	Very Effective	Neutral	Effective
Extractive	Very Effective	Very Effective	Very Effective	Very Effective	Neutral	Effective	Effective	Neutral	Neutral	Effective	Effective	Effective	Effective
Fisher Survey	Very Effective	Very Effective	Very Effective	Very Effective	Neutral	Very Ineffective	Very Effective	Very Ineffective	Ineffective	Ineffective	Neutral	Very Ineffective	Very Ineffective
Mobile Fauna													
Stationary Visual Census	Very Effective	Very Ineffective	Very Effective	Very Ineffective	Neutral	Very Effective	Neutral	Very Effective	Neutral	Neutral	Effective	Very Effective	Very Effective
Rapid Visual Technique	Very Effective	Very Ineffective	Very Effective	Very Ineffective	Very Effective	Neutral	Neutral	Very Effective	Neutral	Neutral	Neutral	Very Effective	Very Effective
DIDSON Acoustic Survey	Very Effective	Very Ineffective	Very Effective	Very Effective	Very Effective	Very Ineffective	Very Effective	Very Effective	Neutral	Effective	Neutral	Very Effective	Ineffective
Visual Transect	Very Effective	Very Ineffective	Very Effective	Very Ineffective	Very Effective	Very Ineffective	Very Effective	Effective	Neutral	Effective	Neutral	Ineffective	Neutral
Video Transect	Effective	Very Ineffective	Neutral	Very Ineffective	Very Effective	Very Ineffective	Very Effective	Effective	Neutral	Neutral	Neutral	Ineffective	Ineffective
Manta Tow	Very Effective	Very Ineffective	Very Effective	Very Effective	Neutral	Very Ineffective	Neutral	Effective	Effective	Effective	Neutral	Effective	Effective
TOWV	Very Effective	Very Effective	Very Effective	Very Effective	Neutral	Very Ineffective	Very Effective	Effective	Very Effective	Very Effective	Effective	Effective	Neutral
ROVs	Very Effective	Very Effective	Neutral	Effective	Very Effective	Very Effective	Effective	Very Effective	Effective	Effective	Effective	Effective	Effective
E-DNA	Very Effective	Very Effective	Very Effective	Very Effective	Ineffective	Very Ineffective	Very Ineffective	Very Effective	Very Effective	Very Ineffective	Very Effective	Neutral	Effective
Extractive	Very Effective	Very Effective	Very Effective	Very Effective	Neutral	Effective	Effective	Neutral	Effective	Effective	Effective	Effective	Effective
Fisher Survey	Very Effective	Very Effective	Very Effective	Very Effective	Neutral	Very Ineffective	Very Effective	Very Ineffective	Ineffective	Neutral	Neutral	Very Ineffective	Very Ineffective

Very Effective   Effective   Neutral   Ineffective   Very Ineffective

Conclusion

The physical trials of these HES monitoring techniques embodied in the Reef Vision project evaluated the effectiveness of these methods to meet the Sea Dumping Act monitoring requirements on the Bunbury and Dunsborough artificial reefs (Table 17). The Reef Vision BRUVs component was the most successful for biological/ecological monitoring and can also be used for social, environmental and to some degree, position/structural monitoring methods. The manual observation post was the most effective method for social usage monitoring. While the mapping had potential application, for various reasons both the automated observation post and logbook trials were ineffective monitoring methods in this project (although they have been used effectively elsewhere), yet all of these methods could have potential application with increasing technological advancement and user-friendly formats.

Table 17: The effectiveness of HES monitoring methods trialled. Methods include Baited Remote Underwater Video systems (BRUVs), Logbooks, Manual Observation Posts (MOP), Automated Observation Posts (AOP) and Mapping.

Trial	Purpose	Effectiveness
BRUVs	Biological/Ecological, Social, Structural and Environmental	Very High
Logbooks	Social, Biological/Ecological	Low
MOP	Social	High
AOP	Social	Low
Mapping	Biological/Ecological, Structural and Environmental	Medium

Desktop studies were used to review monitoring methods which large amounts of existing literature or that were unable to be included in the physical trials (such as icthyocides). A range of different methods were analysed including extractive and non-extractive techniques. The effectiveness of these methods had a high level of variability, however most could be utilised on HES. The individual suitability of these methods was highly dependent on scale, HES depth and type and evaluation criteria.

A Citizen Science Program for Monitoring the Fish Faunas of Artificial Reefs using Baited Remote Underwater Video

Introduction

Artificial reefs are widely deployed around the world and are increasingly becoming a part of the seascape in coastal environments, including in Australia (Diplock, 2010; Fabi *et al*., 2015). The term 'artificial reef' is variously used (Seaman and Jensen, 2000), however, most usage falls within the broad definition of Sutton and Bushnell (2007), *i.e.* “one or more objects of natural or human origin deployed purposefully on the seafloor to influence physical, biological or socioeconomic processes related to living marine resources". One of the most common applications is as a tool in fisheries management to improve fishing (Seaman, 2007; Fabi *et al*., 2015; Becker *et al*., 2017) and, in regions such as Australia and the United States of America, particularly recreational fishing (Seaman and Jensen, 2000; Lowry *et al*., 2014). These installations are popular with recreational fishers as they can enhance fishing experiences and catch rates by providing access to target species and, in the longer term, stimulate *in situ* production, thereby increasing total fish stocks (Bohnsack, 1989; Brickhill *et al*., 2005; Cresson *et al*., 2014; Smith *et al*., 2016).

The artificial reefs used in fisheries enhancement in developed countries are now typically purpose-built, rather than constructed from materials-of-opportunity (Diplock, 2010; Lowry *et al*., 2014), ideally with considerable planning directed towards ensuring that the reef design, configuration and location is suited to its designated purpose (Diplock, 2010; Fabi *et al*., 2015). Post deployment of the structures, it is crucial to assess the extent to which a reef is achieving the intended purpose (Seaman and Jensen, 2000; dos Santos and Zalmon, 2015; Becker *et al*., 2017), and to determine the type and magnitude of any environmental impacts (Department of Fisheries, 2012; Department of the Environment, 2016; International Maritime Organization, 2016). Without such an assessment, there is a risk of repeatedly reusing suboptimal or even undesirable reef materials and designs, and incurring large costs in the process (Diplock, 2010). For example, the size, configuration and location of a reef is known to influence the density, biomass, and composition of the fish fauna and the long-term productivity of a reef, as well as fishing effort (Bohnsack *et al*., 1991; Jordan *et al*., 2005; Fabi *et al*., 2015). However, how these interactions manifest is still poorly understood (Diplock, 2010; Lowry *et al*., 2014). Information on the spatial and temporal variability of the fish fauna on an artificial reef can be used to put in place actions that maximise returns from the fish resources on the reef (dos Santos and Zalmon, 2015), to understand ecosystem-level responses of fishes to the reef (Scott *et al*., 2015) and to integrate the reef into a broader management framework (Lowry *et al*., 2014; Fabi *et al*., 2015). Thus, long-term monitoring of the fish assemblages associated with artificial reefs for fisheries enhancement is essential (dos Santos and Zalmon, 2015; Becker *et al*., 2017). This requirement can, however, add considerable costs to an artificial reef project (Fabi *et al*., 2015).

The financial costs of monitoring the fish faunas of an artificial reef could potentially be reduced by involving citizen scientists. Citizen science describes an approach where members of the public, usually non-experts or non-professionals, participate in scientific research or monitoring on a voluntary basis (Chase and Levine, 2016; McKinley *et al*., 2017). This approach has been applied in a variety of settings (Dickinson *et al*., 2012; Cigliano *et al*., 2015; Follett and Strezov, 2015; McKinley *et al*., 2017) and is being increasingly used in natural resource monitoring (Boakes *et al*., 2016; Chase and Levine, 2016). Although the use of citizen science in marine research and monitoring has recently started to gain traction (*e.g.* Fairclough *et al*., 2014; Thiel *et al*., 2014; Anderson *et al*., 2017), Cigliano *et al*. (2015) have pointed out that there is considerable potential to expand in this area. Citizen science monitoring can be a cost-effective method of data collection, whilst also increasing stakeholder engagement and buy-in (Dickinson *et al*., 2010; Fairclough *et al*., 2014; Aceves-Bueno *et al*., 2015; McKinley *et al*., 2017). However, if the program is poorly designed and managed, it can result in unsystematic data collection, leading to uncertainty about the efficacy of the data (Dickinson *et al*., 2010; Boakes *et al*., 2016). It is also important to consider the 'hidden costs' of administering citizen science programs, such as the recruiting, training and retaining volunteers (Thiel *et al*., 2014; McKinley *et al*., 2017). Ultimately, the costs and benefits of using citizen science in natural resource monitoring are context dependent (see Chase and Levine, 2016; McKinley *et al*., 2017). Success or failure will depend on the outcome of the interactions between a range of key variables, such as the type and goals of the monitoring, the tasks and levels of responsibility given to the member of the public and how the project is administered (Chase and Levine, 2016).

The overall objective of this study was to provide a proof of concept of a citizen scientist program (called Reef Vision), where recreational fishers used Baited Remote Underwater Video systems (BRUVs) to monitor the fish fauna of two artificial reefs. These purpose-built reefs were recently deployed in a marine embayment (Geographe Bay) on south-western coast of Australia, with the aim of enhancing recreational fishing opportunities and experiences. A BRUV monitoring method was chosen because it is cost-effective (Cappo *et al*., 2003); relatively robust to user skills and bias (Thompson and Mapstone, 1997); unaffected by depth and time limitations unlike, for example, diver surveys (Willis *et al*., 2000); actively attracts fish to the camera, thereby increasing the chances of observing more fish (Stobart *et al*., 2015); and has been successfully used by scientists to study the fish fauna of artificial reefs (*e.g.* Folpp *et al*., 2013; Scott *et al*., 2015; Becker *et al*., 2017). BRUVs also provide a permanent record of the data, which means that fish identifications and counts can be done later and checked for accuracy by qualified scientists, thus removing a potential source of error from the data set (Cappo *et al*., 2003; Whitmarsh *et al*., 2017). The specific aims of the study were to (i) elucidate whether sufficient quantities of video footage could be collected to constitute an effective monitoring regime; (ii) determine quantitatively the duration of a video that needs to be examined before there is no significant change in the characteristics of the fish fauna; and (iii) investigate whether data of sufficient quality can be extracted from the video footage to enable robust univariate and multivariate analysis of any spatial and/or temporal changes in fish faunal composition.

Materials and Methods

Study Site

The citizen scientists monitored two artificial reefs in Geographe Bay, a shallow, open embayment in south-western Australia (Figure 39). This region experiences a Mediterranean climate, with hot dry summers and cool wet winters (Gentilli, 1971; Belda *et al*., 2014). Geographe Bay is well flushed with ocean water and the salinity is around full-strength seawater throughout the year (Fahrner and Pattiaratchi, 1995). Water temperatures range from a minimum of ~13 °C in winter to maximum of ~26 °C in summer (Australian Institute of Marine Science, 2017). Tides are semi-diurnal with a low range (usually < 1 m, *i.e.* microtidal; Tweedley *et al*., 2016b) and water movement is predominantly wind-driven (Fahrner and Pattiaratchi, 1995; Dunn *et al*., 2014). The substrate consists of unconsolidated sediments over clay and limestone formations, which are exposed in some areas, and seagrass coverage (predominantly Posidonia sinuosa), is extensive throughout much of the bay (McMahon *et al*., 1997; Van Niel *et al*., 2009). Recreational fishing is a popular activity in Geographe Bay (Geographe Catchment Council, 2008).

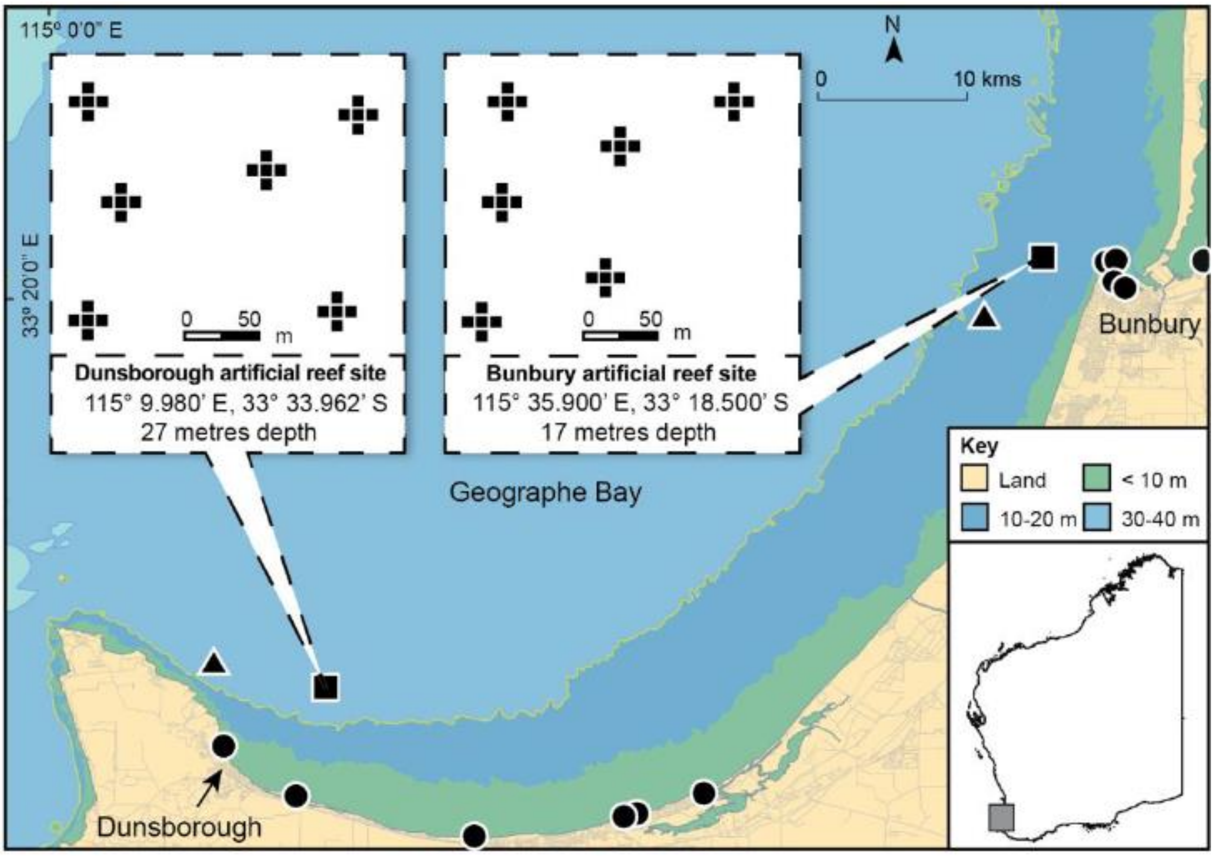


Figure 39: Map showing the location of the Bunbury and Dunsborough artificial reefs in Geographe Bay and the configuration of their 30 concrete FishBox modules into six clusters. Grey square on inset denotes the location of Geographe Bay in WA. ■, purpose-built concrete reef; ▲ sunken ship artificial reef; ●, boat ramp. Map modified from the Department of Primary Industries and Regional Development.

Each of the two artificial reefs comprises 30 'Fish Box™' modules (Figure 42b), placed in six clusters of five units and deployed over a four-hectare area (Figure 39). Each module, which measured $3m^3$ and weighed 10 tonnes was constructed from steel-reinforced concrete with curved cross braces designed to promote upwelling. Both reefs were deployed in April 2013, creating the South West Artificial Reef Trial Project (Tweedley *et al*., 2016a). The reefs were placed in Geographe Bay in the vicinity of two urban centres, *i.e.* Bunbury and Dunsborough (Figure 39), and within 5 km of boat ramps to allow for easy boat-based access by recreational fishers. The Bunbury reef lies at a depth of ~17m, whereas the Dunsborough reef is at ~27m (Figure 39). These reefs were designed to increase the abundance of recreationally-important fish species, such as the sparid *Chrysophorus auratus*, and the carangids Pseudocaranx spp. and *Seriola hippos*, and thus improve recreational fishing opportunities.

Citizen Science Program

Citizen scientists were recruited and managed through a branded citizen science program called 'Reef Vision' (Recfishwest, 2017). Recreational fishers who lived in close proximity to one of the reefs and fished regularly were recruited through a targeted print, radio and social media campaign. Applicants were interviewed to ensure their suitability for the project, *i.e.* they owned a suitable boat and safety equipment, held a valid skipper's licence and fished regularly; with the six most suitable participants recruited to monitor each reef (note this number was selected solely based on the cost of the equipment provided to each participant). Each participant attended a short (2 hour) training workshop held locally in October 2015, where the aims and importance of the research, as well as instructions on how to use the camera equipment, were presented (Figure 40). At the workshop, each volunteer was provided with a BRUV (Figure 42a), waterproof log book, data storage devices, prepaid envelopes, bait vouchers, training manuals and the contact numbers of project staff able to help with any issues (Figure 41 – materials supplied).

Figure 40: Reef Vision training workshop for monitoring the Dunsborough and Bunbury artificial reefs (2015).

Figure 41: The package supplied to volunteers at the workshop including the BRUV unit, promotional material, data storage devices and metadata collection materials.

To facilitate retention, all participants were invited to join a closed Facebook page, which provided a platform for volunteers to interact with each other and project staff. The amount and timing of any monitoring done by a participant was at the discretion of the participant, although it was recommended that each person should monitor one of the artificial reefs for at least one 60-minute period each per month, if possible, over the course of a year (October 2015 to September 2016). While this flexibility had the potential to impact on the number of videos collected, it was preferred to a more regimented approach, which has been shown to result in low recruitment and retention rates in other citizen science projects (Dickinson *et al*., 2010).

The BRUVS (Figure 42a) employed in Reef Vision were designed by Ecotone Consulting and constructed from readily available materials to increase cost-effectiveness and ease of use by volunteers (Florisson, 2015; Tweedley *et al*., 2016a). Each BRUV frame was constructed from Polyvinyl Chloride (PVC) irrigation pipe (rated to 891 kPa) and PVC cement, and covers an area of ~580 mm x 450 mm. The frame was connected to two stabilising skids, each filled with four 680 g lead weights to ensure the unit was negatively buoyant (5.5 kg total weight) and did not fall over upon landing on the substratum. A GoPro Hero 4 Silver Action Camera, which has an ultra-wide angle lens and the ability to record video footage with resolution of 1080 p at 60 frames per second, was mounted on the pipe using brackets. The camera was equipped with a waterproof housing rated to 40 m. A bait arm, with a length of 600 mm from the BRUV central point, and a plastic mesh bait bag (180 mm x 100 mm) placed 500 mm from the camera, was suspended 150 mm above the seafloor. These dimensions are consistent with those used in other BRUV studies (*e.g.* Ellis and DeMartini, 1995; Willis and Babcock, 2000; Heagney *et al*., 2007). To aid BRUV deployment and retrieval, a 35 m rope and float was attached to a tie point (stainless steel loop) in the central PVC cross brace. Each of the twelve BRUVs cost a total of AUD$685 to produce. The largest individual cost was the labour required to construct the BRUV ($315), followed by the GoPro camera and SD card ($254), with the material needed to build the frame and attachments (ropes, floats, boom and bait bag) only costing $116 (17% of the total unit cost).

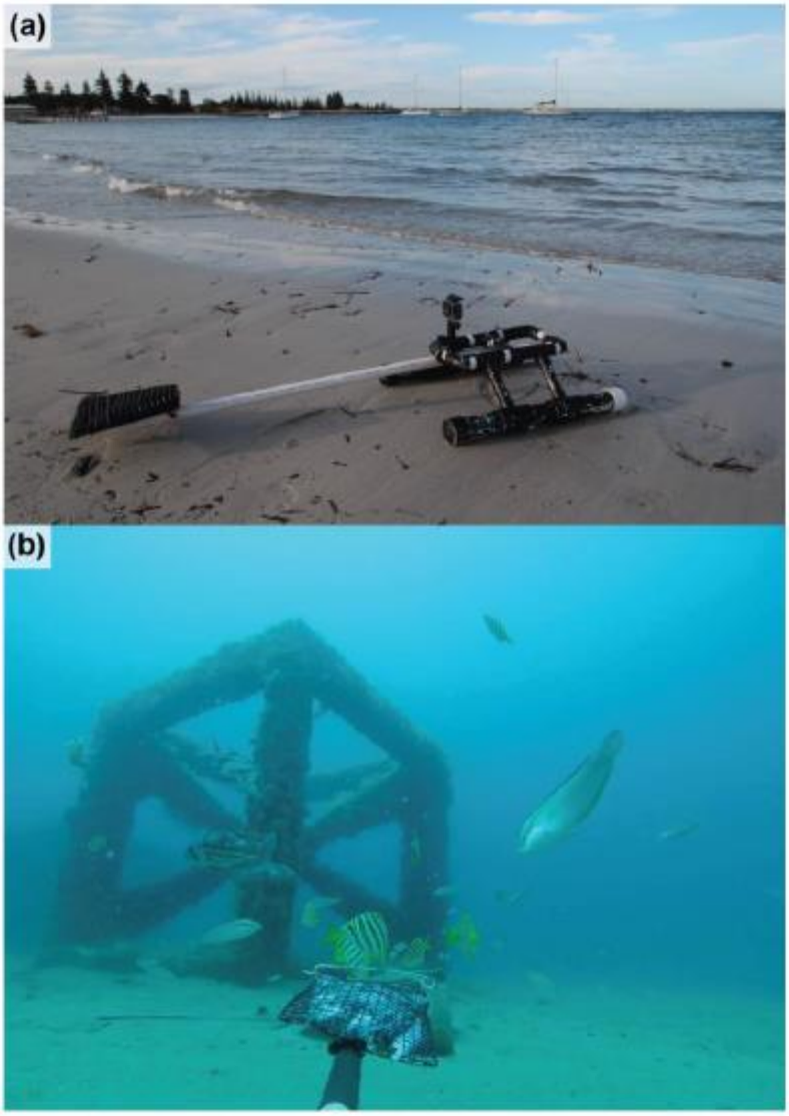


Figure 42: Photographs of (a) the BRUVs supplied to Reef Vision participants and (b) a screenshot of footage collected from the Dunsborough Artificial Reef using the BRUV in (a). Footage in b shows 10 *Coris auricularis*, 10 *Neatypus obliquus*, 2 Pseudocaranx spp., 1 *Pentaceropsis recurvirostris*, 1 *Glaucosoma hebraicum* and 1 *Myliobatis australis*.

Sampling Methodology

Following training, participants began to deploy BRUVs on the two artificial reefs in October 2015. On each sampling trip to their assigned reef (either Bunbury or Dunsborough), a volunteer was asked to deploy the BRUV on one of the six clusters (chosen randomly) for at least 60 minutes and fill out a log book. The book contained the date and time the BRUV was deployed and retrieved, the latitude and longitude of the deployment, cluster number and any other observations (*e.g.* how many people were fishing and what fish they caught). Prior to deployment, 500g of Australian Sardine *Sardinops sagax* was placed in the bait bag of the BRUV, as the soft oily flesh of this species is known to attract fish. This fish is regarded as the most effective bait for BRUVs in WA (Watson *et al*., 2010; Goetze *et al*., 2011; Dorman *et al*., 2012; Mallet and Pelletier, 2014). Once back onshore, participants downloaded the video footage on to a USB drive and posted it, together with the corresponding log-book sheet, to project staff at Murdoch University using the pre-paid envelope. Volunteers were encouraged to watch their videos and could share footage (Figure 42b) on social media, particularly the closed project Facebook page.

Data Extraction

Prior to analysis, each video was examined to determine the quality of the footage. Videos in which the camera faced into the sediment or towards the surface of the water (less than 5% of all videos) were excluded. Excluded footage could be reduced by different camera mounting frames and deployment methodology. One video was selected, at random, from each reef, in each month between October 2015 and September 2016 for analysis (*i.e.* 12 videos per reef, total of 24). The MaxN, *i.e.* the maximum number of individuals of a particular species seen in any one video frame (Figure 42b; Whitmarsh *et al*., 2017), was recorded for each five-minute interval of each video from the moment the BRUV touched the substrate until 60 minutes later. Taxa were identified to the lowest possible taxonomic level, typically species.

Statistical Analysis

Soak Time Analyses

A suite of univariate and multivariate statistical analyses were employed to determine the length of video that needed to be observed before the characteristics of the fish fauna exhibited no significant change with increasing time. The MaxN of each species in each five-minute interval of each of the 12 videos collected from each of the two reefs were subjected to the DIVERSE routine in PRIMER v7 (Clarke and Gorley, 2015) to calculate the number of species, total MaxN (*i.e.* the sum of the MaxN values for individual species) and Simpson's Diversity Index. The resultant 288 values (*i.e.* 24 videos [12 per reef] x 12 five minute intervals) for each of the three univariate variables were then averaged to provide a single value for each variable in each five-minute interval at each reef and thus remove any potentially confounding influence of month. Increases in the mean for each of the three univariate variables with increasing five minute time intervals were plotted as rarefaction curves (Ugland *et al*., 2003).

Changes in species composition over time on each reef were also examined. In this case, the MaxN values of each species in each five-minute interval at each reef were firstly dispersion weighted, by dividing the counts for each species by their mean index of dispersion, *i.e.* the average of the variance to mean ratio in replicate videos (Clarke *et al*., 2006). This pre-treatment then ensures all species have equivalent variability by down-weighting the abundances of heavily-schooling species, such as the carangid *Trachurus novaezelandiae*, whose numbers are erratic over replicate videos relative to those species which return more consistent values, *e.g.* the aracanid *Anoplocapros amygdaloides* (Veale *et al*., 2014; Potter *et al*., 2016). These dispersion-weighted data were then square-root transformed to balance the contribution of relatively abundant species, compared to those with lower MaxN values (Clarke *et al*., 2014a). The transformed data for each five-minute interval were then averaged across the 12 replicates for each reef and used to construct a Bray-Curtis resemblance matrix. This matrix was subjected to hierarchical agglomerative clustering (CLUSTER; Clarke *et al*., 2014a) to determine the time intervals that were ≥95 % similar in terms of their species composition. The matrix was also used to construct a non-metric Multi-Dimensional Scaling (nMDS) ordination plot (Clarke, 1993), which provides a visual representation of the changes in fish faunal composition over time for both reefs.

The dispersion-weighted and square-root transformed MaxN data for each time interval on each reef were used to construct a shade-plot (Clarke *et al*., 2014b). The shade plot is a visualization of the averaged data matrix, where a white space for a species demonstrates that the fish was not recorded, while the depth and colour of shading, ranging from grey shades through the spectrum to black, represents increasing values for the abundance of that species in that time interval. The averaged samples (x axis of the plot) are ordered from lowest to highest time interval for each reef. Species (y axis of the plot) are ordered to optimise the seriation statistic ρ by non-parametrically correlating their resemblances to the distance structure of a linear sequence and constrained by a cluster dendrogram (Clarke *et al*., 2014a).

Differences in Fish Fauna between Artificial Reefs and Seasons

On the basis of the above analysis, a video interval of 45 minutes was deemed appropriate to provide a robust determination of the fish fauna present on each of the artificial reefs (see Results). Thus, the MaxN of each species after 45 minutes from each reef in each of the 12 months were extracted from the above dispersion-weighted and square-root transformed data. These data were used by DIVERSE to calculate the number of species, total MaxN and Simpson's diversity index. Prior to subjecting the data for each variable to Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson *et al*., 2008) in Primer v7, each variable was tested to ascertain if a transformation was required to meet the test assumptions of homogeneity of variance and normality. This was achieved by plotting the loge mean against the loge standard deviation of every group of samples and determining the slope of the relationship, comparing it to the criteria in Clarke *et al*. (2014a). This analysis indicated that only total MaxN required transformation and was loge(X+1) transformed. The data for each of the three dependent variables were used to construct a Euclidean distance matrix, which were, in turn, subjected to a two-way PERMANOVA to determine if the values for that variable differed significantly between Reef (2 levels; Bunbury and Dunsborough) and Season (2 levels; Summer [October-March] and Winter [April-September]). In these, and all subsequent tests, the null hypothesis of no significant difference among a priori groups was rejected if the significance level (P) was ≤ 0.05.

The dispersion-weighted and square-root transformed species composition data were used to construct a Bray-Curtis resemblance matrix, which was subjected to the same two-way PERMANOVA design used above. In this analysis PERMANOVA was primarily used to test for the presence of an interaction and a subsequent two-way Analysis of Similarities (ANOSIM; Clarke and Green, 1988) test used to determine the relative size of the overall Reef and Season effects on fish faunal composition using the universally scaled R statistic (Lek *et al*., 2011). An nMDS ordination plot was constructed from the above resemblance matrix to show the extent to which fish faunal composition differed between the reefs. To simplify and further illustrate the differences between Reef and Season, a centroid nMDS plot was produced using a distances among centroids matrix, which creates averages in the 'Bray-Curtis space' from the six replicate samples representing each season in each reef (Lek *et al*., 2011). A shade plot was constructed from the transformed and averaged data matrix to illustrate the trends exhibited by species with respect to Reef and Season. Note that as 44 species were recorded, many of which only occurred in a few samples, the shade plot was restricted to those 18 and 17 species that represented >2.5 % of the total fish abundance in a reef and season, respectively.

Results

Citizen Science Data Collection

Twelve main volunteers were utilised in the project, with six monitoring each of the two artificial reefs, and a further 20 participants involved as crew members. Over the course of the year-long study (October 2015 to September 2016) there was an attrition rate of 16%, with two of the 12 volunteers leaving the project due to unrelated issues (*i.e.* receiving employment in other parts of WA and ill health). These two volunteers were replaced with two new and trained personnel to ensure the quality and quantity of footage collected was maintained.

Throughout the sampling period 59 and 52 individual videos were collected from the Bunbury and Dunsborough artificial reefs, respectively, totalling ~10,000 minutes of footage (Table 18). At least four videos were recorded from each reef in each month with the exception of June and August in Bunbury and June and September in Dunsborough. In no months were data not collected from each reef. Typically, greater numbers of videos were collected in between November to March, *i.e.* around the austral summer, with fewer video collected in the austral winter (June and August; Table 18).

Table 18: The total number of videos (> 1 h in length) received from Reef Vision volunteers for each of the Bunbury and Dunsborough artificial reefs in each month between October 2015 and September 2016.

Artificial Reef	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Bunbury	3	14	5	8	7	6	4	5	1	5	1	5	**59**
Dunsborough	5	4	7	8	6	6	4	5	2	5	4	1	**52**
Total	**8**	**18**	**12**	**16**	**13**	**12**	**8**	**10**	**3**	**10**	**5**	**6**	**111**

Fish Faunal Composition

A total of 44 species, representing 29 families were recorded from the 24 videos from the two artificial reefs (Table 19). Five species, each of which contributed ≥10% to the total MaxN, comprised the majority of the assemblage (77% of all individuals). These comprised the pempherid *Parapriacanthus elongatus*, which lives in close association to the reef modules, the epibenthic kyphosid *Neatypus obliquus* and labrid *Coris auricularis*, and the pelagic carangids *Trachurus novaezelandiae* and Pseudocaranx spp. (Table 19). This latter taxon, which was a target group for the reefs, ranked third in terms of MaxN and was recorded in 75% of all videos. Other recreationally-targeted species recorded included *Seriola hippos*, *Chrysophrys auratus* (both also target species), *Glaucosoma hebraicum* and *Choerodon rubescens*. In addition to Pseudocaranx spp., other species that were frequently recorded included *C. auricularis* and *A. amygdaloides* (Table 19).

Figure 43: Three of the most common species which comprised 77% of the assemblage, including Pseudocaranx spp., *N. obliquus* and *C. auricularis*.

Table 19: Mean MaxN abundance (N), standard error (SE), percentage contribution (%), cumulative percentage contribution (C%) of each species from the 24 videos recorded by BRUVs on the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. The number of videos in which each species was recorded (F) and the frequency of occurrence (%F) are also provided, as it is the family to which each species belongs. Species representing > 5 % in terms of % (Abundance) or %F (Occurrence) are highlighted in grey. * denotes that a species is targeted by recreational fishers.

		Abundance				Occurrence	
Species	**Family**	**N**	**SE**	**%**	**C%**	**F**	**%F**
Parapriacanthus elongatus	Pempheridae	21.21	18.80	29.51	29.51	2	8.33
Neatypus obliquus	Kyphosidae	9.46	2.31	13.16	42.67	15	62.50
Pseudocaranx spp.*	Carangidae	8.75	2.98	12.17	54.84	18	75.00
Coris auricularis	Labridae	8.17	1.27	11.36	66.20	22	91.67
Trachurus novaezelandiae	Carangidae	8.00	6.92	11.13	77.33	2	8.33
*Seriola hippos**	Carangidae	2.88	1.06	4.00	81.33	20	83.33
Parequula melbournensis	Gerreidae	1.83	0.42	2.55	83.88	15	62.50
Pempheris klunzingeri	Pempheridae	1.71	1.01	2.38	86.26	3	12.50
Anoplocapros amygdaloides	Aracanidae	1.83	0.34	2.55	88.81	19	79.17
Austrolabrus maculatus	Labridae	1.13	0.33	1.57	90.38	10	41.67
Diodon nicthemerus	Diodontidae	0.58	0.46	0.81	91.19	3	12.50
Chelmonops curiosus	Chaetodontidae	0.67	0.17	0.93	92.12	11	45.83
Parapercis haackei	Pinguipedidae	0.46	0.12	0.64	92.75	10	41.67
Myliobatus australis	Myliobatidae	0.58	0.13	0.81	93.57	12	50.00
Trygonorrhina fasciata	Rhinobatidae	0.54	0.15	0.75	94.32	10	41.67
*Pentaceropsis recurvirostris**	Pentacerotidae	0.33	0.14	0.46	94.78	5	20.83
*Arripis truttaceus**	Arripidae	0.25	0.25	0.35	95.13	1	4.17
Cheilodactylus gibbosus	Cheilodactylidae	0.29	0.11	0.41	95.54	6	25.00
*Glaucosoma hebraicum**	Glaucosomatidae	0.21	0.08	0.29	95.83	5	20.83
*Choerodon rubescens**	Labridae	0.25	0.09	0.35	96.17	6	25.00
Anoplocapros lenticularis	Aracanidae	0.21	0.08	0.29	96.46	5	20.83
Chromis westaustralis	Pomacentridae	0.17	0.17	0.23	96.70	1	4.17
Monocanthidae spp.	Monocanthidae	0.29	0.09	0.41	97.10	7	29.17
Suezichthys cyanolaemus	Labridae	0.21	0.08	0.29	97.39	5	20.83
Parapercis ramsayi	Pinguipedidae	0.21	0.08	0.29	97.68	5	20.83
Dasyatis brevicaudata	Dasyatidae	0.21	0.08	0.29	97.97	5	20.83
Chaetodon assarius	Chaetodontidae	0.13	0.09	0.17	98.14	2	8.33
Notolabrus parilus	Labridae	0.13	0.07	0.17	98.32	3	12.50
Tilodon sexfasciatus	Kyphosidae	0.17	0.08	0.23	98.55	4	16.67
*Chrysophrys auratus**	Sparidae	0.17	0.12	0.23	98.78	2	8.33
Pempherididae spp.	Pempherididae	0.08	0.08	0.12	98.90	1	4.17
Upeneichthys vlamingii	Mullidae	0.08	0.06	0.12	99.01	2	8.33
Trygonoptera mucosa	Urolophidae	0.08	0.06	0.12	99.13	2	8.33
*Platycephalus longispinis**	Platycephalidae	0.08	0.06	0.12	99.25	2	8.33
Aptychotrema vincentiana	Rhinobatidae	0.13	0.07	0.17	99.42	3	12.50
Trygonoptera personata	Urolophidae	0.08	0.06	0.12	99.54	2	8.33
Eubalichthys mosaicus	Monacanthidae	0.04	0.04	0.06	99.59	1	4.17
Apogon victoriae	Apogonidae	0.04	0.04	0.06	99.65	1	4.17
Orectolobus maculatus	Orectolobidae	0.04	0.04	0.06	99.71	1	4.17
Enoplosus armatus	Enoplosidae	0.04	0.04	0.06	99.77	1	4.17
Notolabrus angustipes	Labridae	0.04	0.04	0.06	99.83	1	4.17
Aracana aurita	Aracanidae	0.04	0.04	0.06	99.88	1	4.17
*Mustelus antarcticus**	Triakidae	0.04	0.04	0.06	99.94	1	4.17
*Achoerodus gouldii**	Labridae	0.04	0.04	0.06	100.00	1	4.17

Soak Time Analyses

Rarefaction curves for each of the mean number of species, total MaxN and Simpson's diversity index for both the Bunbury and Dunsborough artificial reefs reached an asymptote prior to the 60-minute mark (Figure 44). Approximately 95% of maximum values for each univariate variable recorded from the videos from each reef was achieved after ≤45 minutes, with the exception of total MaxN at Bunbury (92% and 95% at 45 and 50 minutes, respectively). Moreover, the timing at which the asymptote occurred was similar among the two reefs, despite the values for the number of species and total MaxN always being greater at Dunsborough, whereas the reverse was typically true for Simpson's diversity index (Figure 44).

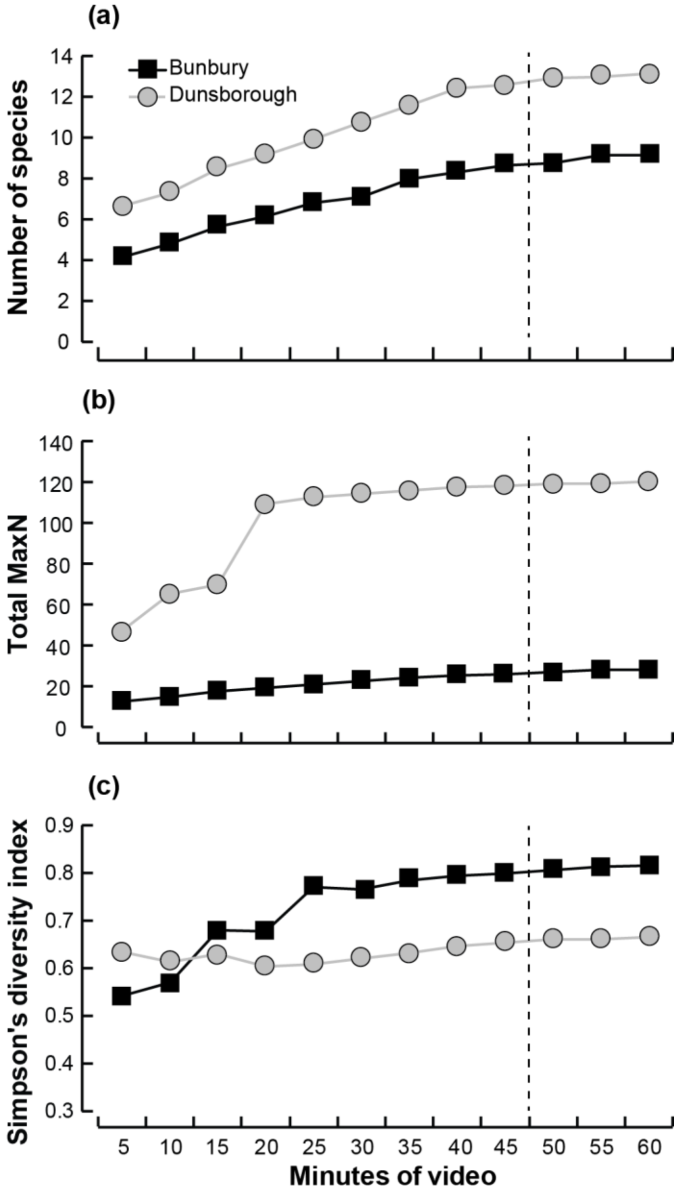


Figure 44: Rarefaction curves for the (a) mean number of species, (b) total MaxN and (c) Simpson's diversity index from consecutive five minute intervals of BRUV footage recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. Vertical dashed line denotes 45 minutes.

A clear pattern of increasing similarity in fish faunal composition among samples for each reef was detected as the duration of the video increased. Thus, for both reefs, samples at 5 and 10 minutes were the most distinct (~75% similarity), whereas those samples derived from video footage at between 40 and 60 minutes were all >95% similar (Figure 45a). As with the univariate variables, similar trends among times were detected for both reefs, despite the fish fauna of the two reefs having a relatively low similarity (58%). In other words, larger differences in fish fauna composition were detected between reefs, than among time intervals within a reef, with the same temporal pattern occurring on both reefs. This is shown on the associated nMDS plot, where the samples representing the different time intervals are well separated for each reef, but show the same pattern of increasing proximity to one another with increasing time (Figure 45b).

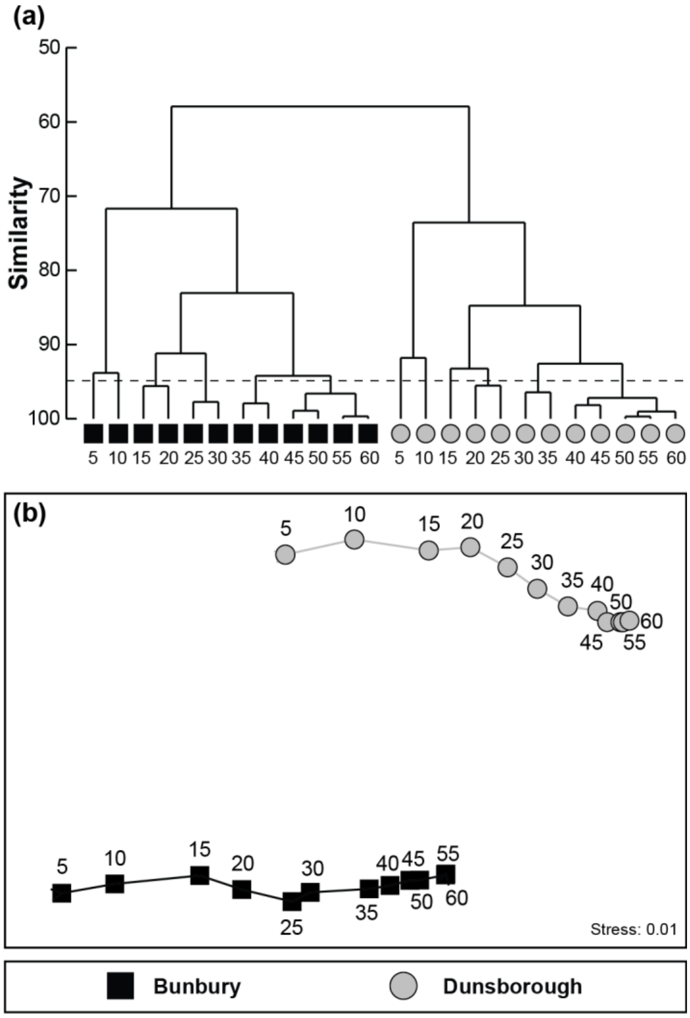


Figure 45: Cluster dendrogram (a) and nMDS ordination plot (b), derived from a Bray-Curtis resemblance matrix, constructed from the dispersion-weighted and square-root transformed and averaged MaxN abundances of each species recorded from consecutive five minute intervals of BRUV footage recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. Horizontal dashed line denotes a Bray-Curtis similarity of 95%.

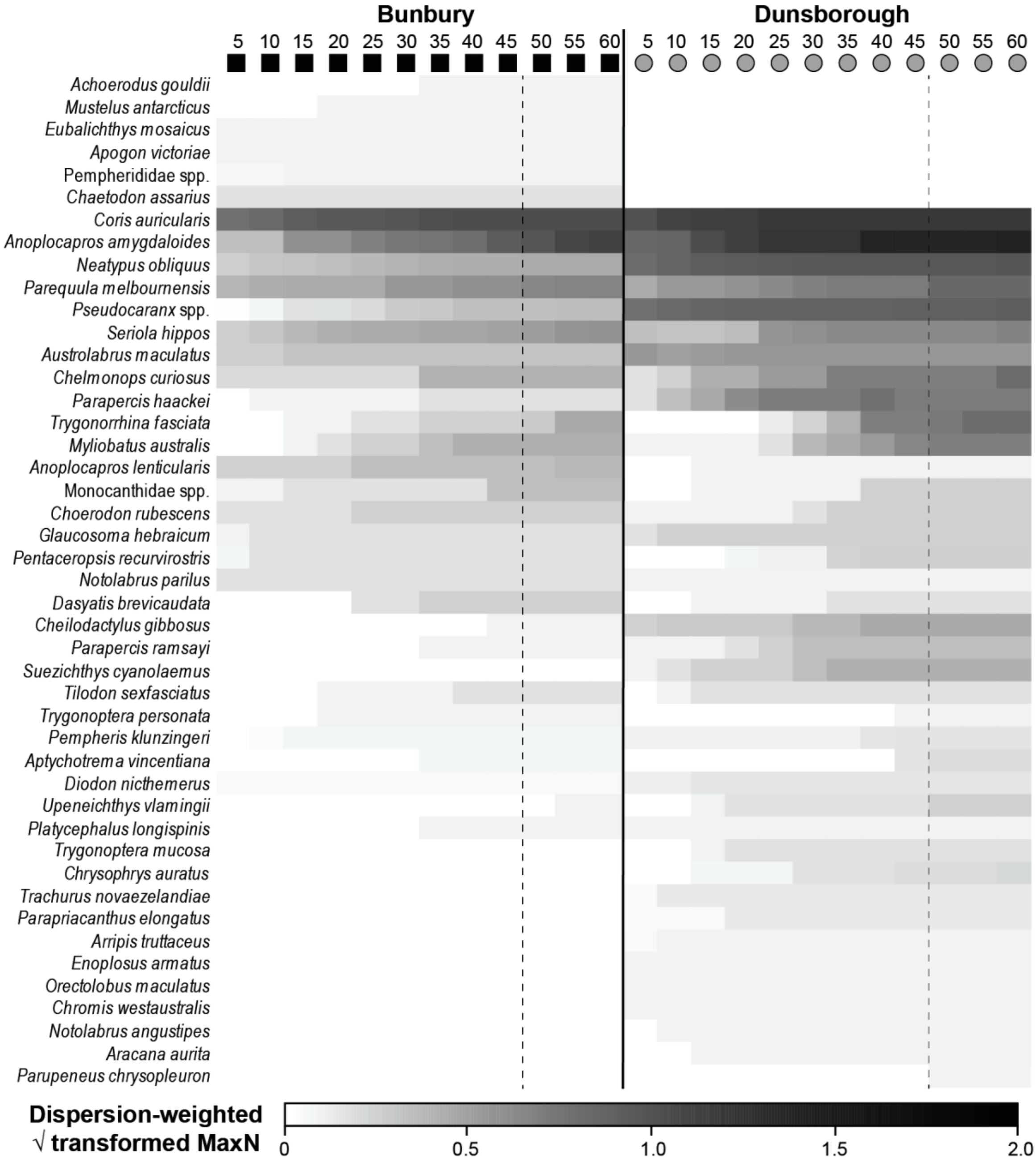


Figure 46: Shade plot, constructed from the dispersion-weighted, square-root transformed and averaged MaxN abundances of each species recorded from consecutive five minute intervals of BRUV footage recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. Vertical dashed line denotes 45 minutes.

The shade plot illustrates that only the mullids *Upeneichthys vlamingii* (Bunbury) and *Parupeneus chrysopleuron* (Dunsborough) were recorded for this first time after 45 minutes, albeit their MaxN values were very low (Figure 46). For most species, including abundant ones such as *C. auricularis,* Pseudocaranx spp. and *N. obliquus*, their MaxN values changed little with increasing time. Moreover, even for those species whose abundance on both reefs did change with increasing time, *e.g. A. amygdaloides* and the gerried *Parequula melbournensis*, these values changed little after 45 minutes (Figure 46).

The above results suggest that 95% of the maximum values for the number of species, Simpson's diversity index, fish faunal composition and, to a lesser extent, total MaxN occur within 45 minutes of video footage. Thus, in the case of the Bunbury and Dunsborough artificial reefs, faunal data extracted from 45 minutes of BRUV footage is sufficient to determine accurately the univariate and multivariate characteristics of the fish fauna.

Differences in Fish Fauna between Artificial Reefs and Seasons

Two-way PERMANOVA demonstrated that the number of species and total MaxN differed significantly between reefs and seasons, but note the Reef × Season interaction (Table 20a,b). The number of species was greater on the Dunsborough than Bunbury artificial reef and during summer rather than winter (both ~13 versus 9; Figure 47a,b). Total MaxN values were more than four times larger at Dunsborough (118) than Bunbury (26) and almost three times greater in samples collected in summer (104) as opposed to winter (40). A significant difference between the values for Simpson's diversity index was detected only between reefs (Table 20c), with values in winter being higher than those summer (0.80 and 0.65, respectively; Figure 47e).

Table 20: Mean squares (MS), percentage of the MS to the total (%MS), pseudo-F (pF) and significant level (P) for two-way PERMANOVAs tests on the (a) number of species, (b) total MaxN, (c) Simpson's diversity index and the (d) fish faunal composition of the two artificial reefs in the two seasons. Significant differences are highlighted in bold. df = degrees of freedom.

(a) Number of species	*df*	**MS**	**%MS**	***pF***	***P***
Reef	1	**96.00**	**50.63**	**6.80**	**0.026**
Season	1	**73.50**	**38.76**	**5.21**	**0.034**
Reef × Season	1	6.00	3.16	0.43	0.516
Residual	20	14.12	7.45		

(b) MaxN	**df**	**MS**	**%MS**	***pF***	***P***
Reef	1	**10.07**	**65.88**	**22.76**	**0.001**
Season	1	**4.13**	**27.03**	**9.34**	**0.005**
Reef × Season	1	0.64	4.19	1.45	0.256
Residual	20	0.44	2.89		

(c) Simpson's index	**df**	**MS**	**%MS**	***pF***	***P***
Reef	1	**0.13**	**61.91**	**5.96**	**0.022**
Season	1	0.06	27.54	2.65	0.119
Reef × Season	1	0.00	0.18	0.02	0.892
Residual	20	0.02	10.38		

(d) Faunal composition	**df**	**MS**	**%MS**	***pF***	***P***
Reef	1	**3560**	**24.23**	**1.95**	**0.036**
Season	1	**5955**	**40.53**	**3.26**	**0.003**
Reef × Season	1	3348	22.79	1.83	0.065
Residual	20	1829	12.45		

Fish faunal composition was shown by PERMANOVA to differ between reefs and seasons and that there was no interaction between these main effects (Table 20d). The $\bar{R}$ statistic value for Season (0.303) was larger than that for Reef (0.255), indicating that temporal rather than spatial effects were slightly more influential in structuring the fish assemblages of the artificial reefs. This is shown on the nMDS plots where the points representing summer and winter typically form more discrete groups than those for the two artificial reefs (Figure 48). Species such as *C. auricularis*, Pesudocaranax spp., *C. rubescens* and *G. hebraicum* were more abundant in summer than winter, whereas the reverse was true for *A. amygdaloides*, *S. hippos* and the labrid *Austrolabrus maculatus* (Figure 49a). Although both artificial reefs contained substantial numbers of *C. auricularis* and *A. amygdaloides*, fish such as *N. obliquus*, Pseudocaranx spp. and the pinguipedid *Parapercis haackei* were more abundant at the Dunsborough Artificial Reef. In contrast, only the relatively uncommon aracanid *Anoplocapros lenticularis* was comparatively more abundant on the Bunbury artificial reef (Figure 49b).

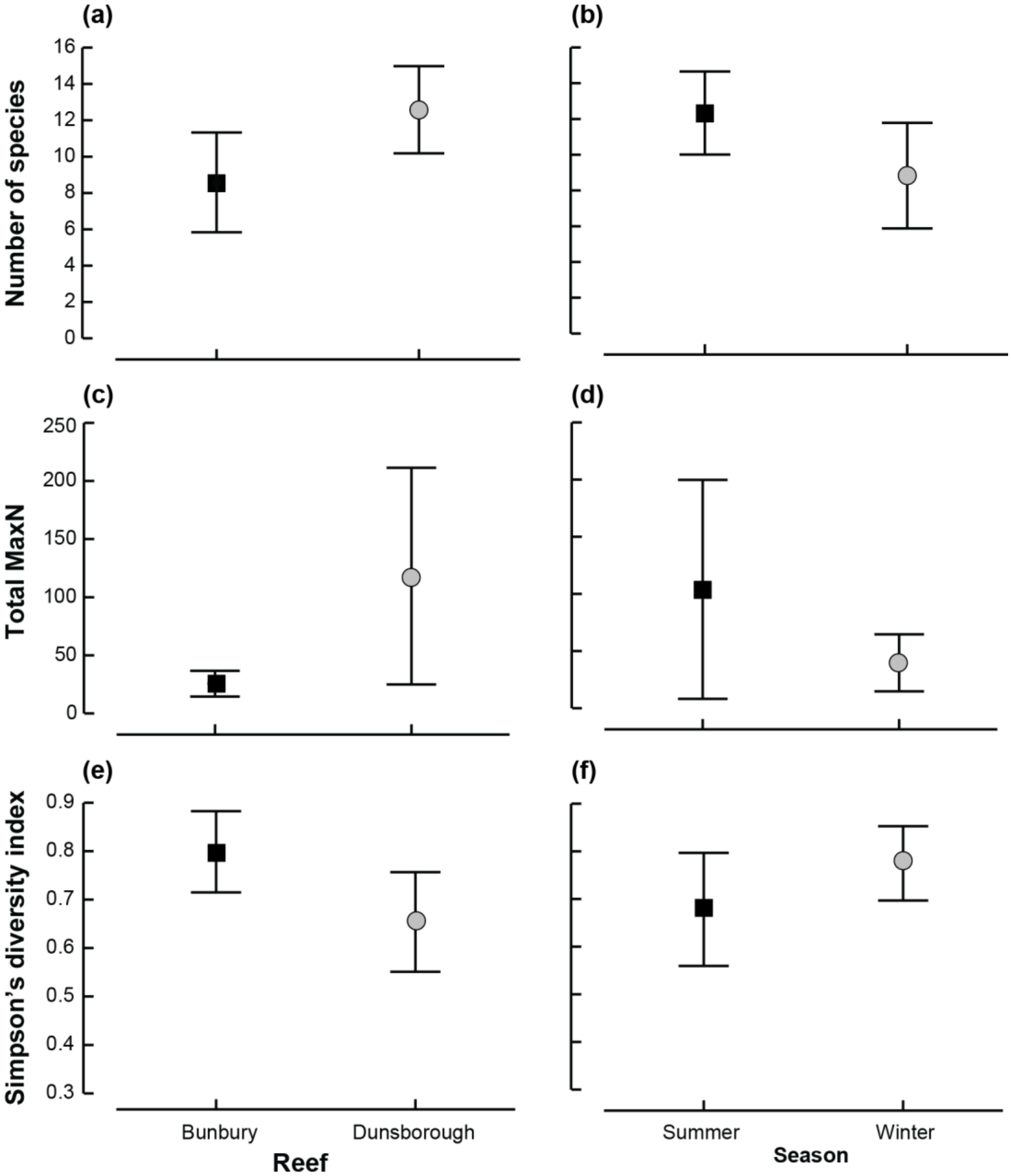


Figure 47: (a, b) Mean number of species, (c, d) total MaxN and (e, f) Simpson's diversity index recorded between reefs and seasons. Error bars represent ± 95% confidence intervals.

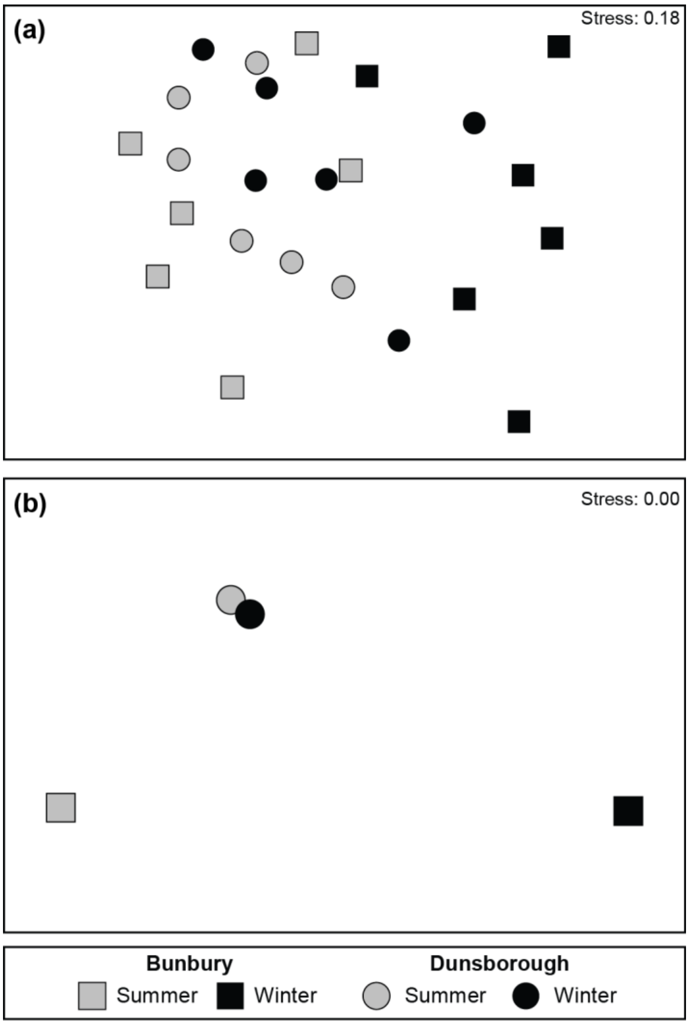


Figure 48: (a) nMDS ordination plot, derived from a Bray-Curtis resemblance matrix, constructed from the dispersion-weighted and square-root transformed and averaged MaxN abundances of each species recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. (b) Centroid nMDS ordination plot, derived from a distance among centroids matrix, constructed from the above Bray-Curtis resemblance matrix.

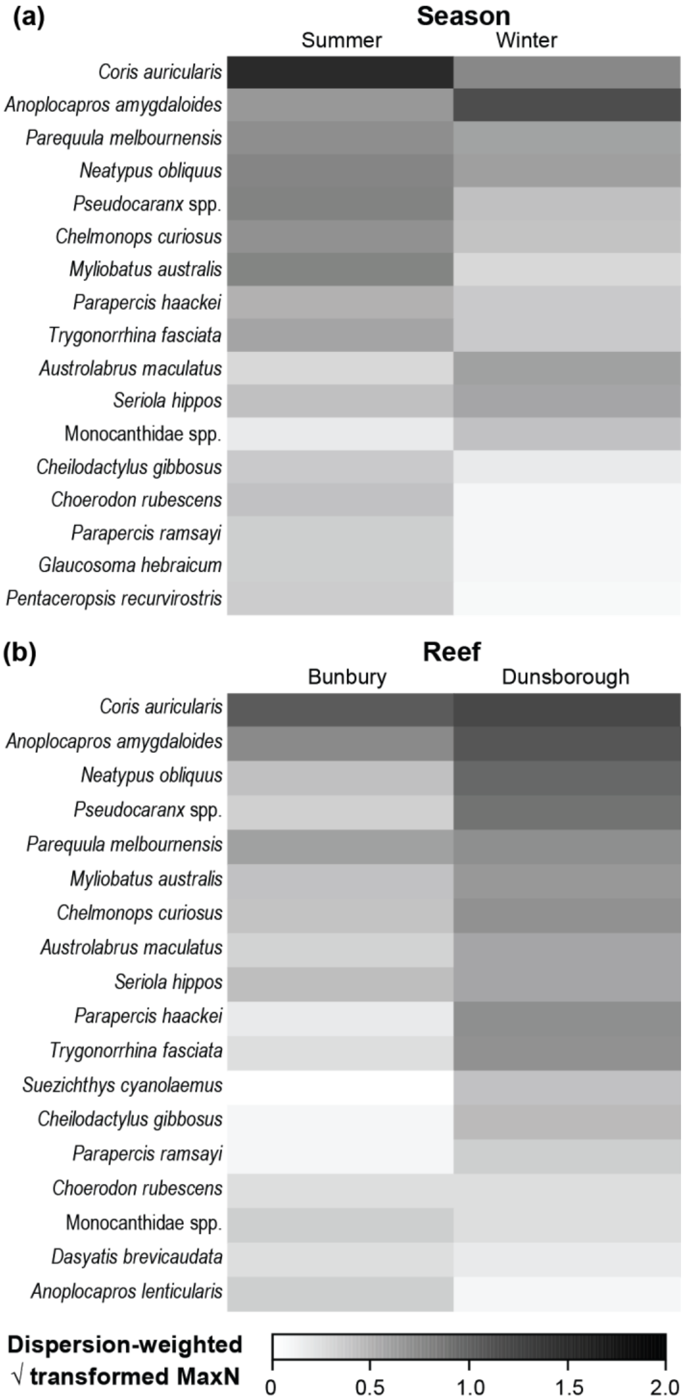


Figure 49: Shade plots constructed from the dispersion-weighted and square-root transformed MaxN abundances of each species recorded from the Bunbury and Dunsborough artificial reefs between October 2015 and September 2016. MaxN abundances averaged for the (a) two seasons and (b) artificial reefs. Note only species that contributed ≥2.5% to the total number of fish to either reef or season are included.

Discussion

There has been a marked increase in the number of artificial reefs being deployed to boost catches of key recreationally-targeted fish species and thus also act as a tool for fisheries and broader ecosystem management by shifting fishing pressure and enhancing ecosystem services (Baine, 2001; Seaman, 2007; Diplock, 2010). Any responsible artificial reef deployment should have clear and measurable performance goals, the successes of which are evaluated using a monitoring program (Becker *et al*., 2017). However, given the fact that longer term monitoring programs, *i.e.* those lasting several years, are required to gain a sound understanding of the influence of these artificial structures (*e.g.* Coll *et al*., 1998; Relini *et al*., 2002; dos Santos and Zalmon, 2015), there is a need to develop cost-effective monitoring regimes. This study determined that citizen scientists using BRUVs could collect sufficient quantities of adequate quality data to develop a robust monitoring program for two artificial reefs in a marine embayment in south-western Australia. It follows that this methodology could be used to help to monitor and determine the effectiveness of other artificial reefs in achieving their aims and goals.

Participant Involvement

Each of the 12 main volunteers were asked to each collect a single video of at least 60 minutes duration from their respective reef in each month of the study using the supplied BRUV equipment. If completed successfully, this would provide six replicates from each reef in each month and thus allow for robust statistical examination of the resultant data. Throughout the sampling period, volunteers were able to effectively collect data from both artificial reefs, amassing a total of 111 videos (averaging 4.9 and 4.3 per month from the Bunbury and Dunsborough reefs, respectively). This success is consistent with other studies employing citizen science, which suggest that this method can result in the collection of large quantities of data over broad spatial and temporal scales, which could otherwise be cost-prohibitive (Silvertown, 2009; Dickinson *et al*., 2010; Pecl *et al*., 2014). Moreover, despite, due to financial limitations, only having six volunteers per reef, at least four videos were collected from a reef in 19 of the 24 reef and month combinations. The months when less than the targeted number of samples were obtained occurred either at the start of the project, while participants were still being trained, or around the austral winter during prolonged periods of poor weather and sea-state. This shows that our participants were actively engaged in the project, but also the value in having as many volunteers as is practically and financially possible. Note however, unlike many citizen science projects, where participants use their own equipment (*e.g.* a smartphone) or are provided with online or printed material (Johnson and Johnston, 2013; Pecl *et al*., 2014; Jenkins *et al*., 2017; Tweedley *et al*., 2017), the current study had to supply volunteers with relatively expensive equipment, which limited participant numbers.

All volunteers recruited to Reef Vision were avid recreational fishers (20% were also SCUBA divers) who lived in the vicinity of the reefs. Participants with these interests were sought out for the project, due to them being frequent users of the artificial reefs and thus able to deploy the BRUVs regularly, but also having extensive knowledge of the local conditions and commonly encountered fish species. Recruiting these types of volunteers increased engagement, thus reducing attrition and helped ensure the provision of regular videos and that safety was not compromised.

Although there has often been stigma about quality of the data provided by citizen science, as it is not collected by experts (Conrad and Daoust, 2008; Dickinson *et al*., 2010), the use of video prevents this issue influencing the resultant data. Thus, unlike observation counts (*e.g.* underwater visual census) and similar *in situ* data collection methods, video footage is able to be permanently archived and analysed by experts (as in the case of the current study) and any footage can be replayed and reanalysed in the future (Willis *et al*., 2000; Tessier *et al*., 2005; Mallet and Pelletier, 2014).

Soak Time Analyses

For a faunal monitoring regime to be successful, it must provide accurate data on abundance of each species, whilst, at the same time, being relatively economical. Although many studies have cited the cost-effectiveness of BRUVs in comparison to visual surveys, mainly due to the reduction fieldwork time (*e.g.* Cappo *et al*., 2003; Watson *et al*., 2005; Langlois *et al*., 2010), the time required to extract the data from the video footage can be considerable (Francour *et al*., 1999; Stobart *et al*., 2007). An obvious way of reducing this cost is to decrease the soak time of the BRUV. However, Gladstone *et al*. (2012) showed that greater improvements in precision occurred from increasing soak time rather than replication. In the current study, a soak time of 45 minutes was found to provide a statistically robust estimation of the abundance, diversity and composition of the fish fauna of the artificial reefs in Geographe Bay.

Whitmarsh *et al*. (2017) in a meta-analysis of 161 BRUV studies found that cameras were deployed between 15 minutes and 120 minutes, with peaks in frequency of 30, 60 and 90 minutes. While the value of 45 minutes calculated in the current study was similar to that recorded for demersal species in Hawaiian coastal waters (Misa *et al*., 2016), it is substantially greater than that for natural and artificial reefs in estuarine and marine waters of NSW (Folpp *et al*., 2013; Harasti *et al*., 2015). Differences in the length of soak time required are likely due to the diversity of species present at a site, with longer soak times needed in more diverse areas (James Tweedley, Murdoch University unpublished data) or in areas with very low and/or highly variable abundance of fish. This is the case in pelagic environments, where 120 minutes of soak time is often used and, even then, can produce zero inflated data (Santana-Garcon *et al*., 2014). While, comparative studies on soak time are rare, Harasti *et al*. (2015), showed that on temperate reefs in NSW, the MaxN for many reef-associated species occurred within 12.5 minutes, with this value rising to 30–40 minutes on similar habitats in SA (Whitmarsh *et al*., 2017). This variability highlights the importance of determining for any monitoring regime, as in the current paper, the soak time required to generate statistically-robust data. Note that, in additional to elucidating how the number of species and total MaxN change over time (*e.g.* Stobart *et al*., 2007; Gladstone *et al*., 2012; Santana-Garcon *et al*., 2014; Harasti *et al*., 2015; Misa *et al*., 2016) there is also value in, as in the current study, assessing how the faunal composition changes over time. This is because while many studies focus on community rather than species level changes in abundance (*e.g.* Wakefield *et al*., 2013; Lowry *et al*., 2014), few demonstrate the effect soak time has on faunal composition.

Differences in Fish Fauna among Artificial Reefs and Seasons

The results of univariate and multivariate analysis showed that the number of species, total MaxN and fish faunal composition differed significantly with Reef and Season and that Simpson’s diversity index changed between reefs. Although not the main focus of this proof of concept study, this demonstrates that the sampling methodology employed by the citizen scientists can generate data of sufficient quality for use in statistical analyses. This was not the case with preliminary trials using cameras that provided a live video stream to the surface, where the resolution and quality of that video was too poor to adequately identify and count fish (Florisson, 2015; Tweedley *et al*., 2016a).

Although based on a relatively small suite of data, the trends reported in the current study mirror those found elsewhere, thus providing reassurance that the data generated are sound. For example, both the number of species and total MaxN differed among seasons, being greater during summer and winter, resulting in a change in species composition. This is thought to reflect an increase in water temperature in Geographe Bay during summer (McMahon *et al*., 1997). Such increases in temperature have been shown to similarly influence the fish communities of several artificial reefs around the world (Bohnsack *et al*., 1994; Relini *et al*., 1994; Mills *et al*., 2017; Rosemond *et al*., 2018).

When comparing between the two reefs, the number of species, total MaxN and Simpson's diversity index were all greater on the Dunsborough than Bunbury artificial reef. While these data are preliminary, their trends do match those obtained by Tweedley *et al*. (2016a) and could be due to the locations of the two reefs within Geographe Bay. The south-west edge of this embayment has a high level of reef connectivity, due to the number of limestone and granite reefs occurring near Cape Naturaliste. These natural reefs have been shown to significantly influence nearby fish communities (Westera *et al*., 2007) and have likely facilitated utilisation and colonisation of the near-by Dunsborough artificial reef by fishes. It is also noteworthy that data collected independently on the Bunbury and Dunsborough artificial reefs using Diver Operated Video and BRUVs demonstrate that the fish faunas of these two reefs are different (Paul Lewis, Department of Primary Industries and Regional Development, unpublished data).

Effectiveness of the Monitoring Program and Recommendations

The effectiveness of the citizen science monitoring of the artificial reefs in this study was facilitated by the BRUV design. The frame was lightweight, durable and built to similar specifications as BRUVs in other scientific studies (*e.g.* Ellis and DeMartini, 1995; Willis and Babcock, 2000; Heagney *et al*., 2007), yet constructed for approximately a quarter of the cost of commercially-available equivalents (Table 21). The total cost of the Reef Vision program, including the development and production of 12 BRUVs, training of volunteers and salary to fund the part-time employment (0.2 FTE) of a volunteer manager was ~AUD$27,000. The estimated costs of a University-led equivalent program, involving the purchase of four commercially-available BRUVs and the travel and salary costs of undertaking one fieldtrip per month to collect videos from each artificial reef, were almost 50% greater at ~AUD$55,000 (Table 21). Thus, in the case of the current study, employing a citizen science approach substantially reduced the cost of the project.

Table 21: Approximate cost (AUD$) of running the Reef Vision program with 12 volunteers (6 per artificial reef) compared to the estimated cost of a science equivalent program run by an Australian university. The science equivalent cost is based on a team of two research assistants using a boat and four BRUVs to collect four videos from each artificial reef once a month for a year. Note that neither budget includes the cost of video processing and data extraction and analyses, which should be comparable for both programs.

Costs	**Reef Vision**	**Science equivalent**
Operating		
BRUV frame	$4,156 (12 units)	$6,660 (4 units)
BRUV cameras	$4,064 (12 units)	$1,016 (4 units)
Bait	$1,440	$1,440
Consumables	$588	$2,400
Travel		
Training workshop	$610	$0
Fieldwork	$0	$21,870
Salary		
Volunteer management	$16,000	$0
Fieldwork	$0	$21,600
Total	$26,858	$54,986

The use of an easy-to-use and commonly-owned small action camera, combined with in-person training made instances where volunteers required technical assistance minimal. This, together with the high-resolution video produced, helped maintain participant engagement and reduced attrition. Engagement and management of volunteers was achieved via a closed group on Facebook containing 20 members (*i.e.* volunteers and project staff). On this private page, participants could share videos and photographs from their stills, experiences, troubleshoot and engage with the project managers.

Throughout the yearlong study, members wrote 169 posts, which were ‘liked’ 685 times and generated 526 comments. Volunteers felt that ‘capturing’ a fish on the camera was a form of fishing. Several of them produced ‘highlight reels’ from the footage they collected and uploaded these to open Facebook groups that were typically related to recreational fishing and, in some cases also YouTube. Participating in the Reef Vision program was seen by volunteers as a way to ‘give back’ to the community and exponents of fishing, thus creating feelings of satisfaction, contentment, sense of achievement, fulfilment, pride and happiness, whilst also increasing ownership and stewardship over the artificial reefs.

While we consider that the citizen science approach (Reef Vision) detailed here could be used to monitor the fauna of other artificial reefs, there are some ways in which the methodology could be improved. Firstly, a larger pool of suitable volunteers is recommended as this reduces the risk of limited data collection during periods of undesirable weather and sea-state. Such a repository of participants would also reduce the impact of any unforeseen volunteer attrition. In the case of the current study, we consider that eight (rather than six) volunteers would be appropriate for monitoring an artificial reef of the size of those in Geographe Bay (Figure 39).

Many studies on the fish fauna of artificial reefs have focused on the changes in community composition that occurred post-deployment and, as such, contain no data on the faunal assemblage prior to the deployment of the structure (*e.g.* Bohnsack and Talbot, 1980; Duffy-Anderson *et al*., 2003; Burt *et al*., 2009; Folpp *et al*., 2011; Becker *et al*., 2017). This baseline data is vital if the performance of the reef is to be measured against its aims and objectives. In the case of the current study, this would require the engagement of community during the planning stages of the artificial reef to ensure a spatially and temporally robust set of data are collected as a baseline. It is noteworthy that both Diplock (2010) and Streich *et al*. (2017) recommend a Before-After-Control-Impact (BACI) monitoring approach be employed to help elucidate the influence a new reef deployment has on local fish assemblages. The choice of a control site is critical, however, as the results of several studies have determined that the characteristics of the fish fauna associated with artificial reefs can differ markedly from those of adjacent natural reefs (Thanner *et al*., 2006; Burt *et al*., 2009; Folpp *et al*., 2013).

Conclusions

This study has demonstrated that citizen science can be an effective tool for monitoring the fish faunas of artificial reefs. The use of recreational fishers to collect BRUV video samples, but having the resultant footage analysed and interpreted by professional scientists, lowers fieldwork costs, circumvents some of the stigma around citizen science and increases community engagement. Reef Vision volunteers were able to collect enough data of sufficient quality to monitor the Bunbury and Dunsborough artificial reefs in Geographe Bay, south-western Australia. These data were extracted from the footage and used in robust univariate and multivariate analyses to determine that a soak time of 45 minutes was sufficient to capture 95% of the diversity and community composition of the fish fauna and detect spatial and temporal differences in those fauna. With the continuing deployment of artificial reefs around the world, the use of citizen science in monitoring can provide valuable data for researchers, managers and decision makers. Projects such as Reef Vision can also benefit volunteers and communities by enhancing social values, creating ownership over research projects and fostering stewardship of aquatic resources.

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Chapter Four: A Guide to Assist Organisations Aiming to Invest in Habitat Enhancement Structures

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Figure 50: A recreational fisher with a nice sized Pink Snapper caught on the Dunsborough Artificial Reef, deployed in 2013.

Foreword

The fourth objective of this project involved summarizing the cost-effective reef design, site selection, approvals, construction, deployment and monitoring strategies for business, industry and community groups wanting to invest in HES. A habitat enhancement guide and flyer were constructed to provide organisations with this information in a user friendly and easy to follow format. The findings from the first three objectives were combined to provide a clear set of options and a framework for groups aiming to undertake HES projects. This framework covered many facets of HES planning, consultation, development, implementation and extension. Once developed the guide was workshopped with project staff, an external creative agency, fishing clubs and recreational fishers to enhance its user friendliness and consistency. The identification of appropriate pathways for organisations wishing to invest in HES will lead to future successful and effective installations, resulting in a range of benefits for the whole community. An in-depth manual, the contents of which are shown below, for organisations and groups in the early stages of artificial reef planning entitled: *Artificial Reefs in Australia, A Guide to developing Aquatic Habitat Enhancement Structures*. A copy of a second highly simplified and condensed version is also provided, which aimed to provide groups with the initial information for starting a habitat enhancement development process.

Figure 51: Members of the Esperance Deep Sea Angling Club, South East Coast Recreational Fishing Council and Recfishwest CEO Andrew Rowland, using the HES guide to assist in a constraints mapping workshop for the placement of the Esperance Artificial Reef.

Introduction

Habitat Enhancement Structure(s) (HES) are purpose-built constructions placed in the aquatic environment (oceanic, estuarine, river or lake) for the purpose of creating, restoring or enhancing habitat for fish, fishing and recreational activities generally. HES involve the use of a range of objects and materials to create new habitat and provide ecological services in an aquatic environment. They include artificial reefs, Fish Aggregation Devices (FADs) and materials of opportunity.

Habitat Enhancement Structures have been created in at least 50 countries around the world for many varying purposes including snorkelling, SCUBA, surfing, energy production, eco-tourism, erosion mitigation, aquaculture, research, infrastructure and conservation (Brock, 1994; Baine, 2001; Diplock, 2010; Ng *et al*, 2014). However, in the majority of cases HES are used for commercial, recreational and artisanal fisheries enhancement. An artificial reef is any man-made or altered material placed into an aquatic environment to mimic certain characteristics of a natural reef. Artificial reefs are often used to create new fishing and diving opportunities, and to shift pressure from other popular locations. To date, at least 150 artificial reefs have been deployed in Australian waters and they are one of the most common types of aquatic infrastructure deployed for fisheries enhancement.

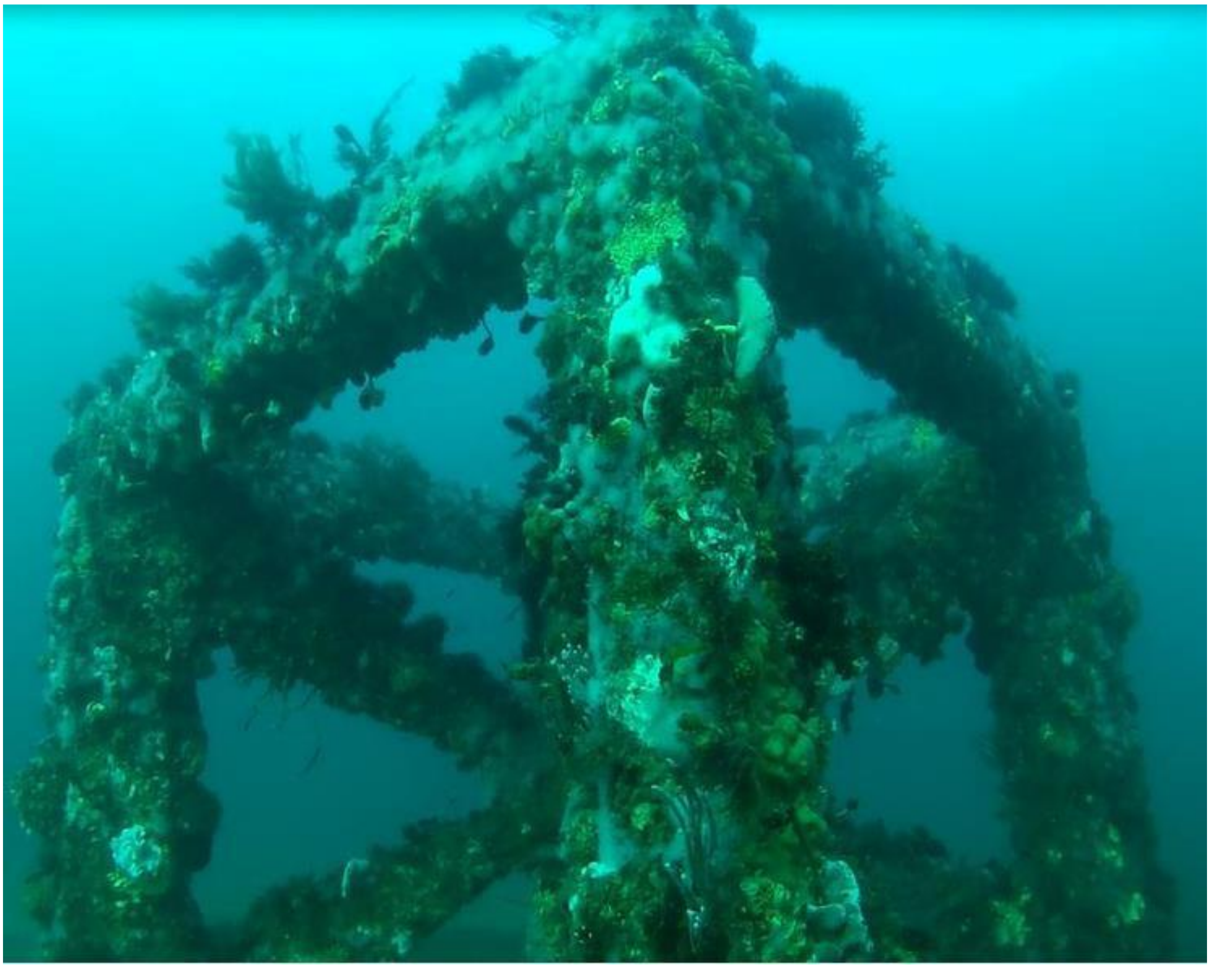


Figure 52: A previously bare surfaced module from the South West Artificial Reef Trial in WA.

The purpose of the guide is to assist organisations to develop HES around Australia by detailing the major steps and considerations that are needed to deliver a purpose-built HES, particularly artificial reefs. The guide does this by containing a background and considerations for HES as well as describing the process (Figure 53) from start to finish for HES development.

While HES also include materials of opportunity, FADs, Large Woody Debris, restoration and translocation (of corals and seagrass), this document will mainly focus on purpose-built artificial reefs, as these are more commonly utilised around Australia, are environmentally friendly and have demonstrated clear ecological, social and economic benefits to communities world-wide through fisheries enhancement. The guide will also only consider HES deployed for the purpose of fisheries enhancement.

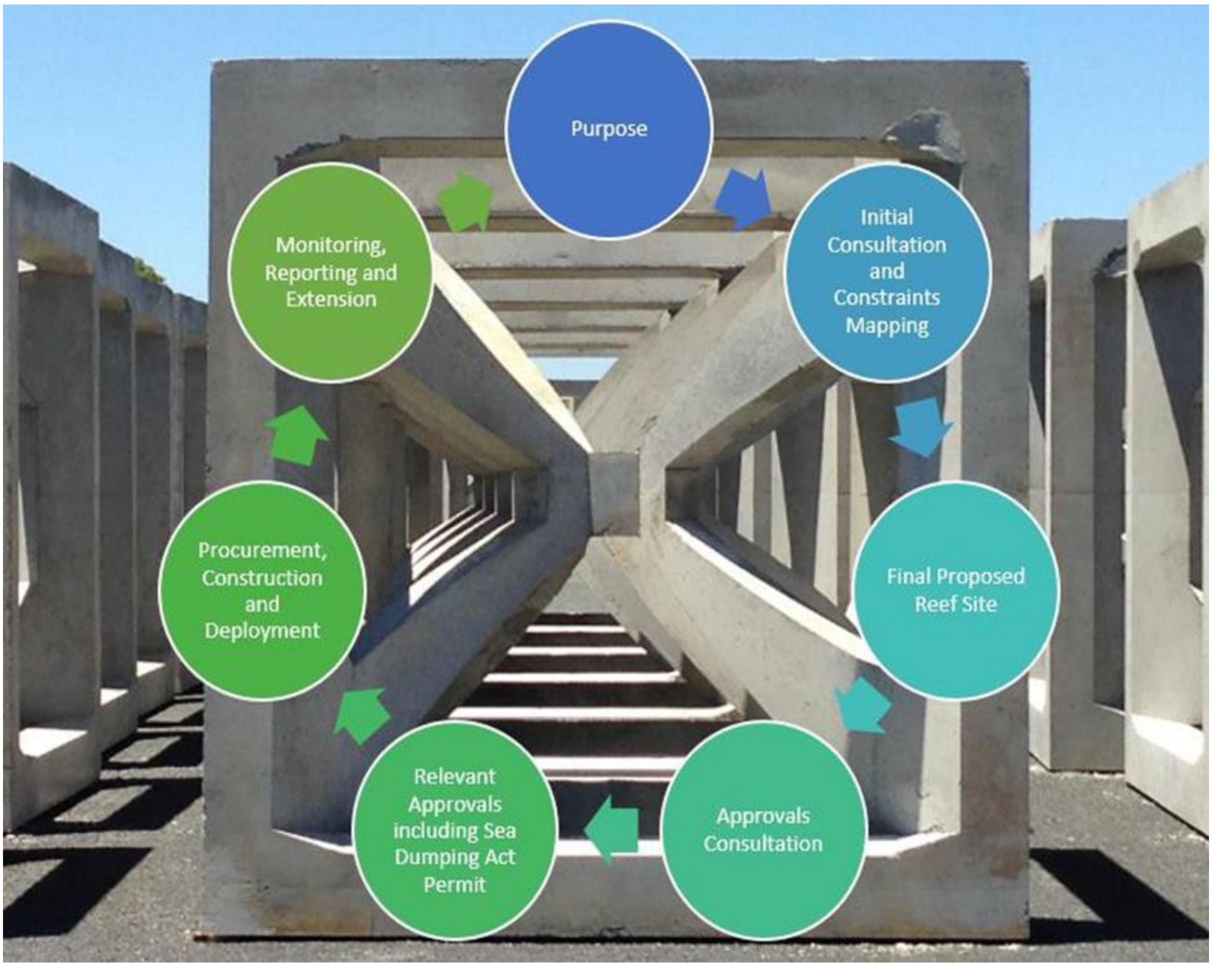


Figure 53: The broad-scale process for developing HES.

History and Development

Artificial reefs and other HES have an extensive history dating back thousands of years. In the Mediterranean, tuna fishers accumulated ballast stones to fish between tuna seasons in Sicily, and Greek temple stones were disposed during harbour construction creating reefs as early as 3,000BC (Riggio 2000; Surman 2015). HES have been created all over the world, earlier HES were mainly constructed of materials of opportunity such as woody debris, rocks and rubble and sunken vessels (from ancient fishing boats to modern warships).

In 1952, the Japanese Government began subsidising artificial reefs, triggering a phase of reef development. Japan now have over 130 diverse reef modules purposely designed to target an array of species such as oysters, octopus, squid, algae, abalone, sea urchins and demersal and pelagic fish (Thierry, 1988; Polovina and Sakai 1989; Barnabe and Barnabe-Quet, 2000; Surman 2015). Since then South East Asia has been at the forefront of HES development with China, Korea and Japan investing well over $3 billion since the 1970s.

Materials of Opportunity

Since 1979, the United States of America has developed a significant program that decommissions offshore oil rigs transforming them from functioning oil extraction plants to artificial reefs. The program is known as ‘Rigs-to-Reefs’ (RTR) and the concept has been extended to several countries throughout South East Asia. With many offshore oil rigs around the world coming to the end of their productive lives, the RTR concept could be expanded globally in the near future. RTR is known as one of the more acceptable ‘materials of opportunity’ still in use and these oil rigs require serious environmental approvals before being converted into a reef.

Figure 54: Materials of opportunity, from left to right; the Tangalooma Wrecks (www.queensland.com), tyre reef at Moreton Bay, QLD (www.divingthegoldcoast.com) and disused oil rig (www.nytimes.com).

Habitat Enhancement Structures constructed from materials of opportunity include pre-existing materials and structures not constructed for the purpose of HES. These materials can include concrete blocks used for building, rubble, stones, polyvinyl pipe, tyres, derelict ships, car bodies, oil extraction equipment and disused armed forces equipment and vehicles. Most materials of opportunity have become unfavourable globally, due to adverse environmental effects and stability during severe weather events. Some of the negative effects include pollution from heavy metal leaching, asbestos and a range of hydrocarbons as well as the destruction of natural habitat when structures that are not stable move on the ocean floor. Current Australian artificial reef policy has shifted to purpose-built HES due to environmental responsibilities, however adequately cleaned and modified (re-purposed) types of materials of opportunity including decommissioned oil and gas infrastructure may have its place in future developments with strict cleaning, alteration, management and monitoring of these structures. Due to general preferences in HES type, this guide will focus only on purpose-built HES.

Purpose-built Artificial Reefs

Purpose-built artificial reefs are specifically designed for target species, habitats, effects (such as upwelling) or purposes having specific shapes, voids, surfaces and profiles. A significant benefit of purpose-built artificial reefs is that the shape, size and form can be altered to increase the abundance of certain species and to meet objectives. Modern purpose-built reefs can have substantial positive effects on surrounding aquatic ecosystems and can be built out of metal framework, steel, steel-reinforced concrete or concrete as well as recycled plastics, ceramics and fiberglass. Examples of these reefs include species specific reefs (such as abalone habitat reefs), larger Offshore Artificial Reefs (OAR), such as the Sydney OAR (a 12m tall metal structure aimed at facilitating the propagation of pelagic species) and concrete fish homes (such as Fish Boxes™ and Reef Balls™) designed to form habitats for a myriad of different species.

Figure 55: Purpose-built artificial reefs, from left to right; Abalone habitat reef, a Fish Box™ and the Sydney OAR (http://haejoo.com/).

Concrete Reef Modules

The most practicable and common artificial reef type in Australia is high strength marine-grade reinforced concrete reefs. An advantage of purpose-built concrete reefs is that moulds can be fabricated to create a range of different sizes, shapes, voids and structures. They are also pH balanced, non-toxic, built with universally available material and can provide more suitable surface textures for colonising organisms, such as corals.

Figure 56: Concrete reef modules awaiting deployment.

There are many different concrete module designs that are used all over the globe. Designs vary for different environments and water depths and are continually evolving (shape, size, and weight, internal and external surfaces) to better accommodate target species. In Japan and Korea, commercial fishers and aquaculturists harvest sea cucumbers, abalone, shellfish, squid, octopus, lobsters and finfish from purpose-built artificial reefs. Variation in module design allows reefs to mimic different natural reef profiles and varying habitat complexity. Knowing the target species and environmental conditions drives artificial reef design choice. For example, larger modules with larger openings and high vertical profile would better suit large cods and groupers as well as pelagic species as they can swim through the modules, while smaller modules with lots of habitat complexity may favour cryptic species and concentrate higher numbers of smaller fish. Many reefs mix differently shaped and sized modules to accommodate larger species abundance and diversity.

Steel/Metal Reef Modules

Along with concrete, welded steel is the preferred material for artificial reef construction (Diplock, 2010 and Surman, 2015). These reefs can be built to be considerably larger than concrete modules. The structures have a large amount of surface area and vertical profile with structures as tall as 35m in Japan.

The large vertical profile allows substantial amounts of habitat in different areas in the water column benefitting benthic or bottom dwelling species (such as flathead and flounder), epi-benthic species (those close to the bottom, such as snapper and emperor) and free ranging pelagic species (such as mackerel and kingfish).

Many steel reefs are specifically designed to congregate smaller baitfish. This is done by providing a large surface area in which colonising organisms such as macro algae are a source of food for smaller invertebrates which are then a food source for baitfish, and providing a protective area for baitfish to avoid larger predators.

Metal panels can also be incorporated into the design of steel reefs to take advantage of currents and tides to create upwelling that increases primary productivity (food sources for larval fish). Steel lattice like structure added to steel reefs can also provide shelter and safe areas for baitfish to congregate.

Figure 57: The Rottnest Fish Towers™ (left) and the 'QLD 'Fish Caves™' (http://haejoo.com/) (right).

A recent study on the Sydney OAR found that the reef provided enough habitat and refuge to safely support around 130kg of mado (a small schooling species of fish found on coastal reefs) on the reef that fuels fish production by feeding on zooplankton supply (Champion *et al*, 2015).

Differing colonising communities will establish on steel and concrete structures, borers preferring concrete over steel until the steel has corroded, however other species, such as corals can prefer metal. For example, a study in Hawaii found that the highest coral recruitment occurred on metal rather than concrete reefs (Fitzhardinge, 1989).

Other Habitat Enhancement Structures

Other HES types aside from artificial reefs, include those that replicate or restore natural habitats including woody debris, shellfish reefs and translocation and restoration of corals and seagrasses. Wood is used for a variety of in-water restoration and enhancement activities including the creation of wood structures and resnagging. In freshwater and estuarine environments, woody debris is put into water bodies where they provide shelter and breeding locations, thermal variation, roosts for water birds and support the food web (Curtiss *et al*, 2006).

Figure 58: Oyster Reef trial in Albany (left) (image by Bryn Warnock) and Wooden ‘Fish Motels’ (fishingworld.com) (right).

Shellfish reefs are complex productive ecosystems that support a wide range of marine organisms. They provide shelter as well as direct and indirect food sources with research into oyster reef restoration in USA finding that restored reefs had 212% more biomass of fish and invertebrates than mud-bottom (Humphries and Peyre, 2015).

They also provide shoreline protection and can filter large amounts of water. Shellfish reefs can largely be captured under either Oyster Reef or mussel bed restoration. Finally, the translocation or relocation of seagrass, corals and mangroves is a type of habitat enhancement that is important globally due to habitat loss and the ecosystem services these organisms provide, however these HES are not included in the scope of this guide. This is because the process of development of these HES greatly differ to artificial reefs and included HES types.

Considerations

This following section outlines the key considerations that need to be taken into account when developing a new HES. These factors include a range of social, legislative, ecological and economic aspects that need to be taken into consideration throughout the process and are all vital to the success of any HES developments.

Purpose and Objectives

The starting point for any proposed HES is to define clearly, the purpose and objectives for the reef. The purpose needs to be based on why stakeholders, end users and managers are aiming to deploy a reef and the objectives need to steer the purpose. For example, a purpose may be to provide a safe fishing location for tourism, and objectives may revolve around safety, accessibility and enjoyment and could include being a safe distance from shore, near a populated coast, in an area protected from wind and large seas as well as creating a habitat that would favour target species in the area such as Pink Snapper or trevally.

Target Species

Target species are fish or other organisms that will most effectively increase end user satisfaction by being present on a HES. Assigning target species is an important factor in guiding the purpose and objectives. The choice of species help guide what sort of HES design will be deployed, the proposed depth, habitat and location. Aspects that need to be considered include natural distribution and abundances of the target species in the area of the proposed reef location, seasonality, life history of target species and requirements and preferences of the species such as habitat (benthic/pelagic, temperature, visibility), shelter (refuges, surfaces, lighting) and food requirements (Surman, 2015).

Figure 59: Potential target species: Samson Fish (top left), Baldchin Groper (top right, other tuskfish species in states other than WA), Mulloway (bottom left) and Pink Snapper (bottom right) observed through the south-west Reef Vision program.

Materials

While materials vary for HES, the two main types include concrete and metal. The advantages and disadvantages of these materials can be seen in the Table below (adapted from: London Convention and Protocol/UNEP, 2009; FRA-SEAFDEC, 2010; FAO, 2015).

Table 22: Advantages and disadvantages of HES materials; concrete and metal.

Material	Advantages	Disadvantages
Concrete	• Compatible with the marine environment. • Durable, stable and readily available. • Readily formed into any shape for the deployment of prefabricated units. • Provides adequate surfaces and habitats for the settlement and growth of organisms, which in turn provide a substrate, food and places of refuge for other invertebrates and fish. • Universal and easily applied by community groups. • Concrete's weight makes modules stable and ensures module do not move during storm events.	• Concrete's weight, which necessitates the use of heavy equipment to manipulate it. This increases the land and marine transport costs. • The deployment of large concrete blocks or prefabricated units requires the use of heavy sea equipment, which is not only costly but also dangerous. • The weight of concrete increases the possibility of it sinking into the marine sediments. However, constraints mapping should ensure that concrete modules are deployed on appropriate substrate to minimise this risk.
Metal/Steel	• Steel is easy to work, can be made in accordance to specific environments and species. • Steel is high strength, has a stable quality and is durable. • Possibility of developing large prefabricated units of very high relief and unmatched complexity. • Steel is free from harmful material and quickly colonised by organism and thus produces effects fast.	• Reduced design life in shallow or highly oxygenated water bodies (*i.e.* rough exposed coastlines). • High relief of large singular modules may cause stability issues requiring increased anchoring considerations of units resulting in increased reef costs. • Unit size may need specialised or large-scale deployment equipment which will increase project costs.

Stakeholder and End User Involvement

Stakeholders and end users should have their needs and expectations met and feedback considered, throughout the project process. This is particularly important in the early stages, when setting a purpose for the HES, as well as in the design, use, location and management of the HES. Formations of steering committees can assist in ensuring adequate representation of various individuals and groups involved.

Approvals

Installation of infrastructure such as HES (artificial reefs) requires environmental assessment and approval from relevant state and Commonwealth agencies and/or authorities. This can be seen in more detail further in the guide.

Design

HES designs need to consider target species as well as other biological, ecological and physical aspects. In terms of biological and ecological factors, different HES designs may have a biological impact on their level of complexity. The creation of holes, crypts and refuges will allow for a large diversity and abundance of organisms to use the modules for shelter. Different organisms prefer different design features, for example, lobster and octopus prefer blind ended holes while other species such as smaller fish may prefer shaded open-ended voids. A variation in size and a large number of voids and refuges increases habitat complexity and thus increases the type and number of organisms that will use the modules, however cost should be considered.

Overall, the total surface area is much more important than the overall size in relation to productivity and reef biomass, so total surface area and internal surface area are also important when looking at different types of artificial reefs. “The higher the surface area available for the settlement of algae and invertebrates, the greater source of food for other levels of the reef community and, therefore the greater productive capacity” (London Convention and Protocol/UNEP, 2009).

Figure 60: Different concrete artificial reef module designs for different purposes and target species (http://www.subcon.com/).

Physical characteristics of reef module designs that need to be considered when planning a HES include:

- Surface texture
- Reef profile and orientation
- Shelter and shading
- Reef size, internal surface area
- Reef configuration
- Hydrological factors
- Interstitial spaces
- Social usage (*e.g.* space for fishers)

Location

The location of a HES needs to take into consideration ecological, environmental and social factors. While explained later in the HES process, the location must meet environmental standards while in an area accessible to end users that is within the distribution and requirements of target species.

Configuration

The configuration of HES varies with purpose, type, depth, current and tides. Artificial reef modules are usually installed parallel to the tide, perpendicular to prevailing currents and/or in clusters. Effective configuration can increase fisheries enhancement around the structures. Species preferences to different hydrological effects such as upwelling, eddies and slipstreams can enhance habitat, move nutrients and create feeding opportunities. Module configuration also creates interstitial spaces (corridors between modules) which in turn create new habitat. Specialised configuration can also enhance fishing opportunities by providing more space for fishers and by redistributing fishing effort.

Figure 61: Artificial reef module being tested in a university flume tank (Subcon Pty Ltd).

Artificial reefs consisting of small clusters of modules have been found to be successful, particularly in WA. This allows fish a high level of habitat complexity in an immediate area, a larger area of interstitial zones (between reefs) and it allows a larger number of fishers to use the reef simultaneously, increasing its societal useability. Interstitial zones are pathways for fish migration between modules and are areas of high diversity and abundance. These areas include a module's interior space as well as corridors between modules. These zones increase liveable habitat for species and decrease mortality rates as fish have 'safer' passages between shelters.

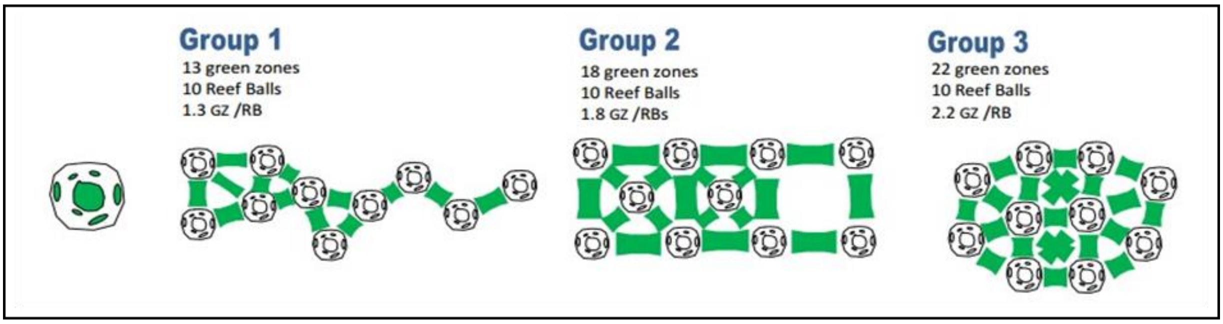


Figure 62: An example of interstitial spaces as 'Green zones' using Reef Ball^{TM} modules (Lennon, 2011).

Storm Events and Depth

Habitat Enhancement Structure designs need to be able to withstand a 1 in 100 year storm events and not become unstable, move position or collapse. They should have strong structural integrity and be deployed in appropriate water depths. Water depth should also be suited to HES design, purpose and target species.

Ecological Interactions

Habitat Enhancement Structures, if deployed for fisheries enhancement, should be in areas with relatively low current fish diversity and abundance. Vulnerable and productive habitats and benthos (such as coral reefs) should be avoided. HES should not be deployed where they could significantly harm or damage any critically listed habitats or threatened species.

Habitat Enhancement Structure Effectiveness

It is extremely important that all aspects of the HES process and the environment are considered prior to deployment in order to maximise the effectiveness of HES. The HES type, design, configuration, materials, construction and deployment need to be considered in relation to hydrology (currents, tides), depth, light penetration as well as sediment dynamics, substrate characteristics and surrounding environments, objectives and target species.

The Design Specific Lifespan

Design specific lifespans of HES needs to be considered and evaluated against the investment going into the project and the benefits the HES will bring as well as the other considerations. Locations can also maximise or minimise life spans depending on hydrological and climatic events at the site. When applicable, HES with the longest lifespans (>30 years) should be utilised to allow for longer ecological development resulting in further economic and social benefits.

Cost-Benefit Analysis

Habitat Enhancement Structures need to be carefully designed, approved and installed to ensure that the ecological, social and economic benefits of the HES outweigh the investment into the infrastructure. Innovative deployment methods and module design, local business contributions and community monitoring increase cost-efficiency across the project. Relevant state fisheries regulators as well as state peak bodies should be contacted to provide indicative HES costs and project budgets.

Monitoring and Evaluation

Habitat Enhancement Structures need to be evaluated against the main purpose and objectives. They must also be monitored to meet legislative requirements. HES need ongoing structural monitoring, while ecological and social monitoring is extremely useful to measure the performance of HES.

Habitat Enhancement Process

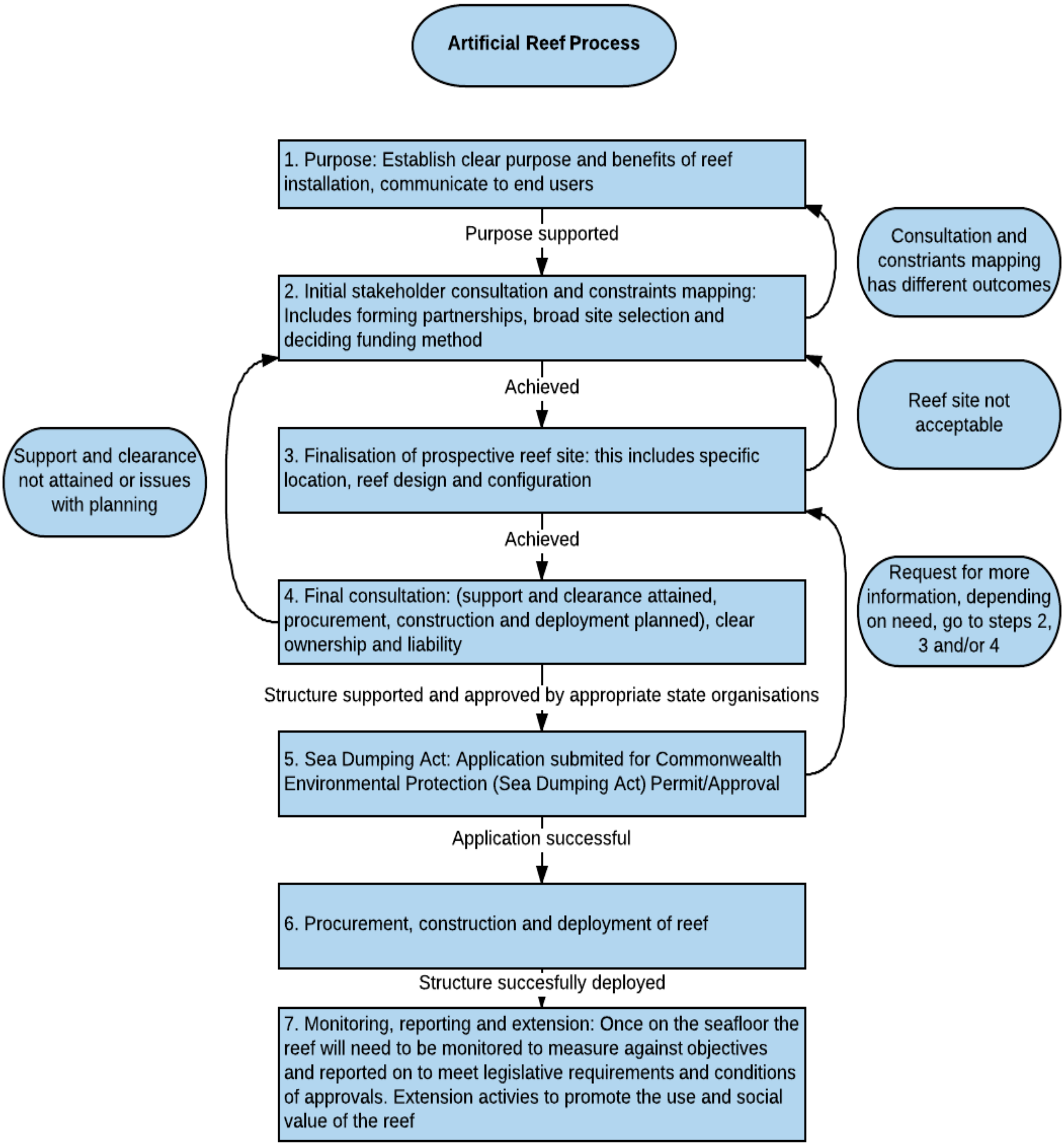


Figure 63: An in-depth flowchart of HES development process from establishing an initial purpose to extension activities in local communities following deployment.

Step 1: Purpose

Deciding the purpose of an artificial reef is the most important stage of the artificial reef process. It underpins the reef's success and dictates which path is taken for each of the steps outlined in this guide. Specific purposes will determine the broad location, specific site, type, target species and configuration. A clear purpose also drives the creation of objectives to assist in measuring the performance of a reef. For example, the purpose could be to enhance recreational fishing leading to objectives around access to target species and proximity to boat ramps.

To establish an effective artificial reef, the need or desire for the reef must be clearly understood. The purpose of the reef should take into account the considerations explored in this guide, to assist in the further stages of development, such as site selection. For example, if the purpose is to provide increased target species in a safe fishing location, the reef should be in close proximity to shore, in a protected embayment and in a populated area. If the purpose of the reef is to concentrate pelagic sportfish for avid anglers, metal structures with high vertical profile should be deployed further from shore at suitable depths and environments for pelagic species (such as in the paths of currents or migration routes).

Step 2: Initial Consultation and Constraints Mapping

The initial consultation is done with other stakeholders (including government and non-government) and end users to establish the target species, reef type (design and configuration), location and other important factors. Individuals and organisations that need to be involved in this stage of consultation include Local Government Authorities (LGA), end users, potential partners, end user peak bodies, clubs and associations and groups with demonstrated capacity and expertise in the area. The objective of this initial consultation is to determine whether the purpose of the reef (step 1) is reflective and the best outcome for the target end users, as well as consider:

- What is/are the target species(s) and why?
- What reef modules/design best suit the target species?
- Which location would best suit the end users and the target species?
- Are the modules and configuration suitable for the location?

Once these questions are answered and agreed upon between project managers, stakeholders and end users, constraints mapping and site selection can begin. Site selection is one of the most integral parts of the process in creating a HES. Like the construction of a park or sports stadium, an artificial reef site has to adhere to environmental requirements, be socially acceptable, be in a location accessible by the population and be in an area that fits its purpose and maximises its infrastructure. Constraints mapping assists in site selection by narrowing down a large area of potential reef locations to a more specific and suitable area.

The most important considerations in constraints mapping include distance (from shore, boat ramps and population centres), shipping activity (lanes, anchorages and port authority zones), depth, distribution of target species and military and mining activities. Mapping software such as ArcGIS can be used to reduce the size of an area by excluding areas that are not compatible with a reef installation such as ship anchorages and depths and is particularly beneficial if pre-existing benthic habitat maps are available to overlay on the map (note: may only be possible if data has already been collected in other studies).

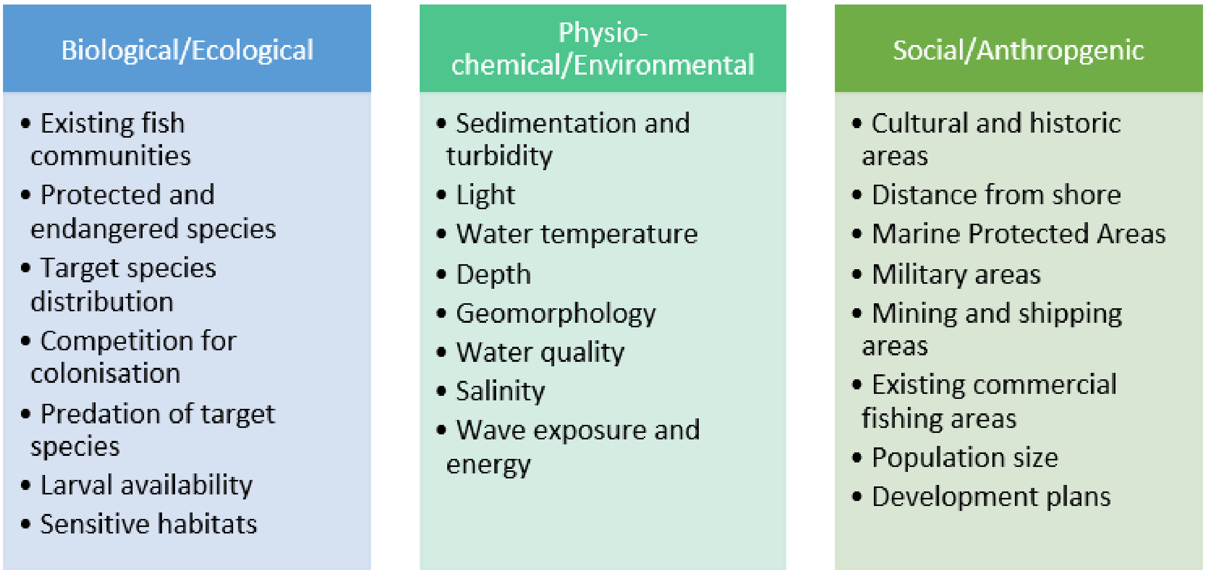


Figure 64: The main components to site selection including biological/ecological, physio-chemical/environmental and social/anthropogenic factors. These will differ depending on the HES design and purpose.

Step 3: Finalisation of Reef Site

Once a broad area is selected, a more specific site can then be finalised. This is usually done by creating a steering committee composed of managers, stakeholders and end users. Constraints mapping is then discussed and a final site selected, which is then tested. This step involves two stages. Stage one involves the biological and environmental analyses of the site and its characteristics to determine an ideal deployment zone/reef site.

Firstly, as part of a pre-assessment survey, a grid needs to be overlaid on the final area chosen, its area varying, depending on the size of the reef to be deployed. For example, a 2km^2 grid when aiming to deploy a 200m^2 artificial reef. At each grid intersection (in the previous example at every 500m), a depth reading needs to be taken and the habitat type evaluated. This can be done by towing an underwater camera along transect lines or dropping cameras at grid intervals to ascertain the habitat type (*i.e.* seagrass, low-profile natural reef, sand, shale, coral etc) and is then best combined with GIS mapping technology (particularly LIDAR imagery). The most suitable area can then be side scanned to find the most ideal location for installation to ensure that the habitat is suitable (for example bare sand).

Once the habitat is identified as acceptable, side scan surveys and sediment probes can be used to look at sediment characteristics to ensure the type and depth of mobile surface sediments will suit the modules and ensure that they will be stable and not shift or sink once deployed. Stability analysis will also need to be undertaken looking at hydrological variables at the site such as wave and current conditions at the site as well as the influence of tides and extreme weather events such as cyclonic activity and 1 in 100 year storm events. This hydrological and climatic data then needs to be compared with reef module design and configuration and depth to ensure that the reef will survive its lifespan, be productive and meet its objectives and purpose.

Finally, there should also be an ecological survey of faunal assemblages of the reef location and immediate area around the area. This is done to establish a baseline of the ecological community that currently exists in the area and to collect baseline data to compare with future monitoring results. The most suitable method for this would be the use of Baited Remote Underwater Video (BRUVs) which can collect footage of the habitat in the field of view as well as the abundance and diversity of other aquatic organisms at the site. Other methods of monitoring may also be used such as towed video, Diver Operated Video (DOVs) or acoustic methods in turbid water.

Stage two involves seeking clearance for the site from factors that may preclude the identified site and the reef purpose and includes aspects such as submerged cables, mining leases, commercial fishing groups, Native Title claims and areas of heritage or cultural significance such as wrecks. Stage two is undertaken in the next step, in the final consultation with the organisations that manage these extra factors.

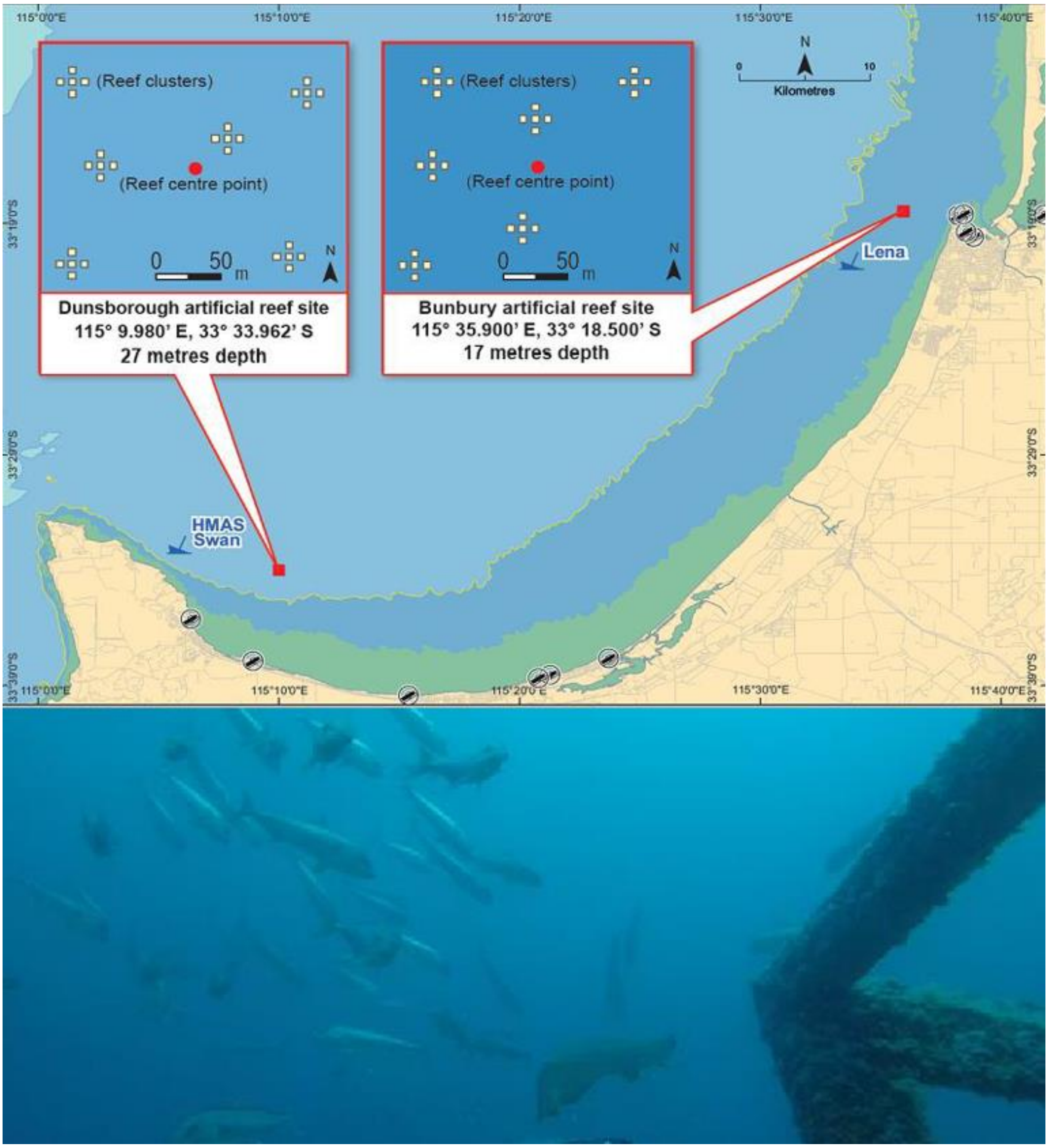


Figure 65: The final reef sites that were chosen after a consultation period in Geographe Bay, Western Australia (top). Progress of the artificial reefs after three years after deployment (bottom).

Step 4: Final Consultation

The final consultation period involves establishing a framework to decide which stakeholders need to be consulted and the desired outcome that is required from this consultation. Local businesses, local interested groups, LGA, government departments and the broader community need to be consulted however, the level of consultation varies between jurisdictions. Communication tools on traditional and social media can be utilised to assist with engaging and informing relevant parties. Some of these tools include community meetings, updates, information pages on websites, advertisements, newspaper articles and establishing online groups and forums. Depending on the purpose of consultation and organisation, the results will vary between informing them, gathering support or attain clearance for the project. Letters of support and clearance from organisations such as the Royal Australian Navy and Australian Maritime Safety Authority are vital for attaining an exemption from the Sea Dumping Act and preferable when seeking funding.

Table 23: Organisations that need to be informed (top) and consulted (bottom) when developing HES projects (note that this list will vary between jurisdictions and while with some of these groups it's a vital legal requirement to consult, others it is just beneficial to inform and gain support from).

Affected Stakeholders (Inform)	
Accommodation Providers	Fishing Stores
Any Mining, Oil or Gas Providers	Historical Societies
Aquaculture Council	Local Businesses
Boating Stores	Local Development Commissions
Chamber of Commerce and Industry	Local NRM and Conservation Groups
Commercial Marine Services	Local Recreational Fishing Councils
Community Groups	Local Shires and Councils
Diving Charters	Local Visitor Centres
Diving Clubs	Logistics Services
Diving Stores	Marine Rescue Services
Fish Stocking Organisations	Regional Development
Fishing Charters	Tourism
Fishing Clubs	Volunteer Sea Rescue Groups

Regulators/Clearance/Approvals (Consult)	
Australian Fisheries Management Authority	Relevant Natural Resource Management Organisations
Australian Hydrographic Office	Relevant Port Authorities
Australian Maritime Safety Authority	Relevant Recreational Fishing Peak Bodies
Maritime Archaeological Associations	Relevant State-based Fisheries Regulators
National Offshore Petroleum Safety and Environmental Management Authority	Relevant Environmental Regulators
Relevant Aboriginal Affairs Organisations	Relevant State-based Heritage Administrators
Relevant Commercial Fishing Peak Bodies	Relevant Transport and Infrastructure Regulators
Relevant Mines and Petroleum Administrators	Royal Australian Navy

Step 5: Sea Dumping Act and Approvals

To minimise any potential adverse environmental impacts of HES, and to optimise social, economic and ecological benefits, the HES process requires approval. Approvals vary with HES design, location, configuration, deployment and jurisdiction. HES in varying distance from shore are likely to require differing support and approval from Local, State and Commonwealth governments as well as organisations that own or manage aquatic areas or resources (see Step 4).

Approvals and permits are necessary to ensure that (DOEE, 2008):

- Appropriate HES sites are utilised
- Construction materials are suitable, environmentally friendly and prepared properly
- There are no significant negative impacts on the surrounding marine environment
- The HES pose no danger to navigation or end users
- That the HES is chartered on maritime maps
- The reef is aligned with state and Commonwealth laws and policies

In Australia, the majority of artificial reefs deployed for fisheries enhancement (aside from some aquaculture purposes), require approval from the state government. There may be an exception in some states with freshwater systems, particularly on private land. Applications may also need to be aligned with state policies on HES. Any groups wanting to deploy HES need to contact fisheries regulatory bodies in their jurisdiction to find any relevant policy positions.

Artificial reefs deployed in Commonwealth waters must also obtain Commonwealth Government approval in the form of an exemption from the *Environment Protection (Sea Dumping) Act 1981*. The Sea Dumping Act fulfils Australia's international obligations under the London Protocol to prevent marine pollution by dumping of wastes and other matter. HES in state waters may also need an exemption depending on the HES type and relevant state and territory policies.

The Sea Dumping Act also ensures appropriate site and material selection to minimise adverse impacts upon the environment and public and is a legislative requirement for HES developments. The only HES deployed in Commonwealth waters that do not require an exemption from the Sea Dumping Act are FADs, however they still require approvals from related State Government Departments such as Transport. While the *Environmental Protection (Sea Dumping) Act 1981* is the relevant legislation at the Commonwealth level, applicable State legislation relevant will also need to be investigated. This may include marine tenure and tenements, marine transport and safety, aboriginal heritage and native title, other user groups including commercial and recreational fishing, aquaculture, local government, environmental protection and those listed in Table 23.

Other approvals may also need to be required depending on relevant location of the selected HES site. If the HES is to be deployed in a Marine Protected Area, related Departments should provide support. If it’s deployed within Port Authority or local shire boundaries, the relevant approvals must also be acquired (obtaining ‘some’ of these approvals may negate the need to acquire an exemption from the Environmental Protection (Sea Dumping) Act).

Step 6: Procurement, Construction and Deployment

Once the relevant approvals are attained, procurement of the reef can begin. Reefs are usually installed by a company or organisation with artificial reef expertise in design, construction and deployment of modules. However, in some cases community groups, commercial businesses and other organisations can also design, build and deploy their own reefs. There is still a requirement to obtain engineering approvals. Artificial reef procurement is usually done at one of two stages:

• Step 2 or 3: Some organisations may require artificial reef expertise in early stages of development to guide consultation and constraints mapping, potentially undertake approvals and to provide input as to the suitability of the design for purpose and the site characteristics.

• Step 5: Some groups, particularly those with previous experience may wish to engage an expert or reef supplier at stage 5 to assist in acquiring the permit. Other groups may choose not to engage an external supplier and to build and deploy their own reefs.

Figure 66: Crane and barge deployment of concrete artificial reef modules in Western Australia.

Installation can be a costly stage of HES projects. Reef modules need to be cleaned, parts tested and an in-depth deployment procedure, including a risk assessment needs to be undertaken. Deployment for HES varies from simply pushing modules off a boat to large ships with cranes deploying 30m tall steel towers. Deployment is logistically challenging due to using large heavy materials and deployment tools in the marine environment. Therefore, deployment is best undertaken in the calmest conditions possible.

The majority of larger artificial reefs deployed are installed by using a crane and barge. Once modules are loaded onto the barge, they are towed to the final reef site. Modules are then lifted by cranes and deployed to the sea floor and deposited using releasing mechanisms. Some crane hook attachments may be specialised to lift large singular modules or even multiple modules at once deploying in clusters. Some metal reefs are then anchored by chains being shackled to the module and mooring weights. For example, the Sydney OAR has 40 tonne moorings attached to each corner of the singular reef unit, while the QLD 'Fish Caves™' also have a similar anchoring system.

Some reefs have other innovative deployment methods such as the Perth Metropolitan Fish Towers™. These two 70t, four storey high modules were deployed in new a cost-effective method that does not require cranes or barges at the deployment site. Instead, the towers each have four buoyancy chambers which double as ballast tanks with valves that can be controlled by an umbilical cord that along with other ropes attach the unit to the vessel. A tug boat is used to tow the unit to the deployment site. The module is transported off the hardstand and lowered into the water via a ship lifter. It is then tethered to its vessel and towed to the site location. Once in the deployment zone, the valves in the ballast tanks are remotely opened and the module sinks to the seafloor. Once settled, the cables and ropes are released from the unit via a release mechanism and float to the surface with the assistance of a large float.

Figure 67: Tug boat towing a 'Fish Tower™' module to its final deployment site.

Other types of HES have differing deployment methods (Figure 68). Timing of deployment is a crucial factor with Shellfish Reefs to ensure the best conditions for natural processes and to minimise mortality of living material. While any HES are being deployed, a notice to mariners needs to be put in place to reduce navigational hazards while working on the installations. An observer should also be on location to look out for interactions with aquatic life, particularly with endangered species. Once deployed, co-ordinates of modules will need to be recorded and given to the Australian Hydrographic Office to be added to navigation charts.

Figure 68: Large snag being installed on the Murray River (Source: Fish Habitat Network).

Step 7: Monitoring, Reporting and Extension

Monitoring is the process of gathering data and information over time to measure changes in an environment. There is a legislative requirement to monitor HES to ensure they have no adverse environmental impacts. HES should be socially, structurally and ecologically monitored to ensure they are performing at or above expectations and fulfilling approvals, objectives and purposes. Monitoring techniques are categorised into two areas, extractive and non-extractive methods. Extractive techniques are those that have an impact on biodiversity in that they extract, displace or disturb organisms, while non-extractive techniques involve observational analysis of species, that can occur at the HES site or off site (such as recording on slate or water proof paper, photography, videography and acoustic research). Non-extractive techniques are generally preferred as they have less of an impact on the marine environment.

Social monitoring is used to analyse the level of use of HES and how they have influenced or impacted the community. This is most commonly done by surveying end-users, stakeholders and beneficiaries regarding their direct and indirect interactions with the reefs. Structural monitoring involves analysing the structural integrity, stability, position and any changes to the surrounding environment that any HES installation may have caused. It can also study excessive scouring, corrosion, sedimentation or fouling by pollution.

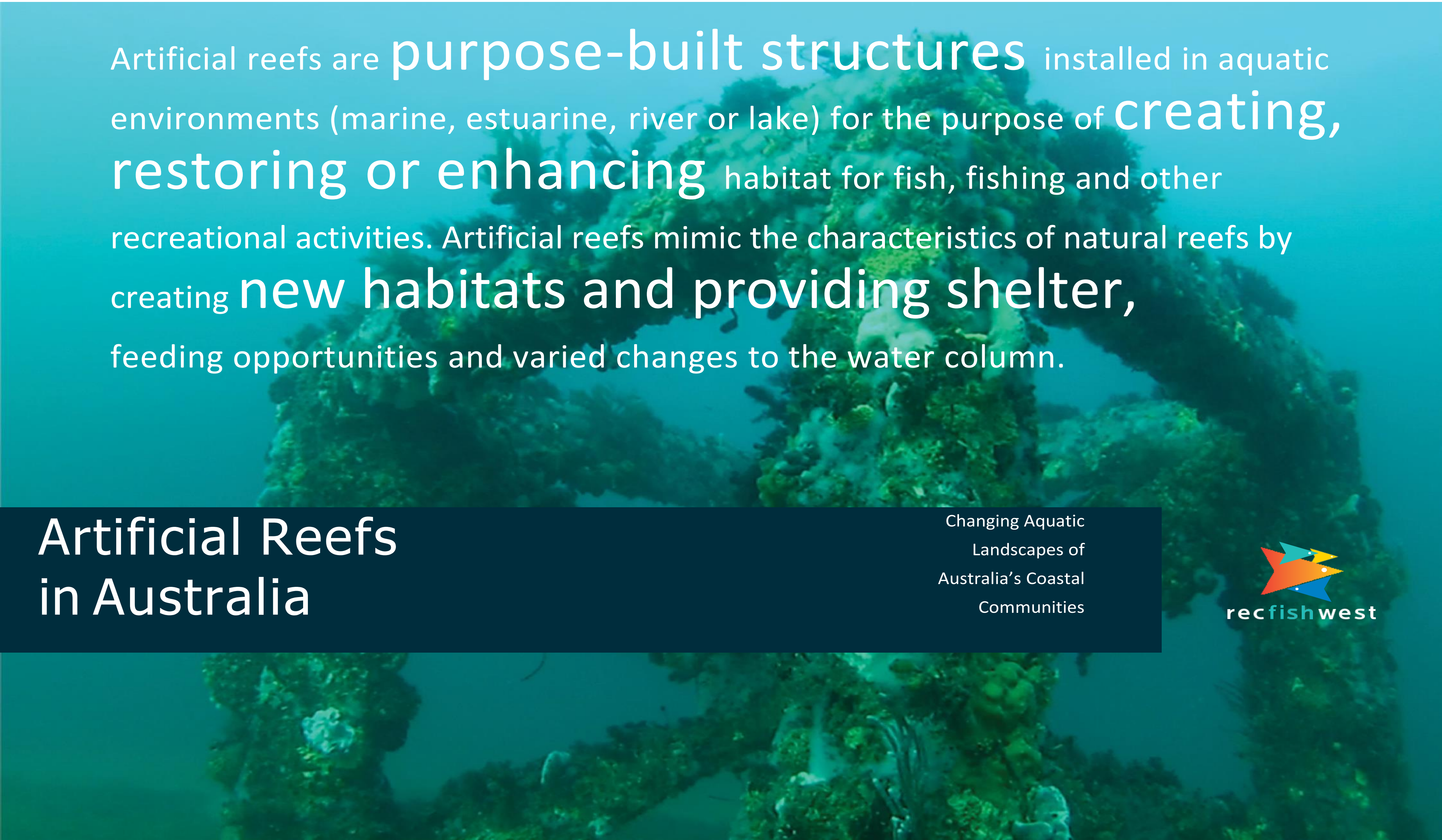
Monitoring HES is best split into two different areas, specialist monitoring and community monitoring. Specialist monitoring involves monitoring to meet environmental approvals including structural, social and some ecological monitoring of HES. If one or more HES are deployed in a state, a streamlined and standardised monitoring approach may decrease costs. The community can also assist with monitoring through data collection and analyses with what is known as citizen science, which is best used for ecological and social monitoring of HES. An example of citizen science is Reef Vision (see Chapter 3).

Figure 69: The Reef Vision Team for the South West Artificial Reef Trial in Western Australia.

Reef Vision monitors the Western Australia (WA) South West Artificial Reef Trial using local fishers and members of the community. Volunteers record boats on the reef and fish caught in logbooks, take part in surveys, record boat numbers using long range scopes and play an important role in BRUV monitoring. Local fishers use cheap, light and durable custom built BRUVs that utilise GoPros and deploy them on the artificial reefs. In October, 2016, volunteers had collected over 160 videos on the reefs lasting over 200 hours. Analysed footage to date has shown over 34,000 individual fish from over 80 species and the program will expand to include other HES in WA. Using citizen science to monitor HES engages the community, provides large and cost-effective data sets and creates stewardship and ownership over HES and aquatic environments.

Figure 70: A Dhufish, an iconic WA species observed in volunteer footage on the artificial reefs.

Finally, it is strongly recommended that any HES developments produce a communications and extension plan to inform the community of deployment and how HES are performing against objectives. The plan should include scheduled discussions, notifications and events with the stakeholders, end users and community. Information on how to use the HES, code of conducts, site co-ordinates and monitoring results are all important to disseminate with the public. With HES objectives often including social utilisation and economic boosts, advertising the structure(s) and the opportunities related to the structure from recreating to commercially harvesting seafood is vital to the success of the HES. With the use of social and traditional media, local communities will often take ownership once the HES begins to develop and disseminate their own information which will in turn assist in support for future HES developments.



Artificial reefs are **purpose-built structures** installed in aquatic environments (marine, estuarine, river or lake) for the purpose of **creating, restoring or enhancing** habitat for fish, fishing and other recreational activities. Artificial reefs mimic the characteristics of natural reefs by creating **new habitats and providing shelter,** feeding opportunities and varied changes to the water column.

Artificial Reefs in Australia

Changing Aquatic Landscapes of Australia's Coastal Communities

recfishwest

Recfishwest

Recfishwest is Western Australia's recreational fishing peak body representing the 750,000 members of the community who go fishing in WA each year. We are a not-for-profit organisation that works hard to ensure high-quality fishing experiences are maintained and enjoyed, as an integral part of the WA culture and lifestyle.

Artificial reefs are rapidly shaping Western Australia's seafloor, with Recfishwest leading the installation of over 1000 tonnes and 120,000 m2 of artificial reef habitat in local waters. Our artificial reef experts, along with our trusted partners, have built extensive artificial reef capabilities and knowledge to ensure artificial reefs have a consolidated place in WA's ongoing conservation of Western Australia's important aquatic habitats.

Recfishwest has a long, trusted working relationship with state and federal governments, world-leading engineers and sub-sea infrastructure experts and, most importantly, with the community. We pride ourselves on using best practice scientific methods and public engagement to ensure maximised environmental and community benefits from all of our reef investments.

Artificial Reefs

Artificial reefs are purpose-built structures installed in aquatic environments (marine, estuarine, river or lake) for the purpose of creating, restoring or enhancing habitat for fish, fishing and other recreational activities. Artificial reefs mimic the characteristics of natural reefs by creating new habitats and providing shelter, feeding opportunities and varied changes to the water column. This leads to a boost in productivity, abundance and diversity of aquatic life. Artificial reefs have been created in at least 50 countries around the world for many varying purposes, including snorkelling, SCUBA, surfing, energy production, eco-tourism, erosion mitigation, aquaculture, research, infrastructure and conservation, however, their most common use in Australia is to enhance recreational fishing opportunities.

Artificial reefs are one of the most popular types of aquatic infrastructure deployed for fisheries enhancement. Not only do artificial reefs provide an ecological benefit, they are also proven to provide positive social and economic gains for local communities. There are four main types of artificial reefs currently used in Australia: concrete, metal, integrated and other.

"Artificial reefs provide a complex habitat for a range of different species. Once algae, corals and invertebrates make themselves at home, they produce additional biomass in the food chain, creating a food source for fish and other species"

Recfishwest Research Officer James Florisson

Concrete artificial reefs

Durable, stable and can be moulded into many different shapes and sizes.

Metal artificial reefs

Pre-fabricated to build large units with unmatched complexity, steel reefs are particularly high strength, durable and easy to work with.

Integrated artificial reefs

Using several different materials, including concrete and steel; these reefs tend to produce the most diverse habitats.

Other artificial reefs

Include 3D printed plastic reefs, ceramic reefs and geotextile Reefs. While some of these reefs have been used for decades, most of these structures are new and innovative concepts which are still being developed in Australia.

Considerations

Social, legislative, ecological and economic aspects need to be taken into consideration throughout an artificial reef development:

- Reef Purpose and Objectives
- Target Species
- Materials
- Stakeholder and End User Involvement
- Regulations and Approvals
- Reef Design (size, texture, profile and orientation)
- Location
- Module Configuration
- Storm Events
- Depth
- Ecological Interactions
- The Design Specific Lifespan
- Cost/Benefit Analysis
- Social Usage
- Monitoring and Evaluation

Getting Reefs in the Water

The process of deploying an artificial reef involves many steps, from establishing a specific purpose for the reef all the way through to post-deployment monitoring.

Purpose → Initial Consultation and Constraints Mapping → Final Proposed Reef Site → Approvals Consultation → Procurement, Construction and Development → Monitoring, Reporting and Extension

Monitoring

The performance of an artificial reef is measured by collecting data over time to track changes in the reef's environment. Monitoring artificial reefs allow us to understand:

The reef's ecology (predominantly fish communities).

Positive social and economic gains for local communities.

Traditional reef monitoring can be expensive so Recfishwest uses community-based 'citizen science' monitoring to collect large amounts of information at a reasonably small cost. It is a requirement to monitor artificial reefs in Australia to see how they change the surrounding environment. We successfully monitor artificial reefs in Western Australia through an engaging volunteer program called Reef Vision. Reef Vision uses fishers and divers to deploy specialised underwater camera equipment known as Baited Remote Underwater Video systems (BRUVs) off their personal boats to collect footage of marine life associated with the artificial reefs. These videos are then used by scientists to analyse the types of marine organisms on the reefs.

Reef Vision volunteers who have monitored two artificial reefs in the South West of WA captured footage of 83 different species. To read more about our monitoring check out recfishwest.org.au/our-services/research/reef-vision-artificial-reef-monitoring.

Future - The Artificial Reef Solution

Artificial reefs have been used all over the world for centuries; however their popularity as an area for recreational activities has only begun to accelerate in Australia during the last few decades. The research and development into reef materials, design, configuration and deployment is continuing to make structures more productive and cost-effective.

With the associated economic boost, social impacts and ecological production, artificial reefs will continue to increase around the Australian coast, providing accessible, safe and enjoyable fishing locations for all.

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Conclusion

This project has explored many facets of Habitat Enhancement Structure(s) (HES) from materials, design and configuration to constraints mapping, consultation, deployment and post-deployment monitoring. It has had a large positive impact on the installations listed throughout the reporting period, and the capacity and knowledge built through this project will continue to develop HES projects well into the future. The project identified a range of HES types available globally, including purpose-built artificial reefs (concrete, steel, integrated modules), materials of opportunity (rubble, vehicles, vessels, oil and gas equipment and infrastructure), FADs, woody debris and shellfish reefs. All these HES have various benefits to the enhancement of recreational and commercial fisheries including the provision of fish habitat and food sources, structure acting as fish nurseries, thigmotropism (association with solid objects) and fish meeting and migration points (Ibrahim *et al*, 1996, Deudero *et al*, 1999). HES benefits to aquaculture was also identified through increasing stocking densities, reducing predation, the creation of different hydrological effects, provision of shelter and food sources, while benefits to the environment discovered can include the mitigation of illegal fishing, reducing pressure on natural systems, water filtration, creation of nursery habitat, detection of introduced species, carbon sequestration, erosion mitigation and other ecosystem services.

Various cost-effective methods were determined to assist in HES monitoring. The most effective of these techniques involved community groups using citizen science to collect data. Physical trials involved automated and manual observation stations, logbooks, mapping and BRUVs to collect ecological and social data. The use of BRUVs under the ‘Reef Vision’ program was the most effective method that used easily available materials and local volunteers to capture over 200 hours of footage on the Bunbury and Dunsborough artificial reefs, with 85 different species identified to date (June 2018). The success of Reef Vision has also been accredited through the acceptance of the method as an artificial reef monitoring tool by the Commonwealth Department of Environment and Energy (for inclusion in the monitoring plan for the dumping at sea permit) as well as various media publications. The use of Reef Vision is not only a cost-effective method of collecting a large amount of spatial and temporal data, it is also a great community engagement tool which provides social benefits and education to the community as well as fostering local ownership of HES and stewardship of aquatic resources.

HES, particularly the developments in Australia over the last decade, have proven to be biologically, economically and socially successful in achieving their goals. HES provide an array of functions to various stakeholders and end users, from offshore environmental and social offsets, to families safely accessing an enjoyable experience fishing inshore. With the growth of these structures along our coastlines, these reefs are a social investment in marine infrastructure, providing jobs and recreation, as well as increasing tourism and boosting local economies. HES are quickly becoming the basketball courts and parks of the ocean, creating new opportunities not only for users of the resource, but also for the many diverse species of fish, coral and algae that inhabit the reef.

Implications

The main overarching outcome from this project is filling the knowledge gaps associated with HES development, particularly in WA. This was achieved through investigating, reviewing and in some circumstances, testing configurations, considerations, installation methods, monitoring techniques and other development processes. This information collected throughout the project period culminated in an easy to follow guide to HES. The HES guide is a valuable resource that has the potential to have a large impact, particularly on consumers and industry. End users such as fishers and divers can be provided with the tools and knowledge to instigate a HES development and local government and organisations can have a greater knowledge of the process and where to start. Thus, all organisations involved can have a key understanding of the considerations and process of HES development. The guide increases the chance of a socially, ecologically and economically successful HES. The guide has already assisted in the planning of a new HES deployment on the mid-west coast of WA, and with the planned monitoring activities of the Esperance and Exmouth artificial reefs. The guide has been promoted to a range of users and is available in several different formats (**see Extension and Adoption**).

Reef Vision is another outcome from the project that has had a large impact on researchers, regulators, and particularly, local communities. Reef Vision has greatly assisted researchers through the provision of cost-effective data collection on the abundance of fish on and around HES. It has also positively impacted regulators by creating an effective method to meet legislated monitoring requirements for HES in being able to effectively measure the social and ecological performance of an installation. Footage can also be used to assess impacts associated with HES such as measuring the ecological performance of different reef designs and configurations, structural integrity and evaluating marine debris on the structure. Most importantly, Reef Vision has had a large impact on local communities through involvement in fisheries research/marine science, engagement through media and footage (particularly of key species) and various other benefits including stewardship and ownership.

This project has resulted in the growth of human capital with new HES expertise with particular focus on fisheries management, and the recreational fishing community. Three Honours students assisted in testing monitoring methods, including Reef Vision and a fourth and fifth will commence studying in 2018 on the effects of different HES types in WA. The initial three students also collected and collated many different local, national and international sources of HES information that greatly assisted investigations during the project. Various project managers including individuals from consultancies, universities, government and the community also assisted in various stages in the project, helping to grow WA's level of expertise in relation to HES developments. It's likely that the generation of this knowledge and expertise initiated through this project will assist management, industry, research and community in not only WA, but Australia-wide into the future.

Recommendations

Habitat Enhancement Structures Development

- The purpose of a HES installation should be clearly defined and accepted by stakeholders and the regulator prior to any other components as this will assist in establishing design, budget and location as well as ensure stakeholder needs, community expectation and regulatory requirements are met.

- A cost-benefit analysis should be undertaken to ensure that the ecological, social and economic benefits of a HES outweigh the investment in infrastructure. Innovative deployment and module design as well as cost-effective monitoring can help decrease costs.

- Module design needs to consider target species and their life history phases, local ecology (including colonising organisms and hydrological variables). This is not limited to shape, but also void size, internal and external surface area, rugosity, material, vertical and horizontal relief, shade and structural integrity. Generally, a larger quantity of low-profile habitat can be favourable for demersal species, while pelagic species prefer a higher level of vertical relief.

- Reef configuration, including number of modules, spacing, orientation and design needs to consider ecological, physical and social aspects. Specific positioning in relation to prevailing tides and currents can increase productivity through the creation of eddies, slipstreams and upwelling. Edge effects, interstitial spacing, complex habitat and halo effects can also increase biodiversity. An installation should also be suitable for the end user, not just target species, thus total fishable area should be considered to increase opportunity, and reduce conflict for end users.

- Concrete, metal and integrated (combination of metal and concrete) reefs have been the most effective materials and should be used in HES developments. Concrete reefs are durable, stable and can be moulded into many shapes, metal structures can be prefabricated into large units with a high level of complexity and integrated reefs can produce more diverse habitats.

- Fish Aggregation Devices are a relatively cost-effective type of HES that can be used to concentrate a range of pelagic sport fish. Consideration needs to be given to depth, current and distribution of the target species.

- Habitat Enhancement Structures need to have a design specific lifespan that considers hydrological and climatic events at the site, they should be designed to withstand a 1 in 100-year storm event. Typically, the longer a HES lifespan, the better the ecological development resulting in further economic and social benefits.

- Site selection should carefully examine several factors including biological/ecological (protected and endangered species, target species, competition and nearby habitat), physio-chemical and environmental (sedimentation, light penetration, temperature, depth, geomorphology, wave exposure and energy) and social/anthropogenic factors (population size, distance from shore, cultural or historic areas, marine protected areas, military areas, shipping and development plans).

- Consultation needs to include ***informing*** affected stakeholders (such as local shires, tackle stores and dive shops) and ***consulting*** with regulators and approval providers (such as environmental regulators, Commonwealth and state/territory governments, port authorities and the navy). Local, state and national approval processes need to be followed.

- Cost of long-term effective monitoring should be included in the initial funding amount for an installation.

- Habitat Enhancement Structure developments should produce a communications and extension plan for the project to inform and engage the community with relation to the performance of the installation. This assists in creating ownership, fostering stewardship and growing community wide support for future projects.

- There is an opportunity for a wider HES uptake and development in the commercial and aquaculture sectors that should be adopted. This could include introducing HES types such as artificial seagrass to increase stocking density without competition in the aquaculture of crustaceans, ranching of gastropods and creation of bivalve reefs, continued development of lobster and cephalopod reefs and increasing finfish production through many HES types.

Cost-effective Monitoring of Habitat Enhancement Structures

- Where possible, monitoring techniques should be non-extractive to decrease adverse biological impacts on fish stocks. Photography of sessile organisms and videography of moving organisms and modules provides a permanent and comparable record that can be used for ecological and structural monitoring when possible.

- The use of citizen science or community monitoring is a cost-effective method to collect a large amount of spatial and temporal data on HES installations. It also engages the community and has various social benefits such as improved scientific literacy, community involvement, project ownership and stewardship of aquatic resources.

- While it's a strong recommendation to utilise citizen science and it can be more cost-effective than traditional data collection by professional scientists, it should be noted that volunteer recruitment, engagement and management does take considerable resources and time and may not be suitable in all certain circumstances. Adequate volunteer insurance also needs to be considered.

- Contacting and recruiting volunteers should be enhanced by using both traditional and social media, with a greater scope for promotion and advertising to recruit a large quantity of higher quality volunteers. This will also allow a higher level of succession planning to alleviate potential volunteer attrition.

- Clear, concise and consistent instructions and simplified monitoring protocols will decrease volunteer attrition rates as well as spatial and temporal biases. This increases the accuracy and quality of the footage.

- Volunteer management can be optimised by adequate and consistent communication and engagement with the volunteers. More experienced volunteers (local champions) can assist with communication between the two parties. Two-way communication should be utilised when needed to disseminate results and information with volunteers and for volunteers to give feedback, data observations and other details to project managers when relevant.

- Positive engagement will increase volunteer attendance and interest, fostering stewardship and ownership of the reefs for the volunteers and local community.

- Involving and partnering with other community groups, local business and organisations broadens engagement, and can potentially reduce project costs through additional funding and donations of incentives.

- In the physical trials in this project, custom made BRUVs with small action cameras were found to be the most effective method to collect footage of installations by volunteers. The units should be cheap, durable, compact and easy to use by the volunteer.

- Observation posts for measuring usage, logbooks or smart phone applications for catch data and mapping using sounders are also potentially developing viable and engaging options for monitoring.

Further Development

While the project met the milestone requirements during the project, due to the project scope, time restrictions and evolution of technology and research methods, there are several areas that require further research and actions.

- The use of HES for the enhancement of commercial fisheries in South East Asia, Korea and Japan is a common, productive and profitable practice, with HES technology and knowledge that is ahead of the rest of the world. However, much of this information is inaccessible due to commercial IP and language barriers. While delegations have been sent from Australia in the past, it would be beneficial to further develop relationships with academic institutions and industry in these countries to share HES developments and to improve our HES knowledge base.

- The positive impact of oil and gas infrastructure, such as pipelines, buoys, rigs and extraction equipment, on ecological productivity and thus end users such as commercial and recreational fishers should be explored and evaluated further. In particular, the role repurposed structures could play in future HES deployments should be investigated.

- Limitations to the cost-effective monitoring methods explored in this project, such as deeper water HES installations and water clarity need to be explored further. Monitoring methods such as acoustics, tagging, Remotely Operated Vehicles and DIDSON (Dual-frequency IDentification SON) could be trialled. The use of stereo-BRUVs, which allows size estimates, for citizen science could also be trialled to analyse fish density and growth on HES.

- The potential for the use of HES for carbon sequestration and related ecosystem services should be considered. This includes biomass of carbon absorbing sessile organisms on artificial reefs, the effects of shellfish reefs, coral seeding and seagrass translocation. This could be utilised as potential carbon offsets in the future with the secondary benefit of fisheries enhancement.

Extension and Adoption

The project was extended to end users, managers, industry and the broader community through traditional media, social media and events, following the Habitat Enhancement Structure Extension and Adoption Timeline 2015-2017. Project communications and associated content will be covered below in **Project Coverage**. The main outputs from the project included the HES guide and pamphlet, a culmination of all investigated HES information, and Reef Vision; a cost-effective HES monitoring methodology.

The HES guide was strongly promoted and is being adopted by both industry and community. The guide was communicated and promoted at Recfishwest events and workshops in 2017, and has been adopted since, being utilised by the Shires of Carnarvon, Karratha and Port Hedland in artificial reef planning. It has also been adopted by the South East Coast Recreational Fishing Council in Esperance to assist with site selection, design, configuration and monitoring for the Esperance Artificial Reef. The guide was also sent to Australian state recreational fishing peak bodies and 21 coastal Local Government Authorities which had a population of over 1000 residents. The document was included on the Recfishwest website for promotional purposes. On average the Recfishwest website has 27,984 page views per month and the average time spent on the page is two minutes and thirty seconds. Over 50 different countries have accessed the site. After Australia, the three largest users of this guide include the United States of America, United Kingdom and Singapore. Furthermore, a project investigator also presented the guide at the 8th World Recreational Fishing Conference in Victoria, Canada between the 16th to 20th July (2017). The conference allowed a unique opportunity to not only present the project and guide to the international community, but to also discuss it in networking opportunities throughout the conference. A presentation on the guide and project was included in symposium three: recreational fishers driving habitat outcomes, entitled: The Development of Habitat Enhancement Structures in Western Australia - Outcomes for the World. The Guide was also discussed at the 11th Conference for Artificial Reefs and Aquatic Habitat in Malaysia (2017) and after considerable interest, has been sent to organisations in the United Kingdom, Turkey, France, Italy, Indonesia, Brunei and Malaysia.

Reef Vision was the main project output resulting from testing different cost-effective monitoring methods. Since initial trials, Reef Vision has been further developed and become extremely successful with significant adoption by managers, researchers, industry and importantly, the community. There was extensive adoption by local communities which included businesses funding prizes and bait for the project and many volunteers and volunteer families giving up their own time to collect data. Reef Vision has expanded to over 50 volunteers in the South West of WA alone, and is currently looking to be used on other HES installations including artificial reefs in Exmouth, Esperance, Perth, Mandurah and potentially oyster reefs in Albany and Port Phillip Bay (Victoria).

The success of Reef Vision and the quality of data collected saw the project also be adopted by secondary and tertiary school students. The videos collected during the Reef Vision program are used in a first-year unit at Murdoch University called ‘BIO180 Introduction to Marine Biology’. The unit provides an introduction to marine organisms and ecosystems and thus a framework for further study of marine biology. Students develop specialist knowledge in marine biology and skills in the identification of marine organisms and the conduct of marine research. The main topics covered are: (i) the marine environment; (ii) the types and variety of marine organisms; and (iii) major ecological categories of marine organisms. During the unit, the students are offered the choice of one of four coursework assignments; (a) a literature review on two topics, (b) Reef Footage project (using the Reef Vision data) and (c and d) two field-based projects conducted on local beaches. In the first year, out of 121 students that enrolled in the unit, 30 chose the Reef Vision project. This was higher than expected as this project did not provide the students with the chance to do any outdoor fieldwork. In brief, groups of students were given six, ten-minute clips from both the Bunbury and Dunsborough artificial reefs and asked to watch the footage and produce a species list for each reef and compare the number of two key species of their choice between the reefs. This work was supported by four tutorials run by Dr James Tweedley. Each group of students was required to produce a ten minute PowerPoint presentation and write a substantial report. Feedback from students indicated that they really enjoyed the project.

Following the success of Reef Vision, Murdoch University also committed funds to develop the ‘BRUV in a Box’ project. The idea is to engage with teachers and students at high school in the Perth area with a marine science program. The kit includes two BRUVs broadly based on the design used in the current study, together with laptop computers, hard drive of existing data from the artificial reefs and coral reef systems and instructions and suggestions for class activities. The contents of the kit allow high school students to collect data themselves, using the BRUVs and/or use existing videos and generate data. To help develop and test the kit, Murdoch University have formed a partnership with South Fremantle Senior High School. Staff from Murdoch are actively engaging with teachers there to ensure the kit meets their needs and provide training and support. Dr James Tweedley travelled to Coral Bay to work with members of the high school’s marine science program to deploy the BRUVs on the world heritage listed Ningaloo Reef. It is also planned that Esperance Senior High School will be involved with both data collection and analyses on the Esperance Artificial Reef, when deployed in summer 2019.

Results from the monitoring study have been presented to different towns in the South West including Dunsborough, Busselton and Bunbury, six times throughout the project by staff from Recfishwest, Department of Primary Industries and Regional Development, Murdoch University and Ecotone Consulting. Presentations on Reef Vision were also given at the 11th Conference for Artificial Reefs and Aquatic Habitats in Malaysia (2017), the 8th World Recreational Fishing Conference in Canada (2017) and the National Recreational Fishing Conference in Darwin (2017) all generating local, national and international interest. This also resulted in discussions for potential adoption of the project in other countries, particularly for the involvement of citizen science in artisanal fishers. Finally, Reef Vision has also been adopted by the academic community, with weekly requests for information from similar studies, a general methodology for monitoring oyster reefs which is currently being reviewed and peer reviewed paper published in the international *Journal of Fisheries Research*.

Project Coverage

The project was communicated using a range of different traditional and social media platforms. Traditional media included television, radio and newspaper articles. Social media utilised Facebook, website articles, Recfishwest E-News and YouTube.

Project Coverage - Social Media

The entirety of the project, including individual aspects such as Reef Vision and the HES deployments, was covered and shared mainly on Facebook. This was done on the Recfishwest Page as well as a page initially called South West Artificial Reefs, which was later titled Artificial Reefs WA, to accommodate for future developments of HES around the state. The aforementioned page was established to provide information to stakeholders on a weekly and monthly basis through various posts and shares as set out in the HES Extension and Adoption Timeline. Until April 2018, this cyber community group has had a large amount of engagement with the public and stakeholders, particularly enhancing two-way dissemination of information regarding the project and assisting with recruiting volunteers to assist with monitoring. These pages currently have over 19,000 followers between them and have had almost 150 HES related posts with over 5,126 likes and a reach of 1,185,900 to the community (Table 24). The content of these posts meets many of the objectives from the communications strategy including priorities such as:

- Raising awareness and understanding of the biological, social and economic benefits of HES and that artificial reefs are beneficial to the environment and community in various ways.

- Promoting the participation of monitoring of HES developments using easily available materials and data collection by community and industry group.

- Promoting HES where beneficial to recreational fishing, fishing businesses, the environment and broader community.

- General promotion of the project.

Table 24: Engagement tool analytics used by the social media pages for the project.

Engagement Tools	Artificial Reefs in WA	Recfishwest	Total
Posts	79	64	143
Likes	1,771	3,355	5,126
Reach	340,283	845,617	1,185,900
Shares	278	564	842
Comments	444	929	1,373
Total Followers	3,600	16,336	19,936

Articles and information related to the project was shared and stored on the Recfishwest website. This included sharing the latest HES related news as well as information on FADs and artificial reefs around WA, Reef Vision, the artificial reef guide and the project itself. Between February 2017 and February 2018, over 280,000 people viewed this page on the website, where the average time spent on the site was 2 minutes and 11 seconds and it has been accessed by over 50 countries.

Recfishwest also has a YouTube channel with 87 videos and 472 subscribers. There are four HES videos on the channel with over 3800 views combined. Reef Vision volunteers also upload and post their own homemade videos from the Reef Vision monitoring on YouTube, particularly when footage captures schools of target species such as samson fish and pink snapper or when irregular/rare species are observed such as turtles, short boarfish and sawsharks. Two of the videos alone from the DIVErsion (Reef Vision volunteer's own channel) received over 5,000 views combined and was shared on several different pages on Facebook. Throughout the project period there has also been over 20 different articles in Recfishwest's 'Broadcast' electronic newsletter relating to this project and a range of HES developments including FADs, oyster reefs and artificial reefs. The electronic newsletter is received by over 73,000 people and has an average open rate that is 10% greater than open rates of industry or e-marketing publications. The Recfishwest 'Broadcast' also has a click rate double that of the industry average. Examples of the project coverage on social media included Facebook, YouTube, the Recfishwest website and the 'Broadcast' electronic newsletter can be seen in the appendices.

Project Coverage – Traditional Media

Throughout the project period there was a vast amount of content covered by traditional media outlets. Updates and details of the project, HES developments, artificial reefs, oyster reefs and monitoring methods were observed through television, radio, magazines and newspaper articles by the mainstream media, government and industry. Across the duration of the project (2014 – 2017), there were 81 different articles including 18 web articles, 29 newspaper articles, 14 radio interviews, six magazine articles, 11 television appearances and three media releases throughout the project (Figures 71-73).

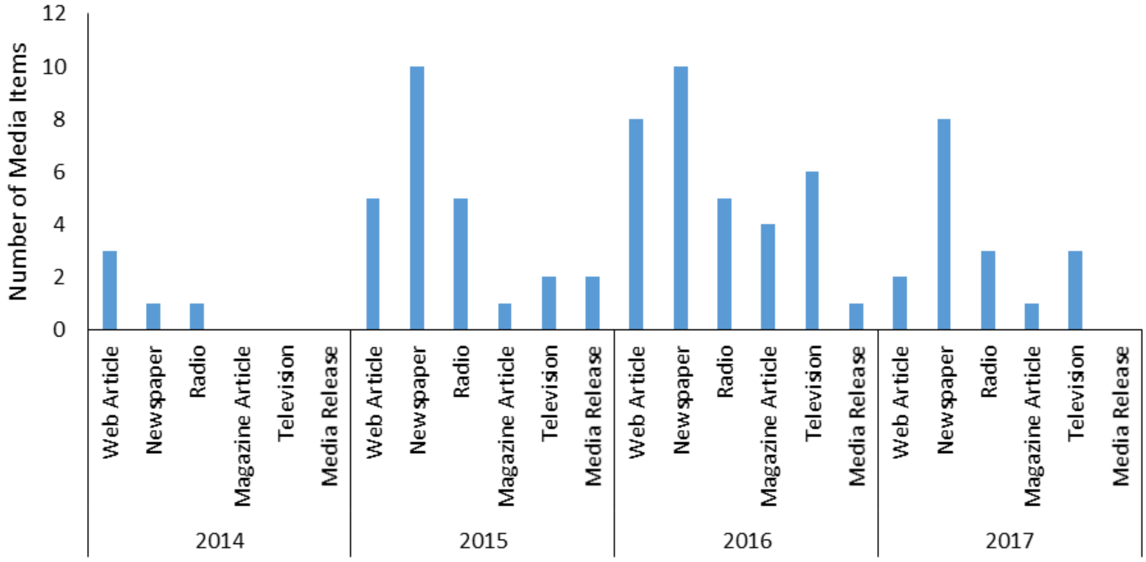

Figure 71: Number of media items covered by web, magazine and newspaper articles, radio interviews, television appearances and media releases for each year of the project.

Out of the 81 distributed media articles related to the project, just over 75% of these were covered by the media, 16% was covered by industry, and the government covered 8%. It should be noted that this is a conservative estimate picked up by Recfishwest's media trackers and it is likely that there would be more media that was distributed by the government and mainstream media.

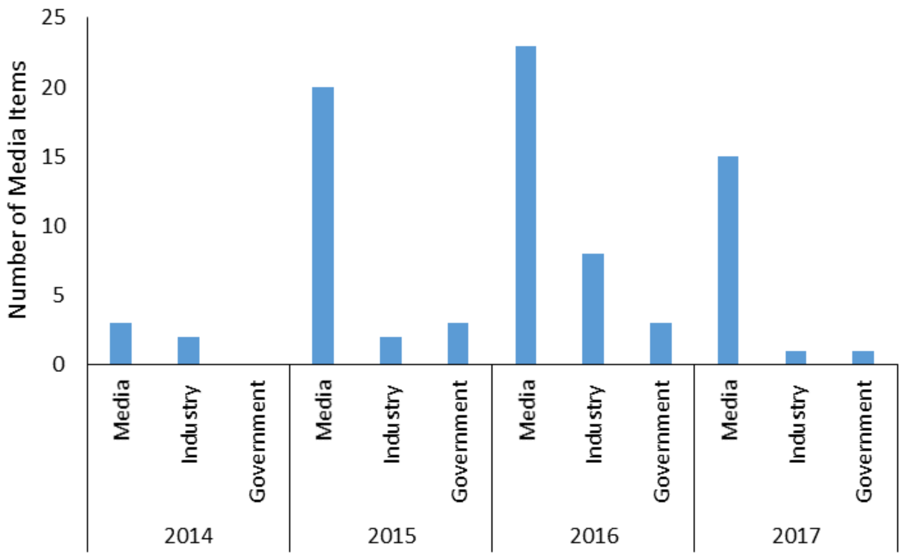

Figure 72: Number of media items covered by industry, government and the media throughout the duration of the project.

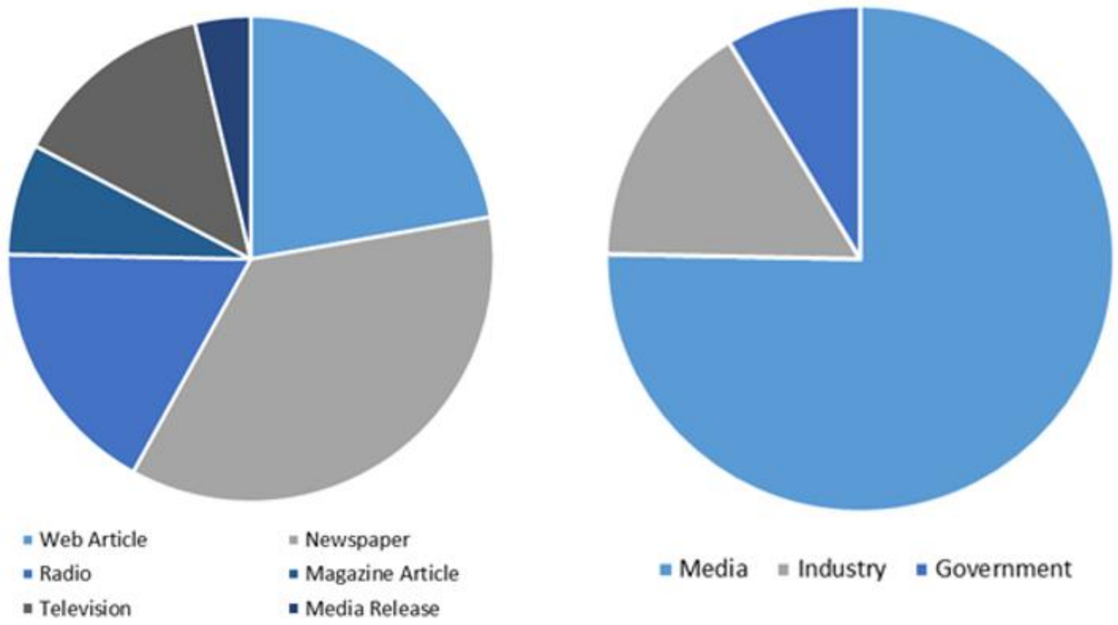

Figure 73: The proportion of different types of media (left) and the proportion of different organisations that covered the media (right) during the project.

Examples of traditional media platforms utilised throughout the project, as well as the full traditional media log are included in the appendices.

Project Materials Developed

All materials explained in this section have been included as separate attachments to this report. The HES Guide was the main output and project material developed and has been promoted locally, nationally and internationally. The document is a 21-page easy to follow guide for organisations and individuals requiring information and/or wishing to invest in HES. It provides a background, considerations and details the HES Process. The full guide is attached to this report and can also be downloaded from the Recfishwest website. A smaller four-page pamphlet is also attached. Inserted text from both documents can be seen in Chapter 4.

Three Honours projects were also completed on cost-effective monitoring methods and artificial reefs throughout the project. These theses are attached and the abstracts are as follows:

Can Recreational Fishers Provide an Effective Means of Monitoring Artificial Reefs?

Honours thesis, James Florisson (2015) Murdoch University.

Abstract

Artificial reefs have been constructed and deployed globally to enhance the productivity of aquatic habitats. In April 2013, two artificial reefs were deployed in Geographe Bay, Western Australia for the purpose of enhancing recreational fishing opportunities. These reefs are designed to create varied complex spaces and habitats, as well as to create shallow water upwelling to drive nutrients up into the water column. The deployment of artificial reefs in Australia has recently become the subject of specific focus of policy makers and regulators. Monitoring costs to meet legislative requirements can be prohibitive, however, a potential method to reduce these costs is to utilise volunteers from the general public to collect data (*i.e.* citizen science). Thus, the overall objective of this project was to determine whether recreational fishers could potentially provide an effective means for monitoring artificial reefs.

A small number of recreational fishers were provided with underwater video cameras and asked to record footage of artificial reefs and nearby natural reefs. Unfortunately, only limited amounts of data were received due to the lack of participation, unseasonal weather and the short timeframe of the project. However, enough videos were received to undertake a preliminary analysis of the differences in the characteristics of the fish faunas of the two types of reef. The results demonstrated that artificial reefs had much higher levels of mean and maximum abundance, number of species and ecological group affinities (Figure 74). However, multivariate statistical analyses did not detect any differences between the fish faunal compositions between artificial and natural reefs. This was due to the dominance of the labrid *Coris auricularis* and the large amount of variability between replicates.

Given the limited data provided by the above citizen science program, a literature review on other similar projects to evaluate the effectiveness of the citizen science components of the pilot project was completed and provided a set of key recommendations. These included enhancing the methods of contacting and recruiting volunteers, providing simplified and consistent instructions and consistent communication and engagement with volunteers.

Finally, Baited Remote Underwater Video (BRUV) systems, constructed from readily available materials, were deployed randomly around the Busselton artificial reef to test the applicability of this method for future use as a citizen science artificial reef monitoring tool. The video footage was analysed to determine whether there was a difference in fish assemblages between artificial reef modules and the surrounding area, *i.e.* videos observing areas in which artificial reef modules were, and were not, observed in the camera’s field of view. The results demonstrated that mean number of species and the number of benthic and epibenthic species were greater on footage recorded when the camera faced the modules. There was also a difference in the faunal composition. The footage observing artificial reef modules also exhibited 52.63% more recreational target species than surrounding areas. It was concluded that the BRUV technology employed here could be used, by citizen scientists, to monitor the fish faunas of artificial reefs. However, as this study has also demonstrated that there were significant differences in the characteristics of the fish faunas recorded depending on the direction the camera was facing, consideration is needed to design an unbiased and robust quantitative monitoring regime.

It is concluded that recreational fishers did not provide an effective means for monitoring artificial reefs during this project. This result, however, is a consequence of a lack of data stemming from an absence of volunteer engagement in a limited pilot project with a short time frame and unseasonal weather. This does not exclude the potential for using citizen scientists to monitor artificial reefs, following some changes in the methodology, technology and management of citizen science protocols, and thus it is possible to utilise recreational fishers as an effective means for monitoring artificial reefs. This project was subjected to restrictive and limiting factors but more importantly, discovered ways to overcome these issues by provided key recommendations on technology, methodologies and community engagement that should be followed to increase the effectiveness of using recreational fishers to provide sound scientific information in the future.

Artificial Reefs: Types, Applications, Trends in Deployment and the Development of a Cost-effective Method for Monitoring their Fish Faunas.

Honours thesis, Thomas Bateman (2015) Murdoch University.

Abstract

The focus of this thesis is on the design and use of artificial reefs and the development of a cost-effective method for monitoring their fish faunas. A review of habitat enhancement structures around the world, focusing primarily on artificial reefs, found that these structures have been used for a wide range of purposes such as sediment stabilization, mitigation of illegal trawling, enhancing recreational fisheries and the provision of additional habitat and nurseries for threatened fish stocks. Over time, there has been a growing trend in the use of purpose-built reef modules as opposed to the use of materials of opportunity. Within Australia this has been most evident in the shift away from the use of tyres and steel vessels, to the use of specially designed concrete reef modules. As these structures can require financial investments within the millions, it is important to evaluate their effectiveness through post deployment monitoring.

A central part of the citizen science monitoring project being developed by Recfishwest in Western Australia is the use of university students to extract information from the Baited Remote Underwater Video (BRUV) footage collected by recreational fishers. This study found that whilst observers recorded similar numbers of species and abundance (total Max-N), significant differences were present between observers in terms of their faunal compositions. This indicates that if inexperienced observers are used in the future as part of a cost-effective monitoring project, observer bias may be a potential source of error in the data and should be mitigated through observer training.

Statistical analysis of footage collected from the Bunbury and Dunsborough artificial reefs using BRUVs found a significant difference in species composition between the footage from the two reefs but not between camera positions. However, increased camera soak time and footage collection over a greater temporal scale are needed to increase the reliability of the data. Whilst improvements to the sampling regime are recommended, the use of cost-effective BRUVs shows potential as an effective method for monitoring the fish fauna of artificial reefs using citizen science.

Characteristics of the Fish Faunas of Artificial Reefs in Geographe Bay Determined from Video Footage Collected by Recreational Fishers.

Honours thesis, Timothy Hugh Elliot Walker (2016) Murdoch University.

Abstract

The number of artificial reef deployments around Australia has increased in recent years due to their popularity amongst recreational fishers. As these reefs modify the environment and its associated fauna, monitoring is required to ensure that any negative impacts to the surrounding area are assessed and minimised. Given this and the high cost of purpose-built artificial reefs, there is a need to develop cost-effective monitoring methods to determine their faunal composition. To address this need, this thesis reviewed methods for monitoring the faunas of artificial reefs and utilised the Baited Remote Underwater Video (BRUV) method to survey the fish faunas of two artificial reefs in Geographe Bay.

Fourteen fauna monitoring methods, in their application to artificial reefs, were critically evaluated against five criteria, *i.e.* deployment, accuracy, precision, time and cost. Not all methods were found to be applicable to the different types of artificial reefs, with the accuracy of each technique depending upon the scale at which monitoring occurs and the type of fauna being targeted. The fastest and cheapest techniques were those that either utilised only minimal equipment and/or did not require observers. Remotely operated underwater video, particularly BRUVs, were found to provide a relatively inexpensive and effective tool for monitoring fish communities of artificial reefs.

This finding supported the choice of the BRUV method, which was deployed through citizen science, to monitor the fish communities of the Bunbury and Dunsborough artificial reefs in Geographe Bay, south-western Australia, between October 2015 and July 2016. The resultant videos were analysed, using two-way ANOVA, to determine if the number of taxa, total MaxN, Simpson's Index, as well as the MaxN of several key recreational species, differed between reefs and over time, whilst PERMANOVA was utilised to identify whether the composition of the fish communities differed spatially and temporally. Most of the 60 taxa recorded were resident teleosts, however, nine species of elasmobranch were also recorded. In terms of the number of individuals, most were either pelagic or epibenthic and fed on zooplankton or zoobenthos. Significant differences were found among reefs in all variables, except Simpson's Index, with greater values typically being recorded on the Dunsborough reef. Monthly differences were detected for the number of taxa, total MaxN and the abundance of two recreationally important species, with greater values occurring mainly during summer. The greatest differences in the above univariate variables and fish community composition were always found for the reef factor, indicating that the location of the reefs to nearby habitat was predominantly responsible for shaping their associated fish communities. The lower, but still influential, temporal differences were influenced by seasonal changes in water temperature and oceanographic currents.

The data collected during this study demonstrate that BRUVs, deployed through citizen science, can be a useful and cost-effective tool for monitoring the fish faunas of artificial reefs.

Type A: *Pentaceropsis recurvirostris* (Longsnout Boarfish).

Type A: *Trygonorrhina fasciata* (Southern Fiddler Ray).

Type B: *Glaucosoma hebraicum* (Western Australian Dhufish).

Type B: *Anoplocapros amygdaloides* (Western Smooth Boxfish).

Type C: *Lagocephalus lunaris* (Rough Golden Toadfish) with *Pseudocaranx georgianus* (Sand Trevally).

Type C: *S. hippos* (Samson Fish).

Figure 74: Examples of species recorded on South West Artificial Reef Trial. The type category refers to the Nakamura ecological classification (Florisson, 2015).

There were also three different literature reviews as part of the second milestone. These are attached and include:

- ***Habitat Enhancement Structures (HES) or Artificial Reefs: a Review of design, application and deployment for Australian Waters***. Literature Review, Dr Chris Surman (2015) Halfmoon Biosciences.

- ***The application, needs, costs and benefits of habitat enhancement structures in Western Australia: Trends in artificial reef construction, design and management in Australia***. Thomas A. Bateman, James R. Tweedley & Jennifer A. Chaplin. Centre for Fish and Fisheries Research, Murdoch University.

- ***The application, needs, costs and benefits of habitat enhancement structures in Western Australia: Bibliographic analyses of scientific literature on habitat enhancement structures***. James R. Tweedley & Jennifer A. Chaplin. Centre for Fish and Fisheries Research, Murdoch University.

Finally the international Journal of Fisheries Research published a peer-reviewed study conducted by project managers and co-investigators on the BRUV component of Reef Vision:

Florisson, J., Tweedley, J. R. Walker, T., Chaplin, J. 2018 Reef vision: A citizen science program for monitoring the fish faunas of artificial reefs. Fisheries Research. 206, 296-308.

Appendices

Involved Personnel

Recfishwest

Dr Andrew Rowland, James Florisson, Leyland Campbell, Michael Tropiano, Stephanie Watts

Murdoch University

Dr James Tweedley, Tom Bateman, Tim Walker, Dr Mike Van Keulen, Dr Jennifer Chaplin, Dr Howard Gill

Department of Primary Industries and Regional Development

Mark Pagano, Paul Lewis

Ecotone Consulting

Andrew Matthews

Halfmoon Biosciences Consulting

Dr Chris Surman

Original Reef Vision Volunteers (South West)

Michael Daly, Ian Maunder, Chris Daou, Clive Tanner, Garry Dyer, Kevin Moore, Paul Tas, Henry Sieradzki, Jaxon Sieradzki, Cody Langridge, Darren Brindley, Lesley Langridge, Damien Langridge, Phil Baker, Jarrad Baker, Errol Jackson, Ben White, Jackie White, Torry Goodall, Nathan Larsen, Howard George, Dave Cole and Damian Lane

Intellectual Property

The information produced in this study is not suited to commercialisation.

Attachments

- I. Can recreational fishers provide an effective means of monitoring artificial reefs?
- II. Artificial Reefs: Types, applications, trends in deployment and the development of a cost-effective method for monitoring their fish faunas
- III. Characteristics of the fish faunas of artificial reefs in Geographe Bay determined from video footage collected by recreational fishers
- IV. Habitat Enhancement Structures (HES) or Artificial Reefs: a Review of design, application and deployment for Australian Waters
- V. The application, needs, costs and benefits of Habitat Enhancement Structures in Western Australia: Trends in artificial reef construction, design and management in Australia
- VI. The application, needs, costs and benefits of Habitat Enhancement Structures in Western Australia: Bibliographic analyses of scientific literature on Habitat Enhancement Structures
- VII. ASFB – Newsletter – 214 – 12 – 17
- VIII. Artificial Reefs in Australia: A Guide to Aquatic Habitat Enhancement Structures
- IX: Habitat Enhancement Structure Extension and Adoption Timeline 2015-2017
- X: HES Pamphlet
- XI: Reef vision: A citizen science program for monitoring the fish faunas of artificial reefs

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Media Log

Table 25: 2014 Media.

Date	Topic	Outlet	Article title
16th August	Artificial Reefs Albany	Albany Advertiser	Artificial Reefs Proposed for King George Sound
2nd November	FADs	Sunday Times (Perthnow.com.au)	Latest FADs Bring on the Game Fish
1st December	ABC South West Radio (Artificial Reefs, Herring Limits, Crabs in Australind)	ABC South West – with George Manning talks with RFW	South West ABC Radio
4th December	FADs	Perth Game Fishing Club Newsletter	PGFC and Recfishwest FADs
6th December	FADs deployment media	Boat Sales.com	FAD Deployment

Table 26: 2015 Media.

Date	Topic	Outlet	Article title
January	FADs	Western Australian Fishing Magazine	World Class Perth Fishing more than just a FAD
22nd April	Artificial Reefs	ABC News WA TV	NA
14th May	RFIF Reef Monitoring	Fishing World Online	Recfishers asked to monitor artificial reefs
31st May	FADS RFIF	Sunday Times	Japanese Technology Helps Perth anglers
25th August	Mandurah Reef Announcement	ABC 720 Radio	NA
25th August	Mandurah Reef Announcement	Mandurah Mail	Artificial reef on the way for Mandurah anglers
25th August	Mandurah Reef Announcement	Minister Media Statement	Artificial reef on the way for Mandurah anglers
25th August	Mandurah Reef Announcement	News.com.au	Artificial reef double the size of the MCG set for the peel coast
25th August	Mandurah Reef Announcement	The West (video)	Man-made reef to be built of Mandurah
25th August	Mandurah Reef Announcement	Channel 10 News	Making a splash across our coast
25th August	Mandurah Reef Announcement	Perth Now	Artificial reef double the size of the MCG set for the Peel Coast
25th August	Mandurah Reef Announcement	Courier Mail	Artificial reef double the size of the MCG set for the Peel Coast
25th August	Mandurah Reef Announcement	6mmm radio Mandurah	Four hectares of artificial reef set for Mandurah
26th August	Mandurah Reef Announcement	The West	NA
26th August	Mandurah Reef Announcement radio	1116 6am Mandurah radio	NA

31st August	Mandurah Reef Announcement	Sound Telegraph	Mandurah to get artificial reef
2nd September	Mandurah Reef Announcement	Mandurah Coastal Times	NA
11th September	Steel Reef towers	Sound Telegraph	NA
11th September	Steel Reef towers	The Weekend Courier (Rockingham)	NA
17th September	Reef Vision	Busselton Dunsborough Mail	NA
21st September	Oyster Reef announcement	Minister Media Release	Project aims to bring oysters back to Albany
21st September	Oyster Reef announcement	ABC Great Southern	NA
21st September	Oyster Reef announcement	ABC South West	NA
22nd September	Mandurah Reef	Fisheries Catch Newsletter	Artificial reef on the way for Mandurah
23rd September	Oyster Reef announcement	Albany Advertiser	Oyster reef improves water health
24th September	Oyster Reefs Albany	Great Southern Weekender	NA

Table 27: 2016 Media.

Date	Topic	Outlet	Article title
9th January	FADs	Weekend West	FAD Breakoff
19th January	Artificial Reefs	Coastlines Government Publication	NA
17th March	Reef vision	FISH (FRDC Magazine)	NA
30th March	Artificial reefs	Western Angler	Embracing artificial reefs
12th April	Mandurah Reef	Minister Office	New lure for fishers off Mandurah
12th April	Mandurah Reef	Mandurah Coastal Times	Artificial reef announced for waters off Mandurah
12th April	Mandurah Reefs	Ch7 News	NA
12th April	Mandurah Reefs	Ch10 News	NA
13th April	Mandurah Reefs	The West Country	NA
13th April	Mandurah Reefs	The West	NA
13th April	Mandurah Reefs	Mandurah Mail	Mandurah artificial reef a shore thing
20th April	Mandurah Reef	Today Tonight	NA
20th April	Mandurah Reef	Fishing World	Mandurah reef module deployment
11th May	SW Artificial Reef Catch	Hook Up (PGFC ENEWS)	NA

19th May	Artificial Reef Monitoring	ABC Southwest	NA
23rd May	Artificial Reef Monitoring	The West Australian	new artificial reefs draw more fish varieties
23rd May	Artificial Reef Monitoring	Radio South West (AM)	NA
23rd May	Artificial Reef Monitoring	Hot FM	NA
25th May	Artificial Reef Monitoring	RTR FM	NA
4th June	Oyster Reef	ABC News	Crucial element of south coast oyster program completed
4th June	Oyster Reef	ABC News	NA
4th June	Ozfish Unlimited	Fishing World	Ozfish unlimited aims to change the way aussies fish
15th June	Oyster Reef	Great Southern Weekender	NA
June	Artificial Reefs	Red FM	NA
7th July	Oyster reef	Dept of Planning Newsletter	NA
5th August	Habitat Forum Albany	Great Southern Weekender	NA
1st November	Oyster Reef	Science Network	Promising progress for pilot shellfish reef restoration program
11th November	Reef Towers	Kwinana Courier	artificial reef towers to create sustainable fishing hot spot near garden island
11th November	Mandurah Reef	Mandurah Mail	Artificial reef making strides for Mandurah's marine life photos
29th November	Reef Towers	Wangler	NA
8th December	Reef Towers	WA Today	Fish towers to be sunk off Perth this summer to help bring bumper catches
16th December	Habitat in WA	OZ Fish Newsletter	NA
20th December	Reef Tower Deployment	Ch 9 news	NA
29th December	Esperance Reefs	Esperance Express	Reef receives tick

Table 28: 2017 Media.

Date	Topic	Outlet	Article title
6th January	Esperance Reefs	Esperance Express	Reef location still sought
9th January	Exmouth/ Dampier Artificial Reefs	ABC NorthWest	NA
11th January	Esperance Reef	ABC Goldfields	NA
12th January	Reef Towers	PGFC Enews	NA
13th January	Reef Towers	Weekend Courier	NA
14th January	Reef Towers	Channel 9 News	NA
17th January	Fish habitat and Reef Towers	Coastlines	Fish Towers to be deployed this summer
21st February	Liberals Artificial reef announcement	Albany Advertiser	Peak fishing body backs reef planning
21st February	Albany Reef	Albany Advertiser	NA
30th April	Fish Towers	WA Today	Gone fishing-new artificial reefs in place off Perth to bring anglers more luck
11th May	Artificial Reefs	South west Times	Fish numbers up at artificial reefs
15th May	Artificial Reefs	Today Tonight	NA
6th June	Artificial Reefs	South Western Times	Artificial reefs hosting unusual species
6th June	SW Reefs	GWN 7 News	NA
30th September	Crayfish, Demersals, App, Peel Reef Vision	Red Fm	NA
2nd October	Reef Vision	Kalgoorlie Miner	Fishers make splash with underwater camera for artificial reef research
2nd October	Reef Vision	Mandurah Mail	Recfishwest on the hunt for fisher scientists

Media Examples

Social Media

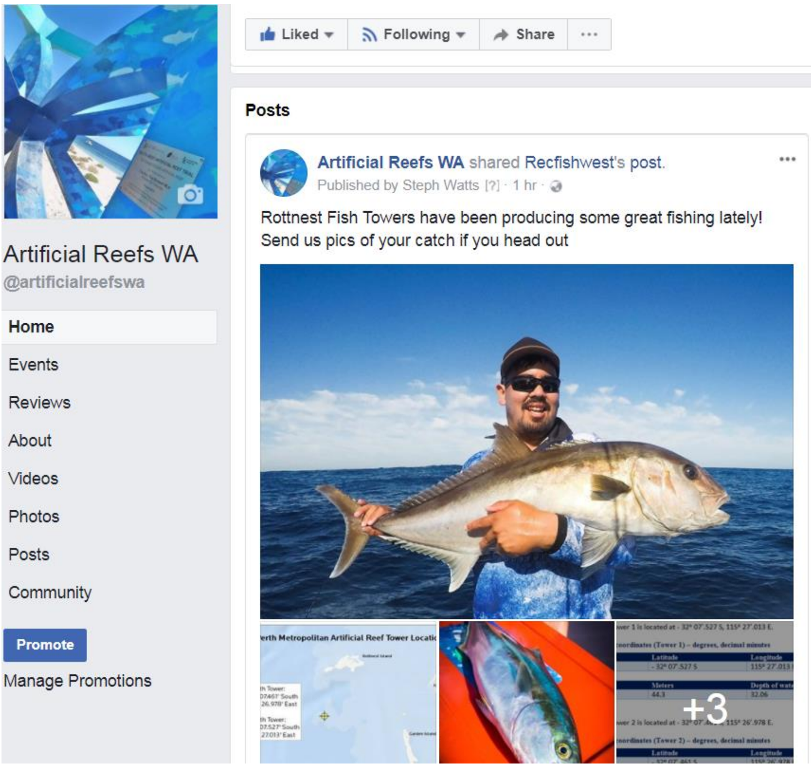


Figure 75: Snapshot of the Artificial Reefs WA Facebook Page.

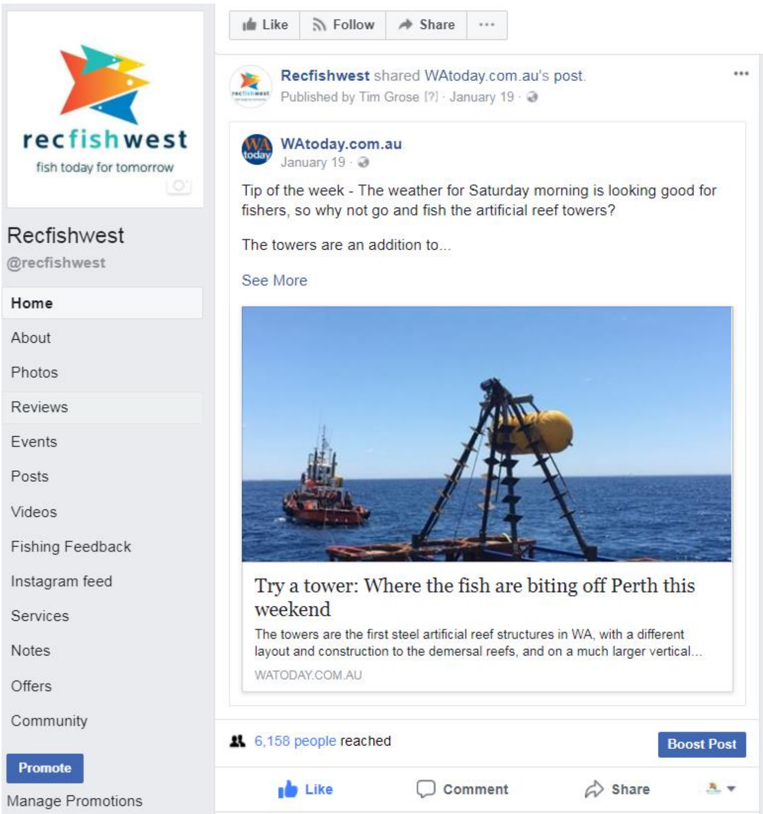


Figure 76: The Recfishwest Facebook Page with HES content.

Figure 77: The closed Facebook group for Reef Vision volunteers to share content and communicate.

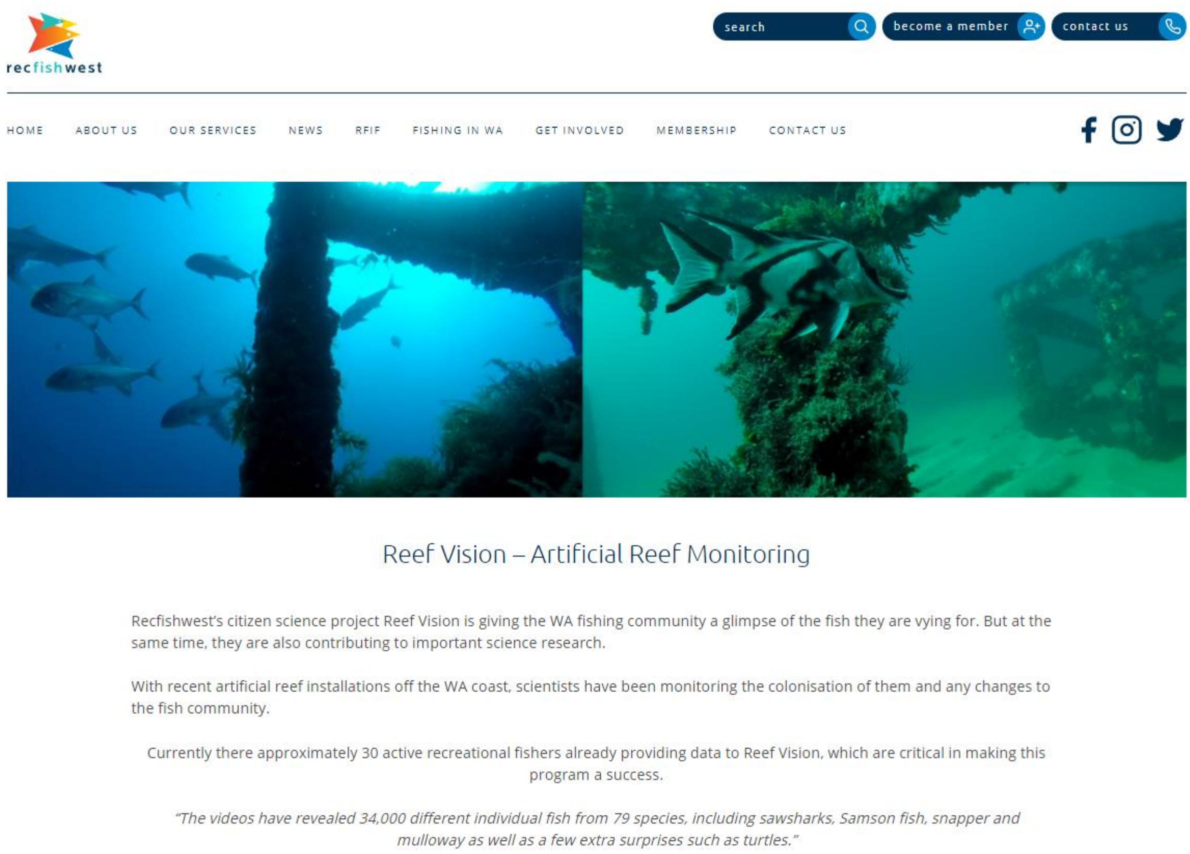


Figure 78: The Reef Vision webpage on the Recfishwest website, one of many pages on HES, accessible at: https://recfishwest.org.au/

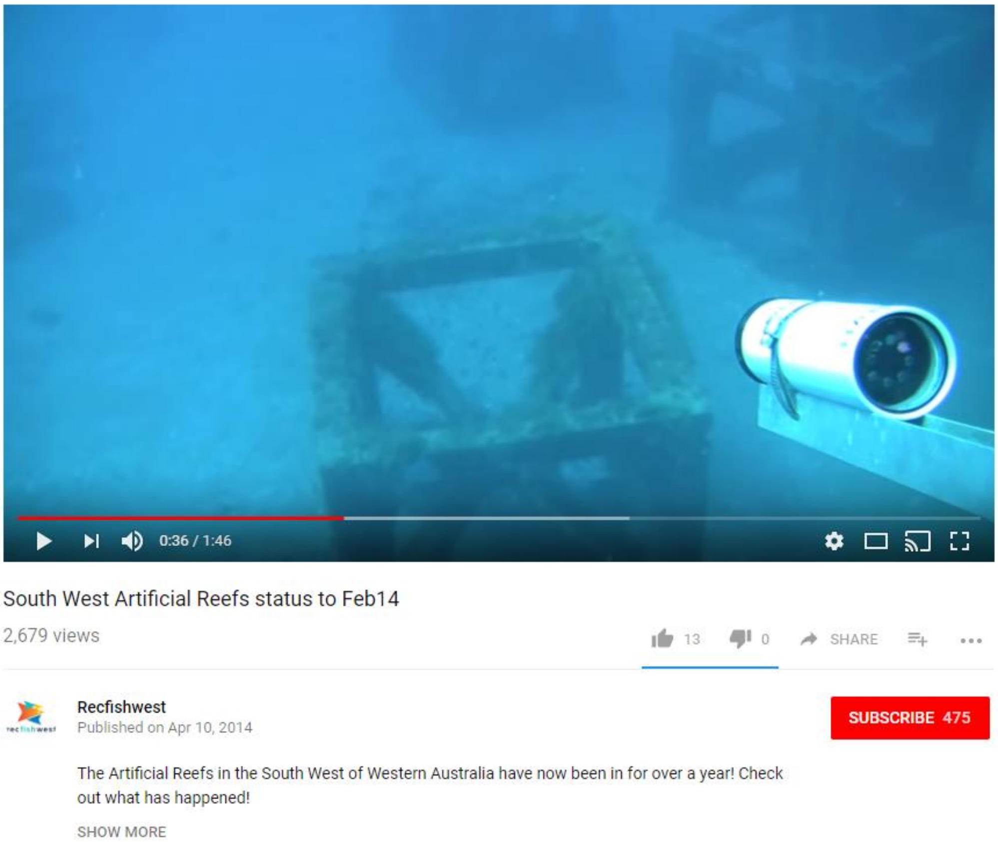


Figure 79: An example of a HES video from the Recfishwest YouTube channel**.**

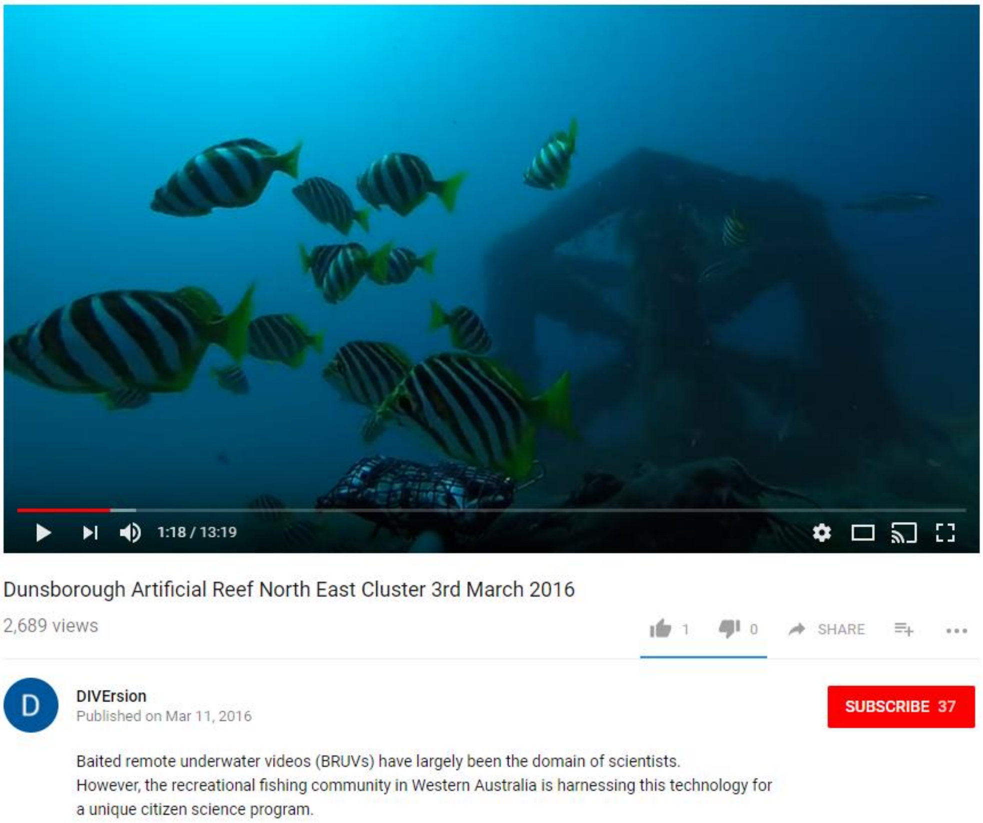


Figure 80: An example of a HES video produced and shared by a Reef Vision volunteer.

recfishwest

Edition #61

Broad Cast

Recfishwest Broad Cast 1 June 2017

Our Purpose: Great fishing experiences for all in the WA community forever.
Our Commitment: To protect, promote and develop sustainable, accessible, enjoyable and safe fishing for the benefit of the community.

Life on MARS: Mandurah Artificial Reef System

todaytonight

Underwater haven one year on

It has now been a little over one year since the Mandurah Artificial Reef was deployed. With nearly 30 species identified already, it is looking promising for the future of artificial reefs in WA.

Get your first look here.

Figure 81: An example of a HES article on Recfishwest's electronic newsletter.

Traditional Media

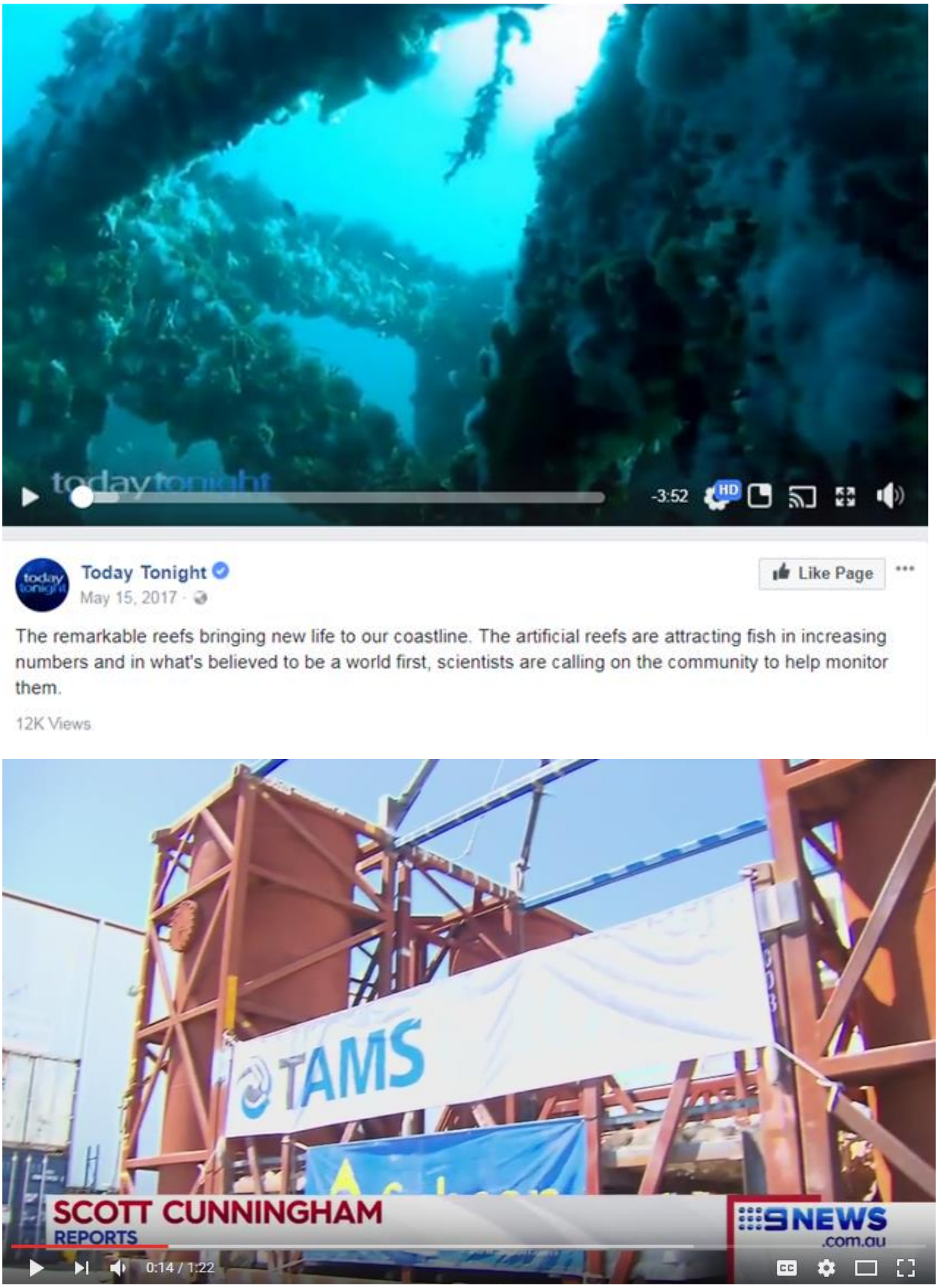


Figure 82: Television coverage of HES developments in WA.

FISHERS CAPTURE UNDERWATER WORLD FOR SCIENCE

The fishing community are becoming scientists by filming under the waves while fishing over reefs.

EARTH | June 9, 2017

Recfishwest's citizen science project Reef Vision is giving the WA fishing community a glimpse of the fish they are vying for.

But at the same time, they are also contributing to important science research.

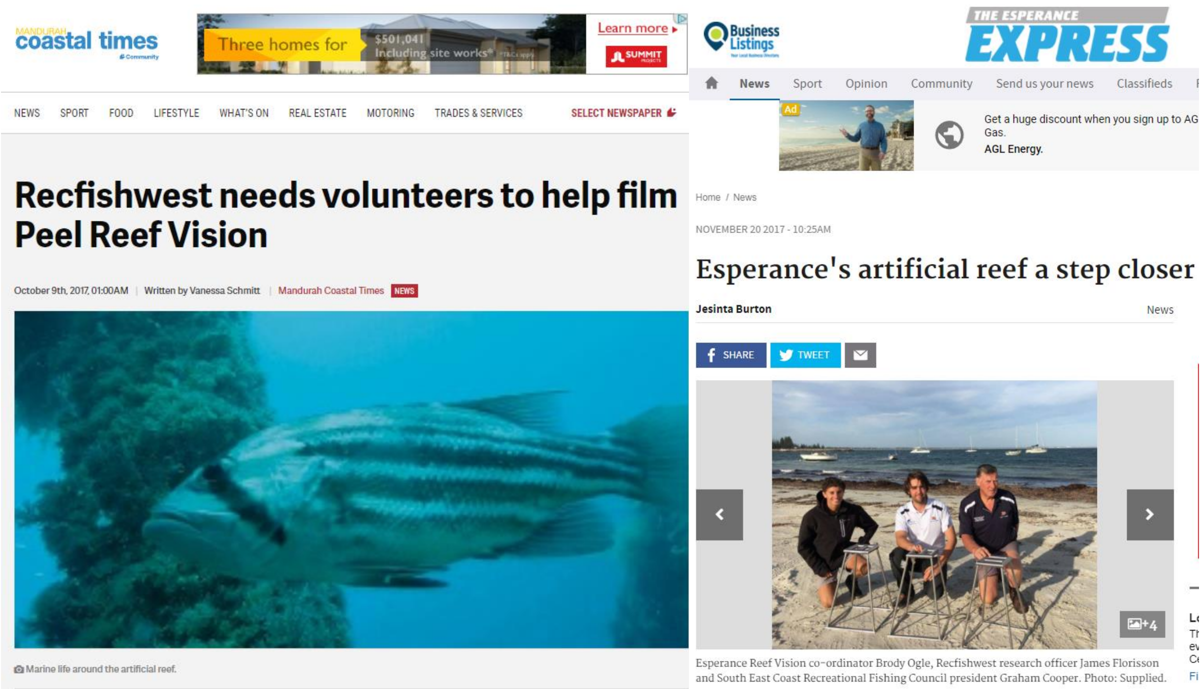
Two artificial reefs were sunk 4 years ago off the coast of Bunbury and Dunsborough.

Since then, scientists have been monitoring the colonisation of them and any changes to the fish community.

Recfishwest Research Officer and artificial reef specialist James Florisson says the project is getting fishing communities engaged with science.

It's also an extremely cost-effective way to gather large amounts of data over long time periods.

Figure 83: Examples of project coverage in industry and scientific magazines including FRDC's FISH (left) publication and Scitech's Particle (right). An article in the Australian Society for Fish Biology is also attached.



Recfishwest needs volunteers to help film Peel Reef Vision

October 9th, 2017, 01:00AM | Written by Vanessa Schmitt | Mandurah Coastal Times NEWS

Marine life around the artificial reef.

Home / News

NOVEMBER 20 2017 - 10:25AM

Esperance's artificial reef a step closer

Jesinta Burton

News

SHARE TWEET

Esperance Reef Vision co-ordinator Brody Ogle, Recfishwest research officer James Florisson and South East Coast Recreational Fishing Council president Graham Cooper. Photo: Supplied.

Figure 84: Examples of traditional print media coverage of the development of HES in WA, from the Coastal Times (left) and Esperance Express (right).

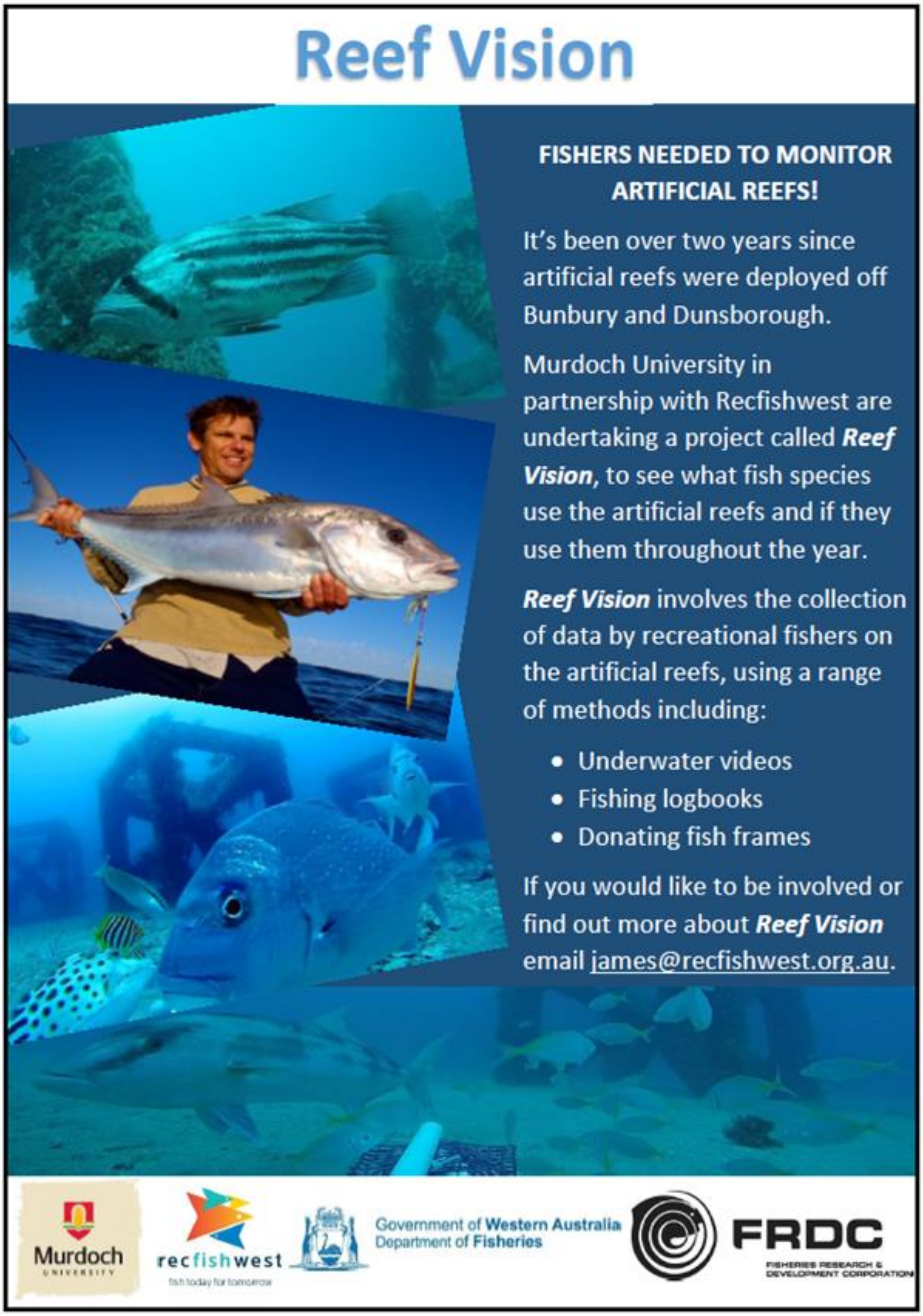
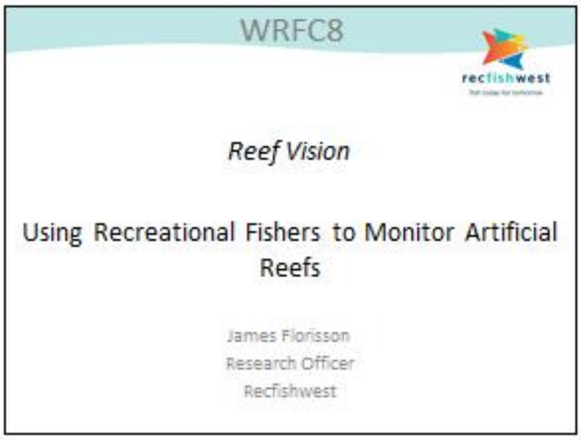
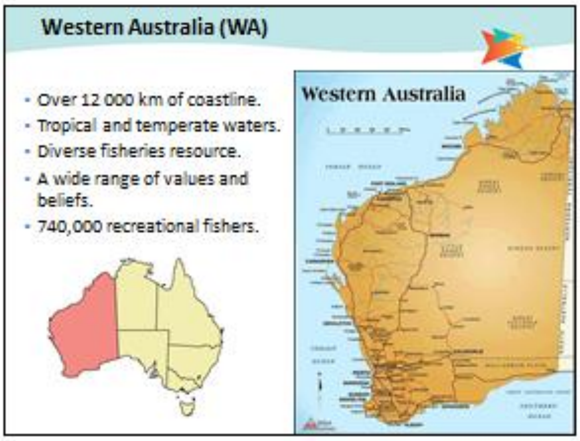


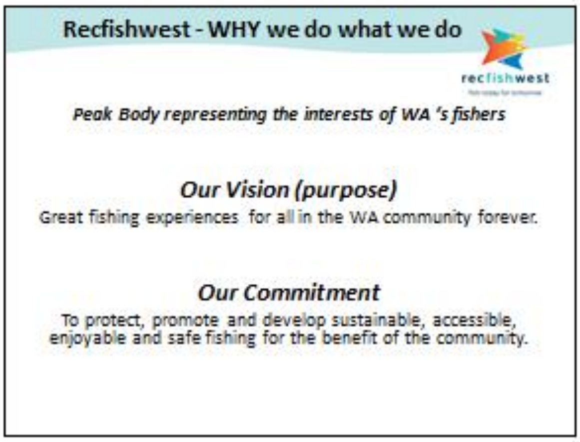
Figure 85: One of the many pamphlets used for recruiting Reef Vision volunteers. These were available from tackle stores, displayed on Facebook and advertised in local newspapers.

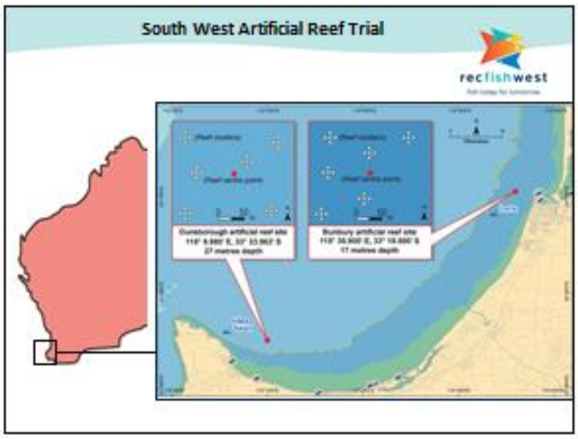
Presentations

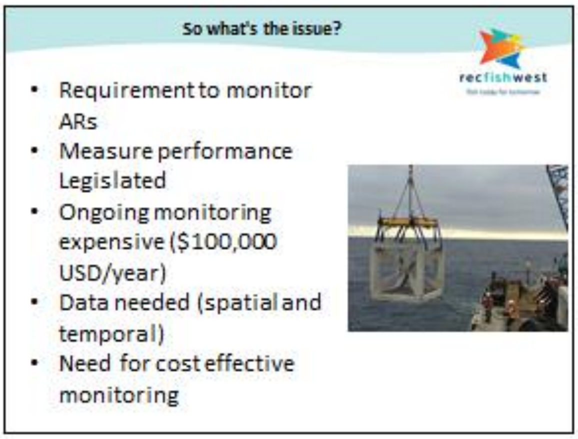
There were more than ten presentations on the project throughout the reporting period. These were mainly given in Western Australia, but also in Darwin, Malaysia and Canada. These two examples are from the 8th World Recreational Fishing Conference in Canada in July 2017.







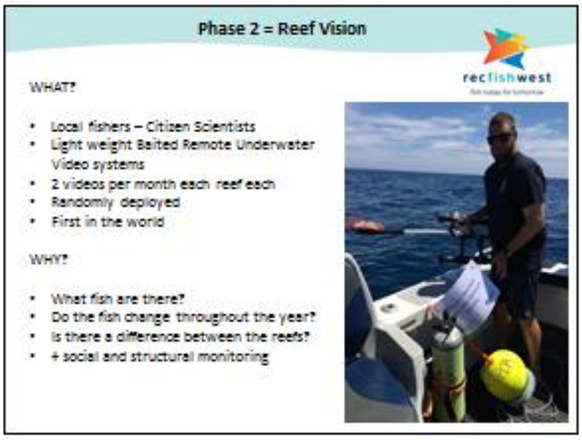




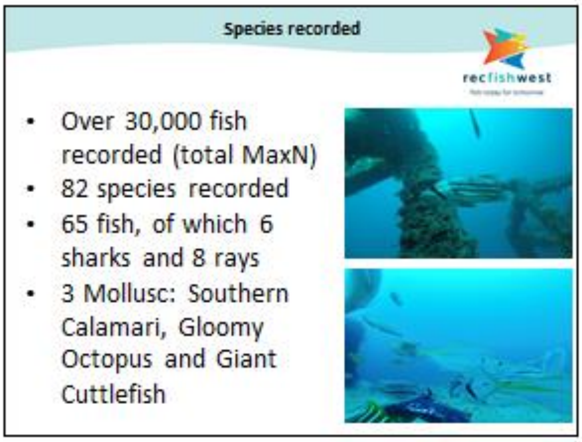
Presentation One

Florisson, J., Rowland, A., Campbell, L. and Tweedley, J. 2017. Reef vision: successfully using recreational fishers to monitor artificial reefs using baited remote underwater video systems [Powerpoint Presentation]. Presented July 2017. Session 2: Citizen Science and Recreational Fisheries (D1). 8th World Recreational Fishing Conference, Victoria, British Columbia, Canada.

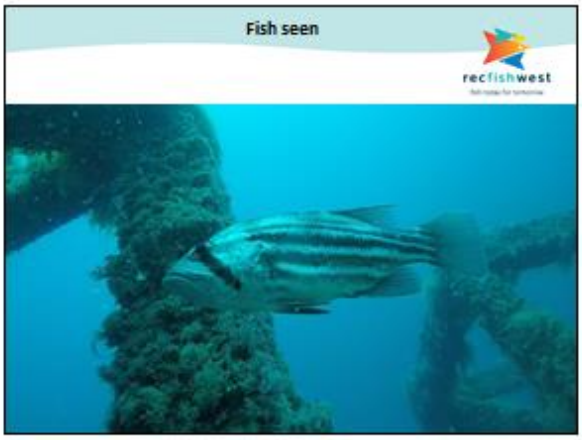

BRUVs
recfishwest
• Cheap to build
• Easy to use
• High quality
• Strong
• Better footage = better data

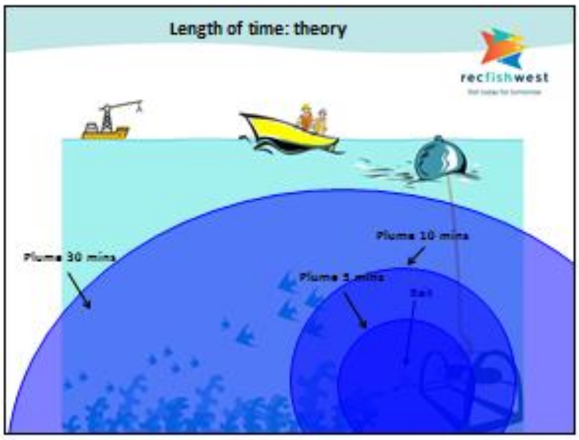

Phase 2 = Reef Vision
recfishwest
WHAT?
• Local fishers – Citizen Scientists
• Light weight Baited Remote Underwater Video systems
• 2 videos per month each reef each
• Randomly deployed
• First in the world
WHY?
• What fish are there?
• Do the fish change throughout the year?
• Is there a difference between the reefs?
• + social and structural monitoring

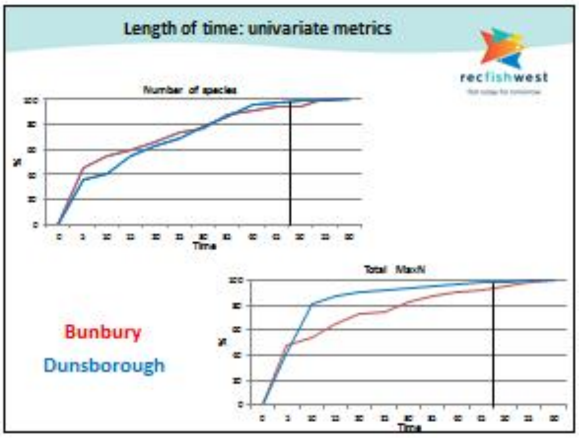

So far….
recfishwest
• Since Oct 2015
• Fishers completed 184 drops of BRUV
• Recorded over 250 hours video!
• Over 500gb data

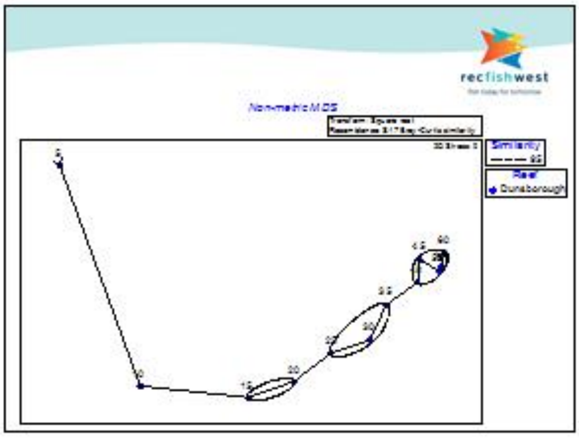

Species recorded
recfishwest
• Over 30,000 fish recorded (total MaxN)
• 82 species recorded
• 65 fish, of which 6 sharks and 8 rays
• 3 Mollusc: Southern Calamari, Gloomy Octopus and Giant Cuttlefish


Recreational species (order of abundance)
recfishwest
1. Samson Fish
2. Mulloway
3. Boarfish
4. Dhufish
5. Baldchin Groper
6. Pink Snapper
7. Gummy Shark
8. Flathead (2 species)
9. Squid
10. Salmon
11. Western Blue Groper

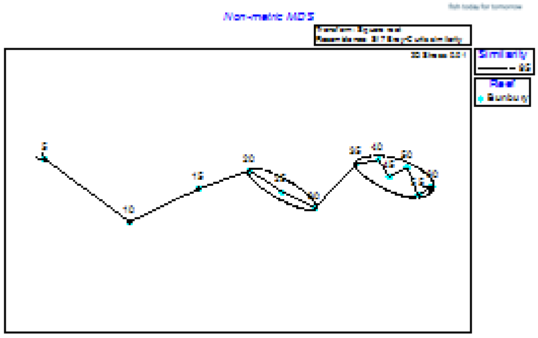

Fish seen
recfishwest


Length of time: theory
recfishwest
Plume 30 mins
Plume 10 mins
Plume 5 mins
Bait


Length of time: univariate metrics
recfishwest
Number of species
Time
Total MaxN
Bunbury
Dunsborough

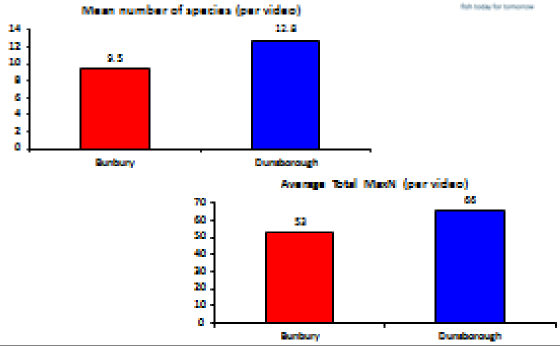

recfishwest
Non-metric MDS
Similarity
Reef
Dunsborough

recfishwest



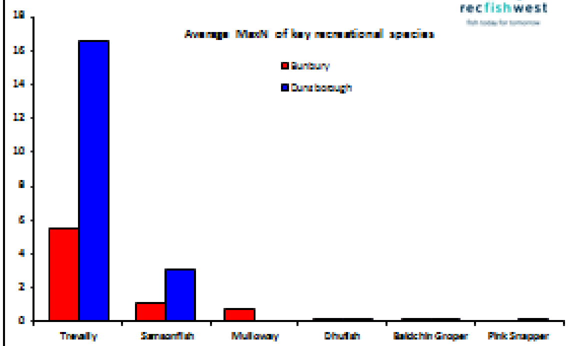
Bunbury vs Dunsborough

recfishwest



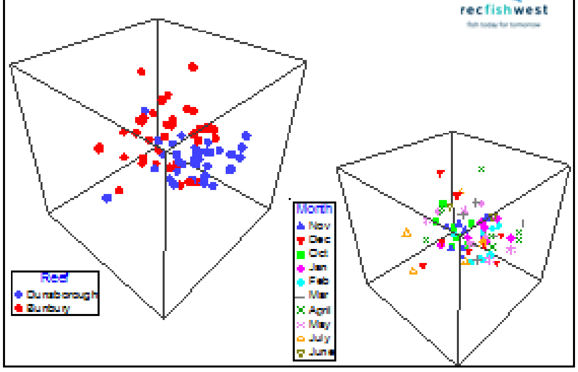
Bunbury vs Dunsborough

recfishwest



Bunbury vs Dunsborough

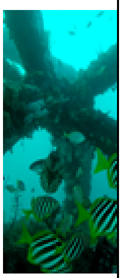
recfishwest

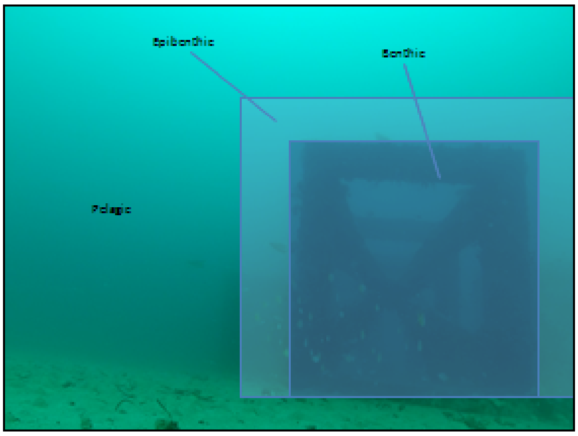


recfishwest

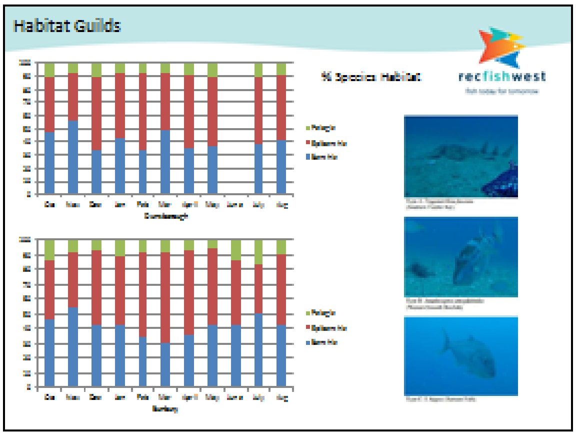
Abundant species	% Contribution	% occurrence
Pseudocaranx spp (Trevally)	21.01	82.35
Coris auricularis (Western King Wrasse)	17.93	97.06
Nectypus obliquus (Western Footballer)	12.40	47.06
Trachurus novaezelandiae (Yellowtail Scad)	11.45	8.82
Parequula melbournensis (Silverbelly)	5.53	61.76
Diodon nichthemerus (Globefish)	4.25	20.59
Seriola hippos (Samsonfish)	3.91	82.35
Pempheris klunzingeri (Rough Bullseye)	3.69	8.82
Anoplocapros amygdaloides (Western Smooth Box Fish)	3.30	76.47
Austrolabrus maculatus (Black-spotted Wrasse)	1.68	29.41
Chelmonops curiosus (Western Talma)	1.45	52.94
Myliobatis australis (Southern Eagle Ray)	1.45	61.76
Trygonorrhina fasciata (Southern Fiddler Ray)	1.34	50.00
Dasyatis brevicaudata (Smooth Stingray)	0.95	32.35

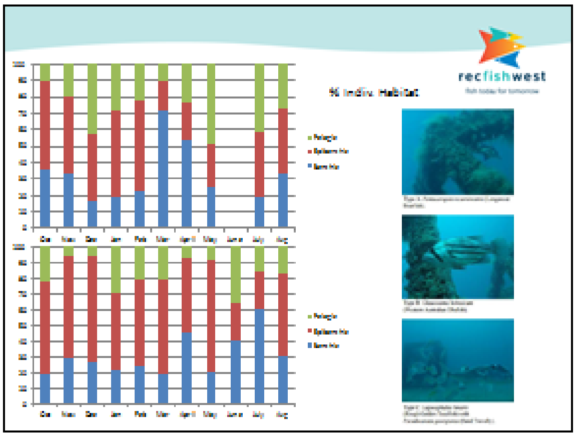
Selected recreationally targeted species	% Contribution	% occurrence
Argyrosomus japonicus (Mulloway)	0.67	2.94
Glaucosoma hebraicum (West Australian Dhufish)	0.22	11.76
Choerodon rubescens (Baldchin Groper)	0.22	11.76
Chrysophrys auratus (Pink Snapper)	0.17	5.88
Mustelus antarcticus (Gummy Shark)	0.17	5.88
Sepioteuthis australis (Southern Calamari)	0.08	2.94

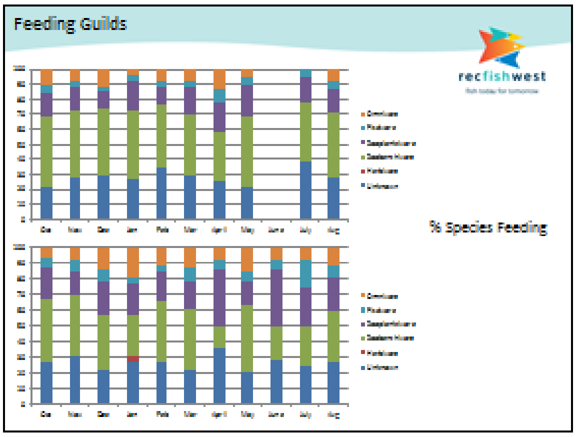




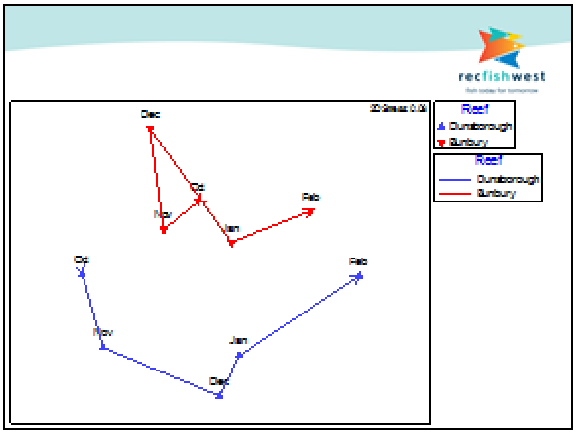

recfishwest
Benthic
Epibenthic
Pelagic


Habitat Guilds
recfishwest
% Species Habitat

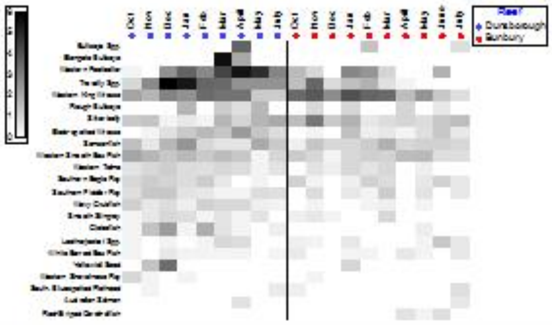

recfishwest
% Indiv. Habitat


Feeding Guilds
recfishwest
% Species Feeding


recfishwest
% Indiv. Feeding


recfishwest
Dec
Oct
Nov
Jan
Feb
Reef
Dunsborough
Bunbury

Bunbury vs Dunsborough



Our Findings

- Extremely Successful
- 46 volunteers collecting data on 4 reefs
- Community engaged
- Cost effective (50%, $25,000 USD/Year)
- Program accepted by regulators, academia and community
- Media sensation!

Benefits and the Future

Benefits and the Future

- Community ownership and stewardship
- Social benefits to volunteers
- BRUV in a box
- Community value
- Reef Vision state-wide
- 3 more reefs in next two years
- Oyster reef and FAD monitoring

Key Messages

- Volunteers need to be filtered to reduce attrition
- Community and volunteers need to be engaged
- Easy, safe and durable technology
- Communication and extension important
- Simplistic but rigorous methodology
- Adaptable framework

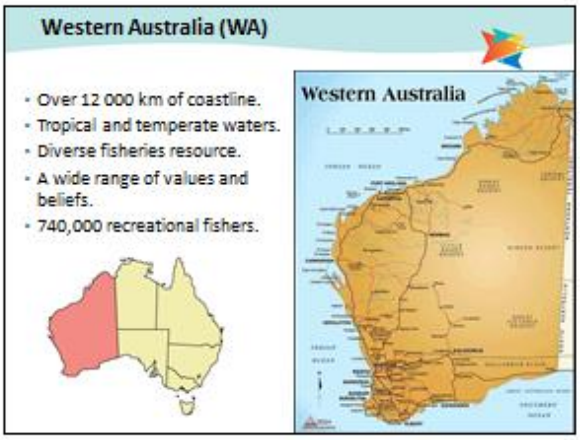
james@recfishwest.org.au

https://www.facebook.com/artificialreefswa/

www.recfishwest.org.au

Presentation Two

Florisson, J., Rowland, A. and Campbell, L. 2017. The development of habitat enhancement structures in Western Australia – Outcomes for the world. [Powerpoint Presentation]. Presented July 2017. Symposium 3: Recreational Anglers Driving Fish Habitat Outcomes (K11). 8th World Recreational Fishing Conference, Victoria, British Columbia, Canada.



What is an artificial reef?

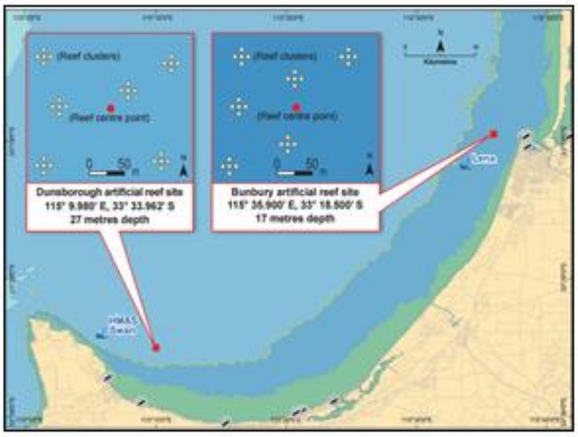
- Man made structure designed to mimic characteristics of a natural reef
- Materials of Opportunity
- Purpose-built artificial reefs

Materials of Opportunity

Purpose-built Artificial Reefs

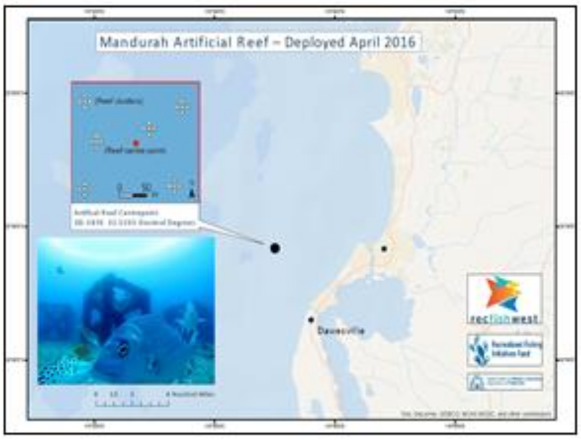
Artificial Reefs in WA

- Community appetite and drive strong
- Opportunities and investigations into applicability in WA
- Government responds with HES Policy
- Local steering committee established
- First reef deployed 2013
- In 2017, four reefs deployed
- Almost $5 million invested (mainly rec licence money)
- 120,000m2
- Over 1000 tonne
- 3 more reefs funded



South West Artificial Reef Trial

- April 2013
- $2.38 million
- 30 ten tonne concrete modules each
- 27 and 17m depth
- Over 80 species identified



Mandurah Artificial Reef

- Deployed April 2016
- Thirty 10 tonne concrete modules
- First reef solely paid for by rec $
- 25m depth
- 28 species identified

Perth Metropolitan Artificial Reef Tower Location

Metropolitan Fish Towers

- Deployed Dec 16/Jan 17
- First metal structure WA
- Biggest in Aus
- 4 Storeys (12.5m)
- 70 tonnes
- World first deployment method
- F13 - Thursday

So what's the issue?

- Ad hoc approach
- No clear pathway or standardised approach
- Cant expect government to do everything
- AR development many variables and factors
- Organisations have little broad experience

How can you deliver the most effective reef with minimal experience or capabilities?

What's the solution?

- Need to clarify the process
- All involved parties (govt, community, contractors etc)
- Solution = WA/Australia guide
- Applicable to the world
- 7 easy steps

We need to effectively work with the community, regulators and engineers using best practise scientific methods and public engagement to ensure the highest benefits from investment.

1. Purpose and Objectives

- Importance overshadowed
- Integral to establish process and effective installation
- Clearly understood and decided by relevant parties
- E.g. effort displacement, safety and tourism

2. Initial Consultation and Constraints Mapping

- Consultation with stakeholders and end users to establish variables
- Consultation over reef type, location, target species and others
- Everyone needs to be at the table on the same page!
- Constraints mapping to find suitable area

2. Constraints Mapping

Biological/ecological	Physio-chemical/environmental	Social/anthropogenic
• Existing fish communities • Protected and endangered species • Target species distribution • Competition for colonisation • Predation of target species • Larval availability • Sensitive habitats	• Sedimentation and turbidity • Light • Water temperature • Depth • Geomorphology • Water quality • Salinity • Wave exposure and energy	• Cultural or historic areas • Distance from shore • Marine Protected Areas • Military Areas • Mining and Shipping areas • Existing commercial fishing areas • Population size • Developement plans

3. Finalisation of Reef Site

- After successful consultation and constraints mapping
- Biological and ecological site characteristic analyses:
  - Habitat Mapping
  - Sidescan Sonar
  - Sediment Probes
  - Faunal Survey

4. Final Consultation (Inform)

[illegible] Consultation (Inform)	
Accommodation Providers	Fishing Stores
Any Mining, Oil or Gas Providers	Historical Societies
Aquaculture Council	Local Businesses
Boating Clubs	Local Development Commissions
Chamber of Commerce and Industry	Local NRM and Conservation Groups
Commercial Marine Services	Local Recreational Fishing Councils
Community Groups	Local Cities and Councils
Diving Charters	Local Visitor Centres
Diving Clubs	Logistics Services
Diving Stores	Marine Rescue Services
Fish Stocking Organisations	Regional Development
Fishing Charters	Tourism
Fishing Clubs	Volunteer Sea Rescue Groups

4. Final Consultation (Consult and Approve)

Regulators/Clearances/Approvals (Consult)	
Australian Fisheries Management Authority	Relevant Natural Resource Management Organisations
Australian Hydrographic Office	Relevant Port Authorities
Australian Maritime Safety Authority	Relevant Recreational Fishing Peak Bodies
Maritime Archaeological Associations	Relevant State-Based Fisheries Regulators
National Offshore Petroleum Safety and Environmental Management Authority	Relevant Environmental Regulators
Relevant Aboriginal Affairs Organisations	Relevant State-Based Heritage Administrators
Relevant Commercial Fishing Peak Bodies	Relevant Transport and Infrastructure Regulators
Relevant Mines and Petroleum Administrators	Royal Australian Navy

5. Approvals

- Approvals investigated and attained for installation
- Australian Sea Dumping Act, other countries have similar environmental legislation
- London Protocol
- Government Approvals (including jurisdictional)
- Other Approvals (first nations/indigenous, military, shipping etc)

- Appropriate HES sites are utilised
- Construction materials are suitable, environmentally friendly and prepared properly
- There are no significant negative impacts on the surrounding marine environment
- The HES pose no danger to navigation or end users
- That the HES is chartered on maritime maps
- The reef is aligned with state and commonwealth laws and policies

6. Procurement, Construction and Deployment

- Engage specialist for building and deployment
- If done by community check local and international guidelines (London Protocol)
- Deployment most costly part of process
- Deployment method suited to reef type and location (also weather dependent)

7. Monitoring, Reporting and Extension

- Requirement to monitor to ensure reefs are meeting objectives and have no negative impacts on environment
- Socially, Structurally and Ecologically monitored
- Rec fishers can be a cost effective monitoring option
- Communications and Extension Plan
- Disseminate results and receive feedback
- Foster stewardship and ownership of the reef

Take Home Messages

- Artificial Reefs extremely effective tool for recreational fisheries enhancement if done properly
- WA has benefitted from experience but using our tools and knowledge could further streamline other installations
- A clear purpose and objectives is integral
- Ensure stakeholders, end users and other beneficiaries are on board for the ride
- Analyse considerations and ensure the site is socially, environmentally and ecologically suited
- Carefully plan procurement, construction and deployment
- Monitor the reefs and provide extension material to engage the community
- Follow this process to most effectively create more benefits from investment!

Figure 86: Project manager presenting on the HES guide at the 8th WRFC in Canada, 2017 (top) and one of the keystone speeches (middle). Reef Vision presentation at the National Recreational Fishing Conference in Darwin, 2017 (bottom).

Figure 87: Participants including a project manager at the 11th Conference on Artificial Reefs and Related Aquatic Habitat in Malaysia 2017 (top and middle) and Chinese and Australian members for the 2016 delegation to China for an International HES Forum (bottom).

FRDC FINAL REPORT CHECKLIST

Project Title:	The application, needs, costs and benefits of Habitat Enhancement Structures in Western Australia and cost-effective monitoring methods		
Principal Investigators:	Florisson, J.H., Rowland, A.J., Matthews, A.C., Tweedley, J.R. and Campbell, L.L.		
Project Number:	2014/005		
Description:	Habitat Enhancement Structures (HES) developments are increasing in Australia and worldwide providing many benefits to the environment and different user groups. With this rapid growth there are still large knowledge gaps evident in relation to HES. This project investigated the application, needs, benefits and costs of HES as well as cost-effective monitoring methods. Post graduate students collated international literature on all aspects of HES and project managers consulted with industry and the community to identify potential applications to different sectors. Different monitoring methods were also tested on the South West Artificial Reef Trial in Geographe Bay, Western Australia. Information and data collected was analysed, reviewed and processed to create an easy-to-follow guide for groups aiming to invest in HES. This is one of the first guides to clearly outline the HES development process in Australia. The project also developed Reef Vision, a world first, cost-effective HES monitoring method that uses citizen science and Baited Remote Underwater Video systems.		
Published Date:	N/A	**Year:**	2018
ISBN:	978-1-921877-23-0	**ISSN:**	N/A
Key Words:	Artificial Reefs, Baited Remote Underwater Video system, citizen science, Fish Aggregation Devices, fish faunal assemblage, Habitat Enhancement Structures, monitoring, Reef Vision.		

Please use this checklist to self-assess your report before submitting to FRDC. Checklist should accompany the report.

	Is it included (Y/N)	**Comments**
Foreword (optional)	N	
Acknowledgments	Y	
Abbreviations	Y	
Executive Summary	Y	
− **What the report is about**	Y	
− **Background – why project was undertaken**	Y	
− **Aims/objectives – what you wanted to achieve at the beginning**	Y	
− **Methodology – outline how you did the project**	Y	
− **Results/key findings – this should outline what you found or key results**	Y	
− **Implications for relevant stakeholders**	Y	
− **Recommendations**	Y	
Introduction	Y	
Objectives	Y	
Methodology	Y	
Results	Y	
Discussion	Y	
Conclusion	Y	

Implications	Y	
Recommendations	Y	
Further development	Y	
Extension and Adoption	Y	
Project coverage	Y	
Glossary	N	
Project materials developed	Y	
Appendices	Y	