Sunken worlds:
Social and ecological dimensions of human-made reefs

Sofía María Teresa Clara Castelló y Tickell
Balliol College
Department of Zoology, University of Oxford

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"Nothing of him that doth fade,

But doth suffer a sea-change

Into something rich and strange."

– William Shakespeare (The Tempest)

The hull of a shipwreck colonised by marine life stands on a sandy bottom. Photo: SCT, Cozumel 2019.

Declaration

I declare that this thesis is entirely my own work, and except where otherwise stated, describes my own research. None of the work included in this thesis has been submitted, in whole or in part, for any previous degree.

Sofía María Teresa Clara Castelló y Tickell
Balliol College

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Abstract

For millennia, the ocean has been seen as beyond human reach. However, human activities are increasingly advancing into marine spaces. As persistent submerged or semi-submerged structures, human-made reefs (HMRs) represent the embodiment of human influence in the ocean and create new opportunities for social meaning and culture underwater. Though some HMRs such as shipwrecks, fishing traps and oil rigs may be long-established, others are increasingly being used to advance political or artistic aims, and as tools to restore or transform the marine environment. Their creation can have significant implications for marine life. In order to carry out marine conservation in a changing ocean, it is crucial to understand both the ecological and social roles of HMRs. While ecological assessment is making progress, it remains focused on a few HMR types, and social assessment is lagging behind.

In this thesis, I explore the historical and current use of diverse HMRs and propose a social and ecological framework to evaluate their conservation potential, regardless of origin. I apply this framework to a case study on the island of Cozumel, Mexico. Here, I locate and characterise over 70 unique HMR sites – over ten times as many sites as previously identified. These included shipwrecks, sculptures, debris, coral restoration modules, infrastructure and rock piles. I observe differences in stakeholder awareness across types and locations of HMRs, typify modes of encounter and describe location sensitivity and barriers to access. Through a socio-cultural analysis, I characterise the provision of a wide range of ecosystem services including cultural services, and identify key factors affecting people's attitudes to HMRs, as well as their costs, benefits and impacts. The results indicate HMRs play complex, unacknowledged and powerful social and cultural roles. I analyse conservation-relevant synergies and conflicts between stakeholders, considering differences in activities and preferences in relation to marine life and suggesting ways forward for collaborative conservation. Finally, I suggest a method for conducting rapid ecological assessments on a variety of HMRs and demonstrate its usefulness in a survey of 70 individual HMR structures, identifying 78 species of fish and five species of mobile invertebrates. The results suggest that structures which are deeper, larger, and contain more holes and internal space are likely to have higher species richness and abundance.

Overall, this thesis suggests that HMRs have significant social and ecological conservation value for marine management, and may already be much more prevalent than expected. HMRs offer a wide variety of ecosystem services and are culturally and emotionally important to the people who create and use them. They can host diverse and abundant communities of marine organisms, which may be curated through processes such as fishing, cleaning or coral "planting". Cooperation between stakeholders to fulfil conservation aims offers challenges, but also many potential rewards, enriching the relationship between human endeavour and marine life in future oceans.

Resumen

Durante miles de años, el mar se ha considerado más allá del alcance humano. Sin embargo, las actividades humanas se están adentrando cada vez más en los espacios marinos. Como estructuras sumergidas persistentes, los arrecifes antropogénicos (HMRs) incorporan la presencia humana en el mar y crean oportunidades culturales nuevas debajo del agua. Aunque algunos tipos de HMRs tales como los naufragios, las trampas de pesca y las plataformas petroleras ya están establecidas, hay otros tipos que se están usando para avanzar objetivos políticos o artísticos y como herramientas para transformar o restaurar el ámbito marino. Su creación puede tener consecuencias significativas para la vida marina. Para llevar a cabo la conservación marina en un océano en cambio constante, es altamente necesario comprender los papeles sociales y ecológicos que están tomando los HMRs. Aunque la evaluación ecológica está avanzando, en muchos casos se restringe a pocos tipos de estructuras, y la evaluación social se ha retrasado.

En esta tesis, exploro el papel histórico y actual de los HMRs y propongo un marco de referencia y evaluación para asesorar su potencial en la conservación, sin importar su orígen. Aplico este marco de evaluación a un estudio de caso en la isla de Cozumel en México. Ahí, localizo y caracterizo más de 70 sitios únicos de HMRs – más de diez veces los que había identificado previamente. Estos sitios incluyen naufragios, esculturas artísticas y religiosas, escombros, módulos para la restauración del coral, infraestructura y montones de piedras. Observo diferencias en el conocimiento de tipos y sitios de HMRs a través de diferentes grupos de interesados, y describo modos de encuentro así como la sensibilidad de localizar los HMRs y las barreras al acceso. A través de un análisis social y cultural, caracterizo la provisión de servicios ecosistémicos incluyendo varios culturales e identifico factores importantes en las actitudes de las personas interesadas hacia los HMRs, así como sus costos, beneficios e impactos. Los resultados sugieren que los HMRs juegan un papel social y cultural complejo, poderoso y poco reconocido. Analizo las sinergias y conflictos entre los grupos interesados, considerando las diferencias y

requerimientos en actividades y las preferencias en relación a la vida marina, sugiriendo maneras de salir adelante y llevar a cabo la conservación como actividad colaborativa. Finalmente, propongo un método para llevar a cabo evaluaciones rápidas ecológicas en una variedad de HMRs y demuestro su eficacia en 70 estructuras individuales, identificando 78 especies de peces y cinco especies de invertebrados móviles. Los resultados indican que las estructuras más profundas, grandes y con más hoyos y espacio interno son más propensas a tener una riqueza y abundancia de especies más alta.

En general, los resultados de esta tesis indican que los HMRs tienen un valor significativo social y ecológico en el manejo marino, y pueden ser más abundantes de lo que se supone generalmente. Los HMRs ofrecen una amplia variedad de servicios ecosistémicos y son culturalmente y emocionalmente importantes para las personas que los crean y usan. Pueden albergar comunidades ricas y abundantes de organismos marinos, que son curadas a través de procesos como pesca, limpieza y la "plantación" de corales. La cooperación entre grupos interesados para alcanzar metas en la conservación presenta retos pero también recompensas, y que puede enriquecer las relaciones entre el trabajo humano y la vida marina en los mares del futuro.

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Onto new adventures!

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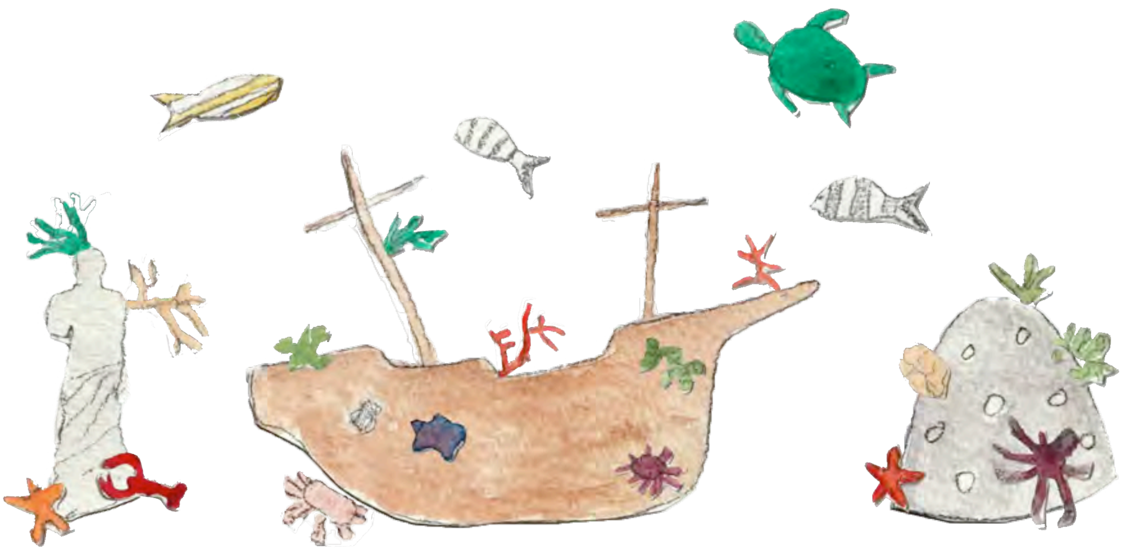

A schematic of HMRs overtaken by marine life, painted in watercolour by SCT in 2017. Elements not to scale.

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List of acronyms & abbreviations

CBD	Convention on Biological Diversity
CONABIO	Comisión Nacional para el Conocimiento y Uso de la Biodiversidad
CONACYT	Comisión Nacional de Ciencia y Tecnología
CONANP	Comisión Nacional de Áreas Naturales Protegidas
FAO	Food and Agriculture Organisation of the United Nations
HMR	Human-made reef
GLM	Generalised linear model
MPA	Marine Protected Area
UN	United Nations

Chapter 1

Introduction

A goldentail moray eel (Gymnothorax miliaris) peeks out of its shelter in a rock pile adjacent to a Reef Ball. Photo: SCT, Cozumel 2019.

1 Introduction

"Man marks the earth with ruin—his control

Stops with the shore"

- *Lord Byron (The Ocean)*

1.1 Background

The ocean, once "a wilderness of waves", is increasingly shaped by human activity (Hughes 1932 p. 18; Jones *et al.* 2018; Lehman 2018). Across land and sea, the extent of anthropogenic modification has led scientists to declare the Earth a "human-dominated planet" in a new epoch marked by the power of people as a geophysical force: the Anthropocene (Vitousek *et al.* 1997 p. 498; Steffen *et al.* 2007). Marine and coastal environments have been heavily transformed by activities such as fishing, climate change and construction of infrastructure such as docks, oil rigs, aquaculture and wind farms (Halpern *et al.* 2015; Jones *et al.* 2018; Bugnot *et al.* 2020). While many of these alterations are considered predominantly negative from a conservation standpoint, others may provide environmental benefits (Firth *et al.* 2016).

Throughout history, conservation has taken many forms, arguably commencing as a "conservation ethic" among indigenous peoples thousands of years ago, enabling sustainable extraction of resources (Johannes 2002 p. 3; Jackley *et al.* 2016). In the 20th century, as the realisation of the potential for largescale anthropogenic environmental transformation and destruction dawned, notions of conservation shaped colonial resource management (Hingston 1931). This led to the notions of protection of "nature for itself" and "nature despite people" which emerged in the 1960s and 1980s (Mace 2014). In a landmark essay, Soulé (1985) defined the field of conservation biology as "mission- or crisis-oriented" discipline which "addresses the biology of species, communities, and ecosystems that are perturbed, either directly or indirectly, by human activities and its agents" (p. 727). With time, the closely coupled fates of people and nature were incorporated into the field of "conservation science" which notes the resilience of many ecosystems and the presence of various stakeholders benefiting from nature in diverse ways, "advocating conservation *for* people rather than *from* people" (Kareiva and Marvier 2012 p. 968).

The practice of conservation comprises a wide variety of “actions that are intended to establish, improve or maintain good relations with nature” (Sandbrook 2015 p. 565). These actions can include, but are not limited to, the protection and restoration of resources and habitats, management of invasive and endangered species, education and awareness, development of policies and legislation, compliance and enforcement, and incentives for alternative livelihoods and behaviours (IUCN 2008). While challenging to achieve, combining social and ecological assessments can make conservation planning and implementation more effective (Ban *et al.* 2013). The use of mixed methods, for example combining social surveys of attitudes and valuation of ecosystem services with ecological surveys of species presence and abundance, can allow researchers to gain a better and more holistic understanding than through one method alone (Hattam *et al.* 2015). Such interdisciplinary research can allow for the incorporation of social context into conservation plans, reflecting what is locally feasible and important to the community, while working within an understanding of ecological processes (Sheridan *et al.* 2015).

In the marine realm, conservation has faced additional challenges, such as the difficulty of accessing field sites, the mobility of organisms in fluid environments, knowledge gaps in understanding of marine biodiversity, and the complexities of governance in a shared and three-dimensional space (Hillebrand *et al.* 2020). In the late 19th century, T.H. Huxley famously declared most sea fisheries “inexhaustible” in the context of fishing methods at the time; a prediction gone severely awry by 2017 when 59.6% of fish stocks were considered maximally sustainably fished and 34.2% of fish stocks were considered overfished (Huxley 1882; FAO 2020). Until the widespread arrival of scuba technology in the 20th century, scientists could not directly observe subtidal marine ecosystems for significant periods of time, which hampered understanding of biodiversity and ecosystem dynamics in relation to their terrestrial counterparts (Witman *et al.* 2012). Problems such as pollution, overfishing, habitat destruction and climate change threaten marine ecosystems worldwide, with coastal ecosystems being particularly impacted as the “area that humans most directly interact with and impact” (Halpern *et al.* 2019 p. 2). However, significant gains have also been made through the regulation of fishing and hunting, pollution reduction, and the protection and restoration of habitat (Duarte *et al.* 2020).

Understanding the extent, pace and impact of change in marine ecosystems has been identified as “a fundamental gap in understanding how humanity is affecting the oceans” (Halpern *et al.* 2019). In many cases, when change is quantified, it is considered as a deviation from concepts such as "wilderness", which can maintain value-laden judgments around the validity of transformed ecosystems (Sloan 2002; Jones *et al.* 2018). The conceptualisation of "novel ecosystems", which are different from those that existed historically and yet contain value of their own, has set the stage for understanding and conserving these places (Hobbs *et al.* 2013). Novel ecosystems present unique challenges for conservation: How does one manage these spaces when traditional historical baselines cannot be used to set goals and humans may have modified spaces to conduct certain activities (Backstrom *et al.* 2018)?

The application of the "novel ecosystems" concept in marine systems has thus far been limited, but includes consideration of altered coral reef ecosystems due to climate change, the creation of man-made structures such as oil rigs, and artificial reefs for restoration purposes (Schläppy and Hobbs 2019; Woodhead *et al.* 2019). The modification of the sea bed by sinking structures of anthropogenic origin such as shipwrecks (Simon *et al.* 2013; Ilieva *et al.* 2019), infrastructure including oil rigs and renewable energy structures (Smyth *et al.* 2015; Fowler *et al.* 2018), artistic sculptures (Beans 2018) and concrete modules (Bohnsack and Sutherland 1985) has received comparatively little attention. These structures are alternatively referred to as "man-made reefs" (Turner *et al.* 1969), "artificial reefs" (Hixon and Beets 1989; Baine 2001), "artificial habitats" (Pratt 1994), "human-made reefs" (Pitcher and Seaman Jr 2000), "anthropogenic structures at sea" (Russell *et al.* 2014), "artificial structures" (Heery *et al.* 2017), "marine built structures" (Bugnot *et al.* 2020), or even as a "housing scheme for fishes" (Carlisle 1961). Their creation, whether intentional or unintentional, can alter the benthic environment, both damaging it and also creating colonisable substrate and shelter and providing food for marine life (Carr and Hixon 1997; Claisse *et al.* 2014; Heery *et al.* 2017). Though the spread of these structures is difficult to track or quantify, studies indicate they take up tens of thousands of km^2 on the sea bed (Halpern *et al.* 2008; Bugnot *et al.* 2020). Their creation can be highly controversial, with the title of one blog post neatly summing up a widespread debate: "Artificial Reefs: Help for Endangered Ecosystems or Ocean Junk?" (Andrews 2017). As the term "human-made reefs" (or HMRs) is considered to be the most neutral, I will use this to refer to them.

HMRs most likely began as a conscious form of altering marine ecosystems millennia ago, with evidence for the use of permanent fishing traps in Palau (Johannes 1981), piles of rocks being used to attract fish in the Mediterranean 3,000 years ago (Fabi *et al.* 2011), sea walls being used to herd fish by the Mayas in Prehispanic times (Garduño Argueta and Caballero Pinzón 1998) and "jakagos" or bamboo baskets filled with rocks being deployed in Japan as early as the 18th century (Thierry 1988). However, they are often presented as a modern invention and this notion can contribute to the controversy that surrounds them. As scuba technology allowed scientists to spend more time in marine environments and access deeper areas (Witman *et al.* 2012), they began to survey structures such as “huge wrecks on the ocean floor that have become flourishing marine communities” (Unger 1966 p. 3). Intentional construction of HMRs ramped up, and Carlisle (1961) cheerily declared, “Artificial reef-building is one construction industry that is still in its infancy!” (p. 75). In America and Europe, the construction of human-made reefs began to bolster fishing (Stone 1982), with uses later expanding into dive tourism and conservation (Leeworthy *et al.* 2006; Kirkbride-Smith 2014).

Because they are created for so many reasons, HMRs are highly relevant to marine conservation and have much to contribute to the Aichi development targets (Convention on Biological Diversity 2010, Table 1.1). They can provide a series of ecosystem services (Schut 2013) and create social and ecological benefits through coral restoration (Hein *et al.* 2019). In some cases, HMRs may contribute to climate change and restoration initiatives as “nature-based solutions” (Seddon *et al.* 2020). The process of building them may also contribute to community cohesion (Trialfhianty and Suadi 2017) and they may create benefits for environmental education. Ecological studies of HMRs initially focused on how to optimise module construction for maximum attraction of marine life (Carlisle *et al.* 1963; Hixon and Beets 1989) and on comparisons to natural reefs (Carr and Hixon 1997). Studies quantifying pelagic and benthic life on existing HMRs have shown that they can host diverse and abundant communities (Turner *et al.* 1969; Claisse *et al.* 2014). The question of “attraction versus production”, or whether HMRs contribute to the production of marine life rather than simply attracting it, has received much attention but is difficult to answer definitively (Pickering and Whitmarsh 1997; Smith *et al.* 2015).

Many questions remain around how to best assess HMRs for social and ecological conservation purposes, especially as many HMRs are not created with explicit quantitative goals (Becker *et al.* 2018). While initial proponents posited that “essentially, the artificial reef is trying to provide the attractions inherent in a natural reef” (Unger 1966 p. 4), HMRs may have unique social and ecological functions that exceed their original purpose or those of “natural” coral and rocky reefs. Therefore, it is crucial to build tools for the identification and assessment of HMRs in their own right and consider their role in the ocean of the future.

Table 1.1 Relevance of human-made reefs to the international Aichi Biodiversity Targets (Convention on Biological Diversity 2010) and Mexican National Targets (MNT, Convention on Biological Diversity 2018).

CBD Target	**Description**	**Relevance to HMRs**
Aichi Target 3 / MNT 3.1-3.2	"incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts"	HMR projects can qualify for subsidies and government funding as part of fisheries and conservation programmes (Headley 2017; FFWCC 2018)
Aichi Target 6 / MNT 6.1-6.3	"all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches"	HMRs are used as a fisheries management tool, and are commonly created and/or used by fishers (Islam *et al.* 2014; Headley 2017). Diversity of ecological communities on HMRs can also be affected by the use of fishing techniques such as trawling (Krumholz and Brennan 2015).
Aichi Target 7 / MNT 7.5	"areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity."	HMRs are used for aquaculture (de Jesús Navarrete 2001).
Aichi Target 10 / MNT 10.1, 10.3	"multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning."	HMRs are being used as tools in the active restoration of coral reefs (Cummings *et al.* 2015; Trialfhianty and Suadi 2017) and considered for use as "sacrificial sites" to reduce diver pressure on coral reefs (Kirkbride-Smith 2014).
Aichi Target 14 / MNT 14	"By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable."	HMRs have been identified as potentially important providers of ecosystem services (Schut 2013) and as modulators of ecosystem services provided by other marine ecosystems (Bishop *et al.* 2017). Conservation claims have been made around multi-purpose structures used for coastal defense (Silva *et al.* 2016) and tourism (MUSA 2016) as well as other purposes. They have been suggested as a fisheries management tool for local communities, capable of increasing resilience
Aichi Target 19 / MNT 19	By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.	Various calls for the tracking of HMR projects at a local and global scale have been made (Bohnsack and Sutherland 1985; Seaman 2007; Schut 2013) and their conservation relevance has yet to be assessed across diverse structures.

1.2 National and local case study context

Mexico is a "megadiverse" country, with great richness across species, ecosystems and cultures and threats to its long-held diversity including land use change, overexploitation, invasive species, pollution and climate change (Sarukhán 2008). The island of Cozumel is the largest in the Mexican Caribbean, located 17.5km east of the Yucatán peninsula with an area of about 478km^2 (Figure 1.1, McFadden *et al.* 2010). Its name is believed to be derived from the Mayan word "Cuzamil" or "island of the swallows" (Stephens 1843). This "jewel of biodiversity" hosts 23 species of amphibians and reptiles, 224 birds, 15 terrestrial mammals and 11 species of bats, though researchers have recorded declines of around 70% in populations of rodents, medium-sized mammals and birds since the year 2000 (Vázquez-Domínguez 2015). Over 400 species of marine fish have been recorded on its reefs, of which 5.8% are classified as being under some kind of risk according to the IUCN Red List (Millet-Encalada and Álvarez-Filip 2007). The surrounding area is prone to hurricanes, and in the mid-2000s the combined impacts of hurricanes Emily and Wilma led to a 56% decline in coral cover (Álvarez-Filip *et al.* 2009). Its waters are subject to three multi-use marine protected areas: the Parque Nacional Arrecifes de Cozumel, the Área de Protección Flora y Fauna del Norte de la Isla de Cozumel, and the Reserva de la Biósfera Caribe Mexicano (SEMARNAT 1996, 2012, 2016).

Cozumel is estimated to have been inhabited since Late Preclassic times – approximately 300BC to 150AD – and was an important Mayan trading post (Andrews and Corletta 1995; Palafox-Muñoz *et al.* 2007). Hernán Cortés landed on its shores in 1519, prior to the conquest that changed the course of Mexico's history (Palafox-Muñoz *et al.* 2007; Río Torres-Murciano 2019). In his description of Cozumel during a voyage around the Yucatán peninsula in the 19th century, prominent explorer Stephens (1843) relates the trickiness of navigation around its coasts, saying, "As the storm raged our apprehensions ran high, and we had got so far as to calculate our chances of reaching the mainland by a raft" (p. 380). He recalls seeing a shipwreck, or HMR by our definition: "on the outer reef was the wreck of a brig; her naked ribs were above the water, and the fate of her mariners no one knew" (p 360-361). Though Stephens begins by calling Cozumel "the desolate island" (p. 362), by the time he leaves he states, "there was no place in our whole journey that we left with more regret" (p. 383). Coincidentally, this expedition enabled the collection of the first bird specimens from the island for scientific study (Macouzet and Escalante-Pliego 2013).

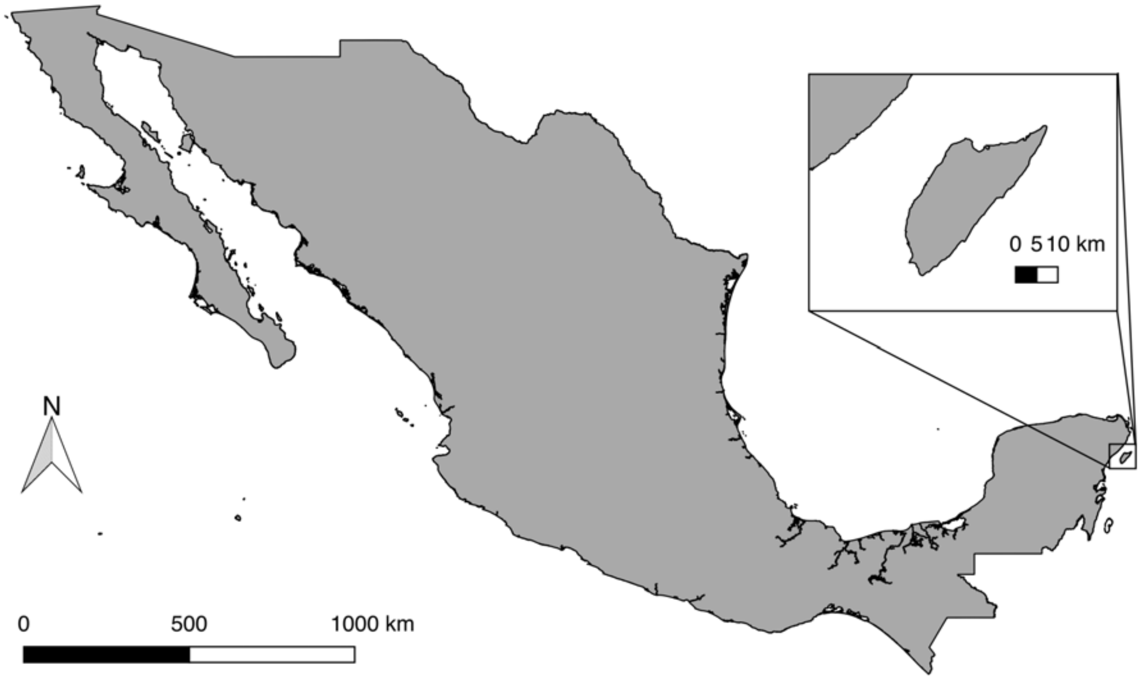


Figure 1.1 Location of Cozumel island within Mexico

In the modern day, Cozumel is anything but desolate, with an estimated population of 100,000 people (Preble 2014) and a wide range of activities centred around the marine environment involving HMRs. Tourism is a major livelihood, with dive and snorkel tourism being widespread (Palafox-Muñoz *et al.* 2007). The construction of three cruise ship piers in the 1990s and 2000s transformed the culture and economic potential of the island (Palafox-Muñoz *et al.* 2007; Preble 2014). The construction of one of these piers was the subject of hot debate and environmental concern, as corals were transplanted away from the development site onto HMRs in the form of prefabricated concrete modules (Moore 1996; Preble 2014). At the time, an article in the Washington Post summed up the conflict as "cruise liners and big money vs. divers and environmentalists" and said, "to hear the scuba divers tell it, a massacre is raging beneath the placid azure waters that lap the beaches of this popular resort island… thousands of sea creatures are being evicted from their underwater habitat" (Moore 1996). In response to local protests, the president of the development company stated, "It's total lies, absolutely lies… It's become like a soap opera. This has become the most difficult project I've had in all my years in the construction business" (Moore 1996). Nonetheless, the project went forward and between January and December 2019 – the year fieldwork for this project took place – Cozumel received

4,569,853 passengers on 1,366 ships, totalling 50.2% of all cruise ship passengers to Mexico and presenting a 6.3% increase on 2018 (SECTUR 2019).

Figure 1.2 Photos of Cozumel, including (top left-bottom right): a) a piece of street art entitled "Restore coral", b) a shipwreck visible from the main town promenade, c) a view of the island from a boat during a survey, and d) a shore-based survey site at a beach club showing the research equipment used in Chapter 6 (cruise ship visible in top right corner).

Amidst (and sometimes for) all these visitors to Cozumel, the seascape continues to be rebuilt and reconfigured by humans. A submerged sculpture of Christ was described as "a pilgrimage for scuba divers" on December 24, 1989 in the New York Times travel section (Riley 1989). A large naval ship, the C-53 or "Felipe Xicotencatl", is a significant tourist attraction (Santander Botello 2009). A pearl farm is in operation, cultivating pearls and oysters and conducting tours (https://www.cozumelpearlfarm.mx). Following hurricane damage to corals around the island, HMRs have been used in restoration attempts by "planting" coral fragments onto the structures (Álvarez-Filip *et al.* 2009; Edwards 2014; https://www.ccrrp.org). An artistic project entitled "Zoë – A Living Sea Sculpture" was created with the intention to raise awareness of climate change (Beans 2018). Archaeological findings of note for have also taken place on Cozumel, including unintentional shipwrecks of canoes and cargo ships dating back centuries, with some individuals even being sent to prison for attempting to transport valuable items out of Mexico (Leshikar 1988; Andrews and Corletta 1995).

I considered Cozumel to be a promising research site because of the potential for a variety of HMRs and related activities in its waters, based on publicly available knowledge and a scoping trip I conducted in August-September 2019. Its status as an internationally recognised site for dive tourism facilitated logistics and allowed for safe diving (e.g. provision of tanks, availability of a hyperbaric chamber on the island). Additionally, initial meetings with the local office of the Government's environmental agency (CONANP) indicated that they were interested and willing to work together. This ultimately led to a fruitful collaboration in which they lent local expertise and enabled me to survey more sites with research assistants and use of their boats. I hope my research will be of practical relevance to them, as we discussed survey methods in detail and agreed to co-write a handbook on HMR assessment based on the results of this thesis. My case study site was chosen with the intention of expanding on what is known and capturing the variation, social and ecological impact of HMRs in Cozumel, as well as understanding their potential implications for conservation.

1.3 Aims and objectives

In this thesis, I explore the ways in which HMRs are currently being used in the marine environment – socially, in terms of ecosystem services they provide and attitudes surrounding their creation, and ecologically, in terms of the communities of marine life they are supporting. By identifying a wide range of structures and interviewing a variety of stakeholders present within my case study area of Cozumel, Mexico, I also investigate ways in which HMRs can have positive or negative contributions to conservation targets, regardless of the purpose they were established for. I focus on the following main objectives:

- To develop new approaches and frameworks to assess the prevalence, variety and conservation potential of HMRs from a social and ecological standpoint
- To enable decision-makers to navigate trade-offs and synergies between different uses and understandings of HMRs, balancing the needs of multiple human stakeholders and the marine ecosystem

1.4 Thesis outline (including author contributions)

This thesis comprises an introduction, five main chapters and a discussion chapter (Figure 1.3). In Chapter 2, I analyse the history of HMRs across disciplines and set out a conceptual framework for their use and assessment in marine conservation. Subsequent chapters describe the operationalisation of the conceptual framework in a case study on the island of Cozumel in Mexico. In Chapters 3, 4 and 5, I present the quantitative and qualitative results of social science research intended to detect, categorise and assess the sociocultural role of HMRs, as well as consider relationships between multiple invested stakeholders and potential for collaborative conservation. In Chapter 6, I propose and trial the use of a rapid ecological assessment protocol for HMRs around the island of Cozumel. The seventh chapter is a discussion chapter in which I take into consideration the results from all previous chapters, synthesising cross-cutting themes and making recommendations for the future.

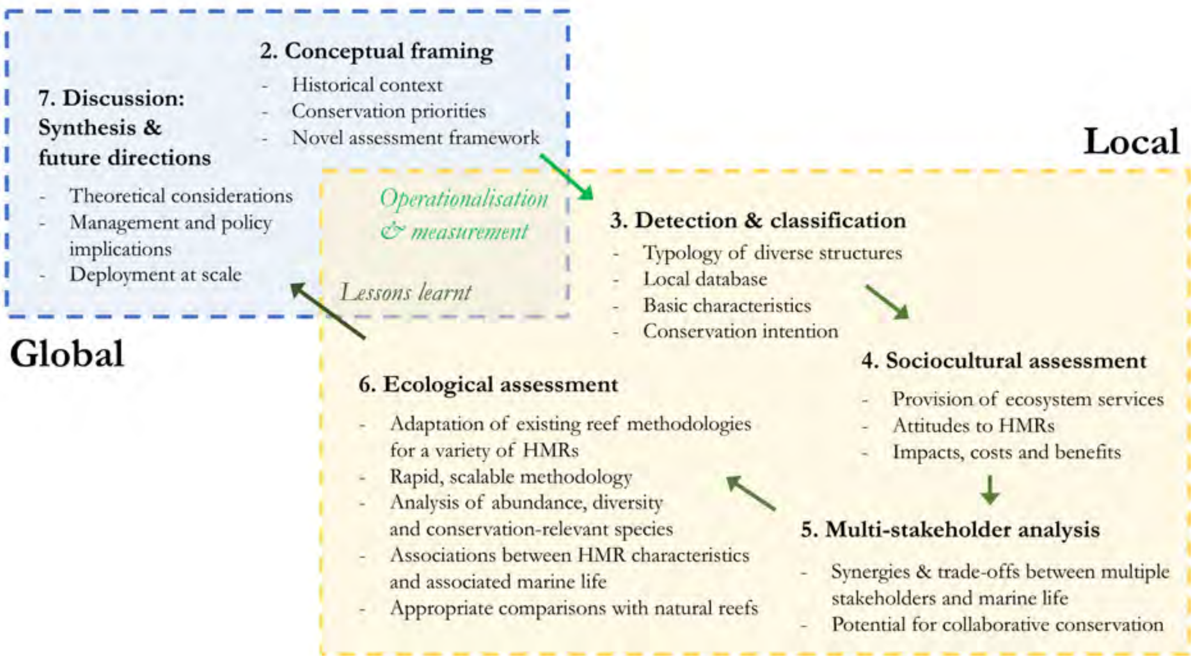


Figure 1.3 Diagram of thesis structure considering global and local nature of chapters following the introduction.

1.4.1 *Chapter 2: The past and future of human-made reefs in marine conservation*

In this chapter, I suggest an all-encompassing definition of HMRs to include all anthropogenic structures in the ocean, arguing they could all provide social and ecological conservation benefits even when created with a different primary purpose. I review literature across disciplines that suggests a rising prevalence of HMRs, and identify knowledge gaps and historical research biases. I advocate for the importance of acknowledging human influence in the ocean in order to shape and manage it, moving beyond controversy to maximise positive impacts and minimise negative impacts. Finally, I propose a novel framework for conservation assessment to evaluate the social and ecological dimensions of HMRs of diverse origins.

Author contributions: SCT proposed, conceptualised and wrote this chapter, with comments and suggestions from EJMG and ASA.

Publication: This chapter was published as a "Forum" piece in *BioScience* in September 2019:

Castelló y Tickell S, Sáenz-Arroyo A, Milner-Gulland EJ (2019) Sunken Worlds: The Past and Future of Human-Made Reefs in Marine Conservation. Bioscience 69:725–735. doi: 10.1093/biosci/biz079

1.4.2 *Chapter 3: Exploring the use of local knowledge to locate and characterise human-made reefs of conservation relevance in Cozumel, Mexico*

This chapter focuses on the process of detecting, categorising and mapping HMRs and is based on a case study in Cozumel. I analyse the qualitative, quantitative and spatial results of 40 semi-structured interviews and mapping exercises with stakeholders including aquaculturists, archaeologists, artists, fishers, environmental consultants and educators, scientists and tour operators. I identify at least 77 unique HMR sites in Cozumel and examine their types, frequency of mentions, and perceived conservation intentions, as well as assessing variation in described characteristics. I discuss factors that affect awareness of and access to HMR sites including primary activities, modes of encounter, barriers to access and location sensitivity, and describe local history and trends in HMR creation. Finally, I discuss the need for more information on HMRs worldwide as well as potential challenges in creating and managing databases.

Author contributions: SCT designed surveys with input from EJMG and ASA, and conducted all interviews, data analysis and writing with comments and suggestions from EJMG and ASA.

1.4.3 Chapter 4: Trialling social and cultural assessment of novel ecosystems on a variety of human-made reefs in Cozumel, Mexico

In this chapter, I assess the social and cultural roles of HMRs as novel ecosystems created and shaped by humans. Through semi-structured interviews with varied stakeholders in Cozumel, I trial a sociocultural assessment in which participants identify a variety of cultural, provisioning, regulating and supporting ecosystem services as emerging from HMRs. I analyse attitudes to their creation as well as perceived impacts, costs and benefits and explore key factors to consider in HMR creation. I discuss how conceptions of "nature", human agency and context can influence opinions of HMRs and reflect on implications for conservation.

Author contributions: SCT designed surveys with input from EJMG and ASA, and conducted all interviews, data analysis and writing with comments and suggestions from EJMG and ASA.

1.4.4 Chapter 5: Untangling complex relationships between multiple stakeholders and marine life to envision collaborative conservation on human-made reefs

In this chapter, I analyse synergies and trade-offs between the activities of multiple stakeholders on HMRs in relation to marine life in Cozumel, and consider potential linkages to conservation. I examine attitudes to the accumulation and types of marine life on HMRs across different activities, and the prevalence of actions taken to enact these preferences. Through this process, I identify potential avenues for collaborative conservation on HMRs. Finally, I discuss practical and theoretical possibilities for the conservation and management of marine life on HMRs used by multiple stakeholders.

Author contributions: SCT designed surveys with input from EJMG and ASA, and conducted all interviews, data analysis and writing with comments and suggestions from EJMG and ASA.

1.4.5 *Chapter 6: Measuring diversity and abundance of marine life across a variety of human-made reefs to determine conservation potential*

In this chapter, I propose and trial a methodology for the rapid ecological assessment of a variety of HMRs including shipwrecks, coral restoration modules, artistic and religious sculptures, infrastructure and rock piles. This method relies on standardised collection of (1) variables such as size, structural complexity, depth, and materials, and (2) "general" metrics of diversity and abundance, as well as "targeted" metrics of conservation relevance such as presence of endangered or invasive species. I draw on existing methodologies for the assessment of coral reefs and single HMR types to compare across different structures and reflect on the successes and problems that emerged as I applied this protocol. I report on the results of my surveys in Cozumel, which detected diverse and abundant marine life on 70 HMRs of varying origins, some of which were intended for conservation and some of which were not. A generalised linear model explores associations between HMR characteristics and diversity and abundance of marine life. I assess the impacts of conservation alterations such as coral planting and adding rocks, and conduct one comparison of similarly sized natural reefs and HMRs created for coral restoration. Finally, I discuss the role of ecological surveys on HMRs in conservation and potential future research.

Author contributions: SCT designed the survey protocols with input from EJMG, ASA, and LW (Lucy Woodall). SCT conducted all surveys with assistance from AVM (Alejandra Verde Medina), DM (Diana Martínez) and BQ (Blanca Quiroga). SCT and AVM conducted video data processing, with SCT supervising and AVM reviewing the majority of videos. SCT conducted all data analysis and writing with comments and review from EJMG, ASA, AVM and LW.

1.4.6 *Chapter 7: Synthesis & Discussion*

In this chapter, I reflect on the contribution to knowledge this thesis offers, synthesise my findings from the case study in Cozumel in the context of relevant academic literature and propose future research and policy directions both locally and globally.

Author contributions: SCT wrote this chapter with comments and review from EJMG and ASA.

1.5 Positionality & research approach

Within social science research and applied fields such as conservation, researchers are increasingly identifying their positionality – including backgrounds, training and research approaches – in order to identify biases and increase awareness of how their subjective position could impact the research process (Takacs 2003; Milner 2007; Pasgaard *et al.* 2017). In this section, I will outline key aspects of my background and research approach and reflect on my positionality.

1.5.1 Background

I grew up largely in Mexico (where my research took place) but also partially in England (where my research institution is based), with dual nationality and one parent from each country. I was fluent in both English and Spanish from a young age, as I spoke both languages with my parents at home. The majority of my schooling took place at a bilingual international school in Mexico City. My undergraduate education took place in the United States, at Brown University, and I graduated with an AB (equivalent to BA) in Biology and an independent concentration in Photojournalism. My education was highly interdisciplinary, beginning with the International Baccalaureate programme at school and continuing with Brown's flexible "open curriculum" which requires students to set their own courses of study rather than follow a pre-established core curriculum. At university I focused largely on ecology and evolutionary biology, creative non-fiction writing and photography, with additional courses in social science such as linguistic anthropology and economics. I believe this self-directed and interdisciplinary approach to learning made me willing to combine different research approaches and embark on wide-ranging projects.

As a research technician at the Witman Lab during and after my degree, I gained experience in subtidal marine ecology, participating in biodiversity and abundance surveys using in situ and video methods, as well as field experiments on trophic cascades and sea star diets. In the course of those field experiments, I witnessed marine life accumulating on recruitment plates and experimental caging units made of concrete and metal (which I would now refer to as HMRs), and became very curious about the role of humans in shaping marine ecosystems. In subsequent placements as an intern at the Zoological Society of London and a research assistant interviewing fishermen and surveying clam populations in Loreto, Mexico, I was fascinated by the combination of social and ecological research methods. I also realised that I derived a strong sense of meaning from applying my research skills to learn about and contribute to marine conservation in the country I grew up in.

To strengthen my research skills, I joined the M.Sc. in Biodiversity, Conservation & Management at Oxford, funded by the Mexican government through a CONACYT scholarship. Here I learned about policy and social science in conservation, ultimately writing my thesis on the "human costs" of enforcement in no-take Marine Protected Areas, supervised by EJ Milner-Gulland. I started the D.Phil. supervised by Professor Milner-Gulland the following year, also becoming involved in the Conservation Optimism movement. I have seen my D.Phil. project as a way to understand people's perspectives on nature and the ocean, as well as an opportunity to contribute to an understudied aspect of marine conservation globally and in Mexico.

1.5.2 Reflections on positionality

I believe being Mexican and fluent in Spanish helped me to connect with research participants, build successful working relationships, and observe patterns and situations with some understanding of cultural background. For example, I could understand slang and references to events in Mexican history, chat casually with research participants, and when I was invited to observe activities related to HMRs such as coral planting or tourist trips, I could easily do so without an interpreter (while always identifying myself as a researcher). I could conduct interviews in English or Spanish, depending on the preference of the participant, and translate the resulting interviews.

Though I grew up and was initially educated within the country, international influence (particularly British and American) has weighed heavily in my family and education. Participants often noticed some element of this, expressing confusion as they said I seemed Mexican but also somehow European or American. I had never visited Cozumel prior to my fieldwork, and the culture is very different to that of Mexico City. This may have created a sense of alienation for research participants since I was not previously familiar with the local context. However, the majority of participants interact with international people (mostly tourists) on a regular basis and many had spent years living in other places. Some of the people I was interviewing had very different socioeconomic and educational backgrounds to my own. To the extent possible, I became engaged in daily life in Cozumel, participating in activities I was invited to, getting to know the island and learning about its history. Though I embarked on this project with academic and fieldwork experience in marine ecology and conservation, it was built in other places, and my research participants' daily experience and knowledge of the sea and local culture obviously far surpassed my own. I am very grateful to them for sharing their time and expertise.

Mexico is a country of vast socioeconomic and educational inequality, with little social mobility and compounding effects of race and gender discrimination (Favila Tello and Navarro Chávez 2017; Krozer 2020). In contrast to being a researcher with no ties to the country, being embedded within Mexican society meant that research participants could clearly situate elements of my background and experience, and this could highlight any similarities or differences between us. For example, some participants asked what neighbourhood of Mexico City I grew up in or what schools I had attended, which could serve as socioeconomic proxies. I answered openly when participants asked such questions as I believed they were being honest with me and I wanted to maintain this standard. My position as a young white woman with dual nationality, advanced international education and a relatively privileged upbringing could undoubtedly play into interview dynamics. I may have been perceived as "out of touch" with the local context or as having an academic perspective out of sync with their day-to-day lives. However, the process of explaining daily routines and priorities in our conversations also brought interesting dynamics to light. 80% of my interviews took place with men and 70% with people who were 10 or more years older than me; on a few occasions I was referred to as a "chamaca" or "niña" ("girl") which I perceived as a form of resistance to women in professional scientific or academic roles. On the other hand, many participants seemed to view me as an expert and were curious to know what I thought of their HMRs or how their projects could be improved. Less than 10% of the people I interviewed had finished Ph.D. programmes and had a more advanced degree than I did, while 25% had not attended university and 15% had left education after primary or secondary school. I noticed that the question about levels of education could be uncomfortable during interviews, with participants looking away or becoming stressed which could also make me feel stressed; on one occasion a participant jokingly referred to me as a "cerebrito" ("little brain") a nickname indicating I was devoted to study. I did not collect information on income or socioeconomic status because it did not feel necessary to address my research questions and seemed likely to make participants uncomfortable.

On the whole, the interviews flowed easily and exceeded the time allowed – sometimes taking two or three hours rather than the allotted half hour, though a couple were completed within this time range – as participants were enthusiastic to share their knowledge and opinions. To make the interviews as comfortable as possible, I asked participants to suggest a venue that was convenient for them and they felt comfortable in. I insisted on a public venue such as a coffee shop or park or a professional venue such as their office unless there was a good reason (such as health) to conduct the interview at their home. I notified someone before going into each interview for fieldwork safety, started the interviews with broad questions in order to gain an understanding of their experience, and asked follow-up questions when participants mentioned elements I did not understand, particularly when they were describing activities I was not personally familiar with. Since the creation of HMRs without appropriate permits may be considered illegal under the "Ley General del Equilibrio Ecológico y la Protección al Ambiente", I asked participants not to give me information on the creators of HMRs unless they were certain the structure had been created with all necessary legal permits.

"Parachute science" has been noted as a problem in marine and conservation science, whereby international scientists from high-income countries conduct fieldwork in lower-income countries and do not invest in, engage or communicate sufficiently with others from that nation (De Vos 2020). In an analysis of publications on coral reefs, Mexico emerged as the 8th most productive country in terms of publications as measured by author affiliations, indicating that Mexican scientists do publish at a high rate, though there may well also be international projects they are not credited for (Stefanoudis *et al.* 2021). I am thankful for the support for my studies provided by the Mexican government through a CONACYT scholarship, and hope that collaborating with the CONANP as a Mexican institution, having a Mexican co-supervisor, hiring and working with local research assistants and basing my case study in Mexico will allow this work to contribute to Mexican marine conservation in the longer term with an added international perspective.

Though I gravitated towards social science methods in my graduate degrees and gained some experience with it as an undergraduate, my initial scientific training was largely based in "natural" science. I have read and consulted broadly in my attempts to employ social science methods with as much accuracy as possible, particularly leaning on Newing et al. (2011).

1.6 Methodology and research approach

In this thesis, I use both social and ecological research methods to assess the conservation potential of HMRs surrounding the island of Cozumel. I will briefly explain how data were analysed and allocated across chapters.

Chapter 2 was based on a literature review conducted between 2017 and 2019.

In Chapters 3-5, I analyse the results of 40 key informant interviews with experts on human-made reefs in Cozumel, conducted between January and May 2019. These experts included people who had specialist knowledge relating to the creation, study, use or management of human-made reefs. They belonged to various stakeholder groups including archaeologists, fishers, tour operators, scientists, fishers, environmental consultants and artists. These individuals were identified through "snowball" sampling due to the specific nature of their knowledge, through an initial online search for individuals or organisations publicly associated with HMRs or through referral by another expert. Some personal introductions also occurred on an informal scoping trip in July and August 2017. Interviews ceased when saturation was reached (Newing *et al.* 2011), either because the number of people who participated in a given activity on the island was limited and all the eligible people I could identify had been interviewed or were unavailable, or because the occurrence of new responses within a given group became very limited (Figure 1.4). While some types of experience dominated the sample (e.g. tour operators) this reflected the makeup of the island with tour operation being the dominant economic activity. Each interview occurred only once and the surveys were designed to explore various themes, meaning different questions were subsequently analysed for different chapters (Table 1.2). After the interviews, participants were categorised in two ways: as "stakeholders" to describe their general backgrounds, taking into account their experience and self-described job titles and according to their self-identified "primary activity" in relation to human-made reefs. The former designation was used to give a sense of the range of people interviewed and code participants' quotes as many participated in multiple activities, while the latter designation was used in analyses where a stakeholder's primary activity was considered the relevant variable as the most direct way of summarising their current experience of HMRs.

Chapter 6 is based on subtidal ecological surveys of the structural characteristics of HMRs and associated fish and mobile invertebrate communities.

Table 1.2 Research methodologies, materials (including specific survey questions), themes and concepts used in each chapter for this thesis.

Chapter	Data collection methods	Research materials	Key themes	Key concepts
2	Literature review	See references	Global conservation relevance of HMRs; Social-ecological assessment	Novel ecosystems; Social-ecological systems
3	Semi-structured key informant interviews	SM1 (Section A: 1-4, Section B: 6, 7 & mapping, 10-12; Section C: 21-24, 26-27, 36)	Multi-stakeholder knowledge and use of HMRs; Assessing location, history and uses of HMRs	Local ecological knowledge; Co-location
4	Semi-structured key informant interviews	SM1 (Section A: 1-5; Section B: 8-9, 13-20; Section C: 21-26, 30-34, 36)	Complex socio-cultural roles of HMRs; Valuation and perceptions of novel marine ecosystems	Ecosystem services; Novel ecosystems; Sociocultural valuation
5	Semi-structured key informant interviews	SM1 (Section A: 1-4; Section C: 21-24, 26, 28, 29, 35, 36)	Multi-stakeholder HMR uses & preferences; Accumulation of marine life; Potential for collaborative conservation	Co-location; Novel ecosystems
6	Subtidal ecological surveys (structural characteristics, fish, mobile invertebrates)	Appendix 6.5.1 & 6.5.2	Richness and abundance of fish and mobile invertebrates	Novel ecosystems; Ecological assessment of varied human-made structures

Figure 1.4 Network plot of people interviewed (blue) and suggested for interview (pink), with arrows indicating when a participant recommended another individual as a relevant expert at the conclusion of the interview. Individuals who were not interviewed may have been ineligible upon further investigation, uncontactable or declined to participate.

1.7 Additional research

Over the course of my DPhil I contributed to the following published research as a co-author. These projects helped to shape my thinking for this thesis and were led by other researchers:

- Cusack JJ, Bradfer-Lawrence T, Baynham-Herd Z, **Castelló y Tickell S**, Duporge I, Hegre H, Moreno Zárate L, Naude V, Nijhawan S, Wilson J, Zambrano Cortes DG, Bunnefeld N (2021) Measuring the intensity of conflicts in conservation. Conserv Lett 1–11. doi: 10.1111/conl.12783
- Short R, Addison P, Hill N, Arlidge W, Berthe S, **Castello y Tickell S**, Coulthard S, Lorenz L, Sibanda M, Milner-Gulland EJ (2019) Achieving net benefits: A road map for cross-sectoral policy development in response to the unintended use of mosquito nets as fishing gear. SocArXiv 1–45.

Chapter 2

The past and future of human-made reefs in marine conservation

Two spotfin butterflyfishes (Chaetodon ocellatus) hover next to "Zoe - A Living Sea Sculpture". Photo: SCT, Cozumel 2019.

2 The Past and Future of Human-made Reefs in Marine Conservation

Published as:

Castelló y Tickell S, Sáenz-Arroyo A, Milner-Gulland EJ (2019) Sunken Worlds: The Past and Future of Human-Made Reefs in Marine Conservation. Bioscience 69:725–735. doi: 10.1093/biosci/biz079

2.1 A rising tide

Human influence reaches into all ecosystems, and is increasing globally in the marine realm (Vitousek *et al.* 1997; Halpern *et al.* 2015). By one estimate, only about 13% of the ocean remains "wild" or under low impact from factors such as climate change, overfishing, pollution and benthic structures (Jones *et al.* 2018). In a conservation context, human activities have historically been considered undesirable; however, some have proposed an alternate framing of a two-way, multi-layered and dynamic relationship between "people and nature" (Mace 2014). Additionally, some conservationists suggest the prevailing sense of "doom and gloom" around human activities may stymie practical action to study them or transform them into conservation opportunities (Duarte *et al.* 2015; Balmford and Knowlton 2017).

The creation of human-made reefs (HMRs) – which we define as hard, persistent structures submerged intentionally or accidentally in the ocean by humans – has received limited attention in the conservation sphere. These diverse structures result from human activities such as fishing (Turner *et al.* 1969; Headley 2017), shipping (Simon *et al.* 2013), oil and gas extraction (Claisse *et al.* 2014), tourism (Stolk *et al.* 2007; Oh *et al.* 2008; Kirkbride-Smith *et al.* 2013), conservation (Seaman 2007; Dupont 2008) and coastal management including storm protection, erosion reduction (Silva *et al.* 2016) and the creation of surf beaches (Rendle 2015). One study mapping global human impacts on the marine environment estimated anthropogenic "benthic structures" in coastal regions affect an area of 300,000 square kilometres (Halpern *et al.* 2008), the approximate size of Italy. A process of "marine urbanisation" is said to be underway (Dafforn *et al.* 2015 p. 82). Though HMRs have been called "tremendously popular" (Bohnsack and Sutherland 1985 p. 31) and the claim has long been made that they are "increasing exponentially"

(Schuhmacher and Schillak 1994 p. 672), there is currently no centralised way of tracking their spread, leading to calls for comprehensive databases (Bohnsack and Sutherland 1985; Seaman 2007). In cases where HMRs have been quantified on a global level, analyses have generally been limited to one type of structure emerging from a specific industry, such as oil and gas (Halpern *et al.* 2008; Jones *et al.* 2018).

Nonetheless, there are indications that HMRs of diverse origins are present in large numbers and proliferating rapidly. By 2007, the Reef Ball Foundation claimed over half a million of its patented concrete structures had been deployed underwater in over 59 countries (Naik 2007). In a single Mexican bay, Headley (2017) estimates that 27,152 artificial shelters have been created for lobster fishing. UNESCO estimates three million shipwrecks lie on the ocean floor, some of which may be thousands of years old (UNESCO 2009). Establishment of HMRs in French coastal waters has accelerated; of the 93,982 m^3 of material deployed since 1968, 50% was deployed since 2000 (Tessier *et al.* 2015). The Florida Fish and Wildlife Conservation Commission has distributed over $26 million dollars in funds for public projects and estimates 70-100 reef sites are built annually off the Florida coast, adding to the 3,330 established since the 1940s (FFWCC 2018). Given their diverse origins, HMRs can vary greatly in size, number of units, reasons for creation, and materials; however, considering them as a group can illuminate the scale at which humans are transforming marine ecosystems.

Ecosystem services and values provided by HMRs are likely to be both substantial and underestimated. For example, an evaluation of a five-county area in North Florida estimated the value of spending on goods and services related to the use of HMRs at $414 million dollars in 1997-1998 (Bell *et al.* 1998). Scuba diving on HMRs can generate substantial tourism revenue – for example, Oh et al. (2008) estimated willingness to pay for scuba diving on HMRs at $101 per trip – while potentially diverting pressure away from natural coral or rocky reefs. Following the deployment of a decommissioned ship as an AR in Florida, Leeworthy et al. (2006) tracked a 3.7% overall increase in local dive charter business, which bolstered local income by $961,800 and created 68 new jobs. As business grew, pressure on surrounding natural reefs was alleviated; the total number of HMR users grew by 118.1% while total users on natural reefs declined by 13.7%. These figures only begin to evaluate economic benefits that could accrue from HMRs; further measures of provisioning, regulating and cultural services are necessary (Schut 2013). In particular, cultural values of HMRs may be considerable and unique. For example, the cultural value of shipwrecks includes providing clues into forgotten aspects of human history and contributing to a sense of cultural identity (Krumholz and Brennan 2015). The process of constructing HMRs can also create opportunities for community bonding and participation (Trialfhianty and Suadi 2017) or unique avenues for education about the marine environment.

Claims of conservation benefit have arisen for a wide variety of HMRs, which commonly state or imply that the provision of new substrate for marine life to grow, take shelter and feed on leads to the creation of productive new ecosystems (Lee *et al.* 2018) or that the structures can relieve pressure on nearby coral reefs (Leeworthy *et al.* 2006). These claims have related to accidental shipwrecks (James and Hibbert 1994; Krumholz and Brennan 2015), rock piles (Fox *et al.* 2019), purposefully sunk naval ships or subway cars (Leeworthy *et al.* 2006), underwater sculptures referred to as "the art of conservation" (MUSA 2016), decommissioned oil rigs (Claisse *et al.* 2014), coastal engineering structures (Silva *et al.* 2016), industrial mitigation projects (Dupont 2008) and even piles of old tyres (Allen 2007). In some cases, conservation is explicitly emphasised to justify creation of structures or halt their scheduled removal from the marine environment (Olsen 2016; Fowler *et al.* 2018). However, beyond a few high-profile cases of success or failure, these conservation claims have not been widely tracked or questioned. Given indications that HMRs could be altering marine ecosystems on a massive scale, it is imperative that critical attention is paid to their conservation impacts. While scientific interest in HMRs is rising, the number of relevant papers in the conservation literature remains low (Figure 2.1).

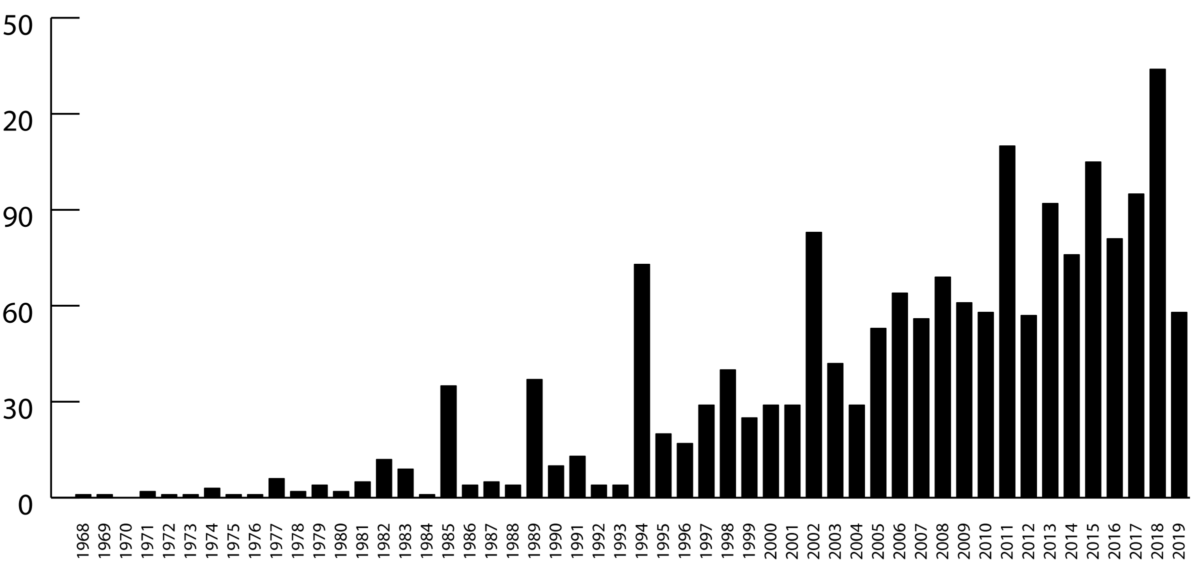


Figure 2.1 Scientific publications (n=1,753) with the topic "artificial reef" or "human-made reef*" or "anthropogenic reef*" from 1945-2019 on the Web of Knowledge database. Only 2.23% of these publications are categorised under the research area "Biodiversity conservation" with the bulk of this literature starting in 2005. Of the remaining publications, 49.6% are categorised under "Marine freshwater biology", 31.7% under "Oceanography" and 24.8% under "Fisheries." (Web of Knowledge, June 2019).*

2.2 A controversial history

A searing debate over the purposeful use of HMRs in fisheries and marine conservation has risen and fallen for almost half a century, spanning scientific, regulatory, and even moral realms (Meier *et al.* 1989; Fronda and French 2015). In fisheries and ecology, this debate has often culminated in the question of "attraction versus production" – whether HMRs contribute to increasing overall marine biomass or biodiversity, or simply aggregate it by drawing it away from natural reefs (Bohnsack and Sutherland 1985). The answer to this question is difficult to determine in most cases, and is unlikely to be binary (Pickering and Whitmarsh 1997). Attraction has almost universally been posited as a harmful process which makes fish more vulnerable to exploitation, but recent work indicates some attraction could be beneficial for some species as dispersion could make fish harder to catch (Smith *et al.* 2015). Regardless of whether they are diverting biomass from natural structures or increasing it overall, HMRs are capable of sheltering high levels of biomass and biodiversity (Turner *et al.* 1969; Claisse *et al.* 2014), though they may vary in trophic structure from natural reefs (Simon *et al.* 2013). Another concern regards the facilitation of invasion by invasive or non-native species, as new hard substrate provided by HMRs could provide footholds for establishment (Simkanin *et al.* 2012). Finally, the assumption that new hard substrate is preferable to the ecosystems it can replace or transform – such as soft sediment communities, which can be highly biodiverse and play a crucial role in nutrient cycling – has been challenged (Heery *et al.* 2017).

In a wider sense, the debate around when, why and by whom HMRs should be created is deeply divided, with HMRs often framed as either hopeful innovations or intrusions on a natural order. On the one side there are warnings of a potential "ocean junk pile whose major value has been as a promotional gimmick" (Turner *et al.* 1969 p. 199), a fisheries management tool that has been "grossly misused" by unqualified people (Meier *et al.* 1989 p. 1055) and "slapping the seas with the big almighty hand of humankind and damaging yet another part of the earth" (Fronda and French 2015). Meanwhile, proponents of HMRs have spoken of "bastions for marine life" (Fronda and French 2015), "one of the richest marine ecosystems on the planet" (Olsen 2016), sites which are "among the most productive marine fish habitats globally" (Claisse *et al.* 2014 p. 15462) and "tremendous potential for habitat enhancement" (Bohnsack and Sutherland 1985 p. 31). Many arguments in this debate are implicitly based on the perception that HMRs are relatively recent additions to marine ecosystems.

However, the practice of building or sinking structures in the sea can be observed over thousands of years across a wide range of cultures, particularly with regard to fishing and aquaculture. In Mexico, hook-shaped structures made of stone are believed to have been used by pre-Hispanic Mayan fishers to herd schools of fish and manatees (Garduño Argueta and Caballero Pinzón 1998). Intertidal rock walls and terraces in British Columbia, built to increase clam production, may have been in use for up to 5000 years (Groesbeck *et al.* 2014). Ancient Hawaiian marine fish ponds were built 1500-1800 years ago with stones, with walls extending over 100m in length (Costa-Pierce 1987). In traditional Palauan fishing, permanent stone structures were used to trap fish with the tides (Johannes 1981). The long history of HMRs has not been sufficiently acknowledged in the scientific literature; many studies continue to cite the first emergence of these structures in Japan in the 17^{th} or 18^{th} century (Bohnsack and Sutherland 1985; Lee *et al.* 2018).

Once HMRs have been deployed, there is often a lack of clarity around responsibility for their impacts, and this has been complicated by the idea that structures can benefit marine life. "Rigs-to-reefs" programmes present a clear example, affecting the fate of over 7,500 oil and gas platforms worldwide, for which complete removal is currently standard practice (Techera and Chandler 2015; Fowler *et al.* 2018). Costs for removal worldwide have been estimated at $210 billion dollars, and some sites have been identified as highly productive for marine life, leading to suggestions for partial removal and monitoring on a case-by-case basis (Claisse *et al.* 2014; IHS Markit 2016; Fowler *et al.* 2018). Generally, while conservation concerns initially revolved around the insertion of new structures, they have now expanded to consider the risks of removing habitat and of maintaining structures with potentially negative impacts (Allen 2007). This opens up crucial questions around best practice for managing HMRs once they exist, underscoring the importance of monitoring and clear metrics for conservation benefit.

2.3 What's in a name?

In order to understand the global prevalence of HMRs, and their potential positive and negative outcomes, there is a need for clarity around terminology. Several terms have emerged from different disciplines, including "artificial reefs", "human-made reefs", "anthropogenic reefs", "underwater structures" and "anthropogenic structures at sea", some of which may bias perceptions and assessment of HMRs.

Though the word "reef" is now most commonly associated with ecosystems based around coral or rocks, its origins and definitions reveal a focus on hard substrate in the ocean, regardless of composition. The Oxford English Dictionary (2009) defines reef as "a ridge or bank of rock, sand, shingle, etc., lying just above or just below the surface of the sea or another body of water, usually in such a way as to pose a hazard to shipping". In English, the word is believed to be derived from the Old Norse *rif*, simply meaning "ridge in the sea" (Dögg Friðriksdóttir 2014). For centuries, reefs were primarily associated with a risk of shipwreck; for example, the term *abrolhos*, marking a reef on a Portuguese 16th century map, is believed to be derived from the command to sailors to "keep your eyes open!" (Bowen 2015 p. 3).

Though the term "artificial reef" is most widespread in the scientific literature and media, Pitcher & Seaman Jr (2000) recommend "human-made reef" since use of the word "artificial" can imply HMRs are an inferior substitute for "natural" reefs . The use of categories that implicitly privilege "natural" systems over ones created or influenced by humans has been challenged more widely in conservation. One could argue the distinction between "natural" and human-influenced systems has been blurred to the point of irrelevance because human influence has become so pervasive (Vitousek *et al.* 1997). Additionally, "novel ecosystems" created or influenced by humans have increasingly been recognised and are not necessarily worse for the species involved (Hobbs *et al.* 2014). Ultimately, conceptualising HMRs as imitations of natural reefs may limit our ability to perceive the unique costs, benefits and opportunities they present.

2.4 Lines in the sand

Beyond nomenclature, dominant definitions in current use for HMRs are also obstructing a full view of the heterogeneity and scale of human presence in marine ecosystems. These definitions are often tied to normative judgments around the role of human influence and the legitimacy of ecosystems transformed by it. Criteria for inclusion as an artificial or human-made reef often hinge on factors that are challenging to ascertain in practice, such as a structure's purpose or its ecological similarity to natural reefs. These normative judgments have perpetuated a lack of nuance in the debate around HMRs and a lack of widespread assessment around conservation claims. By excluding structures from initial assessment through resource-intensive qualification processes and feeding into biases around "natural" systems, these criteria may be limiting learning for conservation.

2.4.1 *The role of purpose*

Purpose-based definitions for HMRs require particular intentionality; for example, for an object to have been "deployed purposefully on the seafloor to influence physical, biological or socioeconomic processes related to marine living resources" (Seaman and Jensen 2000 p. 5). Purpose is a key element in the construction and assessment of HMRs, and a purpose-based approach has the benefit of a benchmark by which to measure outcomes. However, as an initial filter it may frustrate attempts to assess structures for which the initial purpose cannot be confirmed, and exclude unexpected examples of success or failure. In this scenario, a shipwreck or oilrig harbouring high levels of biodiversity would not be assessed for its conservation benefit. Purposes are often not formalised; a meta-analysis of HMRs in fisheries found a clear purpose had only been articulated in 62% of cases (Becker *et al.* 2018). Purposes can be difficult to ascertain as they are subjective and multifaceted, may change over time, and may require access to stakeholders who cannot be reached or choose to claim a different purpose. HMRs are increasingly being designed with multiple purposes (Dafforn *et al.* 2015) or can gain new purposes if their uses change.

Statements of purpose can provide valuable information about social uses and conservation opportunities, and are particularly relevant given the international legislation that governs sinking of anthropogenic structures in the ocean. The London Convention of 1972 and Protocol of 1996, established by the International Maritime Organisation, regulates marine dumping and counts 87 States as its parties. It defines dumping as "any deliberate disposal at sea of vessels, aircraft, platforms or other man-made structures at sea" and states that dumping does not include the "placement for a purpose other than the mere disposal thereof" (IMO 2006 pt. 4.2.2). Therefore, the sinking of anthropogenic structures in marine environments with claims of any purpose other than disposal – for example, conservation – is permitted so long as the placement is not contrary to the aims of the protocol, though individual cases are still subject to local national law (Techera and Chandler 2015). By this logic, the submersion of 2 million tyres off the coast of Fort Lauderdale, Florida, in 1972 – now partially retrieved, at great expense, following disintegration and pollution – was acceptable as it was done with conservation in mind (Allen 2007). Although international guidelines now specifically disavow the use of tyres (London Convention and Protocol/UNEP 2009), proposals for their use in HMRs are still emerging, most recently in Guam (Cerbo 2018).

2.4.2 The role of outcome

Outcome-based definitions for HMRs set down specific requirements in terms of how associated communities develop, such as being “colonised by plant and animal communities resembling those of a naturally occurring reef” (Storrie and Morrison 2003 p. 20) or inciting “the development of productive habitat in an otherwise unproductive location” (Brock 1994 p. 1181). These definitions face two challenges: they are resource-intensive to assess, particularly as ecological communities may continue to change over time, and they reinforce an irrelevant hierarchy by requiring similarity to “natural” reefs. Again, outcomes are key to conservation assessment, but creating initial thresholds excludes opportunities to learn from structures which fail to generate particular outcomes.

Functional comparisons between natural and human-made reefs can contribute to a greater understanding of ecological context, regional biodiversity, and succession. Such comparisons are particularly relevant in cases where HMRs are deployed in an effort to rehabilitate, restore or mitigate damage to coral or rocky reefs. However, HMRs vary hugely in terms of materials, structural complexity, age, location and size, which can make straightforward comparisons with coral or rocky reefs difficult (Carr and Hixon 1997).

The more fundamental problem with outcome-based definitions is that they drive unhelpful biases by focusing on resemblance to natural reefs, implying that equivalence is possible and deviation is undesirable, blocking the perception of unique contributions. One author states: “the natural world is far better at generating the services ecosystems provide than we are at engineering them” (Roberts 2012, p. 19). This viewpoint perpetuates the idea that HMRs aim to substitute natural reefs, either immediately or as soon as some technological threshold is passed. In some cases, its basic premise can create hope or confusion about the potential for replacing coral reefs in light of the profound losses these ancient, complex ecosystems are facing. Comparisons may also direct attention away from a shared marine context; after all, life on HMRs is no more likely to succeed than life on natural reefs if surrounding environmental conditions are dismal (Dupont 2008). A more forward-thinking approach would be to focus on understanding the unique and separate ecological functions, ecosystem services and values provided by HMRs, considering them as ecosystems in their own right rather than as pale imitations of natural reefs. This is particularly relevant in cultural terms, given the potential of HMRs to hold historical or educational meaning for humans. This function-oriented approach to assessing HMRs would not preclude comparison with coral or rocky reefs in relevant cases, but it would avoid using them as a limiting benchmark, and promote a less biased comparison for the purpose of future HMR management.

2.5 The 5 W's and How

In order to plan for a conservation future that can harness and direct this rising tide of HMRs, it would be helpful to move beyond narrow inclusion criteria and instead to assess a large pool of structures of diverse origins (Figure 2.2). The initial categorisation of a structure as an HMR should be made regardless of purpose or outcomes, as long as anthropogenic origins can be confirmed. In practice, purpose and outcomes are not currently assessed on a routine basis, and are impossible to assess for every structure. Despite being highly valuable for learning, these more targeted assessments are therefore more appropriate as secondary stages of analysis.
As a first step towards conservation assessment, it will be necessary to collate information on the basic characteristics of HMRs, first locally and then potentially worldwide. At the local scale, tracking of HMRs can inform management plans by providing a fuller picture of marine landscapes and a sense of how stakeholders interact with or transform them. The process could be usefully structured according to the "5 W's and How", taught as tools for basic information gathering in primary schools, journalism seminars and police training worldwide: where HMRs are; what they are made of; when, why and by whom they were established; and how they are used socially and ecologically. Basic variables could include location, size, number of units, and materials, with information on origin (such as the creator and date of creation), biodiversity and known purpose or social uses being included if available. If collected systematically, available information at the local level could later be submitted to a global database, providing a rough sense of trends worldwide. At various scales, these initial data gathering exercises will be instrumental to assessing the conservation impact of HMRs as a whole, and generating best practice guidelines in the context of their accelerating use worldwide.

Collating information on HMRs is challenging; they may be established informally or even illegally, and people may be unwilling to disclose locations if they believe others could damage or derive value from them (as with fishing spots or archaeological sites). Some HMRs are located in inaccessible areas, such as the deep sea, and most are difficult to find given they are underwater, though some can be identified through satellite imagery. Databases may be enabled by permitting processes, in the case of NOAA or the Florida Fish and Wildlife Conservation Commission, or through the administration of patents, as in the case of the Reef Ball Foundation. However, this information may not always be made public, and the focus on regulation means that accidental, informal or illegal HMRs are not included. Given that HMRs are created for many reasons, systematic local surveys of diverse stakeholder groups could provide information on their location and uses.

Collection of local information on HMRs should be prioritised, given its direct relevance to marine management and the effort required for data gathering; however, gaining a sense of how HMRs are shaping ecosystems at regional and global levels is also important. The creation of databases at larger scales would undoubtedly entail significant logistical challenges – among them the allocation of time, effort and funding. However, it could be carried out by combining a meta-analysis of the scientific literature, collation of databases maintained by state or national agencies, and vetting of information submitted on a voluntary basis. Models could include databases such as conserveareas.org, and data could be included on open access maps of marine change such as that curated by the OcToPUS initiative (octopus.zoo.ox.ac.uk).

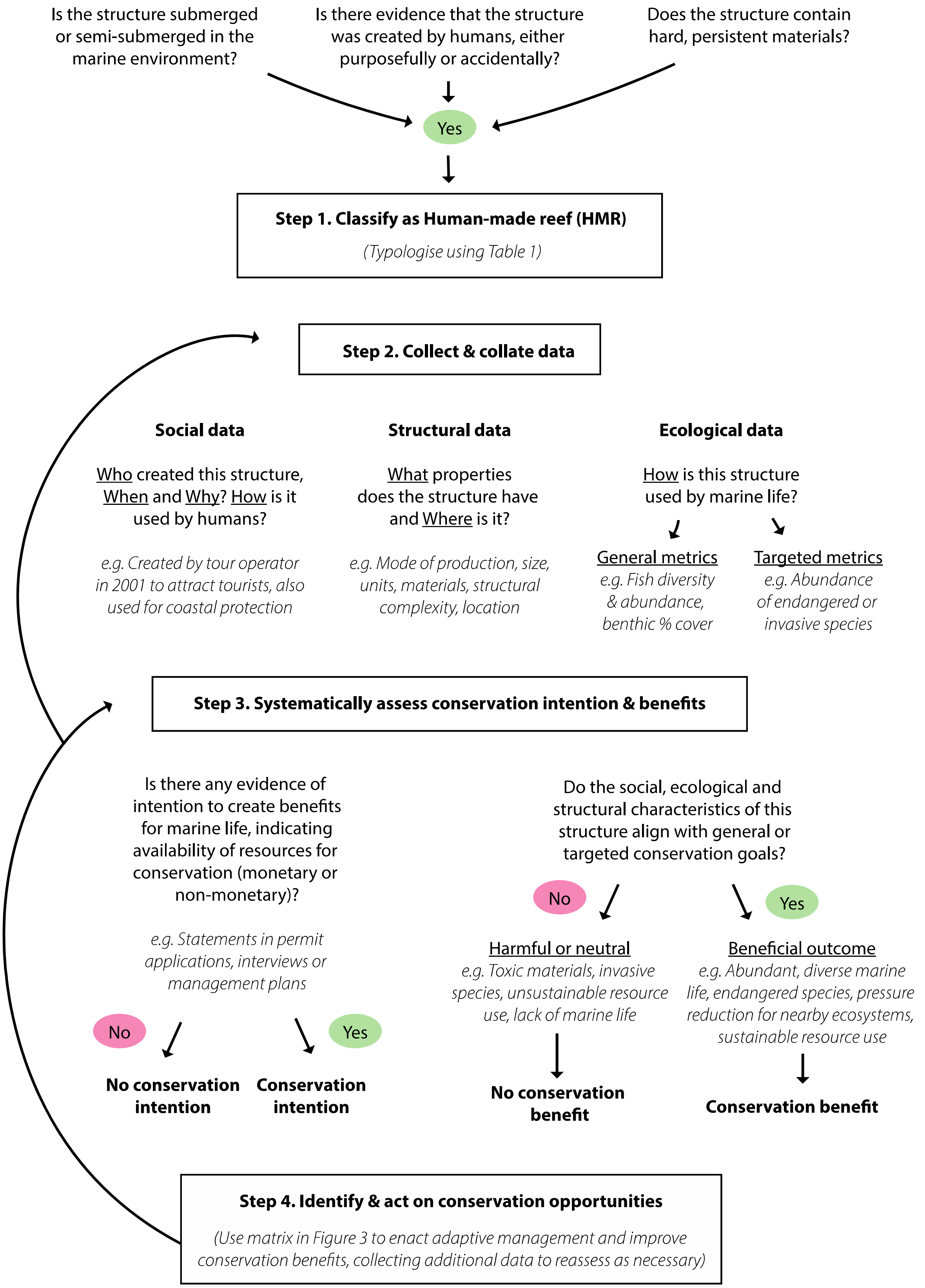


Figure 2.2 A key providing guidance on how to identify a diverse initial pool of HMRs at a local or global level, conduct data collection around the "5W's and How", and carry out systematic assessment of conservation intention and benefits to identify conservation opportunities.

2.6 Moving towards a typology of human-made reefs

Once initially identified and located, the characteristics of a structure can be expressed in a typology, providing an anchor for the collection of available information on conservation-relevant variables (Table 2.1, Figures 2.2 & 2.3). Four categories provide a framework for collating information on the structure in question – its mode of production, known purposes and social uses, conservation intention and conservation benefits. Mode of production is intended as a category which a trained observer could assess through easily visible characteristics without contacting the original creator of the HMR. The category on purposes and uses is intended to broaden understanding of the multiple social values of HMRs beyond a singular purpose, since information on human uses is important but often lacking (Becker *et al.* 2018). Conservation intention represents statements of purpose from a conservation standpoint, and indicates potential for conservation management through resources or willingness to take action. Evidence of conservation intention could be derived from planning applications or interviews with the creators of reefs. Conservation benefits could be assessed through various metrics appropriate to a particular context, including diversity and abundance of target species or functional groups.

This is not the first typology suggested for HMRs; Stolk et al. (2007) proposed one for recreational structures based on the intention to simulate, replicate or transform natural reefs. The use of the broader typology which we propose, encapsulating a variety of structures, would instead record the diverse uses and conservation impacts of HMRs on marine ecosystems.

Table 2.1 A typology of human-made reefs (HMRs) from a conservation perspective, with non-exhaustive examples of the diverse modes of production, purposes and uses, conservation intentions and conservation benefits of HMRs.

Mode of production	**Definition**	**Purposes and uses**	**Examples of conservation intention**	**Examples of conservation benefits**	**Examples of structures**
Artworks	Artistic structures, often created to convey cultural meaning	Tourism, art, education, spiritual, conservation	"The art of conservation"(MUSA 2016)	Diverse algae and macrofauna identified on underwater sculptures (Solís-Weiss *et al.* 2015)	Underwater sculpture museum (www.musa.org)
Prefabricated modules	Individual designed structures produced industrially for a modifying purpose, often produced and deployed en masse	Conservation, coastal engineering, tourism, education, fishing	"Our mission is to rehabilitate our world's ocean reef ecosystems" (The Reef Ball Foundation 2017)	Coral growth rates on Reef Balls vary by species (Cummings *et al.* 2015)	Reef Balls (www.reefball.org); Lobster traps (Headley 2017)
Sunken artefacts	Structures produced for regular human use, subsequently sunk accidentally or on purpose	Accidental, tourism, conservation, culture, archaeology	Sinking of ships to create alternative dive sites and reduce pressure on nearby coral reefs (Leeworthy *et al.* 2006)	89 taxa of reef fish observed across two shipwrecks (Simon *et al.* 2013)	Shipwrecks (Leeworthy *et al.* 2006; Simon *et al.* 2013; Krumholz and Brennan 2015)
Infrastructure	Fixed complex structures built to enable large-scale human activities	Energy extraction and production, trade, tourism, recreation	Unknown	"Oil platforms off California are among the most productive marine fish habitats globally" (Claisse *et al.* 2014)	Oil & gas platforms (Claisse *et al.* 2014); Wind farms (Russell *et al.* 2014); Docks and jetties (Storrie and Morrison 2003)
Traditional structures	Structures created through reconfiguration of locally available natural materials such as rocks or wood	Fishing, coastal engineering, tourism, conservation, water quality	Oyster reefs used to restore hard substrate and oyster populations (Cabral 2014); Rock piles used for coral restoration (Fox *et al.* 2019)	Community oyster reef restoration programme creates opportunities for education and community building (Cabral 2014)	Hawaiian fish ponds (Costa-Pierce 1987); Mayan fishing structures (Garduño Argueta and Caballero Pinzón 1998); Rock piles (Fox *et al.* 2019); Oyster reefs (Seaman 2007; Lee *et al.* 2018)

Figure 2.3 Examples of diverse HMRs categorised according to typology in Table 1. Clockwise from top left: a. Artworks; b. Prefabricated modules; c. Sunken artefacts; d. Infrastructure; e. Traditional structures. All photos taken by SCT in Cozumel, Mexico (2019).

2.7 The road to conservation assessment

Conservation science is a value-based discipline that seeks to benefit people and biodiversity through the use of natural and social science to manage the environment (Kareiva and Marvier 2012). These goals are key to assessing the contribution of HMRs to conservation, since they guide the social and ecological metrics by which success is measured. Previous performance metrics proposed for HMRs range from the suggestion that performance can only be assessed according to the purpose for which a structure was built (Carr and Hixon 1997), to a "reef performance scale" ranging from -3 to +3, with scores based on the fulfilment of desired objectives (Baine 2001).

A different approach would be to determine a set of metrics of conservation benefit and apply them to a diverse selection of HMRs regardless of original purpose, or to a single HMR across time. Ecological metrics could be "targeted" according to conservation goals, and chosen in consultation with relevant stakeholders – for example, measuring presence or abundance of an endangered, invasive or commercially important species – or "general", measuring variables such as diversity of sessile organisms or fish diversity. In conjunction, measurements of social benefit could take place – for example, consideration of tourism revenue as in Leeworthy et al. (2006), or analysis of ecosystem services such as that carried out by Kirkbride-Smith et al. (2013) and Schut (2013). Such a combined, holistic approach to assessment of HMRs could begin to broadly capture the breadth of social-ecological processes of value to conservation, thereby supporting management decisions.

Relevant metrics for conservation benefit could be assessed in relation to conservation intention to manage existing HMRs and guide their future creation, in the context of social and cultural benefits (Figure 2.4). Structures could be held up to greater scrutiny if explicitly designed for conservation, but this process could also allow new insights to emerge from HMRs designed by and for other sectors. In many cases, conservation will be just one of a set of stated objectives (Lee *et al.* 2018), or it may emerge subsequently. However, if any intention has been expressed, treating the structure as conservation-motivated could help to avoid greenwashing in order to gain a licence to operate (Rendle 2015). It could also indicate availability of resources for conservation monitoring and management. For example, statements of conservation benefit in the press or on documents such as permit applications could be a valuable tool for setting specific goals and holding creators of HMRs to account. Importantly, neither "conservation intention" nor "conservation benefits" are static; the creation and monitoring of realistic, measurable conservation-relevant goals could imbue intention, and a structure's conservation benefits could vary with changes in relevant metrics.

The matrix of conservation benefits and intention (Figure 2.4) can be used to identify opportunities and guide decisions around permissions and policy for future HMRs, supplementing existing guidance (Baine 2001; London Convention and Protocol/UNEP 2009). It could aid in decision-making around the protection and management of high-performing conservation structures, as well as about the transformation or removal of structures which actively harm marine ecosystems. Though some elements of success are likely to be localised (Baine 2001), analysing a wide pool of HMRs can help guide understanding of their use and conservation potential across sectors worldwide. The identification of HMRs generating conservation benefits in different contexts will make it increasingly possible to envision and coordinate a future in which these structures help to maintain diverse, functional marine ecosystems, allowing nature and people to co-exist.

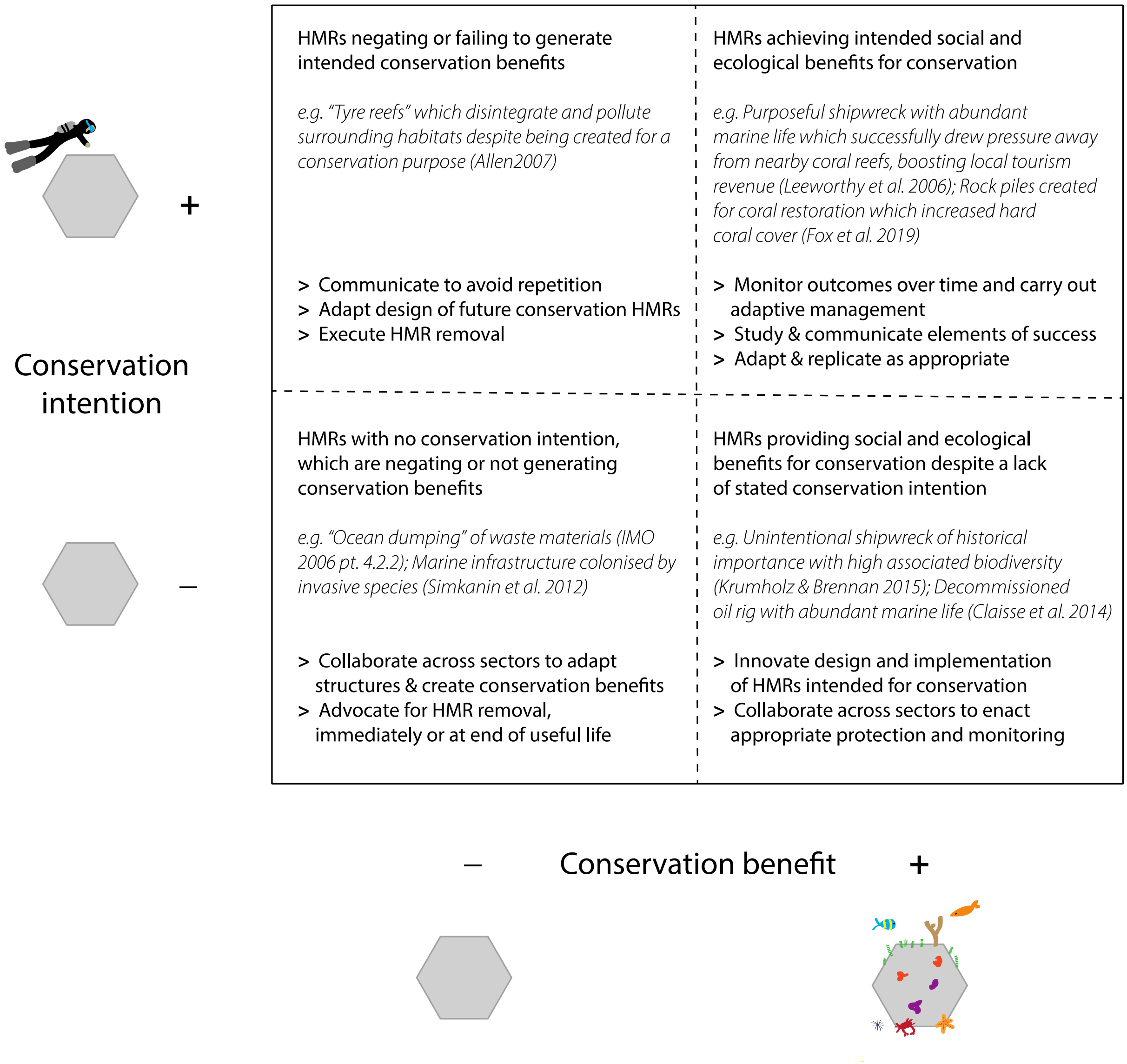


Figure 2.4 Matrix of conservation opportunities for diverse human-made reefs, based on assessment of conservation intention and benefits. Intention and benefits may change over time, meaning that the matrix can be used to track changes on one HMR or to compare across HMRs. Conservation intention is considered either present or absent, based on whether any statement on intended or actual conservation benefit from the HMR has been made (regardless of whether other uses are also intended). Outcomes with respect to conservation benefits are on a continuous scale and assessed through general metrics (such as fish diversity) or targeted metrics (such as presence of an endangered or invasive species). They can also include social dimensions such as provision of ecosystem services.

2.8 Into the future

As ocean landscapes continue to change, conservationists have an opportunity to manage HMRs in a conscious and integrated way, by mapping and monitoring these structures locally and worldwide, deepening understanding of the values they provide, providing guidelines for best practice, and considering whether some might qualify for protection. Acknowledging the longstanding use of HMRs could helpfully inform the debate around their future deployment and management, if only by clarifying they have existed far longer than a few hundred years.

In many parts of the world, there is very little management or oversight of HMRs. Local and global registries and targeted systematic conservation assessment (as outlined in Table 2.1 and Figure 2.2) could inform management decisions (Figure 2.4), using basic information to answer larger conservation questions. For example, Pitcher & Seaman Jr (2000) suggested extending protections afforded to some natural coral or rocky reefs to highly productive HMRs. The marine communities that develop on HMRs are far from immune to damage by humans; one study found 55% lower species richness, 57% lower abundance and 41% lower diversity on heavily trawled shipwrecks than ones classed as "pristine" (Krumholz and Brennan 2015). Some HMRs could qualify for protection as sites of underwater cultural heritage, or be used as a targeted management tool: one study suggests treating natural reef habitats as "crown jewels" and deploying HMRs to offload diving pressure and create additional habitat (Oh *et al.* 2008). Questions over structure removal are also shaping policy and practice across sectors (Fowler *et al.* 2018)

HMRs can defy categorisation, since they represent a mixture of cultural and biological patrimony. However, similar questions arise around land-based structures, such as buildings managed for human use as well as the conservation of endangered species such as bats (Voigt *et al.* 2016). More broadly, a range of human-made ecosystems are recognised for their conservation value, including heathlands and chalk grassland in the UK, and more recently some urban environments.

In the last century, human-made reefs have taken many forms in the cultural imagination: mysterious time capsules filled with treasure, evidence of pollution and corporate greed, siren calls to marine organisms that create bountiful fishing grounds to the detriment of the individual organisms and their species, and symbols of regeneration and hope in an ocean under threat. The "seductive spell of artificial reefs" (Meier *et al.* 1989) – the glow of satisfaction that can result from seeing marine life accumulate on a structure built and left bare months before – has sparked their construction and worldwide debates. It is now time for conservationists to assess their potential role in the oceans of the future. First, it will be important to count and categorise: How many HMRs exist, what lives on them, who uses them, and at what rate are these structures proliferating? Second, to consider: What opportunities and threats do these novel ecosystems provide in a conservation context? Finally, to suggest policies that can steer this growing tide toward a productive future, not only for the ocean but for ourselves.

Chapter 3

Exploring the use of local knowledge to locate and characterise human-made reefs of conservation relevance in Cozumel, Mexico

A shipwreck emerges from the haze beyond a small natural reef. Photo: SCT, Cozumel 2019.

3 Exploring the use of local knowledge to locate and characterise human-made reefs of conservation relevance in Cozumel, Mexico

"The Sea is full -- I know it!
That -- does not blur my Gem!"

- *Emily Dickinson (One Life of so much Consequence!)*

3.1 Introduction

The profile of human-made reefs – hard, persistent structures submerged intentionally or accidentally in the ocean by humans, also known as HMRs and "artificial reefs" – is rising in marine conservation globally, but a distinct lack of information remains over their numbers, locations, origins and conservation outcomes (Chapter 2; Bohnsack and Sutherland 1985; Seaman 2007). Although scientific interest in HMRs has risen sharply in the last five decades (Lima *et al.* 2019), there are few comprehensive databases to track or monitor their impacts, which severely limits assessments of their effectiveness (Bohnsack and Sutherland 1985).

Up to this point, studies on HMRs have tended to focus on a single activity or HMR type, such as oil and gas, fisheries (Headley 2017) or intentional shipwrecks (Ilieva *et al.* 2019) which means HMRs of diverse origins are rarely included in global assessments of human impact on marine ecosystems (Halpern *et al.* 2015). Increasingly, discussions have turned to the potential for multi-use structures which can provide conservation benefits in tandem with benefits such as resource extraction, tourism and coastal management (Mead and Black 1999; Silva *et al.* 2016).

HMRs are created in many ways, including accidental shipwrecks (Krumholz and Brennan 2015), fishing (Turner *et al.* 1969), oil and gas extraction (Fowler *et al.* 2018), tourism (Leeworthy *et al.* 2006; Kirkbride-Smith *et al.* 2013), and coral restoration (Fox *et al.* 2019). Though HMRs are often considered a relatively recent and small-scale invention, they may be much more abundant and older than is commonly understood (Chapter 2).

HMRs of diverse origins can generate social and ecological conservation benefits despite not being created with conservation intention (Chapter 2). The introduction of hard substrate can provide novel habitat for marine organisms, resulting in complex and productive ecological communities (Claisse *et al.* 2014) though the concomitant disruption of soft sediment habitats has been raised as a concern (Heery *et al.* 2017). From a cultural standpoint, HMRs can contribute to marine education, viability of ecotourism, displacement of tourism impacts from sensitive areas, local environmental awareness and sustainable resource use (Leeworthy *et al.* 2006; Trialfhianty and Suadi 2017; Bideci and Cater 2019).

In order to assess the conservation impacts of HMRs and guide their future creation, it is necessary to establish a solid understanding of their numbers and types locally and worldwide. However, this process is highly challenging as HMRs can be difficult to locate underwater; methods attempted to date include satellite imagery (Baeye *et al.* 2016), literature searches (Ilieva *et al.* 2019), and use of databases created by state agencies as part of permitting processes (FFWCC 2018). Many HMRs are created informally or accidentally, meaning that they are not included in such official databases, so local knowledge is often key to their identification (Erreguerena 2013; Headley 2017).

Local knowledge is a valuable component of marine resource management more generally, providing information about marine habitats, life histories, species abundance and distribution, and stewardship techniques (Thornton and Scheer 2012). The term "local knowledge" has often been associated with "traditional" or indigenous knowledge (Johannes *et al.* 2000; Lauer and Aswani 2008). However, it can also refer in a wider sense to environmental knowledge built up at a given site through specific practices and interactions, including by a variety of groups such as artists, farmers, and gardeners as well as indigenous peoples (Turnbull 2009). When diverse social actors are present, the process of "bridging" between knowledge systems can integrate different sources of local expertise and provide insights to help govern shared spaces; for example, by creating maps to understand different perceptions of ecological space (Rathwell *et al.* 2015). The integration of different types of knowledge, which can emerge through personal experience, traditional norms or formalised scientific processes, is complex but is key to the management of natural resources with multiple stakeholders (Raymond *et al.* 2010).

Knowledge created and applied by groups who carry out different activities can ultimately shape the shared spaces they inhabit (Turnbull 2009). Marine and coastal environments can be deeply significant to the stakeholders who frequent them, with modification resulting in strong emotional reactions (Kellert 2005). People's sense of ownership over these spaces can result in "property conflicts that would seem very odd if they occurred away from the ocean" (Thompson 2007 p. 211). Different stakeholders may be enacting varying cultural models of property focused around concepts such as sovereignty, community, landscape, ecology, and moral order, with a lack of sufficiently shared expectations (Thompson 2007).

Islands have historically provided a rich opportunity to study local knowledge of conservation relevance because they simultaneously contain rich biodiversity and are vulnerable to environmental stressors (Lauer 2017). Some areas of the world, including the Caribbean, have been overlooked because marine local knowledge was not perceived to have been consolidated over a long enough period; nonetheless, these areas provide their own opportunities as new knowledge is continuously being created and adapted (Grant and Berkes 2007).

Mapping with local people can be particularly useful when working with species or sites which are hard to detect, providing information about their existence and location as well as insights into local perceptions of space (Newing *et al.* 2011 p. 55). In the case of HMRs, which are submerged in the marine environment and therefore difficult to find and monitor, local knowledge can be crucial to their identification and management. For example, Headley (2017) carried out interviews and physical mapping activities with local fishers to identify the numbers and locations of lobster traps, and Erreguerena (2013) describes the cooperation of archaeologists with local fishers to identify sites of cultural importance such as shipwrecks.

In the marine conservation realm, mapping has been used to characterise coral reefs and benthic habitats with local scuba divers (Loerzel *et al.* 2017) and indigenous fishers (Lauer and Aswani 2008) as well as more abstract concepts such as fishing effort (Thiault *et al.* 2017) and ecosystem services (Klain and Chan 2012). When the results of mapping exercises with local fishers have been compared with those provided by marine mapping techniques such as satellite imagery (Selgrath *et al.* 2016) and sidescan sonar (Teixeira *et al.* 2013), local knowledge has been found to be relatively accurate at a much lower cost, with the additional benefits of stakeholder engagement. These studies identify local knowledge maps as a particularly attractive option for the characterisation of marine systems in developing countries, where conservation resources are often limited (Teixeira *et al.* 2013). However, it is important to note that the process of mapping can shift power dynamics by conferring legitimacy, facilitating surveillance and informing actions and policies; as Harley (1989) states, "power comes from the map and it traverses the way maps are made" (p. 13). Therefore, some stakeholder groups such as fishers, biologists and archaeologists are known to exercise caution around sharing spatial information that could be exploited in disadvantageous ways (Grant and Berkes 2007; Frank *et al.* 2015).

The island of Cozumel (Figure 3.1) is the largest Caribbean and permanently inhabited island in Mexico, measuring approximately 478 km^2 (McFadden *et al.* 2010). It has been inhabited for at least two millennia since the preclassic Maya period, and is one of the first places where Spanish conquerors led by Hernán Cortés landed in 1519; in recent decades, it has become an important tourism destination of particular attraction to cruise ships and scuba divers (Palafox-Muñoz *et al.* 2007). It is a site of marine conservation importance, harbouring part of the Mesoamerican Reef and surrounded by three multi-use marine protected areas (Figure 1, SEMARNAT 1996, 2012, 2016). Several colonial and pre-Hispanic archaeological discoveries have been made in the area, both on land and in the ocean, including shipwrecks as HMRs (Andrews and Corletta 1995). A controversial coral transplantation programme used HMRs in the mid-1990s to relocate corals away from the development site of a cruise ship dock (Muñoz-Chagín 1997). After Hurricane Wilma damaged many of Cozumel's shallow coral reefs in 2005, several HMR projects were put forward with the dual purpose of restoring coral and providing a tourist attraction (Santander *et al.* 2012; Edwards 2014).

The literature identifies a lack of centralised knowledge around the presence and characteristics of HMRs worldwide (Bohnsack and Sutherland 1985; Seaman 2007), the wide variety of stakeholders who create and use them (Chapter 2, Lima *et al.* 2019), and the growing importance of considering novel marine ecosystems such as HMRs in conservation efforts (Schläppy and Hobbs 2019): Therefore, in this chapter I use Cozumel as a case study to address the following aims:

- Explore the use of local ecological knowledge to assess the prevalence, variety, locations, history and characteristics of HMRs in Cozumel
- Trial the compilation of a local database of HMRs of various origins and types and consider the wider feasibility of this approach
- Examine variations in knowledge of HMRs across stakeholder groups, considering the ways in which this information is obtained and shared
- Determine potential links with conservation across stakeholder groups and HMR types

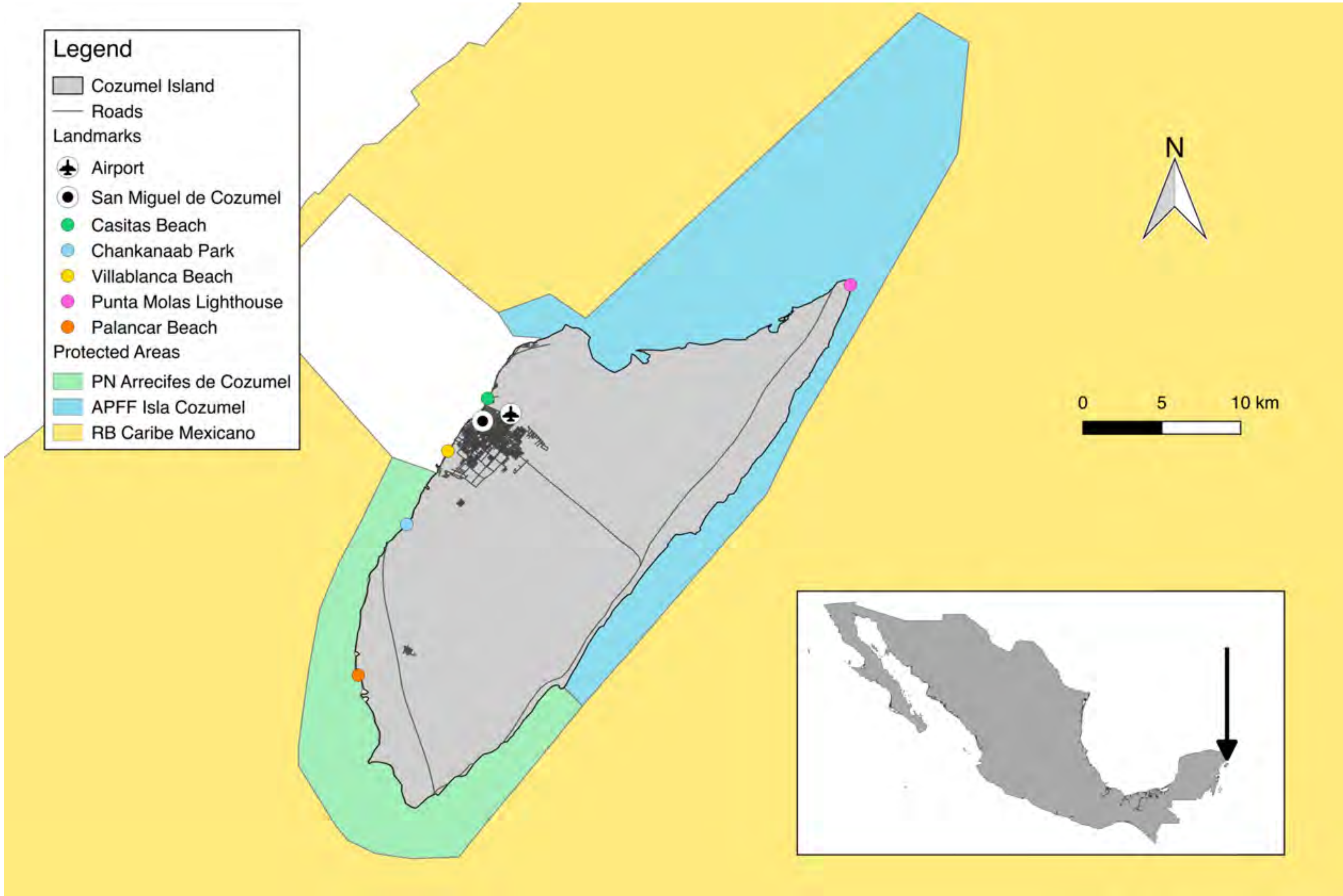


Figure 3.1 Map of Cozumel island indicating the main town of San Miguel de Cozumel; the airport; popular coastal landmarks; the location of the island within Mexico; and the extent of three surrounding protected areas: Parque Nacional Arrecifes de Cozumel (1996), Área de Protección Flora y Fauna Isla Cozumel (2012), and Reserva de la Biósfera Caribe Mexicano (2016).

3.2 Methods

3.2.1 Semi-structured interviews

From January to May 2019, 40 semi-structured interviews were conducted on the topic of human-made reefs (HMRs) in Cozumel with diverse stakeholders such as archaeologists, fishers, tour operators, scientists, fishers and artists (see Section 1.6 and Figure 1.4 for further details). Interviews focused on the distribution of HMRs around the island, as well as their uses, history and characteristics (see Supplementary Materials SM1 and SM2 for interview materials). Snowball sampling was used to identify interview participants due to the specific requirement for expertise in HMRs. Online research was used to identify initial contacts, such as individuals or organisations publicly associated with the creation or use of HMRs. Some personal introductions also occurred on an informal scoping trip in July and August 2017. No names were collected in the course of the research and interviews were pseudonymised. Given Mexican laws around alteration of coastal habitats and the potential for reporting illegal behaviour in the creation of unauthorised HMRs, participants were asked not to disclose personal information on HMR creators. The Oxford University Research Ethics Committee approved this research under Reference R60895/RE001 and the research was also locally approved as following guidelines set out by the research ethics committee at El Colegio de la Frontera Sur (see Supplementary Materials for letters of ethical approval).

All interviews were conducted by the same researcher (SCT) in locations selected by the participant, in English or Spanish depending on the preference of the participant. During interviews, handwritten notes were taken and if the participant consented, the interview was also audio recorded. Handwritten notes were scanned and transcribed for analysis in NVivo 12, referring to audio for clarification when necessary. Qualitative analysis for Chapters 3, 4 and 5 took place through thematic coding of relevant responses as defined by the interview question they pertained to (see Table 1.2 for information on which survey questions applied for each chapter). This process involved exploring the data without predefined codes through an inductive process, then building a set of codes based on the main themes I noticed in responses, and then applying these codes to all relevant text in a deductive process using NVivo (Newing *et al.* 2011). Coding was not checked by another researcher due to constraints on time and restrictions on ethics clearance given the potential for illegal activity. Quantitative data were analysed on RStudio (version 1.2, "Orange Blossom") running R (version 3.6.2) and using the packages *dplyr* and *ggplot*.

Once all interviews had taken place, participants were assigned stakeholder categories which considered their self-selected "primary activity", occupation and the HMR activities and experiences described in the course of the interview (Table 3.1). These categories are used to indicate participant responses using the format "Interview number-Category" (e.g. 01-TOU). Participants had a mean age of 48, with the oldest participant being 76 and the youngest being 23. 80% of participants identified as male and 20% as female; this bias was due to the preponderance of male-biased professions engaging with HMRs.

Table 3.1 Stakeholder categories in relation to HMRs with category descriptions

Category	**Description**	**Number of participants**
Aquaculture (AQU)	Using HMRs to cultivate marine organisms (e.g. oysters)	1
Archaeology (ARC)	Conducting or participating in archaeological work and expeditions to locate, study or excavate HMRs	3
Art (ART)	Creating artistic sculptures for submersion in the ocean	2
Cultural activities (CUL)	Documenting or participating in cultural interactions with HMRs (e.g. historical study)	1
Environmental consulting (ENV)	Working with for-profit companies to ensure developments adhere to environmental regulations	3
Environmental education (EDU)	Using HMRs to carry out environmental education (e.g. coral restoration training, awareness of environmental problems)	2
Fishing (FIS)	Catch and/or sale of fish or lobster	5
Management (MGT)	Management of protected areas and natural resources in a government role	3
Scientific research (SCI)	Conducting research on the colonisation, design, use and/or impact of HMRs	4
Tour operation (TOU)	Conducting dive and snorkel tours and training for paying customers	16
Grand Total		**40**

3.2.2 *Mapping*

During the interviews, participants were asked to identify HMRs they were aware of and hand-draw an approximate location on an A4 base map of Cozumel downloaded from CONABIO, the Mexican government commission on biodiversity (http://www.conabio.gob.mx/informacion/gis/). Spatial information was collected at this coarse level of detail because it was sufficient for my purposes in identifying general areas of HMR prevalence, while taking into account the high sensitivity around the locations of some HMRs (e.g. fishing sites and sites of archaeological importance) which may have prevented participants from sharing information. This tendency was first noted on the scoping trip, and while I did also request GPS coordinates during the fieldwork interviews, no participant shared them. The reasons for this sensitivity were further explored in the interviews.

After fieldwork, hand-annotated maps were scanned on a flatbed scanner and imported into QGIS 2.18 (Las Palmas) as vector layers. They were then aligned to original base maps using the "georeferencing" tool with the same five points on each map. As hand-drawn points were rough estimates on a relatively small map and therefore not expected to correspond with actual coordinates, I deemed this level of accuracy to be sufficient in providing an overall sense of where HMRs were located. A shapefile layer was then created for each map and a digital point was placed in the middle of each annotated numbered point for site location (see Figure 3.2).

Figure 3.2 Example of superimposed scanned and geo-referenced map with digitised points overlaid on handwritten points.

3.2.3 Database and salience analysis

During the interviews, participants were asked to list HMR sites they were aware of, in order to contribute to a database of sites in Cozumel, and to describe variables such as year of creation, number of units placed underwater, reason for creation, references for location such as nearby hotels or landmarks, presence of conservation intention, and current uses. After fieldwork, this information was transcribed into Excel and analysed on RStudio (version 1.2.5033, "Orange Blossom") running R (version 3.6.2) and using the packages *dplyr*, *lattice* and *ggplot2*.

In order to determine distinct sites, where the same unique HMR was being identified by multiple participants, the entire database was reviewed and a new variable was created for "site code". If there were at least two overlapping details to indicate that the same site was being referred to (most often in name, location, and description) then the site was categorised as an observation under a site code. Qualifying details included specific verifiable information such as proximity to named hotels, a well-known name for a structure, or a detailed description. Non-qualifying details included vague information such as "a shipwreck on the eastern side of the island". When non-qualifying levels of detail were provided, it was often impossible to cross-reference between interviews and determine whether respondents were identifying distinct HMR sites. As I chose to be relatively conservative in this respect, it is likely that more distinct sites exist than are currently listed.

Individual HMR sites were categorised into types and subtypes using the categories in a typology suggested in an earlier phase of the research project (Chapter 2). A salience analysis on HMR type was then carried out using the *AnthroTools* Package (version 0.8) running R (version 3.6.2) on RStudio (version 1.2, "Orange Blossom"). The salience score (Smith's S) combined rank, frequency and number of lists to compute a metric of how "salient" or approximately important and well-known sites or categories were to respondents.

3.2.4 Ground-truthing

A "ground-truthing" process occurred at a small number of well-known sites. In this process I visited the site, verified its existence on scuba dives and measured variables such as GPS location, size and depth (Newing *et al.* 2011 pp. 192–3). The existence, state and location of the majority of the other identified sites has yet to be verified due to time and cost constraints. The sites where ground-truthing occurred were: the C-53 wreck; the statues of the Virgin and Christ at

Chankanaab; the Reef Balls at Dzul Ha; the small plane; a set of HMRs opposite Casitas beach (two patrol boats, large concrete blocks); and the Biorock sculptures, concrete restoration structures, busts and Reef Balls at Villablanca.

Location and depth at surveyed structures were determined by combining data from a Garmin GPS 73 and a Suunto Zoop Novo dive computer (method adapted from Collins and Baldock (2007). The GPS unit was secured to a buoy towed by a diver, and set to record tracks at the "Smallest interval". During the dive, the diver used the "bookmarks" function on the dive computer to record the time, depth and temperature at which a particular structure was being surveyed. Using time, GPS tracks were later aligned with bookmarks to provide a verified location point for surveyed structures.

3.3 Results

3.3.1 Identification of HMR sites

40 participants identified a total of 350 HMR sites in Cozumel (Figure 3, Table 3.2), at least 77 of which were unique or clearly distinct from the other sites mentioned. Participants reported 8.7 sites on average, with a minimum of zero and a maximum of 50 sites mentioned by an individual participant. The number and variety of HMR sites identified greatly exceeded the six identified through available literature ahead of the fieldwork period. Participants identified a wide variety of sites, ranging from accidental and purposeful shipwrecks to concrete modules, artistic and religious sculptures, debris from hurricanes, rock piles, infrastructure, and fishing and aquaculture devices (Table 3.2, Figure 3.4).

Although some sites were clearly identifiable across interviews with consistent names and locations, in many cases participants used varying names or descriptions to identify sites to the best of their knowledge. For example, an intentional shipwreck of a military ship officially called the "C-53 Felipe Xicoténcatl" was alternatively referred to as "the C-53" (40-TOU), "the Xicoténcatl" (09-REC), "the Felipe Xicoténcatl" (36-EDU), "the C-59 shipwreck" (15-MGT), "the minesweeper" (30-ARC, in reference to its military past) or "the sunken boat near Chankanaab" (06-SCI, in reference to its location near a well-known reef and adventure park). On occasion descriptions were more cryptic, requiring imagination and triangulation with mentions of location or purpose. For example, descriptions of Reef Balls ranged from the patented name to "balls of concrete" (33-TOU), "upside-down casseroles with holes in them" (35-ART) or even "they look like alien eggs" (26-TOU).

Despite the significant number of sites identified, and an inclusive definition of HMRs being provided at the beginning of the survey, various participants did not believe HMRs were common in Cozumel. One said, "here on the island there are very few" (18-FIS). Another did not believe any were present, saying "they aren't here in Cozumel" (10-FIS) but described various other sites in the state of Quintana Roo. Several participants stated definitively that the sites they had identified were the only ones in Cozumel.

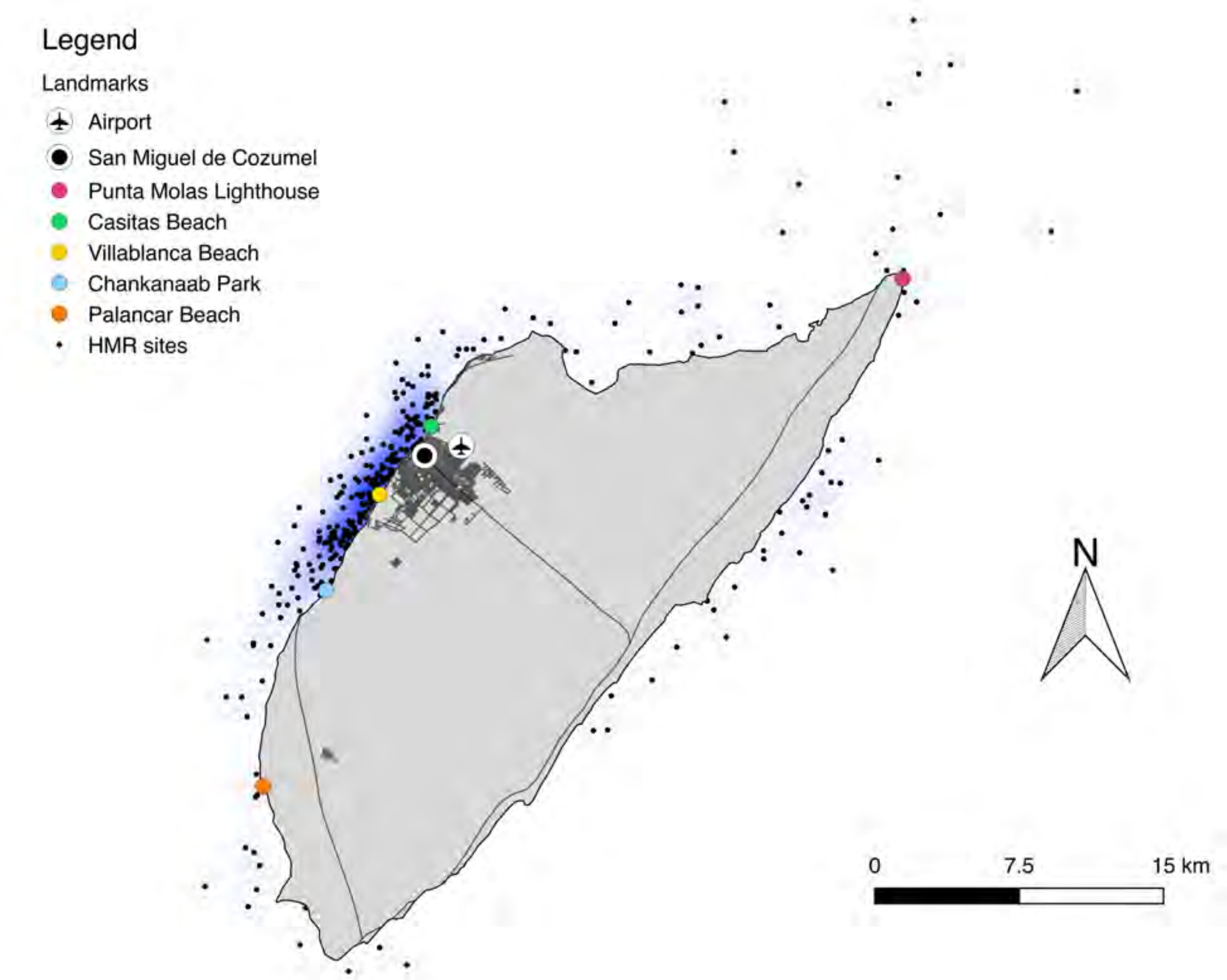


Figure 3.3 Location of all HMR locations identified by participants (n= 350, including over 70 unique sites). Overlaid heat map indicates the concentration of observations, showing the highest incidence of observations near the main town. The majority of the best-known sites were contained within three areas: Villablanca (VB), Chankanaab (CK), and Playa Casitas (PC).

Table 3.2 Types and subtypes of human-made reefs identified by interview participants. Types were derived from typology in Chapter 2 while subtypes were defined according to the examples provided by participants. Shipwrecks were classed as accidental if there was no evidence of intentionality. Total mentions indicate the total number of observations of a given subtype, and could include multiple observations of the same site by different participants. Unique sites indicate the number of individual verified sites fitting the subtype.

Type	**Subtype**	**Examples**	**Materials**	**Total mentions**	**Conservation intention attributed**	**Unique sites (minimum)**
Artworks	Artistic sculptures	Busts (e.g. Jacques Cousteau, Sylvia Earle, Ramón Bravo at VB), Abstract sculptures (e.g. Zoë at VB), Mayan-themed sculptures (e.g. Chac Mol at CK), Replicas of cannons and anchors, Imitations of coral reefs	Concrete, metal, fibreglass, Biorock technology	54	74%	10
	Religious sculptures	Statues of religious iconography (e.g. statues of Christ and Virgin of Guadalupe at CK)	Concrete, metal	18	39%	4
Prefabricated modules	Coral restoration modules	Designed modules created for coral restoration (e.g. Reefballs and Fractals at VB, HAMs at PC)	Concrete, metal rebar, PVC plastic	59	100%	7
	Oyster boxes	Designed boxes used to cultivate oysters	Metal, plastic	4	67%	1
	Lobster traps	Concrete shelters used to attract lobsters for fishing	Concrete, metal rebar	7	83%	5
Sunken artefacts	Accidental shipwrecks	Shipwrecks estimated to be from different points in history (e.g. various Mayan, colonial and modern sites)	Wood, metal, fibreglass	70	3%	19
	Intentional shipwrecks	Planes sunk as tourist attractions or to create habitat for marine life (e.g. C-53 wreck and patrol boats near PC)	Metal, wood,	43	78%	2
	Sunken plane	Planes sunk for a film shoot and as tourist attraction	Metal, other	16	25%	2
	Debris	Debris created by hurricanes or disposal (e.g. dock rubble moved to PC after hurricane)	Concrete, metal, rubber	30	30%	6
	Mayan artefacts	Sac bes (submerged roads), Mayan sculpture	Stone	8	0%	5
Infrastructure	Infrastructure	Piers, underwater cables, anchor bases, ramps, animal pens, underwater signs	Concrete, metal, plastic, wood	24	9%	15
Traditional structures	Rock piles	Piles of rocks created to attract fish or encourage coral growth, sometimes containing dead coral fragments (e.g. rock piles at VB)	Stone, dead coral	4	75%	1
Other				*13*		
			TOTAL	**350**	**49%**	**77**

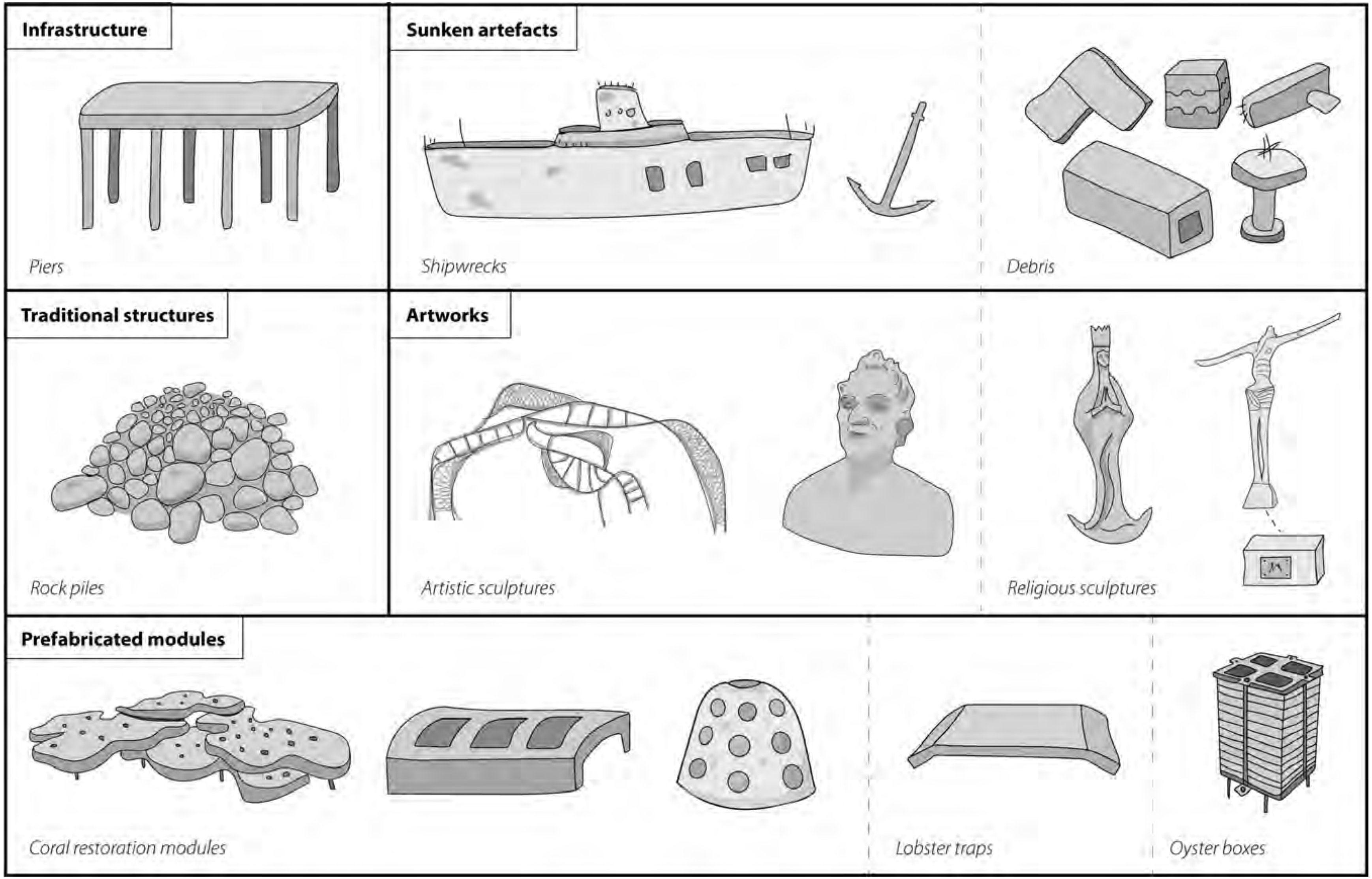


Figure 3.4 Example illustrations of common HMR subtypes described by interview participants.

A salience analysis comparing the rank and frequency of mentions for HMR sites revealed that a small number of sites appear to be extremely well-known, while many are known to only one person (Figure 3.5). For example, the C-53 shipwreck (pictured in Figure 3.4) was mentioned by over half of all participants and ranked in approximately fourth place on average when mentioned. A pair of sunken patrol boats were identified by over two thirds of participants, and two sets of artistic sculptures created using Biorock technology, known as “Zoë” and “Minecraft”, were each identified by over one quarter of participants. Some sites of cultural importance were mentioned by fewer respondents but were ranked very highly; one statue of the Virgin Mary was on average the second site mentioned by respondents who were aware of it. Other HMRs, including accidental shipwrecks and lobster traps, were only identified by one individual. Of the 13 most salient sites, mentioned over five times, all were purposefully created within approximately the last 50 years and 11 were located within highly frequented near-shore dive areas (Figure 3.5).

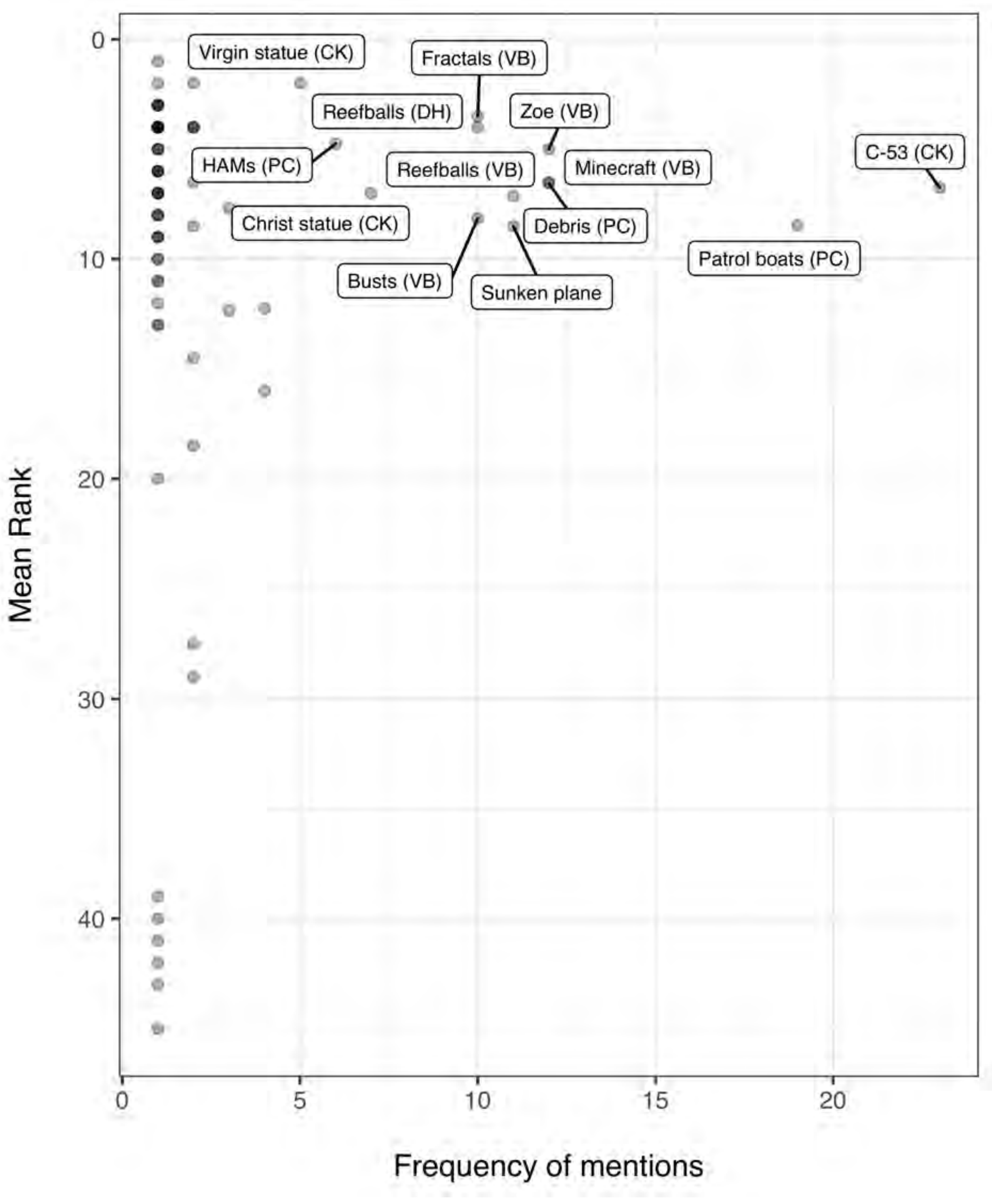


Figure 3.5 Average rank in list and frequency of mentions for distinct HMR sites in lists reported by participants. Sites are labelled if they were mentioned over five times. Of the top 13 sites, 12 were located in three highly-frequented coastal dive areas as denoted in brackets: Villablanca (VB), Chankanaab (CK), and Playa Casitas (PC). The wide range in frequency of mentions indicates a small number of sites (such as the C-53 wreck) are very well-known, while many others are only known by one person or few people.

3.3.2 *Conservation intention*

When asked to describe the origins of all the HMRs they were aware of, participants attributed some kind of conservation intention to approximately half (49%) of all observations (Table 3.2). Almost all observations of prefabricated modules, such as Reefballs and other coral restoration modules, were associated positively with conservation intention (100%), as well as traditional structures such as rock piles (75%) and artworks including artistic (74%) and religious (39%) sculptures. Sunken artefacts such as shipwrecks and Mayan artefacts were less often associated with conservation intention, with the exception of intentional shipwrecks (78%) and infrastructure was rarely associated with conservation intention (9%).

Participants often debated whether conservation intention was genuine, with one participant suggesting it was nothing but a "justification" (07-ENV) and others making normative judgments on the "right" types of conservation intention. For example, one participant described a situation in which they had requested the word "conservation" be removed from marketing materials since they believed habitat provision for marine life was not the main goal in creating the HMR. Though participants were only asked whether any conservation intention had been expressed – regardless of authenticity – in some cases participants refused to have it noted down as such because they did not believe the expressed intention to be genuine or in keeping with subsequent use. Sometimes participants would point to contradictory actions, for example saying "yes, but they never bothered themselves to anchor it" (4-TOU). On the other hand, one participant pointed out a case in which conservation intention had not been present during creation, "but it did work" (19-TOU).

Participants gave varied examples of what they believed qualified as "conservation intention" (Table 3.3), ranging from active attempts at coral restoration to sustainable fishing, the provision of substrate for colonisation by marine life, attempts to preserve an endangered species, choices made in the placement or fabrication of HMRs, and indirect benefits such as diverting tourism pressure from coral reefs. Notably, many of these attributions of conservation intention occurred in the context of other purposes such as tourism, fishing and aquaculture.

Table 3.3 Examples of conservation intention associated with HMR creation.

Conservation intention	**Associated activities**	**Example**
Provision of habitat for marine life	Tourism, Art, Aquaculture, Conservation, Scientific research	"It's meant to be helping biodiversity grow… I wanted very much to make a habitat that would be grown over with life, and serve the bigger picture of helping create a world for coral reefs to flourish" (24-ART)
Diversion of pressure from coral reefs	Tourism, Art, Management	"It can lessen the burden on the coral reefs, and give a very stressed reef a chance to recover if the reef is closed [to tourism] and the shipwreck is visited more often" (19-TOU)
Coral restoration	Tourism, Conservation, Scientific Research, Management	"We wanted to increase the production of corals, or the restoration of corals in the area that was devastated by the hurricane… the structures were designed for coral gardening" (22-SCI)
Environmental education	Tourism, Education, Art, Cultural activities, Conservation	"We have volunteers and people come to learn about corals and caring for it, so it's a vehicle for getting people involved and reef awareness" (24-ART)
Homage to important conservationists	Art, Cultural activities, Spiritual activities, Conservation	"To honour amazing ocean heroes, scuba heroes, divers... it's conservation awareness, honouring, but it's not to grow a habitat" (24-ART)
Use of materials that do not negatively impact marine life	Scientific research, Management, Conservation, Tourism	"We used materials that would not harm the reef" (35-ART)
Sustainable use	Fishing, Conservation	"It interests us to conserve within fishing because it is what we depend on for the future" (10-FIS)
Conserving endangered species	Aquaculture, Conservation	"Preserving the species of oyster. Our species was considered extinct in the Caribbean…in Mexico they thought it was extinct, so you can say we are doing conservation of the species. We are using them to produce pearls, and jewellery, and to do education" (22-SCI)
Selection of site without coral reefs nearby	Management	"Yes, because in that place there is no marine life, it's pure sand" (17-FIS)
Compliance with environmental regulations or conditions set out in project permits	Management, Scientific research	"The origin was the fulfilment of a federal environmental condition imposed on a private company so it could carry out its tourism development" (29-ENV)

3.3.3 Encountering HMRs

Interview participants described several ways of interacting with or encountering HMRs, with varying levels of intention and directness of experience (Table 3.4). The mode of encounter appeared to affect the amount and type of information they could provide, as it was often mentioned as a justification for knowledge or lack thereof. People would often organically describe the way they had encountered a structure when listing sites for the database, as a way of qualifying their responses, and seemed most confident providing information on a site when they had been involved in its creation.

When participants described haphazard encounters, they often seemed to consider the event special and gain a sense of ownership through discovery; as one participant said, "We were diving and we saw it, we discovered it" (28-FIS). Attempts at intentional encounters, such as searching for sunken ships known to be within a certain area, could involve hours or weeks of searching, and often end in disappointment. Many participants described guided encounters with HMRs, as either professional or personal exchanges of information. Professional versions included tour operation or participation in guiding archaeological investigations. It could also include belonging to a particular group such as a fishing cooperative, within which information was shared. Personal exchanges occurred as fun day trips with friends or even as a part of family legacy, with one participant saying "It was through family heritage, I was taken to see it by an uncle, the brother of my grandfather" (38-TOU).

People chose with whom to share information carefully; in describing the kind of people he was willing to take to an important HMR, one participant said, "it needs to be people who are very very, how can I explain this, very intimate. In that case then I'll show them, but I don't show it to any other diver" (33-TOU). A sense of pride seemed to be derived from having found or recognised structures that other people were not aware of. The same participant continued, "there are some relics that divers nowadays don't know how to pay attention to… they swim right over and don't know how to see them" (33-TOU).

Table 3.4 Direct and indirect modes of encounter with diverse HMRs.

	Mode of encounter	**Description**	**Example**
Direct	Creation	Participation in design, creation and/or submersion of HMR	"I designed it and constructed it" (07-ENV)
	Haphazard encounter	Unexpected discovery of an HMR	"I didn't know it was there until I came across it when I was snorkelling, by accident, I just saw it was there" (09-REC)
	Intentional encounter following search	Finding an HMR while conducting an intentional search	"I've participated in a lot of investigations, they always tell me what they're looking for" (33-TOU)
	Guided encounter	Being shown an HMR by a person who already knows of it	"I've found some through pure recreation with my friends, when we say, 'where shall we go' and someone else knows a place and they tell me about it and tell me where to go" (09-REC) "We showed them the places, and we watched them from the surface" (33-TOU)
Indirect	Narrative encounter	Knowledge acquired through story or documentation, but no personal embodied experience of the HMR	"I know they exist, but I haven't seen them other than in photos" (23-ENV)

3.3.4 Access to HMRs

Though participants often began saying "everyone" or "anyone" could access a given HMR, upon reflection many identified factors that could limit the number of people who could interact with or have knowledge of it. These barriers could be practical such as the ability to swim or scuba dive, access to equipment such as a GPS tracker, dive or snorkel gear or a boat, or experience with challenging weather conditions when "going to remote places" (19-TOU). Barriers related to equipment and transportation appeared most salient when sites were deeper or further from shore. In some cases, participants explained that common access points for HMRs (such as beaches) were restricted due to regulations or private property. Therefore, access could require payments for park permits or tours, or the consumption of food and beverages at a beach club. Even when these requirements were not mandatory, they could still be enacted through subtler social pressures – as one tour operator said, "we don't put restrictions but there will always be people who will be embarrassed even though they shouldn't be" (31-TOU). One participant said, "99% of the people there are tourists because locals feel uncomfortable walking through the beach club" (36-EDU) and another said, "it's a bit uncomfortable, you have to go and ask permission" (40-TOU). In reference to archaeological artefacts one participant brought up the ability to "know how to recognise it" (33-TOU) since objects can be overgrown or unrecognisable without archaeological knowledge. Another participant explained, "they have become part of the reefs, there are lots you wouldn't see if you didn't have an archaeologist's eye" (05-ARC). Knowledge of precise location was a key barrier to HMR access and was mentioned by several participants, particularly fishers, tour operators and archaeologists – either in terms of GPS coordinates or simple awareness of a site's existence. Some people considered themselves gatekeepers to structures; when asked who could access a given structure, one participant said "me, because I am the custodian" (05-ARC).

3.3.5 Sensitivity of HMR locations

Various participants discussed the value and sensitivity of location data in relation to HMRs, and many were reluctant to share precise location information including GPS points. One participant explained the importance of GPS in the following way: "I have my GPS [device] well hidden…The main thing about a GPS point is that if you have identified a place, you have the certainty that in any moment you can land again on that point. So the importance is getting the exact security of the point" (33-TOU). The same participant described a trip where the crew spent days combing back and forth over an area because they did not have a GPS point. GPS points were often acknowledged as valuable, and one tour operator joked, "You want the GPS points? It'll cost you a bundle of money" (19-TOU). Another tour operator explained his reputation lay in having spent his whole life in Cozumel, which meant he could take clients to "see sites that no one else is going to show them" (38-TOU). This value did not necessarily have to be monetary, but could be more related to a sense of personal meaning; as one participant said, "to me, it is very important. Since nobody else knows about it, it's even more special for me" (33-TOU).

Some participants described situations in which other people had found HMRs that were important to them and disrupted their patterns of use by removing, damaging or otherwise spoiling their use of them. As one fisher said, "sometimes people steal them, that's why people haven't wanted to make more" (18-FIS), describing situations in which lobster traps had been emptied or relocated by other fishers. He explained that he made one structure at a depth of 140 feet, "so deep that no one will get there" (18-FIS). Archaeologists described "a risk of looting" (05-ARC), and cited concerns about people extracting objects of historic and monetary value. One participant went as far as to say, "anything you put in the sea is a thing that will be stolen" (37-AQU).

The ramifications of losing access to HMRs could be significant, with emotional and cultural value appearing to exceed monetary value. Monetary value was often placed in contrast to cultural value, with another participant warning that it was important not to share information "because someone could have a monetary intention" (33-TOU). One participant described the experience by saying: "Some person, I don't know who, went in and removed the anchors… And of course they got their wad of money but it was a robbery, from us and from the nation, because we liked going to see it, taking our families and showing them what we had. We went back to look for it, but it's not there anymore" (28-FIS). Even in cases where a disruption had not yet occurred, people were wary of the possibility when it came to sites they cared about. One participant said, "Sometimes we go [diving] with a whole group and I'll hover on top of it so no one can see it… one person with a bad intention, and then I'll go back and it'll be gone" (33-TOU).

3.3.6 Stakeholder differences in HMR awareness

Knowledge of sites appeared to vary by the respondents' primary activity relating to HMRs (Figures 3.6, 3.7 & 3.8) despite respondents often taking part in multiple activities. Knowledge of HMRs was occasionally limited to relevant stakeholders or even specific individuals within stakeholder groups. For example, some fishers identified the locations of lobster traps around the island while another fisher insisted multiple times that lobster traps are not used in Cozumel when directly asked; whether this is because of a lack of knowledge or unwillingness to reveal knowledge is unclear.

In mapping the locations of HMR sites identified by participants, spatially distinct areas emerged according to primary activity (Figure 3.6). People who engaged in fishing and archaeology as a primary activity displayed knowledge over the largest geographic areas. The area covered by people engaging primarily in conservation was limited to the vicinity of the main town.

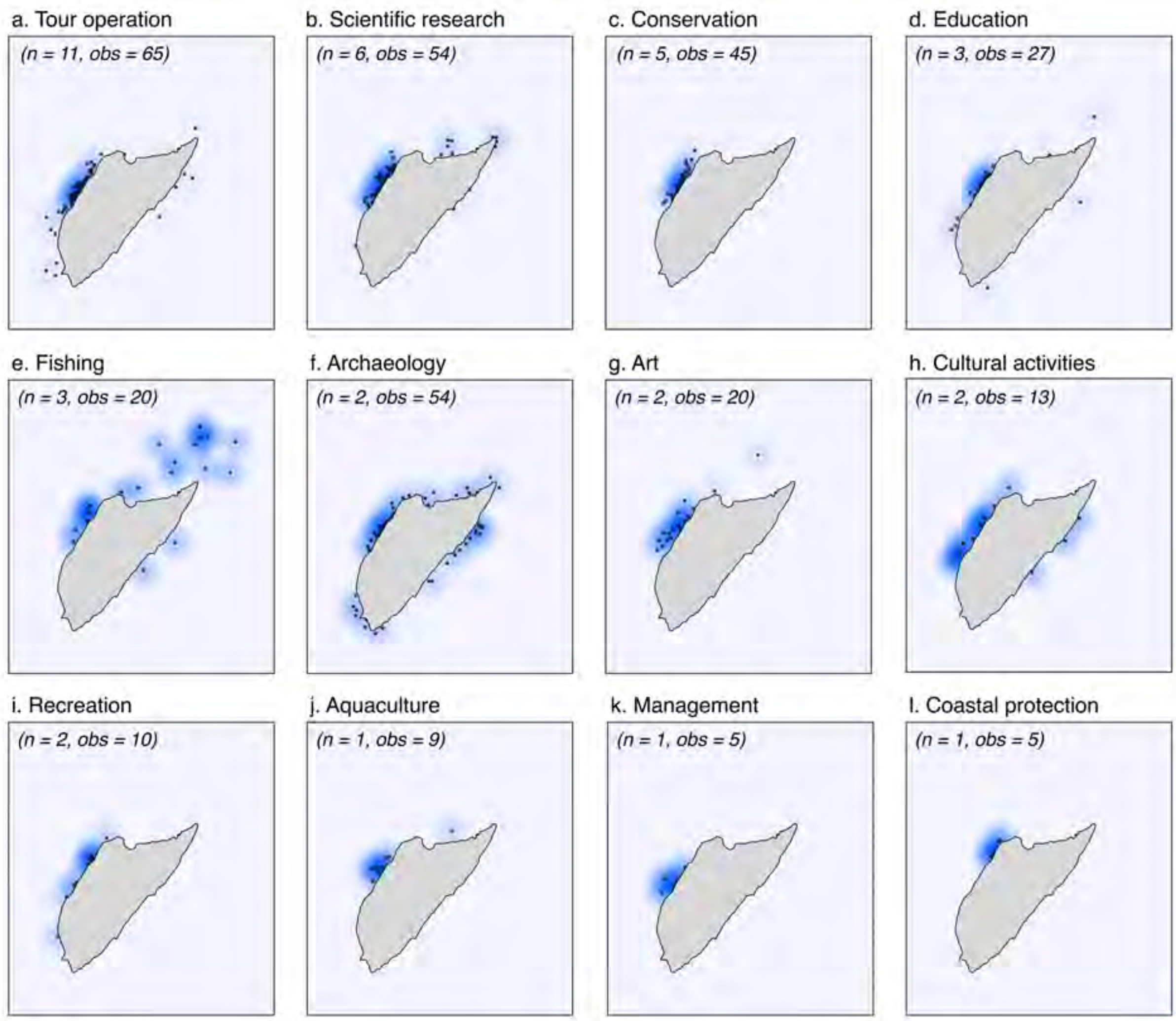


Figure 3.6 Mapped distribution of observations for HMR sites in Cozumel, with observations broken down by interview participants' self-determined "primary activity" (a-l). Points indicate individual observations and heat maps indicate density of observations. Numbers in brackets are the number of individuals in the category (n=) and the number of observations (obs=). Most observations are concentrated on the western side of the island, with fishing (e) observations ranging furthest and archaeology (f) showing greatest coverage around the island. Conservation (c), management (k) and coastal protection (l) show the most limited geographic range.

A salience analysis of HMR subtypes indicated that people involved in different primary activities were aware of and prioritised different types of HMRs (Figure 3.7). These associations aligned logically with the nature of each activity. For example, art was associated with a high salience of artistic sculptures, aquaculture with oyster boxes, tourism and recreation with intentional shipwrecks, conservation and management with coral restoration modules, cultural activities with religious sculptures, fishing with lobster traps, and fishing and archaeology with accidental shipwrecks.

In addition to spatial and typological variations in knowledge of HMRs, people engaging in different primary activities appeared to have different perceptions of the history and longevity of HMRs in Cozumel (Figure 3.8). Archaeologists indicated a longer timeframe for the presence of HMRs in Cozumel, with their estimations of the age of HMR sites being higher than average and indicating that the earliest sites being created over a thousand years ago. On the other hand, conservationists tended to estimate HMRs had been created in the last 50 years (Figure 3.8). This occurred despite all participants twice being given a definition of HMRs which included accidental shipwrecks.

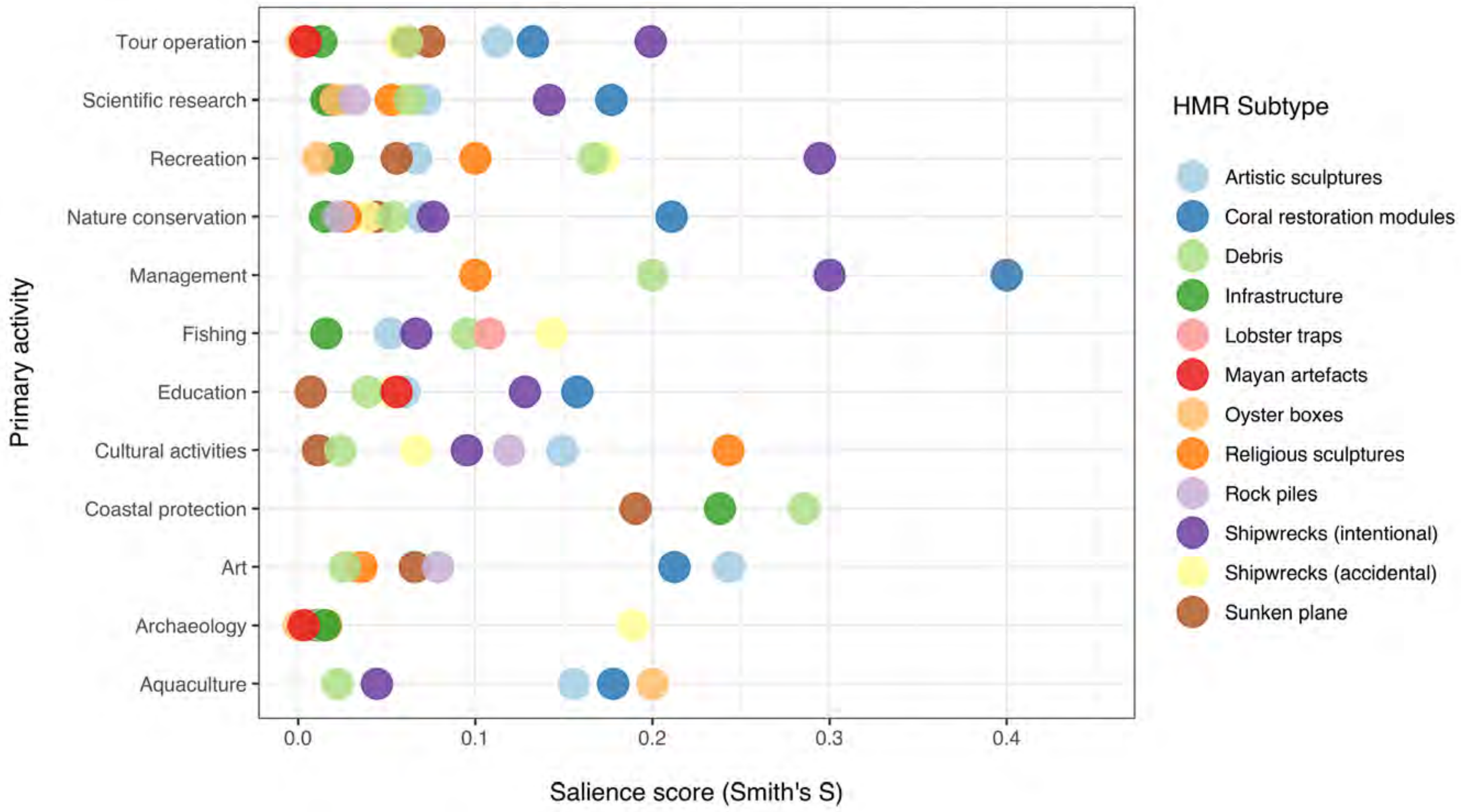


Figure 3.7 Salience analysis of HMR subtypes reported by interview participants, organised by participants' self-determined "primary activity" in relation to HMRs. The most salient HMR subtypes often aligned closely with the primary activity, for example with coral restoration modules being most salient for stakeholders primarily engaging in conservation, management and research; accidental shipwrecks for archaeology and fishing; artistic sculptures for art; oyster boxes for aquaculture; lobster traps for fishing; religious sculptures for cultural activities; and intentional shipwrecks (often intended as dive sites) for tourism and recreation. This analysis indicates people carrying out different activities have different awareness of HMR subtypes, with different HMR subtypes being more closely associated with some activities than others.

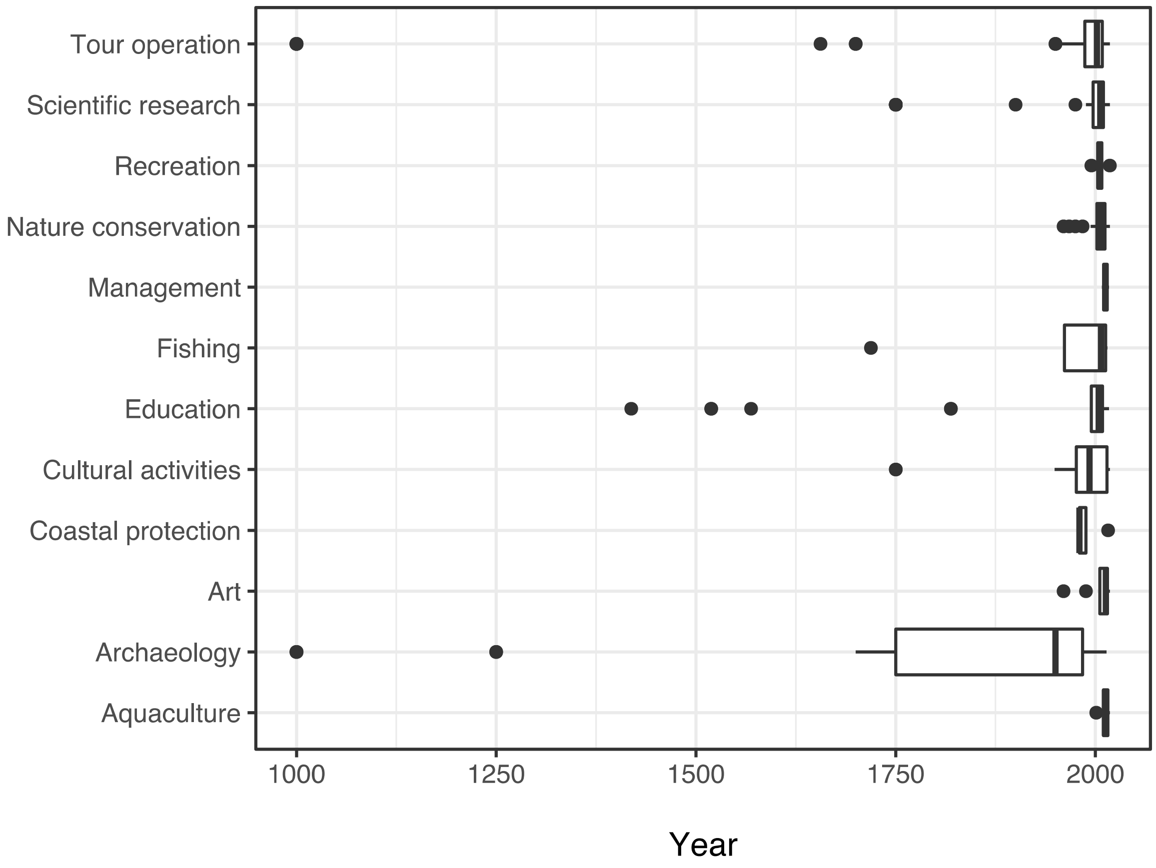


Figure 3.8 Year of creation estimated for HMR sites identified by participants with varying "primary activities", indicating differences in the ages of HMRs stakeholders are aware of. In general, sites identified by archaeologists appeared to span the greatest range of ages, stretching back over a thousand years. HMRs identified by people primarily taking part in conservation, recreation, management, art and aquaculture spanned a shorter period in the late 20th and early 21st century.

3.3.7 HMR characteristics

Participants exhibited variation in their description of the basic characteristics of particular HMR sites, including year of creation (Figure 3.9), depth (Figure 3.10) and location (Figure 3.11). Sites that were older or deeper tended to show greater variation in descriptions. In the case of age, this was probably influenced by the fact that the two oldest structures (statues of Christ and the Virgin Mary) had been re-submerged multiple times due to damage, relocation and theft. Depth was often overestimated, with people assuming that structures were deeper than they were. Variability increased markedly when depth exceeded 10 metres. This is likely to be because it is harder to access or estimate depth accurately for deeper HMRs.

Participants were often reluctant to pinpoint a year of creation, saying they were not sure or asking whether they could look it up or check with another person. In the context of this study this was discouraged and participants were asked to give their best guess. When making these estimates, participants often made reference to a historic event they associated with the HMR, such as hurricane Wilma or hurricane Gilberto, or pointed to important milestones in their own life. For example, one participant said, "Well look, I've been on the island for 42 years, and that piece has been there for about 30 years" (40-TOU). In the case of more recent structures, they often initially used loose terms such as "a few years ago" and later settled on a specific year.

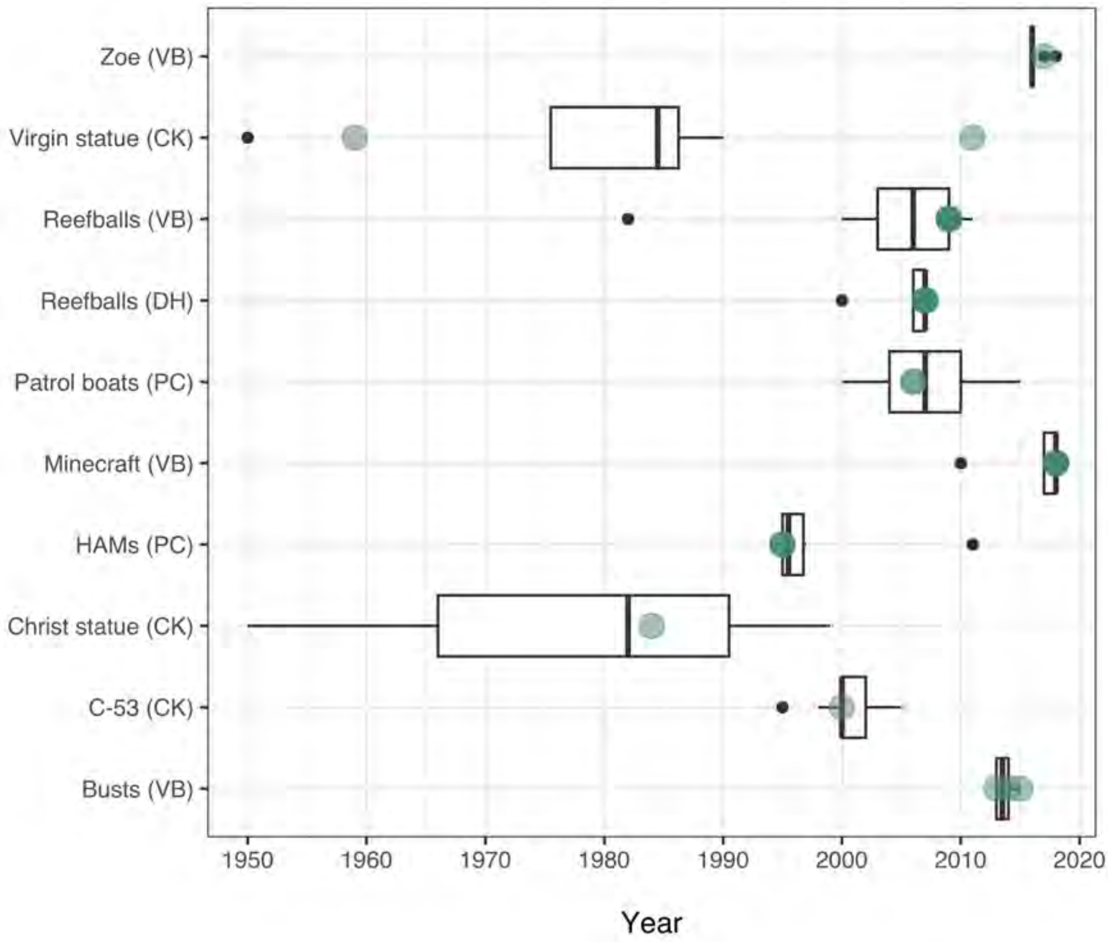


Figure 3.9 Boxplots indicate range of estimates for "year of creation" for HMR sites identified by 5 or more participants. Overlaid points indicate verified data for year of creation, obtained by searching local news sites and local history books. Multiple points indicate either multiple points of submersion (for example, the statue of the Virgin was stolen in 2011 and subsequently replaced) or multiple units within the identified site (for example, three busts – one of Jacques Cousteau, one of Ramon Bravo, and one of Sylvia Earle – were submerged in sequential years). Variation is greater for older structures which have multiple submersion points, including the statue of the Christ which we were unable to verify a precise year of re-submersion for, though written sources confirm this occurred post-1988. after Hurricane Gilberto.

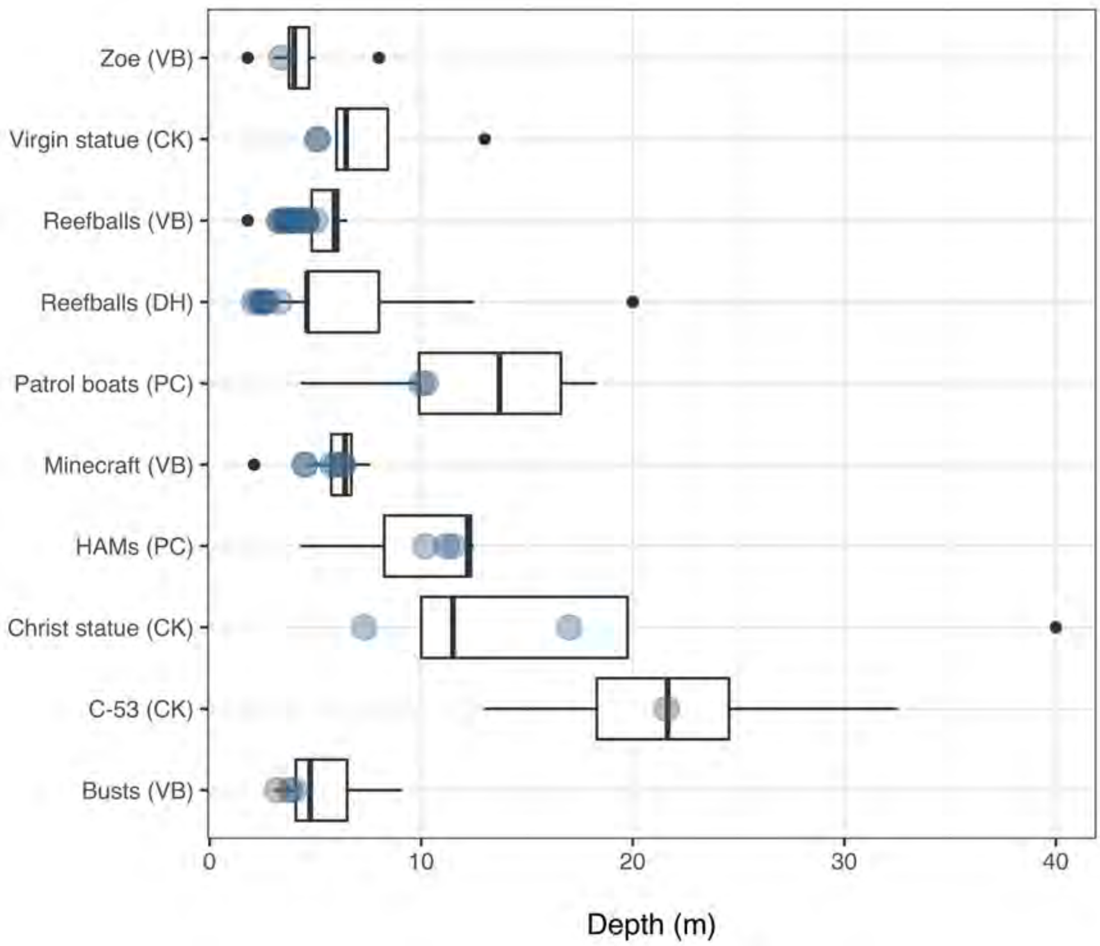


Figure 3.10 Boxplots indicate range of estimates for depth for HMR sites identified by 5 or more participants. Overlaid points indicate verified depth data obtained during scuba diving trips. Multiple points indicate either multiple units within the same site (for example, depth data was obtained for two patrol boats and three bust sculptures) or multiple points of submersion (as with the Christ statue, which was first placed on Palancar reef at a depth of 17 metres, as described in a historical news report, and subsequently relocated to Chankanaab marine park, where it currently rests at a depth of 7.3 metres. Variability appears to increase with depth, and depth was almost always overestimated.

People often seemed most confident providing information on a site when they had been involved in its creation, particularly with characteristics such as year of creation and reasons for creation. In these cases, participants seemed eager to share their wealth of information, giving very precise numbers or descriptions of the methods by which the HMR was created, and going far beyond the scope of specific interview questions. On the other hand, when a participant identified that they only had indirect knowledge of a site, they were less likely to give estimates for various characteristics, instead indicating they did not want to answer.

The "ground-truthing" of a small number of sites (Figure 3.11) revealed that location estimates using this method could vary widely for a single site. Even the smallest polygon containing all estimated points (Reefballs at Villablanca, Figure 3.11b) covered an area of over 6,000 km^2, and the largest (C53 wreck, Figure 3.11a) covered about 30,000 km^2. In the case of a statue of Jesus Christ, triangulating information from interviews with different participants revealed a partial explanation for the variation in estimates; the statue was originally located further south and was relocated after toppling in a storm, leaving behind the statue's anchored base.

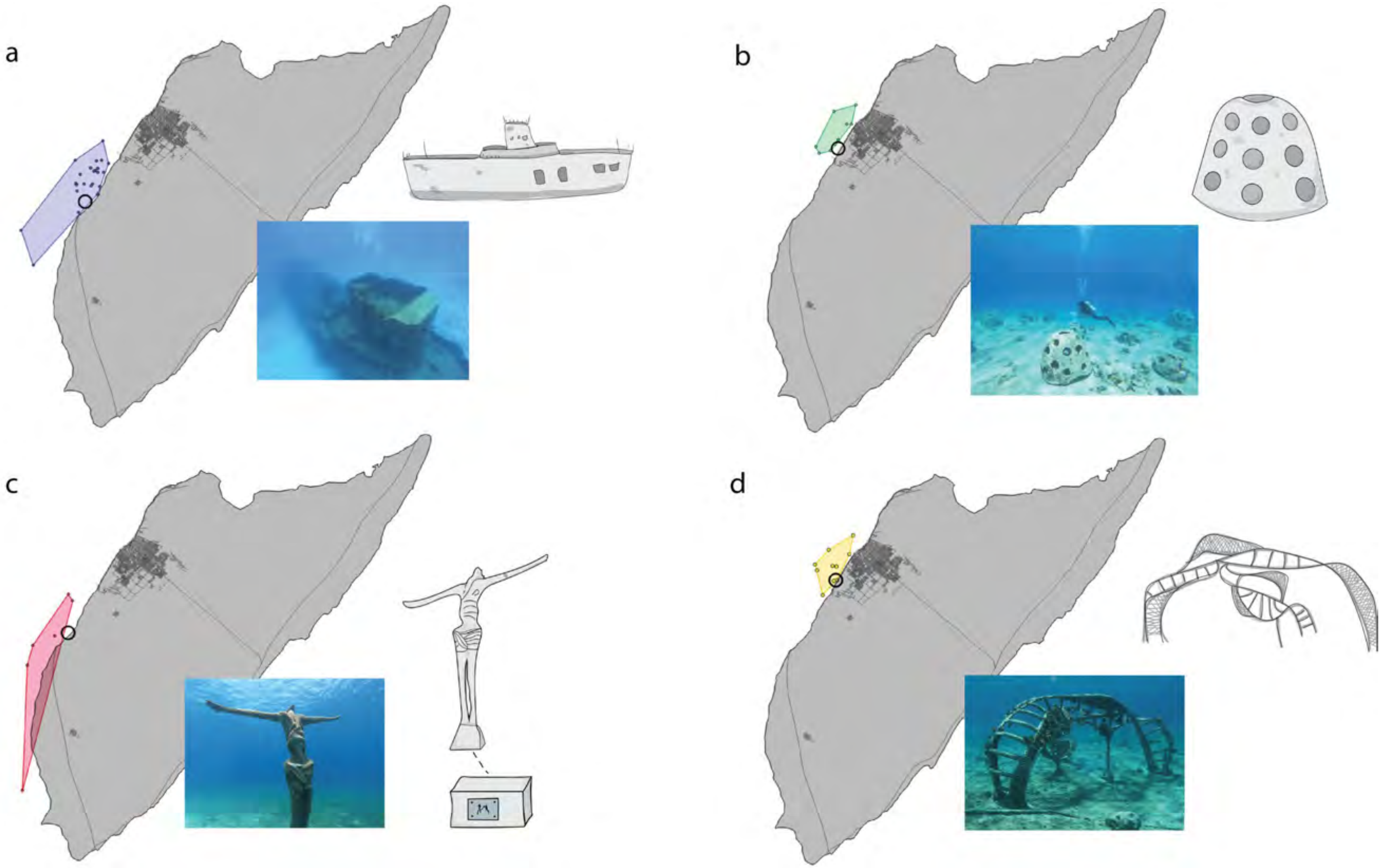


Figure 3.11 Estimated and "ground-truthed" locations of four unique HMR sites: a) C-53 shipwreck (CK); b) Reef Balls (VB); c) Christ statue (CK); d) Zoe sculpture (VB). Small coloured dots indicate estimated locations for a given site based on respondents' maps, and larger rings indicate the "ground-truthed" location points. Coloured polygons indicate the area contained within all hand-drawn estimates.

3.3.8 Local history of HMRs

The majority of respondents (43%) believed that HMRs first began to be created in Cozumel in the 20th century, usually post-1980 (Figure 3.12a and 3.12b). In this case people often made reference to particular HMRs; for example, one participant estimated the initial date of creation to be 1988 and said, "The first structure that was submerged was the Christ, and it is 31 years old" (11-TOU).

Estimates were also often deduced through logical association with known historical events such as hurricanes or the Spanish conquest. Participants were often reluctant to provide a specific year, preferring to give rough estimates such as "more than 10 years ago" (16-MGT), "at least 30 years ago" (23-ENV) or "in the 1980s" (14-TOU) unless they could clearly associate a year with the creation of a known HMR or historical event. People sometimes stressed the distinction between accidental and intentional structures, with one participant specifying "voluntarily, in 1988" but settling on the year 1500 as a final answer due to unintentional shipwrecks (19-TOU). One participant seemed to value personal knowledge very highly, refusing to consider some older structures in their estimate because "it was already sunk" when they came to know it (28-FIS).

Almost a quarter of respondents (23%) believed the creation of HMRs began in the 21st century, with most estimates in 2000-2010 (Figure 3.12a and 3.12b). When describing this period, participants often made reference to the occurrence of Hurricane Wilma, a category 5 hurricane which hit the island in 2005, causing significant economic and ecological damage. Two common explanations emerged for hurricane Wilma's role in catalysing the creation of HMRs in Cozumel. The first was that HMRs were an attempt to salvage marine tourism following the hurricane's negative impacts on shallow-water corals. As an example, one participant said, "In 2005 there was a very strong hurricane, Wilma, and I think people went into panic a bit… people started thinking, we are going to lose a place where people can see the corals… so they brought the first artificial structures, Reef Balls, which they put in various places on the island" (06-SCI). The second explanation related to the unintentional sinking of debris due to destruction during the storm, with one participant commenting, "Wilma was the great sinker of structures, because… no one was forced to remove their trash [from the sea]" (36-EDU).

Respondents who believed HMRs were present in Cozumel before the 20th century (23%) tended to associate their initial creation with one of two events; the pre-Hispanic arrival of Mayans to

Cozumel, around or before the year 1000AD, or the arrival of Spanish conquerors in Cozumel around the year 1500 AC (Figure 3.12a). One participant said HMRs had existed "from the moment the Mayans inhabited the island" (38-TOU) and another said "since the era of the [Spanish] galleons, there's a lot of history there, from the sixteenth century" (19-TOU). Another simply deduced the first creators of HMRs had been "whoever first landed there" (24-ART). Other participants made reference to wider historical and cultural narratives, for example mentioning Hernán Cortés's arrival on the island (20-CUL) or stating "Cozumel has always been a place of navigation, it was the spine of commerce with Central America" (05-ARC).

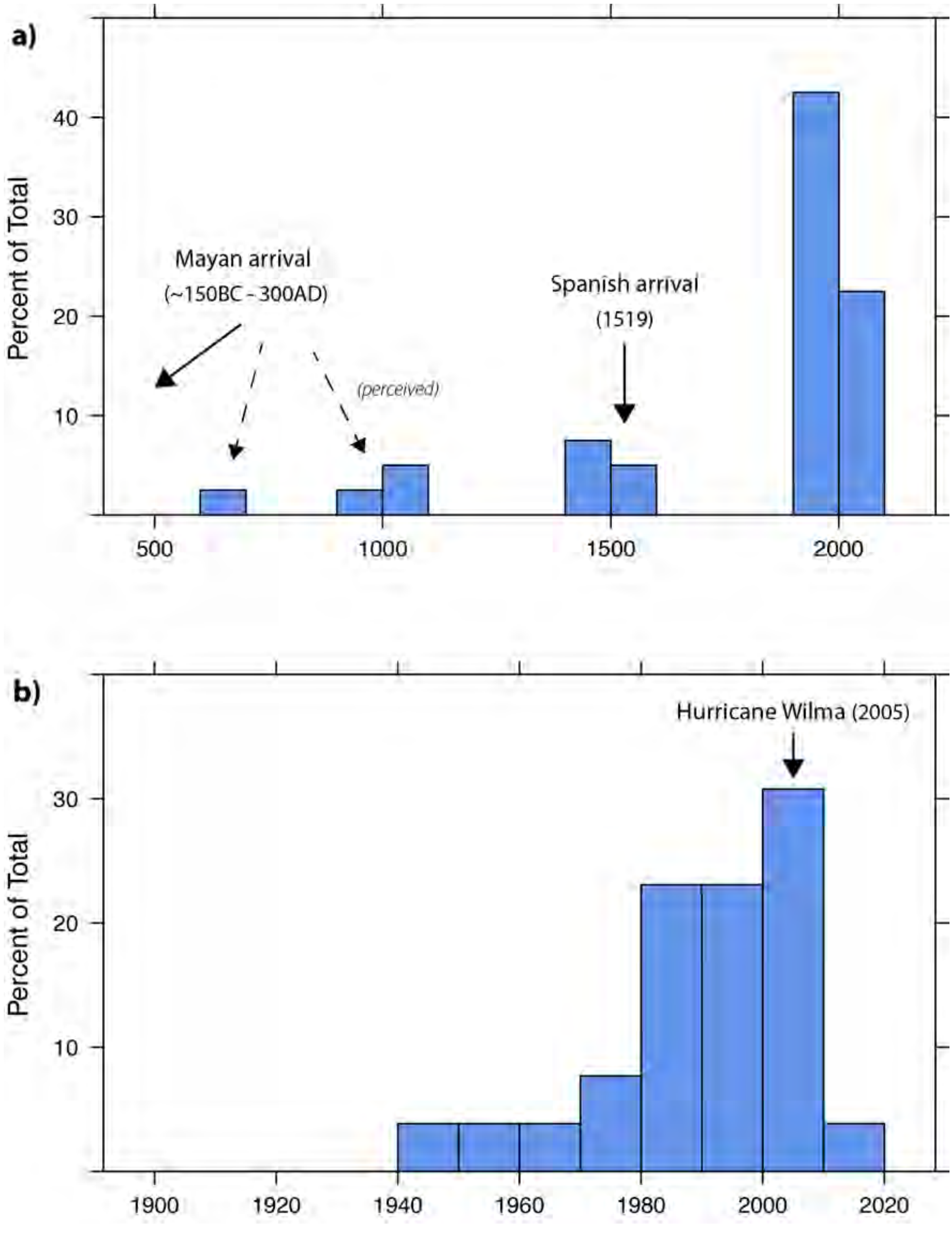


Figure 3.12 Year that HMRs were first created in Cozumel as estimated by 40 interview participants (a. absolute, divided by century, and b. since 1900, divided by decade). Almost 40% of respondents believed that HMRs began to be created in the 1900s, and over 20% believed HMRs began to be created after the year 2000 or prior to the year 1900. Peaks appear around what people described as their estimated arrival of the Mayans (though archaeologists estimate it to be earlier, between 150BC and 300AD) and around the time of the Spanish conquest in 1519, as well as around Hurricane Wilma in 2005.

3.3.9 Trends in HMR creation

The great majority of participants (83%) believed the rate of creation of HMRs had changed since they first began to be created in Cozumel, with almost all of these respondents (96%) believing more HMRs were being created and 4% believing fewer HMRs were being created in recent times. Perceptions of the rate of increase varied, with one participant describing it as "exponential" (04-TOU) and another saying it had increased "lightly" (23-ENV). One participant identified 2012 as the point of "maximum construction" (05-ARC).

In considering their knowledge of HMR growth, some participants described the mechanisms by which they receive relevant information; for example, one participant said "sometimes when they are going to sink things they publish it, and say what they are going to sink and where, but lately I haven't heard of anything" (28-FIS). In keeping with this, other participants declined to estimate the rate of HMR creation during decades they had not lived in Cozumel or before they were born.

When questioned over the relative quantity of HMRs created since 1950, there was a steady increase between 1970 and 2010 in the number of respondents who believed "many" HMRs had been created in a given decade (Figure 3.13). There was also a steady decrease in the number of respondents who answered "Don't know" between 1950 and 2010, potentially indicating their greater familiarity with current times.

In considering trends in local HMR creation, participants suggested that the reasons for creation had shifted toward conservation and tourism. Three participants believed conservation had become a dominant reason for the creation of HMRs, with one saying, "now, they are more oriented toward conservation" (31-TOU), another saying "they have the goal of restoration" (06-SCI) and another saying, "they are being put in place more for objectives of restoration" (02-MGT). One participant noted an overall broadening of rationales for HMR creation, saying justifications had "gone from purely utilitarian to weird reasons, like to promote the legacy of Jacques Cousteau… a lot of things strictly to attract tourism now" (30-ARC). Increased use for tourism was a common refrain, either in terms of building HMRs that would be attractive to tourists such as artistic sculptures, or infrastructure such as docks and dolphin pens to facilitate these experiences.

One participant noted an increase in regulations, saying “every day there are more and more restrictions. It used to be that you could throw things in and there wasn’t anyone to tell you not to” (10-FIS). Another said, “When I was young I worked in a dive shop, in 1960… at that time there weren’t any structures made on purpose… but with time they went depositing structures for people who did recreation” (20-CUL). Another participant suggested changes in HMR types reflected changes in society, saying “they just keep evolving to meet standards of culture” (24-ART).

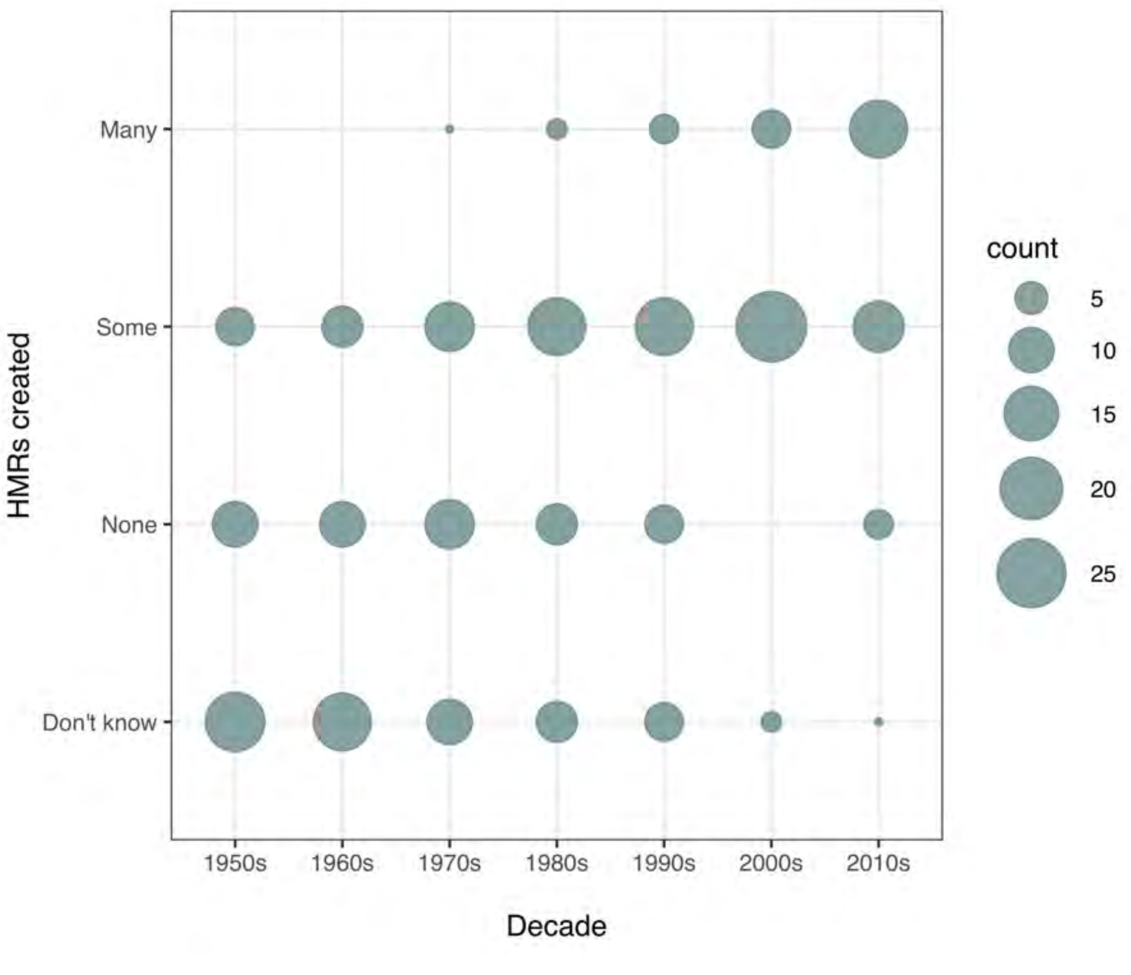


Figure 3.13 Relative estimation of quantity of HMRs created per decade. Confidence in knowledge of HMRs appears to go up with time (as “Don’t know” category decreases) and perceived quantity of HMRs being built appears to increase, with “Many” category peaking in 2010s. All participants who considered themselves to know how whether HMRs had been built in the 2000s appeared to believe that at least one HMR had been built in this period as not a single participant responded “None”.

Participants also noted changes in the materials, techniques and shapes used, with an overall theme of innovation and learning from past mistakes. One participant said, "now we use innovative structures" (08-EDU) and another noted "a bit of evolution in materials in techniques" (22-SCI), while another focused more specifically on "materials appropriate for corals" (27-TOU). Five participants referencing a shift away from concrete, five mentioning increased use of Biorock technology, and one mentioning fibreglass. However, one participant disagreed and said "they are always made with the same materials" (40-TOU). In terms of HMR shapes, participants indicated a greater range of artistic forms, since "they are more creative designs" (29-ENV). One participant suggested a shift away from the replication of natural habitats to create structures that were more recognisably of human origin, saying "it used to be about trying to replicate the coral reef, now they put geometric figures, archaeological replicas, different characters" (16-MGT).

Participants appeared divided over whether appropriate care and planning was going into HMR creation. Some seemed to believe planning and intentionality had increased, with one participant saying "they are made more thoughtfully" (06-SCI) and another said "now, they are created to be sunk, they are fabricated with that purpose" (35-ART). However, this contrasted with a common theme in wider interviews, criticising the practice of "hundir por hundir" ("sinking to sink") or the thoughtless and unguided creation of HMRs.

Finally, various participants noted changes to the structures themselves – either destruction or disintegration over time, or the accumulation of marine life leading to integration with surrounding habitat. In some cases, destruction by hurricanes appeared to be seen as a relatively neutral consequence of the passage of time, with one participant saying "The plane is in pieces now, parts have flown away in the hurricanes" (19-TOU), though it could also be perceived as a negative process leading to structures being "deformed" (05-ARC). Disintegration without hurricanes seemed to be used as evidence of errors in the selection or manufacturing of HMRs, for example when structures were "tending to crumble under their own weight" (32-TOU). The accumulation of life was also seen as a significant change, with six participants describing the aggregation of fish and corals, saying, "at first there was no marine life, but now it has adapted" (39-TOU).

3.4 Discussion

Despite the high and increasing relevance of HMRs to marine conservation, information on their existence, uses and impacts is still limited. The elicitation of local knowledge about HMRs on the case study island of Cozumel has provided new information on known HMR sites as well as an opportunity to assess perceptions of history, knowledge and conservation intention held by diverse stakeholders. It also provides insights into the feasibility, ethics and value of creating databases of HMR locations.

3.4.1 Use of local ecological knowledge

The elicitation of local knowledge often results in the expansion of scientific knowledge, as in the case of Robert Johannes's work with local fishers in Palau who identified twice as many reef fish as were known by scientists at the time (Ruddle 2008). This was also true for this study: The overall number of sites identified by participants was much higher than expected by the researchers and by research participants themselves (Figure 3.3). The fact that even people who had been identified as likely to be knowledgeable about HMRs by other well-informed individuals believed there were no or very few HMRs in Cozumel is striking. It indicates large numbers of HMRs can be present without much awareness, reflecting the limited knowledge held by any one individual and limits to the flow of information. It also aligns with a larger global trend revealing swathes of unacknowledged modification in seascapes (Bugnot et al. 2020). The perceived ramp-up in HMR creation (Figure 3.13) aligns with increases in scientific interest and available data on HMR proliferation worldwide (Chapter 2; Lima et al. 2019; Bugnot et al. 2020). HMR creation often goes undocumented and they can be difficult to detect underwater (Baeye *et al.* 2016).

The very high salience of a few of the sites, as opposed to many which were identified only by one person, indicates great variation in how well-known sites can be (Figure 3.5). This is informed by their origins, accessibility and uses, with all the best-known sites being purposefully made in near-shore areas close to town or beach clubs, and frequented by tourism operations. The accessibility component reflects the findings of (Jobstvogt *et al.* 2014) who found divers and fishers valued fishing and dive sites accessible by shore and boat. The popularity of shipwrecks, particularly the large C53 wreck which was sunk in a ceremony noted by national newspapers, aligns with previous work indicating that divers have an affinity for a mix of history and marine life (Stolk *et al.* 2007; Kirkbride-Smith *et al.* 2013). It makes sense that HMRs created for personal use and benefit, such as lobster traps, should not be widely known. The mode of encounter (Table 3.4) is pivotal to understanding knowledge and distribution of HMRs; in particular, the trust and sensitivity contained within guided encounters seems key. Given that individuals are unlikely to stumble upon HMRs outside of highly-frequented areas, and that several participants were concerned about the "wrong" people finding highly-valued HMRs, information may be contained to small networks.

The methodology of this study did not allow for accurate pinpointing of locations of most sites using GPS points, given concerns around data sensitivity. However, in those that did undergo a ground-truthing process, estimated locations covered large areas (Figure 3.11). To some extent, this reflects inaccuracies in the hand-drawn method but it is also likely to express variations in understanding of locations. These variations may not be wholly inaccurate, but could be based on outdated or misunderstood second-hand information. As with the Jesus Christ statue which was moved, it will often be necessary to speak to multiple stakeholders and gather "puzzle pieces" to understand variations in the data and compile a full narrative. More extensive ground-truthing would have to occur in collaboration with local stakeholders, due to the near-impossibility of locating subtidal HMRs without first-hand knowledge of GPS coordinates. Various participants did offer to take me to visit the sites they had marked on the map. Given the expense associated with other technologies such as side scan sonar (Teixeira *et al.* 2013) and remote sensing, which can be up to five times more expensive than elicitation of local knowledge (Selgrath *et al.* 2016), the process of mapping used in this study can provide a way to gather preliminary information on existing HMR sites, while also building links and trust with local stakeholders to facilitate future research and database creation.

3.4.2 Feasibility of multi-stakeholder databases

The enormous sensitivity of location information demonstrated in this study raises significant ethical questions in the collection and sharing of data around HMR locations. This is not entirely surprising as elements of this pattern had been identified before, both during the scoping trip and in the academic literature. Frank et al. (2015) identified zoologists and archaeologists as groups who are particularly sensitive about location data of known underwater sites, given concerns about exploitation of endangered species and looting. Grant & Berkes (2007) similarly noted that fishers make efforts to keep the location of their fishing grounds secret, as other fishers will note particularly good catches and use GPS points to shape current and future fishing practices.

This sensitivity poses clear barriers to the creation and use of an open database. In order to facilitate community documentation of HMRs, clear data access rules need to be created when information is provided by individuals rather than being collected from published sources. The modes of encounter detailed in this study (Table 3.4) enabled us to begin to explore some of the methods by which information on HMRs is currently shared; guided encounters in particular tend to require trust as people are wary of damage or exploitation by others. Though people cannot legally keep other people from accessing an HMR, I did note efforts to enact control through guarding knowledge of locations and leaning on barriers to access, which may be physical, equipment-driven or social. In addition to contributing to economic livelihoods, such as tourism and fishing, HMR sites can clearly hold great personal meaning for individuals. The intricate social dynamics around HMR sites require further investigation, as the process of mapping can shift sensitive dynamics of power and access (Brosius 2006).

As Harley (1989) wrote in relation to maps more generally, "to catalogue the world is to appropriate it" and some individuals clearly do not want these sites appropriated or used by other stakeholders (p. 13). However, in some cases, the creation and use of maps documenting diverse HMRs could serve as a tool to facilitate "sufficiently shared expectations for behaviour" in discussions around marine management (Thompson 2007 p. 212). The question of ownership in regard to HMRs is a complex subject which requires further investigation, not only in terms of legal designations but in terms of practical use.

3.4.3 Multi-stakeholder characterisation of HMRs & conservation potential

Gee (2019) asks, "What are we actually able to locate and own in the sea?" (p. 26). The answer appears to vary with experience, with variations in the types (Figure 3.7), locations (Figure 3.6) and perceived history (Figure 3.8) of HMRs identified across stakeholder groups. This indicates that participants engaging in different activities may inhabit different 'worlds' with boundaries maintained by knowledge of HMR locations. However, the variation in sample sizes across groups, with some including only one person, precludes robust comparison across groups and suggests the need for further investigation.

The large geographic spread of HMR sites identified by fishers as opposed to any other group (Figure 3.6) reflects the extensive nature of their knowledge of marine environments, as documented in other studies (Johannes *et al.* 2000; Lauer and Aswani 2008; Teixeira *et al.* 2013). Whereas fishers are often consulted as local knowledge experts in conservation projects, and collaborations with tour operators have occurred as well (Loerzel *et al.* 2017), some of the other stakeholders I interviewed are less often included in studies to access local knowledge, such as archaeologists, artists and historians who participate in "cultural activities" (Figure 3.6). These stakeholders often provided valuable and unique observations that had been gained in the context of their own knowledge systems and experiences (Rathwell *et al.* 2015). For example, archaeologists demonstrated widespread spatial knowledge of HMR sites, and had strikingly different perceptions of the history of HMRs, identifying much older sites than other participants. Given that conservation was the activity associated with the smallest geographic area of knowledge, these results show how crucial it is for conservationists to collaborate with other stakeholders in the identification and management of HMRs. It may also indicate that some activities involve different modes of encounter, with searching encounters being more common in archaeology and creation and haphazard encounters being better known in fishing. Differences in salience across activities (Figure 3.7) again reinforce the idea that perceptions of ecological space differ according to people's activities and forms of knowledge (Rathwell *et al.* 2015), serving as another indication that conservationists need to expand beyond the structures they are aware of in order to understand the full extent of HMR presence in an area.

The increased association of conservation with HMR creation over time is important to note, as conservationists may increasingly be perceived as responsible for the outcomes of HMRs. The association of conservation intention with almost half of identified structures indicates that participants have a strong sense of conservation being related to HMR presence, even if individuals attributed this intention differently (Table 3.2, Table 3.3). Additionally, the variety of conservation intentions expressed by different stakeholders may indicate the possibility for broader collaboration in the management or monitoring of HMRs for conservation benefit (Table 3.3).

There is much left to uncover about HMRs and their locations, characteristics, history and cultural meaning, and these are likely to vary across cultures and local contexts. As this process proceeds, it will be crucial to consider the most effective ways to harness local knowledge and deal with the sensitivity of location data. Local knowledge can provide information on HMRs which is either impossible or prohibitively expensive to gather in other ways, though it contains particular biases. It is clear that marine conservationists must widen their understanding of how long these sites have existed, the varied groups of people who make and care about them, and what conservation can mean for these places and for different people. HMRs play a growing role in the social and ecological dynamics of modern marine environments, and their future must be shaped in association with diverse stakeholders and with the people who have a personal stake in a shared ocean.

Chapter 4

Social and cultural assessment of novel marine ecosystems: a case study of human-made reefs in Cozumel, Mexico

Fish including sergeant majors (Abudefduf saxatilis) and brassy chubs (Kyphosus vaigiensis) swim around a sculpture of the Virgin Mary. Photo: SCT, Cozumel 2019.

4 Social and cultural assessment of novel marine ecosystems: a case study of human-made reefs in Cozumel, Mexico

"The sea alone
with its multiplicity
holds any hope."

- *William Carlos Williams (Asphodel, That Greeny Flower)*

4.1 Introduction

Marine and coastal environments have long held deep cultural and personal meaning, and are increasingly being modified by human activities such as fishing, climate change and construction (Kellert 2005; Jones *et al.* 2018). As levels of human influence and interaction rise in marine spaces, social and cultural assessment will be crucial to understanding the motivations, activities, values and attitudes that surround and drive change (Sloan 2002; Liquete *et al.* 2013; McKinley *et al.* 2019).

The measurement and valuation of ecosystem services, or the "benefits people obtain from ecosystems", has informed conservation policy and decision-making for decades (Costanza *et al.* 1997; Millennium Ecosystem Assessment 2005; Chan *et al.* 2012). The categorisation of services as provisioning, regulating, supporting or cultural is intended to capture the wide range of benefits provided by nature; however, material benefits relating to natural resources have been explored in more detail as they can be easier to measure than immaterial cultural ones (Satz *et al.* 2013). A review by Liquete *et al.* (2013) found cultural ecosystem services to be particularly underrepresented in the marine context. The potential commodification of nature and one-directional flow of benefits implied in ecosystem services has been questioned, leading to alternative conceptualisations such as "services to ecosystems" and "nature's contributions to people" (Comberti *et al.* 2015; Pascual *et al.* 2017).

The conception of human-influenced or -created spaces as novel ecosystems – defined by Hobbs *et al.* (2013) as "a system of abiotic, biotic and social components that, by virtue of human influence, differ from those that prevailed historically" (p. 58) – has birthed debates around appropriate conservation management on land and in the sea (Chapin and Starfield 1997;

Schläppy and Hobbs 2019). Once human influence is acknowledged, questions of accountability and desirability arise; in other words, "the point at which human impact becomes unacceptable" (Sloan 2002 p. 300). Understanding the social components of novel ecosystems, including the values and attitudes that shape norms, is key to local conservation management (Backstrom *et al.* 2018). Defining the role novel ecosystems can play within conservation requires a greater understanding of their contributions, including the ways they may restore, introduce or increase the provision of cultural, provisioning and regulating ecosystem services (Collier 2014; Evers *et al.* 2018; Woodhead *et al.* 2019).

In marine conservation, social and cultural assessment is considered increasingly important (Brooks *et al.* 2020) with applications to marine protected area designation (Jobstvogt *et al.* 2014), marine spatial planning (Gee *et al.* 2017), fisheries management (Liu *et al.* 2019) mangrove conservation (Reyes-Arroyo *et al.* 2021) and coral restoration (Hein *et al.* 2019). Socio-cultural assessment is a comprehensive term, which can include analysis of attitudes and perceptions, social values, and activities, as well as overlapping with concepts such as cultural heritage and the provision of ecosystem services (McKinley *et al.* 2019). By incorporating qualitative social and cultural values that monetary valuation omits, it can allow for a more holistic understanding of people's relationships with ecosystems (Pascual *et al.* 2017) and draw out the immaterial benefits of a wide variety of ecosystem services, not only cultural ones (Scholte *et al.* 2015). This can aid conservation planning and decision-making through a deeper understanding of the social and cultural context (Reyes-Arroyo *et al.* 2021). Furthermore, some research has focused on understanding the impacts of change, with potential for "novel ecosystem services" including cultural recreational benefits emerging as coral reefs are affected by climate change (Woodhead *et al.* 2019).

The creation of human-made reefs (HMRs), or "hard, persistent structures submerged intentionally or accidentally in the ocean by humans", is adding a controversial human dimension to marine environments worldwide (Chapter 2). HMRs can be created accidentally as in the case of shipwrecks, purposefully by a range of stakeholders as tools to enhance human activities such as resource extraction or tourism, or in direct attempts to restore marine habitats as in the case of coral restoration modules. As they represent the embodiment of human influence in the ocean, HMRs may create new opportunities for social meaning and culture underwater. Though HMRs such as fishing traps (Johannes 1978) and oil rigs (Fowler *et al.* 2018) have long been a means to extract resources including food and energy from the ocean, other types of HMRs are increasingly being used to advance political or artistic aims (Brahic 2011; Bugnot *et al.* 2020), as well as being protected as spaces of historical importance (Krumholz and Brennan 2015) and utilised as tools to restore coral (Bayraktarov *et al.* 2020). Their creation can have significant implications, positive and negative, for marine life facing threats such as climate change, overfishing and pollution (Heery *et al.* 2017).

Value judgements about what is "natural" often come into question around HMRs, calling up debates around the legitimacy and value of ecosystems on HMRs in comparison with "natural" coral and rocky reefs (Chapter 2; Pitcher and Seaman Jr 2000). Some HMRs such as oil and gas platforms have specifically been labelled as novel ecosystems in an attempt to attribute standalone value to them, rather than limiting understanding to "restoration" of pre-existing ecosystem types (Hobbs *et al.* 2014; van Elden *et al.* 2019). In the context of ecotourism, a similar debate has concerned the role of "modified spaces" fundamentally altered by humans, specifically in reference to artificial reefs (Lawton and Weaver 2001). HMRs have been referred to as "prime examples of modified spaces, where human intervention is noticeable but not necessarily detrimental to flora and fauna" (Stolk *et al.* 2007 p. 346). On the other side, the placement of human-built structures such as residential developments and wind farms amid "seascapes" can cause social conflict and galvanise environmental activism (Thompson 2007; Kearns and Collins 2012). In some cases, the modification or degradation of marine and coastal environments can elicit strong emotional reactions including "extreme feelings of loss" (Kellert 2005 p. 18).

Due to the anthropogenic creation and use of HMRs, alongside their impacts on and use by marine life, it is crucial to consider them as combined social-ecological systems and assess them accordingly (Chapter 2). While ecological assessment of HMRs has been ongoing for decades and is making progress (Carr and Hixon 1997; Smith *et al.* 2016), their social assessment is lagging behind (Chapters 2 & 3). HMRs can be difficult to both find and assess (Baine 2001; Baeye *et al.* 2016; Ilieva *et al.* 2019). Nonetheless, from a cultural standpoint, HMRs can contribute to marine education, viability of ecotourism, displacement of tourism impacts from sensitive areas, local environmental awareness and sustainable resource use (Leeworthy *et al.* 2006; Trialfhianty and Suadi 2017; Bideci and Cater 2019). In a recent review, (Lima *et al.* 2019) described socioenvironmental aspects of HMRs as generally "neglected" in research and emphasised the need for interdisciplinary studies in situ (p. 90). This information can be key to decisions around the creation, extraction or management of HMRs, guiding marine conservation decisions in a changing ocean (Schläppy and Hobbs 2019).

The Caribbean island of Cozumel in Mexico is approximately 46km long and 16km wide (Fenner 1988), prone to hurricanes, and contains a confluence of various anthropogenic marine activities. First, it is an important tourism destination, particularly with regard to scuba diving and cruise ship tourism, but also has an active commercial fishing community (Palafox Muñoz *et al.* 2015). It has been the site of various subaquatic archaeological discoveries, including the cargo of a presumed Mayan canoe-wreck (Leshikar 1988) and colonial shipwrecks (Albright 1987; Barba Meinecke 2017). It is also an area of marine conservation importance, containing a portion of the Mesoamerican Reef system and over 400 fish species, though it has seen decreases in coral cover and some trophic groups of fish (Millet-Encalada and Álvarez-Filip 2007; Martínez-Rendis *et al.* 2020). One site in particular had a recorded drop in coral cover from 44% to 4% over the course of a decade (Reyes-Bonilla *et al.* 2014). With the exception of an area opposite the main town, Cozumel's marine ecosystems are largely covered by two multi-use protected areas, each divided into zones where certain activities (such as diving and some forms of fishing) are allowed: the "Parque Nacional Arrecifes de Cozumel" (Cozumel National Park), established in 1996, and the "Área de Protección de Flora y Fauna del Norte de la Isla de Cozumel" (Flora and Fauna Protection Area), established in 2012 (SEMARNAT 1996, 2012). I considered Cozumel to be an ideal study site for understanding the sociocultural dimensions of HMRs because of its potential to harbour diverse HMRs and stakeholders due to varied marine activities and its high importance for marine conservation.

The goal of this study was to conduct a socio-cultural assessment of Cozumel Island's HMRs, reflecting the different values stakeholders associate with the creation and use of these structures. Given the limited understanding of social and cultural factors around novel marine ecosystems such as HMRs (Lima *et al.* 2019), including the benefits and values they provide within seascapes containing "natural" coral and rocky reefs, I chose to focus on the following research questions:

- What ecosystem services, impacts, costs and benefits do people perceive as emerging from HMRs?
- What attitudes do people have towards HMRs, and what factors underpin their opinions of HMRs as positive or negative?

- To what extent are comparisons between HMRs and natural coral and rocky reefs considered valid, and what factors underpin the validity of these comparisons?
- What factors are considered important in the creation of HMRs, and how does participation in HMR creation affect opinions toward them?

Together these questions enable us to address the overarching aim of developing an integrated understanding of people's varied relationships with HMRs, thereby guiding future approaches to managing HMRs for a range of purposes in a socio-culturally sensitive way.

4.2 Methods

Between January 2019 and May 2019, semi-structured interviews were carried out with 40 diverse stakeholders including artists, archaeologists, tour operators, scientists and fishers, regarding the topic of human-made reefs on the island of Cozumel in Mexico (see Section 1.6 and 3.2.1 for further information on sampling and interview process, and SM1 and SM2 for relevant interview materials).

Interview questions analysed for this chapter (Table 1.2, SM1, SM2) contained a mix of quantitative and qualitative questions regarding perceptions and uses of HMRs. Participants were presented with a list of ecosystem services derived from the Millennium Ecosystem Assessment (2005) and asked to select those which applied to HMRs in Cozumel, and to describe their relevance (see Supplementary Materials for cards used to represent ecosystem services). They were also asked to assign ratings to their approval of HMRs in general and well-known case study HMRs, to explain these opinions, and to discuss costs, benefits and impacts of HMRs as well as their relationship to "natural" coral and rocky reefs. Participants were assigned to stakeholder categories (Table 3.1) after all interviews had concluded, taking into account their selected "primary activity" (from a pre-defined list based on informal interviews carried out during a scoping trip), their self-described occupation and the nature of HMR experiences described during the interview. In the results, participants are coded as "Interview number-Category" (e.g. 01-TOU = the first interview carried out with a tour operator).

Qualitative analysis for this chapter took place using NVivo 12 to thematically code responses (see Section 3.2.1 for an explanation of the inductive and deductive coding process) and subsequently using the "matrix coding" function to examine associations between variables (e.g. between levels of approval and factors affecting attitudes). Quantitative analysis took place using RStudio (version 1.2, "Orange Blossom) running version 3.6.2 of R and using the packages *ggplot* and *dplyr*.

4.3 Results

Respondents discussed ecosystem services, attitudes, impacts, comparisons to "natural" coral and rocky reefs and factors around HMR creation for a wide range of HMRs, including accidental and purposeful shipwrecks, coral restoration modules, debris, lobster traps, Mayan artefacts, oyster boxes, religious and artistic sculptures and rock piles.

4.3.1 *Provision of ecosystem services*

Participants identified a range of ecosystem services as being provided by HMRs in Cozumel, including cultural, provisioning, regulating and supporting services (Figures 4.1, 4.2 & 4.3; Table 4.1). Habitat was selected most often generally, and chosen by about a third of respondents as most important to them; recreation & tourism and education followed closely behind (Figure 4.1). Some ecosystem services were more closely affiliated with particular HMR subtypes, such as accidental shipwrecks with cultural heritage (Figure 4.2), or certain activities, such as art with aesthetic value or tour operation with recreation and tourism (Figure 4.3).

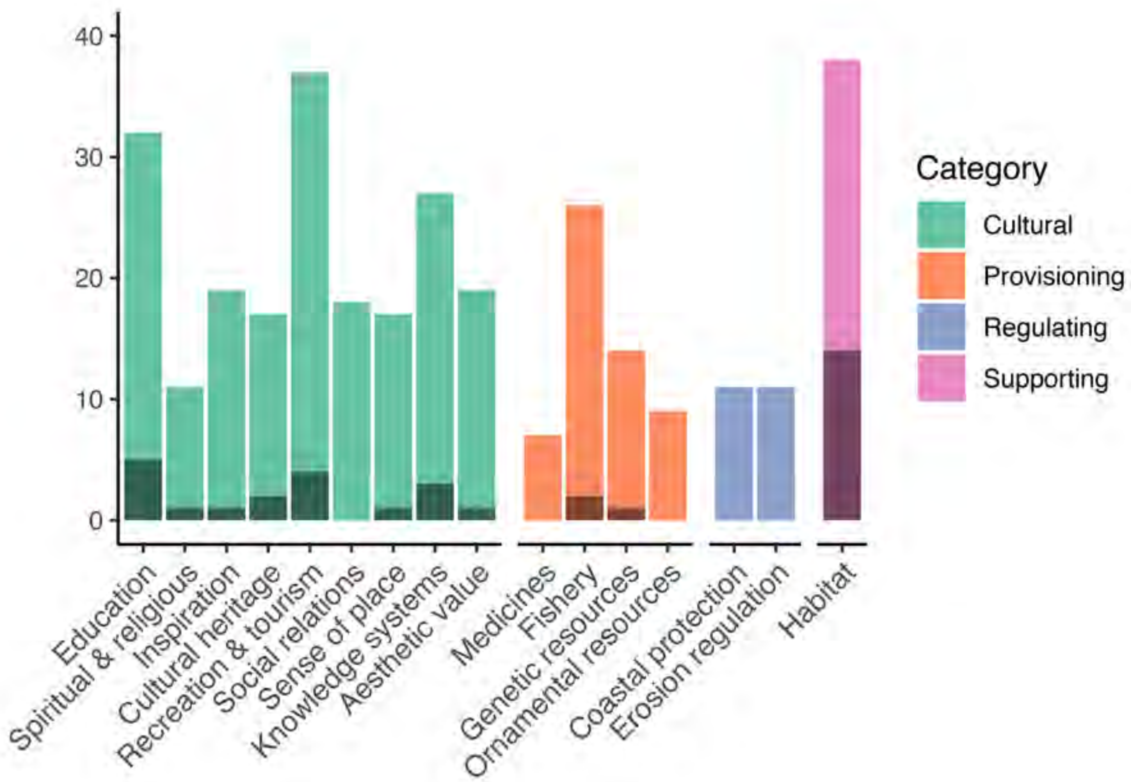


Figure 4.1 Ecosystem services provided by HMRs on Cozumel, as identified by interview participants. Shaded bars indicate the number of times an ecosystem service was chosen as "most important" to a participant. Habitat was selected most often (both in general and as most important), followed by Recreation & Tourism (3rd most important) and Education (2nd most important).

In selecting ecosystem services provided by HMRs, participants took different approaches. While the majority of participants selected benefits relating to specific HMRs, two participants – who were most familiar with modules used in coral restoration – explained that they selected all benefits applying to coral reefs because these HMRs were enabling the benefits of coral reefs to continue. Some confusion emerged around whether the potential provision of a benefit in the future would qualify, and participants were asked to choose benefits they believed were currently being provided by existing structures.

Supporting ecosystem services relating to habitat largely referred to the accumulation of marine life and increasing complexity of associated ecological dynamics. When it came to regulating ecosystem services, participants said HMRs could enact coastal protection or regulate erosion, but most did not see these as very impactful with respect to existing structures in Cozumel.

Provisioning ecosystem services involving fishing usually referred either to lobster fishing with traps or line or spearfishing, which could be made easier and more efficient when marine organisms took shelter in HMRs and a fisher could "stab them right in the Reefballs" (24-ART). Explanations for the role of HMRs in providing genetic resources included changes at the population level in response to a changing environment or the practice of coral "gardening" or seeding. Ornamental resources included marine animal products such as shells and taxidermy, but also items of "treasure" taken from shipwrecks such as jewellery, figurines and coins.

Participants selected a wide range of cultural ecosystem services, with explanations running the gamut from practical uses to practices associated with a strong sense of identity and emotion (Figure 4.1, Table 4.2). On the practical side, tourism was described as the backbone of the island's economy, and HMRs could expand the range of offerings or make dives more convenient. Several tour operators built their own sites in front of a restaurant or beach club, which was particularly convenient for short-term visitors off cruise ships. Education could be associated with dive instruction, with instructors using structures as obstacle courses to test buoyancy skills, or taking advantage of shallow, near-shore HMR sites with less delicate marine life as entertaining training grounds for inexperienced divers. HMRs could also be used as examples in ecotourism, ecology classes or in conservation efforts. Knowledge systems were often linked to scientific research, for example marine ecology experiments or long-term monitoring, or with the trial-and-error approach to design of HMRs. Visually attractive HMRs, such as sculptures and shipwrecks, were associated with aesthetic value.

Sense of place was associated with unique HMRs serving as marine landmarks, which could help divers orient themselves underwater and build local identity as points of attraction for visitors and pride for local people. Social relations were linked to group activities around HMRs, such as fishing or coral restoration, which could bring likeminded people together and foster bonding through the process. Inspiration could be linked to pro-environmental motivations such as coral restoration, the enjoyment of dives on historic shipwrecks, or the experience of seeing marine life colonise an HMR.

Cultural heritage could be linked with sites of archaeological importance such as shipwrecks or Mayan artefacts, or more modern sites such as religious sculptures or artistic busts built of well-known figures. Some participants also mentioned the importance of fostering a culture of environmental awareness and passing it onto future generations.

Spiritual and religious associations with HMRs were complex and vibrant. In three cases, artistic sculptures were used to pay direct homage to the memory of deceased individuals, with two busts representing important figures in marine conservation and one abstract artistic sculpture intended for planting corals in honour of a young marine biologist. As the artist who created it said, "We do it in the hope of creating more corals, but also in the memory of people we loved" (24-ART). Some HMR sites simply appeared to feel sacred; as one participant said, "You would arrive there and feel an incredible sensation of peace, like when you feel really relaxed, you even breathe more peacefully, like you are in communion with something… It was like entering into a temple. You feel peace, you forget your problems and focus in a different way" (33-TOU).

Religious iconography and ceremonies came into play with sculptures of the Virgin Mary and Jesus Christ. Participants often explained these sculptures as being placed to safeguard individuals undertaking risky activities in the ocean, such as fishers or divers, providing a form of spiritual protection. In the case of the sculpture of Jesus Christ, put forward by a prominent marine conservationist, there was also an element of protection for marine life. As one participant explained, "He believed, and I personally heard him say this, that having a religious image there would create a bit more respect for the reef. In terms of not leaving rubbish, not ripping things away… The idea was that it would protect scuba divers and the reef" (20-CUL).

One participant described the sinking of a statue of the Virgin Mary to resolve a conflict with local fishers who resented the presence of an aquaculture project, saying it was a way to "make friends with the fishers. They would cut cables, steal buoys, burn palapas… The virgin protects the area and she's an offering. The fishers go out and they have to go very far, it's dangerous… it's a form of blessing them" (22-SCI). Anecdotally, the participant mentioned that while a full-time guard used to be necessary, they have not had any problems since the sculpture was submerged.

A few participants mentioned an elaborate annual ceremony in which another statue of the Virgin Mary would be taken out of the sea, cleaned, placed in a church overnight and re-submerged following a procession through town and a Catholic mass on the beach. One participant described the ceremony in detail: "They would take her out of the water, clean and polish her… decorate the church with ocean things, with a little blue blanket and flowers and plastic fishes and things like that… she would stay in the church for a day and then she would be taken out. People would be waiting and she would be placed in a truck to do the route and cross the national park. People would run behind the truck or follow on their bicycles, some on roller skates, until we arrived… they would hold a mass on the beach and divers would come, people from afar, and they would go in to install her, make a circle of divers and some people with their faith would say a prayer" (39-TOU). This ceremony took place every year until the statue was stolen; though it has since been replaced, the new sculpture no longer appears to hold the same place in the local imagination.

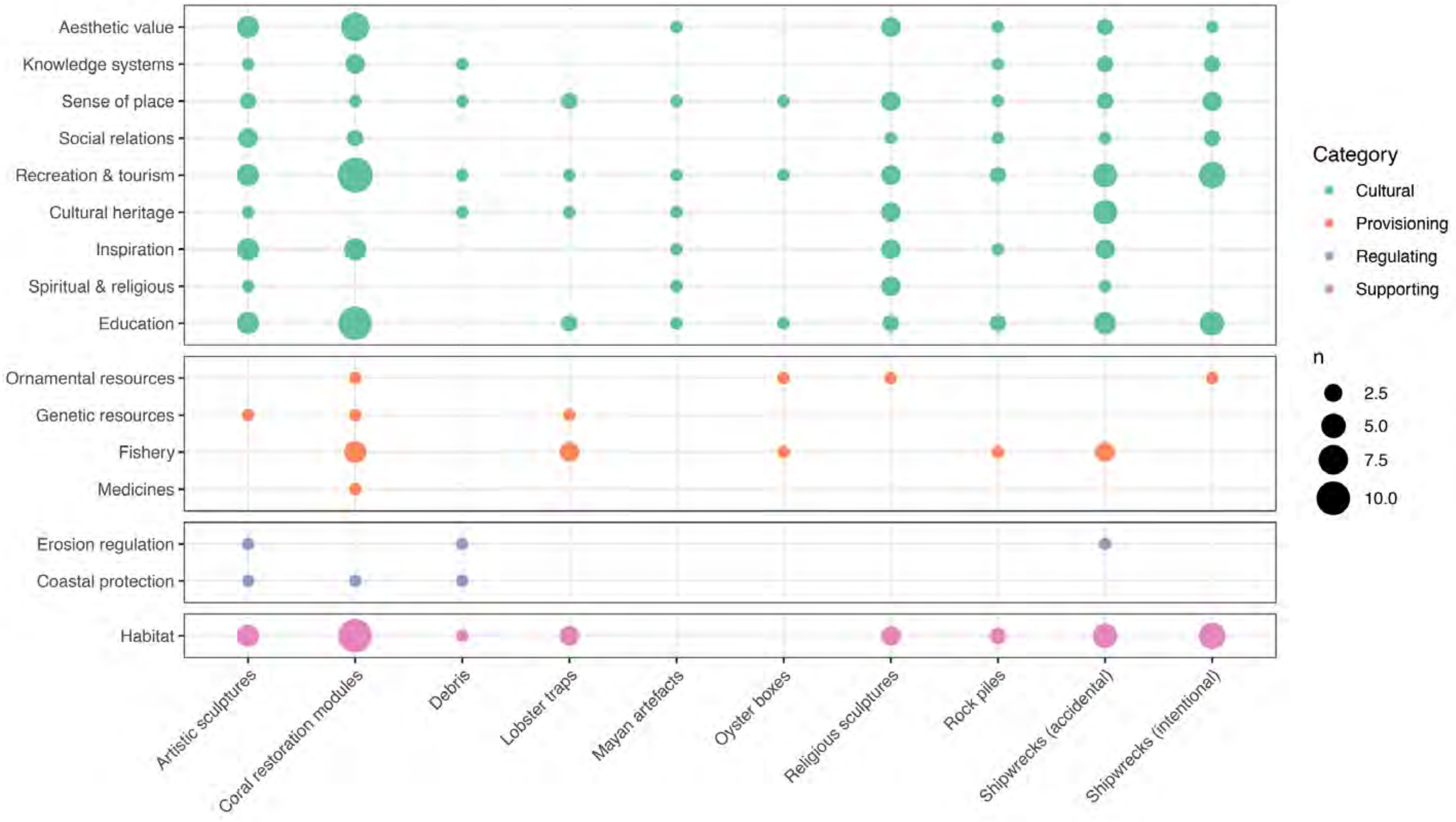


Figure 4.2 Ecosystem services associated with HMR subtypes, as identified by participants in relation to case study HMRs. Coral restoration modules, shipwrecks and artistic sculptures appeared to be associated with the greatest variety of ESs, while Recreation & tourism and Sense of place were identified as emerging from all HMR types.

Finally, participants appeared to value the ecosystem services provided by HMRs differently according to their primary activity, as evidenced when they were asked to select their top three priority ecosystem services (Figure 4.3). Though almost all activities highlighted the provision of habitat for marine life as a key ecosystem service, other associations were more targeted, particularly in the case of provisioning and cultural services. For example, aesthetic value was most strongly tied to art; cultural heritage to archaeology; knowledge systems to scientific research, fisheries to fishing, and recreation and tourism to tour operation. While the cultural services identified were highly diverse, provisioning and regulating services received less recognition.

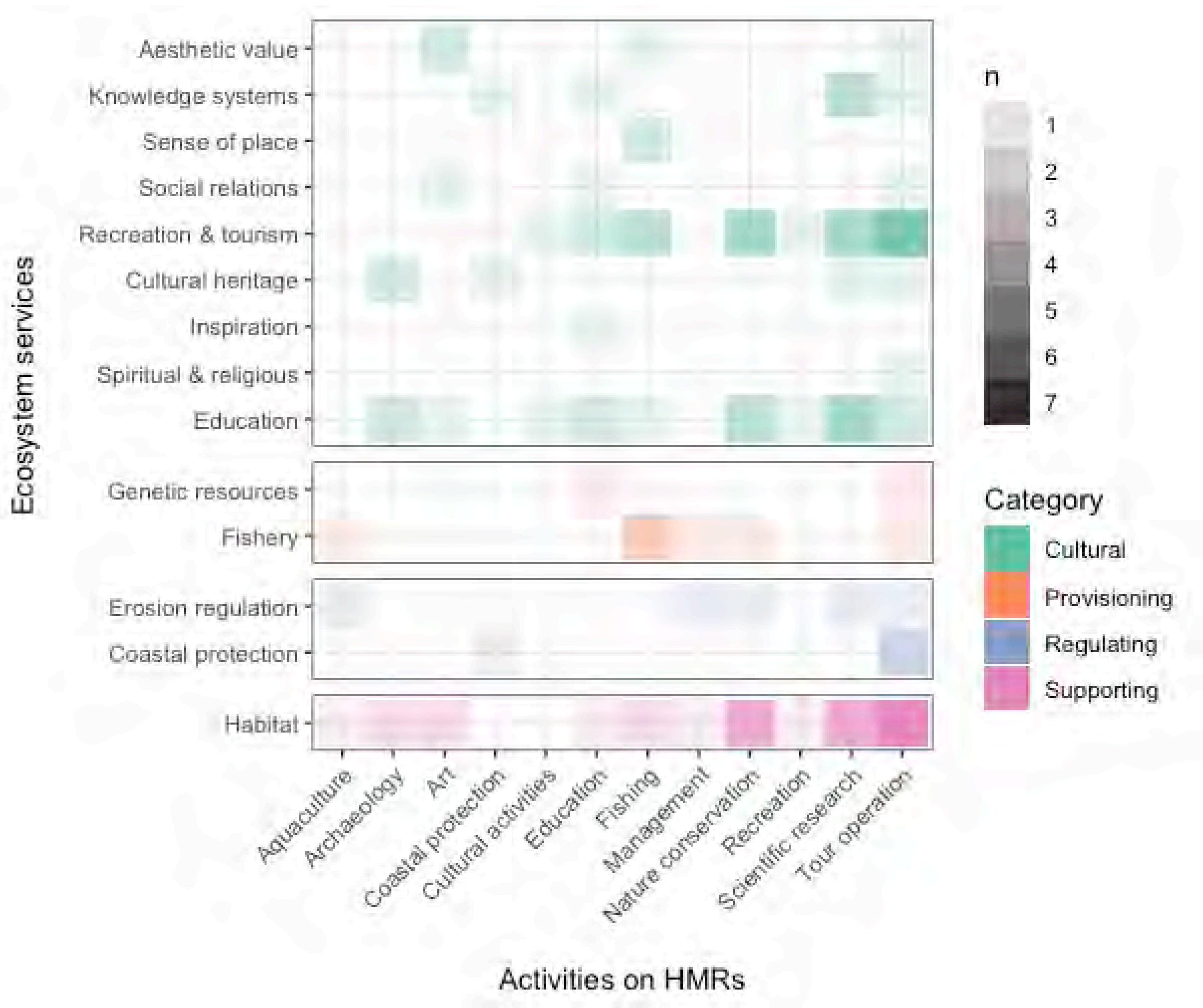


Figure 4.3 HMR ecosystem services identified as most important during interviews, organised by participant's self-selected top three "priority activities". Notably, cultural heritage was identified as being particularly important for archaeology; habitat for conservation, scientific research and tour operation; recreation and tourism for tour operation; and knowledge systems for scientific research.

Table 4.1 Examples of ecosystem services identified as being provided by HMRs. (C = Cultural, P = Provisioning, R = Regulating, S = Supporting). Definitions are taken from the Millennium Ecosystem Assessment (2005)[1] *and* Woodhead *et al.* (2019)[2].

	Ecosystem service	**Examples**	**Quotes**
C	Education: *Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.* [1]	Designed concrete coral restoration modules used to teach "gardening" techniques or discuss threats to coral; Concrete debris blocks used as dive "obstacle courses" to teach buoyancy skills; Shipwrecks and artefacts used to discuss history; Environmental education and values	• "I use them to check buoyancy and skills or to teach people to dive" (07-ENV) • "I explain to people how the fish take ownership of [the structure]" (09-REC) • "People come to learn about corals and caring for it, so it's a vehicle for getting people involved and reef awareness" (24-ART)
C	Spiritual & religious: *Many religions attach spiritual and religious values to ecosystems or their components.* [1]	Homage to well-known figures in marine conservation; Memorial for deceased person; Rituals such as sculpture of Virgin of Guadalupe which was cleaned and re-submerged every year with parade around town; Sculpture of Jesus; Meaningful process of creation; Visits to sites with personal spiritual significance; Use in religious rituals and ceremonies	• "I wanted to honour Captain Cousteau" (35-ART) • "We do it in the hope of creating more corals, but also in the memory of people we loved" (24-ART) • "It was a way of blessing them because the virgin is there looking at them, protecting them" (22-SCI) • "Every year we have a mass and we take [the Virgin Mary sculpture] out and clean her, and do a ceremony because she protects the scuba divers" (39-TOU) • "For me they are magical places, isolated places, where you can feel part of what you truly are… It's where I integrate with the island, and recognise myself as part of it, as someone who belongs here" (38-TOU). • "In a place like that you enter into peace, you dream of that place, you find yourself in peace (33-TOU) • "He believed, and I personally heard him say this, that having a religious image there would create a bit more respect for the reef. In terms of not leaving rubbish, not ripping things away… The idea was that [the sculpture of Christ] would protect scuba divers and the reef" (20-CUL)
C	Inspiration: *Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture and advertising.* [1]	Meaningful process in creation / maintenance of coral restoration modules; Sparking of curiosity to undertake further learning	• "You feel like you are doing something bigger… I feel like I am helping the planet" (08-EDU) • "It incites your imagination to think what the galleon was like, what it had in it… It inspires you to learn more about history" (19-TOU) • "The experience of seeing how life would arrive, I got very emotional, it was something really lovely" (31-TOU)

C	Cultural heritage: *Many societies place high value on the maintenance of either historically important landscapes or culturally significant species.* [1]	Historic importance of accidental shipwrecks and artefacts; Homage to important figures in marine conservation; Sense of local identity through history; Sense of engaging with culture during activities on HMR; Emphasising the importance of conservation within culture	• "Feeling that excitement of diving through history, through years of history in the Caribbean… it's like going to a museum, but underwater" (19-TOU) • "To honour amazing ocean heroes, scuba heroes, divers" (24-ART) • "In the end it's our history. It generates a sense of identity, it allows us to understand where we came from and where we are going" (25-ARC) • "Creating a culture of the importance of conservation" (34-TOU)
C	Recreation & Tourism: *People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area.* [1]	Conducting paid dive or snorkel tours to visit HMRs including shipwrecks, or creating designed modules and artistic sculptures; Taking recreational trips with friends or family (also social relations)	• "There's a very specific tourism for shipwrecks… it created an attraction which was additional because before they didn't come" (27-TOU) • "The tourists who go out to see it are really impressed" (30-ARC) • "We wanted to generate something attractive for people at the resort, so we wouldn't have to go to the reefs in the south every day" (40-TOU)
C	Social relations: *Ecosystems influence the types of social relations that are established in particular cultures.* [1]	Excursions with friends or family; Community-building through creation or maintenance of HMRs; Sense of family identity and heritage; Community ceremonies	• "I've found some through pure recreation with my friends, when we say, 'where shall we go' and someone else knows a place and they tell me about it and tell me where to go" (09-REC) • "It brings the community together to fight for a common cause" (32-TOU) • "I know it through family heritage, my great uncle took me there. They would take me fishing and my uncle hunted crocodiles" (38-TOU) • "I've been working on this for 15 years since my children were toddlers, I wanted to leave them with what my wife and I had when we first came to the island. My hope is to allow my kids and grandkids to enjoy a love of the environment and oceans and ecosystems" (32-TOU)
C	Sense of place: *Many people value the "sense of place" that is associated with recognized features of their environment, including aspects of the ecosystem.* [1]	Orientation during scuba dives; Builds sense of local identity	• "It helps me orient myself underwater… When I see it, I know that I am in Palancar" (09-REC) • "It has become part of the identity of the dive site that is Cozumel" (12-SCI) • "It can give a sense of place, of belonging… it's part of the history of your place" (25-ARC) • "It creates a sense of place. People do use it as a reference, where is that, the Cousteau, it gives a sense of belonging and of place" (36-EDU) • "She is the Virgin of Cozumel" (39-TOU) • "When people from somewhere else would come, we would take them to show off what we have" (28-FIS)

C	Knowledge systems: *Ecosystems influence the types of knowledge systems developed by different cultures.* [1]	Conducting ecological research on marine species; Conducting research on HMR design; Conducting archaeological research	• "It helps us understand the cycles of development of marine species" (04-TOU) • "We can learn from the mistakes we make, because it's a more controlled environment and we can get similar information" (12-SCI) • "We have been exploring successional changes in the invertebrate community" (21-SCI) • "It's an artificial laboratory" (23-ENV)
C	Aesthetic value: *Many people find beauty or aesthetic value in various aspects of ecosystems.* [1]	Visual appreciation of shipwrecks; religious sculptures; artistic sculptures	• "Each cannon was made by hand, it's a unique piece of art" (05-ARC) • "It's like a spectacle to see how it changes over time" (22-SCI) • "It's a marvel, it's something very beautiful" (25-ARC) • "They look really pretty" (26-TOU) • "It's my baby, it's beautiful" (35-ART)
P	Fishery: *the services and benefits gained from fishing on reefs.* [2]	Lobster fishing; Spear fishing	• "We want it to be all clean inside so more lobsters can fit" (18-FIS) • "It was a really good fishing spot" (28-FIS)
P	Genetic resources: *This includes the genes and genetic information used for animal and plant breeding and biotechnology.* [1]	Coral "gardening" or seeding; Genetic adaptation of marine life to new conditions	• "For example with oxidation, they might adapt to the pollution" (09-REC) • "Taking their youth and moving them forward" (24-ART)
P	Ornamental resources: *Animal and plant products, such as skins, shells, and flowers, are used as ornaments, and whole plants are used for landscaping and ornaments.* [1]	Pearl farming, Looting of shipwrecks, Taxidermy and shells	• "You can take gold, and also animals that I make into taxidermy" (28-FIS) • "In the shipwrecks there are lots of empty shells that were eaten by the octopus" (33-TOU) • "There was an American who was trying to leave with gold coins, he was helped by some local divers and they all went to prison" (33-TOU)
R	Coastal protection & Erosion regulation: *The presence of coastal ecosystems such as mangroves and coral reefs can reduce the damage caused by hurricanes or large waves.* [1]	Blocking wave surges; Purposeful placement of structures to protect against storms; Avoiding loss of sand on beaches	• "The cannons make a little barrier" (19-TOU) • "It protects against storms" (32-TOU) • "They said the virgin protected against hurricanes and stuff" (39-TOU)

S	Habitat: *the services and benefits gained from having a reef ecosystem that provides key habitat.* [2]	Colonisation by marine life	• "The octopus would travel and it had its home by the concrete block" (04-TOU) • "The first ones to arrive were some little fish, then some sardines, logically their predators, pelicans and seagulls to eat the sardines" (04-TOU) • "Opportunities are created to occupy spaces and niches that wouldn't have existed without these structures, like for urchins" (07-ENV) • "They always give shelter to a lot of marine life" (14-TOU) • "When something gets submerged it turns into a reef and it stays there for the marine species. Lots of animals come and take shelter, they use it as their refuge" (28-FIS)

4.3.2 Attitudes to HMRs

Attitudes to HMRs, measured in general and in relation to individual case studies, generally appeared to be neutral or positive, though some aspects could lead to negative opinions, such as perceived damage to marine life (Figure 4.4, Table 4.2). Several themes emerged as participants explained the factors that informed their attitudes, including a sense of uncertainty, concern for marine life and ecosystems, intention behind the HMR, conceptions of nature, implementation, their outcomes in relation to objectives and emotional reactions (Figure 4.4, Table 4.2).

In assigning their opinions to categories, participants often attached a strong sense of uncertainty or conditionality, and this was particularly apparent in the case of general opinions (Table 4.2). In most cases, they seemed to want to reserve judgment for individual cases; as one participant said, "some have been wisely done and some have been unwisely done" (24-ART). Sometimes participants expressed a lack of agency and detachment, with statements like "It was sunk, I don't know" (05-ARC). One participant acknowledged the complexity at stake, saying "there are so many variables" (32-TOU), while another acknowledged a multiplicity of viewpoints saying "there are opinions for and against" (27-TOU). One person suggested it might be too soon to draw conclusions since "we are barely in a process of experimentation" (04-TOU). One participant distinguished between intention and implementation, describing one HMR as a "good idea but in a bad place" (38-TOU). Some participants expressed that they would agree with HMR creation **if** certain conditions were met: for example, if monitoring and evaluation or "adequate planning" (09-REC) took place, the marine ecosystem wasn't affected, or if the structure appeared natural. In other cases, they identified factors which their opinion would depend on, such as planning, materials, sites and structure types.

The attraction or generation of marine life, or conversely damage to it, emerged as a key factor in shaping opinions. Participants applauded the creation of habitat and the accumulation of fish, coral and other marine organisms, to the extent that benefits to marine life could override other concerns. As one participant stated, "in the end it's trash, but at least it's trash that gives life" (05-ARC). On the other hand, participants expressed concern around invasive species, as well as damage to existing corals and marine life from installation or from hurricanes shifting HMRs. As one participant put it, "it's not very cool for the little animal that gets squashed" (39-TOU). Impacts on the larger surrounding environment and ecosystem were also important in forming opinions, with concerns around change to existing ecological patterns and impacts on the seabed or nearby reefs. On the other hand, the reduction of dive tourism pressure on nearby coral reefs emerged as a strong benefit, with one participant saying it was important to "take away a bit of stress so the reef can rest" (40-TOU).

Perceptions of intention appeared crucial, with one person explaining that their opinion "depends on the objective" (15-MGT). The presence of a conservation intention such as to "help reefs and biodiversity" (24-ART) could justify a project in itself, with one participant going as far as to say "if it is for conservation it is positive" (21-SCI). Purposes such as the creation of sites for tourism and recreation were deemed acceptable when considered necessary for economic or recreational reasons. Proceeding with HMR construction despite pre-existing knowledge of potential damage was considered unforgivable, with one participant saying "they put that dock on top of a coral knowing it was there" (06-SCI). At the same time, a strong resistance emerged to the creation of projects without a clear purpose or sufficient acknowledgment of the seriousness of the undertaking. This attitude was referred to by several participants as "hundir por hundir" or "sinking to sink" (27-TOU). As one participant explained, "there are people that think simply by dropping something they are doing good. There is a lack of seriousness in the people who do it" (12-SCI). Another participant described two sides to this apparently common tendency; while creators can gain a sense of agency in confronting larger problems, "in their eagerness to make something, they have made some horrifying things" (07-ENV). A lack of human agency or intention in creating an HMR seemed to create an absence of judgment; for example, in the case of a shipwreck, one participant said "it's not good or bad, nature itself created it" (28-FIS).

Conceptions of nature often played into opinions on HMRs in the sense that the "natural" was often considered ideal and HMRs were perceived as altering or enabling nature. In several cases, HMRs were viewed as unfortunately necessary interventions, with one participant saying "the less we interfere with nature the better, but sometimes… we do have to get involved" (37-AQU). Resistance to the anthropogenic nature of HMRs could be both moral and aesthetic, with one person saying "they invade because they are not natural… we have to make them look natural, rather than making a Disneyland under the water" (06-SCI). This sense of wanting HMRs to blend in or imitate nature was common, with another participant describing efforts to emulate "natural" shapes and variability in relief, and another saying "it shouldn't be a visual shock. The more natural, the better" (22-SCI). In one case, an HMR seemed to enable the participant to witness the power of nature as marine life colonised it, saying "I saw how marvellous nature is, that it only needs a little bit to function, to continue, to recover" (31-TOU). One person considered HMRs somewhat redundant, saying "there are already natural structures that can be used to conserve coral reefs" (02-MGT). Coral reefs often seemed to be associated with conceptions of nature in a way that HMRs were not, and one person said, "it is never going to replace a coral reef" (23-ENV).

A context of environmental damage or destruction seemed to be a prerequisite in some cases, with one participant describing HMRs as "a good tool in places that have had natural or human impacts" (34-TOU). This could apply to localised or one-time events – for example, as one person said "before the hurricane I was in strong disagreement, but now in a lot of sites the corals that were there before are gone" (27-TOU). It could also apply to larger worldwide trends, with one participant saying "at this point in global warming I think any kind of structures that will help the ocean are good" (32-TOU). In some cases, it seemed a sense of imminent environmental risk could create a sense of urgency and reduced options, leading to the acceptance of controversial actions – in one case, someone described a coral transplant facilitated using HMRs by saying, "at that point it was the only alternative" (23-ENV).

The implementation of an HMR project – including planning, installation, monitoring and management – could make or break opinions "because it depends on the process, and environmental prerequisites need to be fulfilled with a lot of care" (36-EDU). One participant described HMRs as "super good if they are well done, with care, and anchored appropriately" (22-SCI). Another indicated this was the source of their resistance to HMRs, saying "if they were done well, I would completely agree" (12-SCI). Financial cost was brought up as a major issue, with one project described as "very expensive" (26-TOU) and another as a "good investment" (19-TOU). Costs could include materials, construction, obtaining permits and maintenance. Site choice was considered to be an important factor, taking elements such as currents and proximity of corals into account, and anchoring was often brought up in the context of hurricanes. A few participants raised the issue of planning, monitoring and evaluation, with one participant indicating approval because "it was a well-structured project" (12-SCI) and another indicating custom design was beneficial.

Certain characteristics or attributes of HMRs seemed to influence attitudes as well. The materials they were made with were considered important – in particular, whether these polluted or otherwise harmed marine life – and whether they were resistant to storms. Aesthetic concerns were also prominent, and whether a structure was considered "beautiful" (35-ART) or ugly. If a structure was unique, or "something you don't see anywhere else" (33-TOU) this was a very positive attribute. Finally, a sense of being "functional" (05-ARC) or fulfilling some purpose appeared to be important.

Outcomes were key to forming people's opinions of HMRs, and seemed to be measured according to colonisation by marine life, social uses and perceptions, and whether an HMR fulfilled original objectives. In terms of marine life, the presence of corals was particularly positive in a conservation and tourism context, and the growth of oysters was considered positive in an aquaculture context. Important social uses included the generation of snorkel and dive tourism leading to financial gain, recreational enjoyment of natural spaces, logistical benefits from infrastructure, and the formation of conservation awareness, along with cultural understanding from Mayan structures. One religious sculpture was perceived as providing "anti-stealing and anti-sabotage" benefits after its submersion eased social tensions with another group of individuals who had previously been destroying equipment (37-AQU). Some structures were seen as particularly novel and important in their outcomes, with one coral restoration example described as "pioneering and it showed that transplants can occur under certain conditions" (23-ENV). In general, participants seemed to approve most strongly of an HMR that "fulfilled its objectives" (29-ENV, 35-ART, 36-EDU) or even surpassed them. A high compliment seemed to be paid to a structure that was "beautiful, very well thought out and it works" (35-ART).

Emotions also seemed to factor into some participants' opinions, with descriptions of experiences with HMRs that led to joy, concern, disillusionment, interest or satisfaction. One participant said "I felt in ecstasy" (31-TOU) watching the changes in marine life after creating an HMR. Another described concern in monitoring HMRs, saying "I see other plaques that nothing sticks to. I think there is something that is not good for marine life and it worries me" (35-ART). Another person described a sense of disillusionment participating in HMR projects related to environmental mitigation, and how "priority should be given to life, and development sites should be changed, but unfortunately the reality is different. I would prefer not to have to do it" (29-ENV). In describing the impetus that leads people to create HMRs, one participant said "they are happy to put their little grain of sand" (07-ENV). Finally, a participant described the experience of diving on a shipwreck and said "I love it, it is a very interesting place to visit... It feels good" (19-TOU).

Marine life

- \+ Attraction / generation
- \+ Habitat / substrate creation
- \+ Reduced pressure (e.g. diving)
- – Invasive species
- – Changes to ecosystem
- – Damage to marine life (e.g. during installation)
- * Impact on corals

Intention

- \+ Clear objectives
- \+ Conservation intention (e.g. helping biodiversity)
- \+ Addressing socioeconomic needs
- – "Sinking to sink"
- – Proceeding despite knowledge of potential damage
- * Agency = accountability

Outcomes

- \+ Diversity / abundance of marine life
- – Damage to marine life
- * Fulfilment of objectives
- * Social uses / activities

Natural vs. Unnatural

- \+ Similarity to natural structures
- \+ Reminder of regenerative power of nature
- \+ HMRs as tools for restoration of nature
- – Unnecessary interference with natural processes
- – Replacement of adequate natural solutions
- * Comparisons with coral reefs

Context

- \+ Repairing environmental damage (e.g. hurricanes, global warming)
- \+ Avoiding imminent risk ("desperate times")

Implementation

- \+ Careful planning (e.g. design, site choice)
- \+ Adherence to environmental policies
- \+ Methodical installation (e.g. anchoring)
- – Damage to marine life
- * Monitoring & management
- * Financial cost

Characteristics

- \+ Resistant materials
- \+ Unique / unusual form
- – Polluting materials
- * Functionality
- * Aesthetic appeal

Emotions

- \+ Ecstasy / joy
- \+ Curiosity / engagement
- – Worry / concern
- * Disiullusionment
- * Sense of agency

Uncertainty

- * Judging on a case-by-base basis
- * Complex problem
- * Validity of different opinions
- * Conditions / requirements ("if...")
- * Involvement level ("wasn't me!")

Figure 4.4 Factors affecting attitudes to HMRs, as derived from thematic analysis. Plus signs (+) indicate a positive association; minus signs (–) indicate a negative association; and asterisks (*) indicate factors that could be positive or negative, requiring further discussion.

Table 4.2 Coded explanations of attitudes to HMRs in response to the question: "How do you feel about the creation of HMRs?". Handwritten notes in response to questions around attitudes to HMRs, both in general and in relation to a case study well-known to the participant, were thematically coded based on codes that emerged from the responses rather than being pre-defined. Shading represents the number of times a code was mentioned by a participant; multiple codes or references could be present within a single response.

Code	**General**					**Case study**				
	Strongly agree	Agree	Neutral	Strongly disagree	***Total mentions***	Strongly agree	Agree	Neutral	Disagree	***Total mentions***
Context	4	5	0	0	9	0	2	0	0	2
Emotions	0	1	1	0	2	5	0	0	0	5
HMR Characteristics	2	2	2	0	6	4	1	0	0	5
Implementation	4	9	4	0	17	4	3	1	0	8
Intention	4	8	5	1	18	2	2	1	0	5
Marine life	4	8	4	2	18	0	0	0	2	2
Natural or Unnatural	1	2	2	2	7	1	0	1	0	2
Outcomes	8	9	3	1	21	12	5	0	0	17
Uncertainty	3	27	10	2	42	3	2	6	0	11

4.3.3 Comparisons to "natural" coral and rocky reefs

When participants were questioned about the validity of comparisons between HMRs and "natural" coral or rocky reefs, 38% of respondents indicated that they believed comparisons could not be made, and several themes emerged as important.

The question often elicited strong reactions in people who did not believe comparison between natural reefs and HMRs was possible, with one participant simply responding "never" (07-ENV). These responses almost always drew on conceptions of nature as separate from human endeavours, with participants making statements such as "because it's artificial" (40-TOU), "it's not natural" (22-SCI), "because they're made by man" (14-TOU), and "the artificial will never get to be the same as the natural, no matter how much we may want it to" (26-TOU). Some participants equated human influence with harm, with one participant going as far as to say "never ever, because nature is perfect and we humans have shown ourselves to be somewhat imperfect. We are selfish, in the marine world there is no waste but we do leave behind our waste and it creates an imbalance" (35-ART). Some participants seemed to believe comparisons reflected a sort of hubris, "because the natural design of reefs is perfect, it would mean trying to win against nature which I consider impossible" (37-AQU). Even when participants believed HMRs were not comparable with coral or rocky reefs, that did not necessarily mean they were against their creation: as one participant said, "they can help, but something artificial is never going to be the same as something natural" (31-TOU).

Time appeared to be a key factor in determining whether or when it would be possible to make valid comparisons between HMRs and natural coral or rocky reefs. Many participants argued that time increased the ability to compare; as one participant said, "eventually, yes" (05-ARC) and another said, "if it's new, then no way" (09-TOU). The main reasoning behind this appeared to be the accumulation of marine life, since "over time, they all end up full of corals and sponges. After forty years, no one would realise it was a man-made structure" (11-TOU). Several participants gave specific time frames after which comparison would be possible, with one suggesting "you could compare them after sixty or eighty years" (01-TOU) and another saying "over the long run, yes, after more than fifty years" (21-SCI). Some participants used time as a reason that HMRs could not be compared, saying "it's impossible for us to compare with nature. We are talking about millions of years of geological development, we can't compare that with something we make ourselves" (04-TOU). One participant echoed this mismatch in timescales, saying a coral reef “takes so many years… the artificial reef is a design we made quickly and submerged” (27-TOU).

Some participants believed HMRs and “natural” reefs could be compared on a functional basis, assessing factors such as “the capacity of [marine life] aggregation or provision of refuges” (12-SCI), “ecosystem services and habitat” (02-MGT), “morphology, diversity and richness of species” (29-ENV) and “how coral adheres” (33-TOU). One participant suggested that even if HMRs were not the same as natural reefs, they could provide “a good substitute for habitat” (23-ENV). One participant wrestled with the idea of functionality, saying “they don’t have the same function but they can be attractive to people, but they’ll never be the same… the ecosystem services will never be the same” (36-EDU). One participant was careful in parsing the ways in which HMRs could compare to natural reefs: “they will never have the structural complexity or the ecological functions. They can serve as a substrate” (09-TOU). Another participant considered the quality of design and implementation of the HMR to be crucial, saying “if they’re done right, yeah. A substrate’s a substrate, it just needs to be permanent” (30-ARC).

Many participants often seemed to view the ideal HMR as one that could perfectly imitate a natural reef, even as they believed such a standard was impossible to reach. One participant explained, “you try to imitate” (08-EDU). One participant suggested improvements in HMR design could make them comparable to natural reefs, saying “potentially in the future, but at this point in time so many techniques and technologies are a proving ground, trying to figure out what will work best” (32-TOU).

The accumulation of marine life could clearly influence the comparability of HMRs and natural reefs, with one participant saying comparison could occur “if over time it gets overtaken or overgrown” (24-ART). Marine life was also given significant agency in the process of transforming HMRs to enable comparison, with one participant saying “they become equal” (13-FIS) as marine life accumulates and another saying, “the animals that grow generate a substrate that ends up being really the same” (25-ARC). Marine life was seen as capable of obscuring the man-made nature of an HMR, because eventually “you can see where the boat was, not where it is” (06-SCI). However, differences in marine life also served as a reason that comparison was impossible, with one participant issuing a challenge: “coral is something unique, at some point it takes on a life completely different from a submerged structure. It’s formed naturally without any need for help, you need millions of symbioses… It can't be equalled. Can *you* substitute those millions of organisms with one thing?" (34-TOU).

4.3.4 *Impacts, costs and benefits of HMRs*

When asked to assess the impacts of individual case study HMRs they were familiar with, participants mostly rated impacts on marine life and tourism as positive, while sometimes ascribing neutral and negative impacts only to fishing and the health of nearby coral and rocky reefs (Figure 4.5). In a separate question around general impacts on "natural" reefs, 91% of respondents believed HMRs could have a positive impact and 83% believed they could have a negative impact. In assessing impact, participants were also asked to describe costs and benefits of HMRs they had witnessed in their local area.

Benefits of HMRs were most often related to the enabling of activities such as fishing, recreation, tourism, conservation, scuba diving or snorkeling, education, management, and research. Some identified practical benefits, such as ease of access to boats through piers or the provision of electricity in the case of cables. Social and cultural benefits were highly varied, including a sense of community and an understanding of local history which could build identity or bring recognition to the area, as well as activities such as religious rituals and conferences related to HMRs. One participant cited the "entertainment value" (32-TOU) of HMRs. Two participants linked HMRs with reductions in criminal behaviour and protection, particularly referring to a statue of the Virgin Mary. Various participants linked positive emotions or experiences with HMRs, including amazement, awareness, connection, curiosity, enjoyment, enthusiasm, happiness, hope, a sense of identity, inspiration and scientific interest.

In terms of costs, the mobility of unanchored structures during hurricanes was brought up as a major concern, with one participant explaining "it becomes flying debris during a hurricane and damages [coral] reefs" (30-ARC). Several participants cited concerns about pollution, due to construction with inappropriate materials or subsequent activities around the HMR such as the sediment, sewage and noise of boats or the excrement of animals contained within HMRs such as dolphin pens. They were also concerned about the accumulation of "rubbish" (04-TOU, 07-ENV) in the sea, with some HMRs being considered refuse. More abstract costs included the propagation of inaccurate perceptions – including the impression that HMRs could serve as a replacement for coral reefs, or misunderstandings about the impacts of certain projects – or the expression of human hubris, with people creating structures for the wrong reasons. Costs of "time and energy" (24-ART) and the coordination of logistics were also linked to the creation and management of HMRs.

Some costs and benefits were mixed around similar themes. For example, in terms of aesthetics, "pretty" (28-FIS) or attractive HMRs were seen as creating a benefit, whereas "ugly things" (24-ART) were seen as detrimental or even creating a negative "visual impact" (07-ENV). Financial or economic benefits included income from tours, the provision of opportunities for work and the creation of sites which could be used to conduct livelihood activities. Conversely, costs of this kind were linked to installation of HMRs, with respondents citing costs of materials, labour and infrastructure involved in wiring up structures with electricity or bolting them down, obtaining patents, the use of noisy machinery which could cause marine life to flee or damage to nearby coral colonies if a structure was placed too close to them. Other costs were related to maintenance, including electricity, repairs, and hiring people to clean or monitor structures which could also include paying for tanks, brushes, food and epoxy. Finally, one participant cited costs for access to HMRs such as needing to pay for permits or tickets to the area where HMRs were located.

HMRs were often perceived as agents of change, whether positive or negative. Some positive forms of change were conceptual, with one participant suggesting HMRs could create awareness and serve as a "catalyst" for change (24-ART), and another suggesting they could serve as a proof of concept or set a "precedent" (23-ENV). Beneficial versions of change included the deviation of tourism and diving pressure away from coral reefs and increases in existing benefits such as tourism clients. It also included the creation of new opportunities including new, different or additional attractions, potential for research or employment, and the regeneration of resources such as fish or spaces used as habitat or for tourism. However, negative versions of change included modifications to the marine environment which could alter coastal dynamics or give a foothold to "opportunistic" species (12-SCI) or generally "affect the natural equilibrium" (34-TOU). Participants also suggested that the creation of HMRs could encourage damaging activities such as illegal fishing and careless behaviour by users such as "snorkelers who kick, rip and pull, and they all feed the fish which means they won't eat the algae and that is why we are full of algae" (36-EDU).

In the context of this potential for change, many participants discussed impacts on marine life and the role of humans in either "creating damage" (27-TOU) or taking action to "save" (23-ENV), "rescue" (06-SCI), "destress" (40-TOU), restore or provide "help" to marine life (17-FIS). In relation to marine life, benefits of HMRs included the creation of a small new ecosystem; fostering a positive environment into which to transplant coral; fish reproduction and the growth of corals and sponges; increases in abundance and biodiversity; and the provision of habitat or shelter for marine organisms. One participant alluded to HMRs being "colonised by nature" describing an ideal state when "it becomes part of the [coral] reef, they become one" (25-ARC).

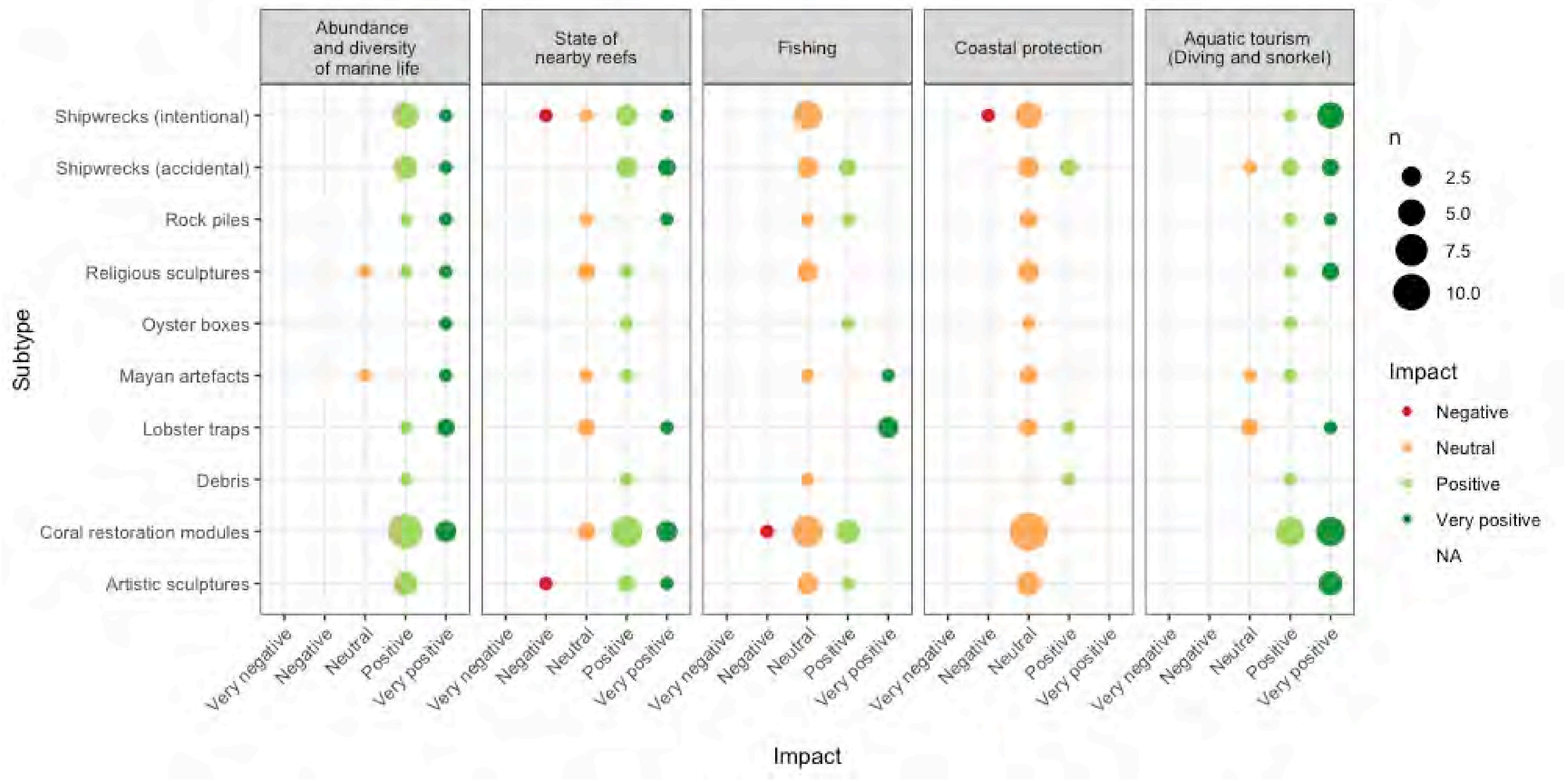


Figure 4.5 Perceived impact of case study HMRs (ranging from "very negative" to "very positive") on various factors, with size indicating the number of participants who selected a category and colour indicating direction of impact. HMRs were generally perceived as having had neutral or positive effects, as no participant selected "very negative" for any impact factor. HMRs were most often seen as having had a "very positive effect" on aquatic tourism, a "neutral" impact on coastal protection and fishing, and a "positive" impact on abundance and diversity of marine life and state of nearby coral and rocky reefs.

4.3.5 The role of HMR creation

Being involved in HMR creation seemed to affect attitudes. The degree of positivity varied depending on the participant's role in creating the HMR, and participants appeared to agree most strongly with the creation of individual HMRs they had created themselves (Figure 4.6). A sense of pride and ownership was often expressed by people who were involved with the creation of HMRs. This was reflected by results of a Likert scale analysis indicating participants' greater agreement with the creation of HMRs when they had been involved in their creation, and very strongly in the case of HMRs they had created themselves (Figure 4.6). During interviews, participants who had created HMRs often spent significant time going into detail with their reasoning for choosing certain features or explaining the impacts of their projects.

The pride of creating an HMR could be associated with innovation, as one participant said the type of structure he used had "never been sunk here, and it was something that occurred to me to do, and it worked" (18-FIS). It could also be related to power and prestige, with another participant explaining "for me personally it is one of the most important projects I've ever done, it had a spectacular influence, and I got to be part of all that influence" (07-ENV). Finally, it could be rooted in an emotional affection akin to that of a parent, with one participant simply saying, "it's my baby, it's beautiful" (35-ART). Beyond individual pride and ownership, HMR creation could stoke competition between groups, with one participant explaining that once one organisation "had their boat, the [other organisation] wanted their boat… it was a fight for control" (27-TOU).

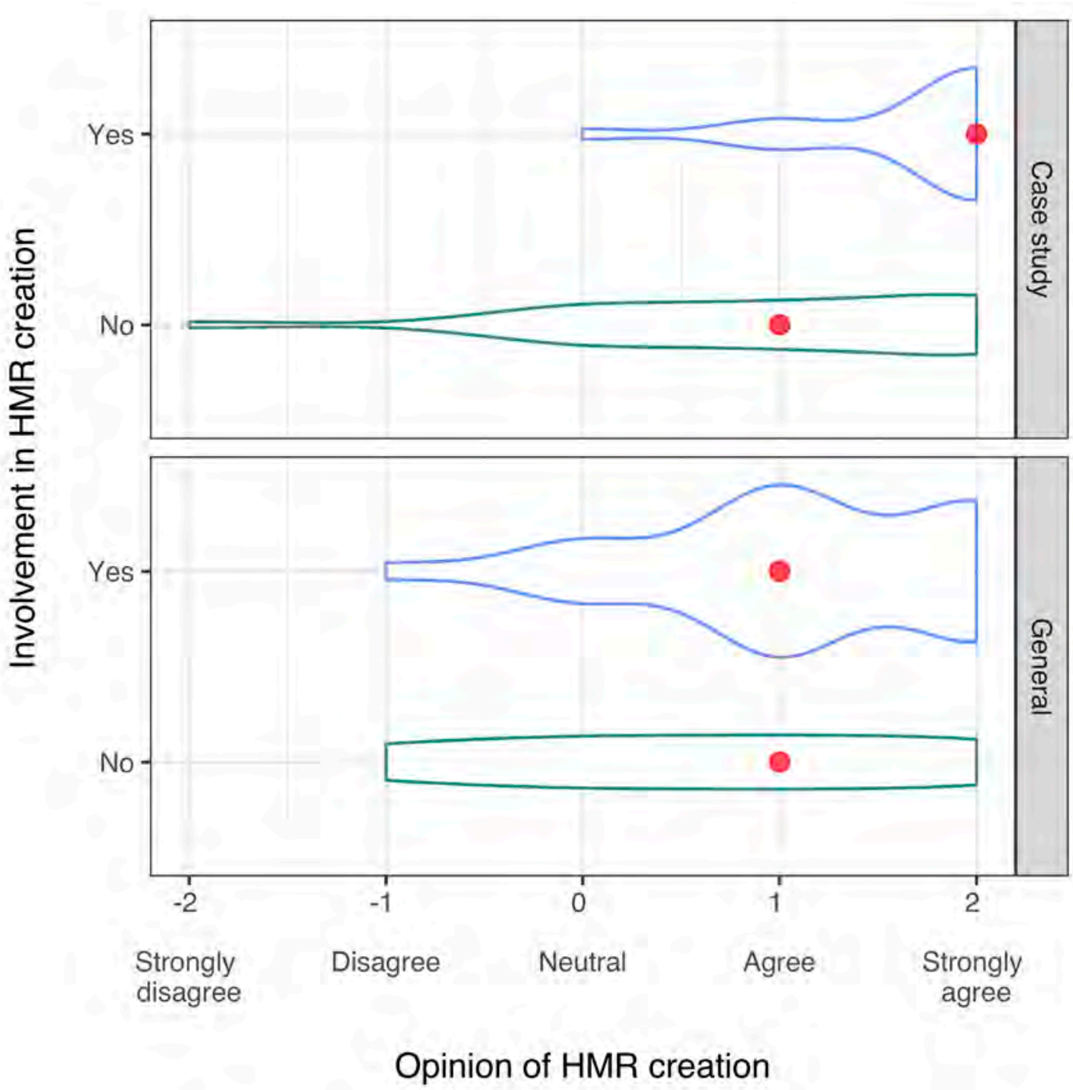


Figure 4.6 Opinions of purposeful HMR creation, in general and in reference to a specific case study HMR. Small grey dots indicate individual observations, and larger red dots indicate the median. In general, participants agreed with the creation of HMRs, with some displaying neutral or strong opinions and only a handful expressing disagreement. Participants tended to agree more strongly when they had been involved in creating HMRs themselves; this effect applied in general and was very strong in relation to specific case study HMRs. Almost all participants who had created an HMR stated they strongly agreed with its creation, and opinions varied most in relation to case study HMRs that participants had not been involved in creating. A Mann-Whitney test indicated a significant difference ($n = 39$, $W = 112.5$, $p = 0.019$) in opinions on specific case study HMRs according to involvement in creation, but not in general opinions of HMRs ($n = 40$, $W = 137.5$, $p = 0.146$).

4.3.6 Factors to consider in HMR creation

Based on their experiences, participants identified several factors which they believed important to consider in the purposeful creation of an HMR. These ranged from context to design, purpose, the experience of the person creating it, site, impact of marine life and the installation process, additionally stipulating specific considerations which fell within each factor (Table 4.3).

The role of purpose was emphasised at various points. On case study HMRs, 86% of participants believed the HMR had fulfilled the purpose it was created for and 14% said it had not. Successful purposes included environmental education, fishing, spiritual reasons, an homage to an important person, conservation, coral restoration, a lightened load on nearby coral reef ecosystems, tourism and research. Purposes which were considered unsuccessful included restoration, research, and a lessened load on nearby coral reef ecosystems.

Table 4.3 Factors to consider in creating HMRs, as identified by interview participants.

Factor	**Considerations**	**Example**
Social context	Local community approval, political will, economic priorities and distribution of benefits, local regulations	"It has to be accepted so it is respected" (08-EDU)
Environmental context	Weather patterns, condition of nearby reefs, water quality	"In a hurricane, the structure can break and it can break others nearby" (10-FIS)
Purpose	Purpose, problem to address	"What do you want it for?" (16-MGT)
Design	Aesthetics, financial cost, materials, units, size, type, uniqueness, weight, shape, similarity to "natural" reefs	"They need to look adequate for the environment" (05-ARC)
Experience	Knowledge of coastal dynamics, previous experience creating HMRs, ego, stress	"You need to find someone who has done it before and find out what problems they had, try not to repeat the same mistakes" (03-TOU)
Site	Currents, depth, wave action, proximity of coral reefs, existing marine life, stability of sea floor, preliminary studies, environmental impact assessment	"The most appropriate place" (11-TOU)
Installation	Anchoring, controlled sinking process, labour, financing, cleaning of toxic substances, compliance with regulations	"If it's a boat, it needs to be free of oil and so on" (19-TOU)
Impact on marine life	Damage to existing marine life, toxicity of materials	"You can't damage coral that is already there" (14-TOU)
Management	Maintenance & monitoring	"You need to think about the impact in the long term" (02-MGT)

4.4 Discussion

4.4.1 HMRs as novel ecosystems

The association of HMRs with change, and the accompanying feelings of hope or resistance, seems tightly interlinked with ideals of anthropogenic influence in nature. Such ideals come up often around the management of novel ecosystems, with advocates uplifting new configurations and backdrops for life, opponents seeking to maintain what remains of former systems, and most conservationists struggling to optimise in between (Backstrom *et al.* 2018). These dynamics are highly relevant to the management of HMRs in conservation; for example, one recent paper suggests using the level of alteration in a marine ecosystem to "triage" existing resources for conservation intervention, setting appropriate conservation goals according to how much benefit is possible and how much management is required (Schläppy and Hobbs 2019).

The variety and description of ecosystem services associated with HMRs (Figure 4.1 & 4.2, Table 4.1) does suggest that they are unique systems, occupying a socially distinct niche from "natural" coral or rocky reefs, and need to be studied and managed differently. In particular, the cultural ecosystem services took different forms than those postulated by Woodhead *et al.* (2019) for modified coral reefs. Beyond the suggestion of Collier (2014) that cultural ecosystem services could be generated in spaces where they did not previously exist, this could indicate that such services are expressed differently in novel ecosystems such as HMRs. In accidental shipwrecks, for example, items of "looted treasure" and shells were both identified as providing ornamental value, and archaeological knowledge systems were enhanced by the presence of marine life that could help estimate historical timestamps (Table 4.1). The use of religious idols and artistic sculptures to pay tribute to deceased individuals, purposefully coupled in some cases with the accumulation of marine life, presents a different form of aesthetic, spiritual and religious use from existence value and nature-based worship (Table 4.1, Millennium Ecosystem Assessment 2005; Cooper *et al.* 2016). HMRs occupy an unusual position in marine conservation because they can serve not only as transforming entities (e.g. shipwrecks and oil rigs) but also as tools for the restoration of what came before (e.g. coral restoration modules). This duality may inform participants' preference for HMRs in areas which have already faced substantial damage; in such places, the possibility of "natural" structures is foregone and the creation of something new does not cause as much conflict.

HMRs are often perceived as liminal spaces, with Lehman (2018) referring to them as "hybrid sites… often colonised by marine species such that the lines between natural and cultural object are blurred" (p. 294). They are not entirely natural, but not entirely human either. However, in one survey, 86% of recreational scuba divers agreed that diving on an HMR would be a "nature-based experience" (Kirkbride-Smith *et al.* 2013). Judging by the emotional descriptions of marine life provided by participants in this survey, people appear to derive not only resources but a deep sense of meaning from the fact that HMRs are also occupied by marine life. This relationship requires further investigation, particularly to understand the differences in stakeholders' approaches to marine life on HMRs. As is stated in Meier *et al.* (1989), the "rush of satisfaction observing the life created at the reef" can be hard to resist – but this may not hold true for all users (p. 1056).

4.4.2 Assessment & management of HMRs

The fact that participants tended to have much more positive opinions of HMRs they had created themselves while doling out occasionally severe criticism to HMRs created by others (Figure 4.6) may be indicative of the so-called "IKEA effect", which can lead both experienced people and novices to place additional value on self-made creations (Norton *et al.* 2012). This bias must be taken into consideration in HMR assessment, as discussions with the creator are an undoubtedly useful (and sometimes the only) way to gather information on individual projects, but won't be sufficient or appropriate for comparing between HMRs. The disparity in opinions could also reflect different priorities and purposes held by individuals, as reflected in their selection of the "most important" ecosystem service (Figure 4.1) and the association of ecosystem services with different activities (Figure 4.3). Further study is needed to understand how these disconnects and overlaps in priorities could affect conservation on HMRs in practice.

"Sinking to sink" may be the latest iteration within a history of well-meaning but ill-informed conservation interventions where the compilation of evidence can inform future action (Sutherland *et al.* 2004, Figure 4.4). Participants' descriptions of their motivations for HMR creation can seem prompted by a desire for personal action and catharsis in the face of pressing environmental problems, not unlike Kiik's (2018) description of conservationists "feeling morally justified by helping save at least some life on this 'burning planet'" even when such interventions do not go to plan (p. 404). Participants' strong call for planning, evaluation and expertise echoes one made in Meier *et al.* (1989, p. 1055) over thirty years ago: "We need to alter our (almost) national feeling that treats artificial reefs as 'fun projects' for anybody to do". Nonetheless, the prevailing conclusion that more planning and design are needed in the creation of HMRs may bode well for future projects if learning and impacts can be shared more centrally. This could potentially occur in focus groups bringing together various stakeholders and HMR creators, but any such gathering would need to be managed carefully given the strength of opinion and emotion involved with HMR creation and the wariness around sharing locations (described in Chapter 2).

4.4.3 Social & cultural aspects of HMR use

The strengths of emotion and opinion exhibited by participants mirror those found in other debates about HMR use in academic and public-facing literature (Meier *et al.* 1989; Fronda and French 2015). More widely, human alterations to marine and coastal environments have previously been found to elicit strong emotional reactions and even galvanise environmental activism (Kearns and Collins 2012). The community- and awareness-building element of HMR creation in this situation has also been previously described by Trialfhianty and Suadi (2017) in a context of coral restoration. The level of care and investment participants exhibited around HMRs shows they could be a lightning rod for marine conservation issues, providing a major opportunity to engage with people but also containing potential for significant upset and division if they do not feel appropriately involved.

While the cultural aspects of shipwrecks and other archaeological sites have been well-documented and discussed (Erreguerena 2012; Lehman 2018), the cultural dimensions of other HMRs have received much less academic attention despite clearly having rich and complex social impacts. In our study, comparisons of HMRs to terrestrial cultural spaces such as temples and museums were notable, as if people were finding ways to recreate or expand cultural experiences underwater. Perdomo (2012) similarly describes the experience of visiting an underwater sculpture garden saying, "The eerie result combines the aesthetic of Atlantis, the fabled lost city, with Rodin's garden" (p. 82). Verrips (2015) calls for further investigation of religious and spiritual sculptures underwater, describing various submerged religious Catholic, Buddhist and Hindu statues created since World War 2, as well as memorials to deceased individuals. He also describes an Italian ritual with marked similarities to the one described by one of our participants: divers swim out to an underwater sculpture of Jesus Christ with torches and place a wreath at its base to commemorate people who lost their lives at sea, followed by prayers and a mass on the beach (Verrips 2015). The practice of using Reef Balls with cremated ashes incorporated into the concrete to enact burials at sea is also growing and is often marketed using conservation-related language. It is described on the website of one provider in the following way: "Eternal Reefs combine a cremation urn, ash scattering, and burial at sea into one meaningful, permanent environmental tribute to life" (Eternal Reefs 2020). Finally, while the religious connotations of the Virgin Mary statue used to promote enforcement and heal a rift appear unique, Greenpeace have recently also dropped boulders as HMRs to stop trawling in UK protected areas (Rowlatt 2021).

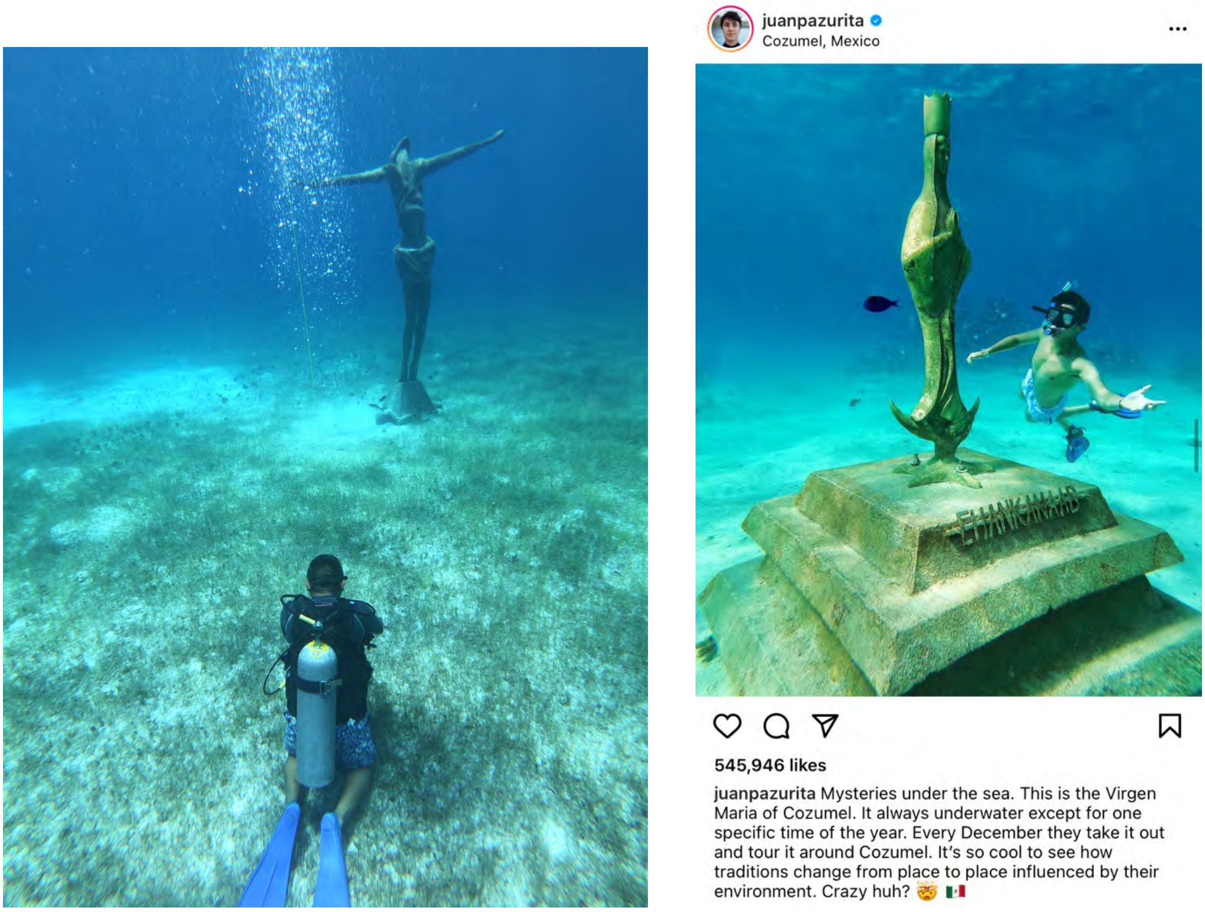


Figure 4.7 Photos of religious sculpture HMRs in use in Cozumel. Left: A diver kneels in front of a statue of Jesus Christ in Cozumel (SCT, May 2019). Right: A Mexican Instagram influencer (@juanpazurita) poses with a statue of the Virgin Mary in Cozumel, in a post from January 12, 2020 with over 500,000 likes.

4.4.4 *Assessing impacts of HMRs*

Carr and Hixon (1997) write, "methods used to evaluate the performance of an artificial reef will vary according to the purpose for which the reef was built" (p. 28). Our participants often focused on intention and original purpose (Table 4.2), reflecting a wider focus on purpose in the literature. However, original goals for HMRs are not always articulated or recorded (Becker *et al.* 2018) and HMR creation can clearly unleash costs and benefits beyond the original purpose.

The list of factors to consider in HMR creation (Table 4.3) overlapped considerably with the table of "crucial factors and issues" highlighted in a review by Baine (2001), though participants in our study focused more specifically on impacts to marine life, the experience of the person creating the HMR, monitoring and management, as well as going into further detail around social concerns. Aesthetic values are known to mediate perceptions of cultural ecosystem services (Cooper *et al.* 2016) which aligns with the strong importance ascribed to supposed beauty or ugliness in attitudes to HMRs (Figure 4.4).

The ecosystem services framework provided a useful structure for exploring the benefits and values provided by HMRs. However, particularly in the case of cultural dimensions I found further analysis through the lenses of costs and benefits and attitudes provided a fuller window into the social roles of HMRs. The association of different HMR types with different ecosystem services (Figure 4.3) indicates that a portfolio of structures has developed and will continue to be necessary to enable the activities of different stakeholders. No one type of HMR is likely to provide all services or work for all activities, so the development of multipurpose structures (Dafforn *et al.* 2015) and adaptation of existing infrastructure such as seawalls, wind farms and oil rigs (Causon and Gill 2018; Fowler *et al.* 2018; Morris *et al.* 2018) is crucial.

4.4.5 *Applications to conservation*

Given that many types of HMRs may be providing benefits of conservation relevance, key future questions for conservationists will revolve around working with different HMR types and stakeholders to achieve conservation aims (Chapters 2 & 3). These could range from ensuring that the "habitat" provided by different HMR types is adequate and beneficial for marine organisms (Abelson and Shlesinger 2002) to building environmental education and awareness programmes around aesthetically appealing artistic HMRs (Beans 2018), or collaborating with archaeologists to protect sites where cultural heritage and ecological importance overlap (Krumholz and Brennan 2015). It may also mean looking out for unintended consequences of HMR creation even when projects are well-intended, such as the accumulation of litter (Aguilera *et al.* 2016) or pollution as materials decompose (Allen 2007).

The production of locally appropriate guidelines for HMR creation may also be key, aiding in the creation of structured decision-making processes around permits because "local decision-makers do not have the experience to apply to an artificial reef proposal and many rely on existing anecdotal data and 'expert' testimony" (Williams 2006, p. vi). While some guidelines have been created (London Convention and Protocol/UNEP 2009; Fabi *et al.* 2015) there is an opportunity to build on these by including social and cultural aspects which can clearly be so powerful and divisive. The consideration of social factors in HMR projects more widely – including community involvement, awareness-raising, rituals and of course tourism – may open up exciting new channels for marine conservation.

It will be key to continue to adaptively assess and learn from existing HMR projects as they re-shape the marine environment, and to utilise social assessment in conservation interventions involving HMRs. As Gee (2019) states: "The more human intervention changed nature, the greater the need became to account for and guide human action" (p. 35).

Chapter 5

Untangling complex relationships between multiple stakeholders and marine life to envision collaborative conservation on human-made reefs

Tourists and fish swim over a field of Reef Balls. Photo: SCT, Cozumel 2019.

5 Untangling complex relationships between multiple stakeholders and marine life to envision collaborative conservation on human-made reefs

"I am the sea
And nobody owns me!"

- *Pippi Longstocking*

5.1 Introduction

Human activities are exerting greater influence in marine spaces than ever before, with few areas exempt from their intense reach (Jones *et al.* 2018). Though the ocean has typically been considered beyond private ownership, people often enact a sense of ownership in marine and coastal environments through their activities, resulting in conflict between different stakeholders (Thompson 2007; Gee 2019). Determining the nature and impact of these activities, while balancing the priorities of different stakeholders and protecting marine life, has emerged as a key conservation challenge (Havice and Zalik 2018; Zaucha and Gee 2019).

Human-made reefs (HMRs, or hard, persistent structures submerged intentionally or accidentally in the ocean by humans) are increasingly varied and widespread in the world's oceans (Chapter 2; Bohnsack and Sutherland 1985; Dafforn *et al.* 2015; Ferrario *et al.* 2016; Ilieva *et al.* 2019; Bugnot *et al.* 2020). HMRs are used by a variety of stakeholders including artists, conservationists, educators, ecologists, fishers, archaeologists and tour operators (Kirkbride-Smith *et al.* 2013; Krumholz and Brennan 2015; Lee *et al.* 2018; Lima *et al.* 2019). Though the use of HMRs has historic origins in fishing and aquaculture and they continue to be used in this context, non-extractive uses such as marine tourism, conservation and education have expanded greatly (Chapter 4, Van Treeck and Schuhmacher 1999; Stolk *et al.* 2007; Lee *et al.* 2018). Despite being created for a wide variety of reasons, many HMRs can have significant social and ecological impacts for marine conservation (Chapter 2, Firth *et al.* 2016; van Elden *et al.* 2019).

When conservation takes place alongside other activities on HMRs, this "co-location" requires collaboration with other stakeholders to identify and prevent conflicts (Christie *et al.* 2014; Chapter 2). As Hicks *et al.* (2013) state, "To be successful, natural resource management should integrate conservation priorities with the goals of local resource users" (p. 1444). A greater understanding of the various activities that take place on HMRs, the people who carry them out, and the factors that lead to positive experiences within them, could help conservationists understand which goals and activities are likely to align. This could help identify fruitful areas for collaboration or at the very least contribute to "compatible coexistence" between stakeholders (Van Treeck and Schuhmacher 1999). Along these lines, Stolk *et al.* (2007) highlighted the need for more research to understand the varied social roles currently played by HMRs and inform management policy.

Ultimately, many HMRs are shared spaces, in which multiple human activities co-occur with marine life. As Bideci and Cater (2019) state, "the development of marine life around the artificial reefs attracts both wildlife and recreational scuba divers" (p 28), and various other users may be poised to join the mix. In a verbal parallel that captures the concentrated nature of human and wildlife interactions on HMRs, they have been described as both "fish aggregation devices" (Brickhill *et al.* 2005; Smith *et al.* 2015) and "diver aggregation devices" (Van Treeck and Schuhmacher 1999 p. 504).

The simultaneous use of HMRs for different activities has led to some debate, with Brock (1994) suggesting consumptive activities such as fishing and non-consumptive activities such as marine tourism and education are fundamentally mismatched since "the exploitation and viewing of marine life at a single location are not compatible activities" (p. 1186). Bohnsack and Sutherland (1985) suggested various HMR sites should be designed and designated for different uses, noting "conflicts often arise" between and amongst fishers and divers carrying out different activities (p. 31). Krumholz and Brennan (2015) describe "marine usage conflicts" around fishing and trawling on shipwrecks of archaeological interest, while also identifying a potential synergy through protection of important fish species (p. 127). On the other hand, HMRs are often used in ecotourism projects with the intention of creating multiple benefits, entertaining visitors while providing substrate and shelter for marine life (Shani *et al.* 2012).

Research on the conservation implications of HMRs has often focused in the ecological realm rather than on their complex social aspects (Belhassen *et al.* 2017) or on the interactions between human activities and marine life. Levels and types of marine life are often closely monitored in marine conservation, shaping objectives and serving as measures of ecosystem health. HMRs are now known to have the potential to develop diverse and productive ecological communities (Claisse *et al.* 2014; Consoli *et al.* 2015) which may differ from "natural" rocky and coral reefs in composition and trophic interactions (Simon *et al.* 2013; Ferrario *et al.* 2016; Becker *et al.* 2017). Some work has taken place to assess impacts of fishing on fish abundance, richness and diversity on HMRs (Krumholz and Brennan 2015) and of disturbance events such as touching or kicking in recreational scuba diving (Belhassen *et al.* 2017). Additionally, some user groups such as divers and fishers are known to have preferences regarding the abundance and coverage of marine life (Kirkbride-Smith *et al.* 2013) or for particular species (Milon 1989; Rudd and Tupper 2002; Stolk *et al.* 2007).

In order to reach a deeper understanding of the motivations and impacts involved in various HMR activities, some research – particularly in relation to fishing and tourism – has focused on the experience and preferences of different stakeholders. Milon (1989) found that having a previous positive experience is one of the most important reasons for continued use of specific HMR sites. While Bideci and Cater (2019) identified novelty as a key aspect of positive interactions with HMRs in a tourism context, Kirkbride-Smith *et al.* (2013) assessed satisfaction in recreational diving on HMRs in relation to several attributes, and found fish abundance to be the most important attribute for both novice and experienced divers. Stolk *et al.* (2007) suggested a conceptual model for the experience of scuba diving on an HMR, incorporating characteristics of the HMR itself – such as size, ease of access, cultural and historical significance, and "extent of colonisation" by marine life – as well as the background and encounters of the individual scuba diver, and the wider context of government and industry. In a comparison with "natural" reefs, Belhassen *et al.* (2017) found divers felt more relaxed around them than HMRs. Perceptions of and experiences on HMRs have been recognised as an underdeveloped area of study, as "social-science-based research to determine the experiential attributes of non-consumptive forms of recreation (particularly scuba diving) hosted by artificial reefs is lacking" (Stolk *et al.* 2007 p. 347). Beyond tourism, however, little is understood about how experiences of varied activities on HMRs may differ, or how they may impact marine life.

The island of Cozumel is located off the Caribbean coast of Mexico. It is a major tourism destination for snorkelers, cruise ships and scuba divers (Palafox Muñoz *et al.* 2015), an area of conservation importance containing two marine protected areas (Gress *et al.* 2018), and the site of several archaeological discoveries (Leshikar 1988; Hajovsky 2015). As such, it contains a diverse set of HMRs and stakeholders who are highly culturally and emotionally invested in their activities on these HMRs (Chapters 2 & 3). Given the need to build a greater understanding of relationships between different stakeholders and marine life on HMRs, in this chapter I use the island of Cozumel as a case study to ask:

- What activities do people carry out in relation to HMRs in Cozumel, and in what ways do these relate to conservation?
- How does the accumulation of marine life, or specific organisms, affect human activities? In what ways could it create conflicts and synergies, either 1) between humans and particular marine organisms, or 2) between humans carrying out different activities on HMRs?
- How can potential conflicts and synergies between activities or with particular types of marine life be acknowledged and worked with, to identify avenues for collaborative conservation?

5.2 Methods

40 semi-structured interviews regarding HMRs on the island of Cozumel were carried out with diverse stakeholders between January 2019 and May 2019 (Table 5.1, see Sections 1.6 and 3.2.1 for further details). Snowball sampling was used to identify research participants as they needed to have experience with HMRs; eligibility was determined through an initial online search and personal introductions on an informal scoping trip in 2017. Interviews were conducted in Spanish or English according to the preference of the participant, with the interviewer taking handwritten notes and audio-recording if the participant consented. Only one interviewer was present, and the interviews took place in locations selected by participants. Analysis for this paper took place based on handwritten notes, and no names were collected. The research was approved by the Oxford University Research Ethics Committee under Reference R60895/RE001 and followed local ethics procedures set by ECOSUR university in Mexico.

Table 5.1 Primary activity relating to HMRs, as identified by interview participants. Options for primary activities were defined based on informal interviews carried out during a scoping trip.

Activity	Participants
Archaeology	2
Art	2
Coastal protection	1
Cultural activities	2
Education	3
Fishing	4
Management of natural resources	1
Nature conservation	5
Recreation	2
Scientific research	6
Tour operation	11
Aquaculture	1
Grand Total	**40**

During the semi-structured interview questions analysed in this chapter (Table 1.2, SM1), participants were questioned about their use and understanding of HMRs, as well as their preferences, knowledge and actions regarding HMR-associated marine life. Participants were questioned about HMRs in general, but also about a particular case study they were aware of. In this case, participants were asked to think of a "case study" HMR they were familiar with and describe the activities they engaged in around this HMR, as well as the marine life they believed to be present on it and the impacts of this life on their activities. To determine the impacts of marine life on human activities, participants were presented with a diagram to indicate levels of marine life (Figure 5.1). They were asked to describe or imagine the experience of carrying out activities on their case study HMR with each of these levels of marine life. They were asked to rate this experience on a scale of 1-10, with 1 being a "terrible" experience and 10 being an "excellent" experience. After assigning a ranking, participants explained the reasoning behind their ranking. In order to more fully understand relationships to abundance of marine life, participants were then asked whether any particular organisms affected their experiences of carrying out activities on case study HMRs, either positively or negatively. Qualitative responses were coded thematically in NVivo 12 and further analysed using matrix coding. As in previous chapters, quotes by respondents are coded according to their stakeholder category (e.g. 01-TOU; for further details, see Chapters 2 & 3). Quantitative data were analysed on RStudio (version 1.2, "Orange Blossom") running R (version 3.6.2) running and using the packages *dplyr* and *ggplot*.

Figure 5.1 Levels of marine life as presented to interview participants when asking questions about preferences regarding abundance of marine life. From left: "None", "Some" and "Abundant".

5.3 Results

5.3.1 Activities on HMRs

Almost all interview participants identified themselves as taking part in multiple activities on their case study HMRs (Table 5.2, Figure 5.2). Participants chose five activities on average, with a maximum of 10 activities in two cases and a minimum of one in one case. They selected a wide range of case study HMRs for further discussion, consisting of prefabricated coral restoration modules (31%); purposeful shipwrecks (15%); artistic sculptures (15%); accidental shipwrecks (13%); lobster fishing traps (8%); historical Mayan artefacts (5%); religious sculptures (5%); piles of rocks and dead coral (5%); and oyster boxes for aquaculture (3%).

When asked to select the top three "priority activities" which they undertook on their case study HMR, participants selected conservation, tourism and education most often, followed by research, recreation and fishing (Table 5.2). Tourism was most often selected as the primary activity, whereas conservation was most often selected as the secondary activity, and education as a tertiary activity (Table 5.2). Out of 40 respondents, 75% (30 people) chose conservation as one of their activities and 20% (6 people) chose it as their primary or most important activity.

Table 5.2 Activities which participants stated they engaged in with respect to a case study HMR well-known to them, displaying the top three priority activities in order as determined by the respondent and the total number of times the activity was mentioned at any level of priority (All). Participants could select as many activities as they wanted. Conservation was highly popular, selected by 75% of participants in total, over 50% of participants as a priority activity, and 20% of participants as their primary activity. Tourism, education, scientific research, management and recreation were also selected by many participants.

Activity	**Priority**			**Total**	**Total**
	1st	*2nd*	*3rd*	(Priority)	(All)
Aquaculture	1	0	0	**1**	**4**
Archaeology	2	1	0	**3**	**4**
Art	2	1	1	**4**	**8**
Coastal protection	0	0	0	**0**	**2**
Conservation	6	8	9	**23**	**30**
Cultural activities	1	1	0	**2**	**10**
Education	5	6	9	**20**	**31**
Fishing	3	1	0	**4**	**6**
Management	1	0	1	**2**	**17**
Recreation	3	7	3	**13**	**28**
Scientific research	4	4	7	**15**	**20**
Spiritual activities	1	0	0	**1**	**5**
Tourism	10	8	5	**23**	**26**

Participants classified a variety of professional and amateur undertakings for themselves within each activity on HMRs, with the professional side often informing their prioritisation. Aquaculture could refer to the cultivation of oysters for pearls in specialised boxes or the practice of "coral gardening" including the planting and cleaning of coral fragments on concrete modules. Archaeology included participation in formal archaeological expeditions and investigations, but could also involve independent research and exploration of historical shipwrecks including the unsanctioned retrieval of artefacts sometimes referred to as "looting". Art included professional artists creating artistic sculptures for pay, as well as people photographing or filming HMRs and creating communication materials. Coastal protection referred to the use of HMRs to reduce erosion. Cultural activities included historical research on shipwrecks or Mayan artefacts, organisation of or participation in public events, and attempts to inform the public or change prevailing attitudes. Education included academic classes in subjects such as marine ecology, training in scuba diving or coral restoration, information given to tourists on tours, but also exchanges of information with family and friends. Fishing was mostly commercial but occasionally recreational, with one participant explaining that they only took a couple of lobsters for dinner. Management of HMRs could be within a government context, including activities such as enforcement or monitoring of marine life within a protected area, or within the context of a tourism operation where HMRs were constantly being cleaned and maintained. Recreation referred to visits to HMRs for personal reasons such as fun, curiosity or a deeper sense of meaning. Scientific research included the study of archaeological artefacts, as well as marine ecology and optimal design of HMRs. Spiritual activities included participation in formal rituals around religious structures such as the Virgin Mary, involving a Catholic mass performed by a priest, or a more abstract sense of peace or spirituality in the presence of HMRs (see Chapter 3 for more detail). Tourism referred to taking paying customers to see HMRs, and is a major livelihood in Cozumel.

Conservation involved a particularly wide swathe of undertakings, often couched within the practice of other priority activities. This was reflected in the high level of overlap or co-occurrence between conservation and other activities (Figure 5.2). When described most directly as a priority activity, conservation tended to focus on coral restoration or education efforts. For example, within tourism, participants described conservation efforts including the choice of dive site as a way to avoid damage to oversaturated coral reefs (33-TOU), as well as the opportunity to share information with tourists about environmental issues, build an ecotourism programme around teaching people coral restoration (07-ENV), create habitat for marine life while creating HMRs to serve as attractions for tourists (31-TOU), or restructure daily business operations to reduce water use and carbon emissions (34-TOU). Within fishing, sustainable practices such as not overfishing and respecting temporal or spatial closures were considered to be conservation. Within education and art, a focus on environmental issues was described as conservation due to a desire to build awareness and inspire change. Linking to scientific research and management, an emphasis on designing, deploying or monitoring coral restoration structures, or tracking the development of marine life on a new HMR, was considered conservation. Aquaculture provided an interesting example as it could involve the cultivation of endangered species such as oysters (22-SCI) or coral (06-SCI) and was therefore considered conservation.

When being carried out by the same person, some activities overlapped with conservation more often than others, both as general co-occurrences and priority activities (Figure 5.2). When considering the proportion of overlap in the context of total mentions, management, fishing, scientific research and education showed the greatest alignment with conservation, closely followed by tourism and art (Figure 5.2).

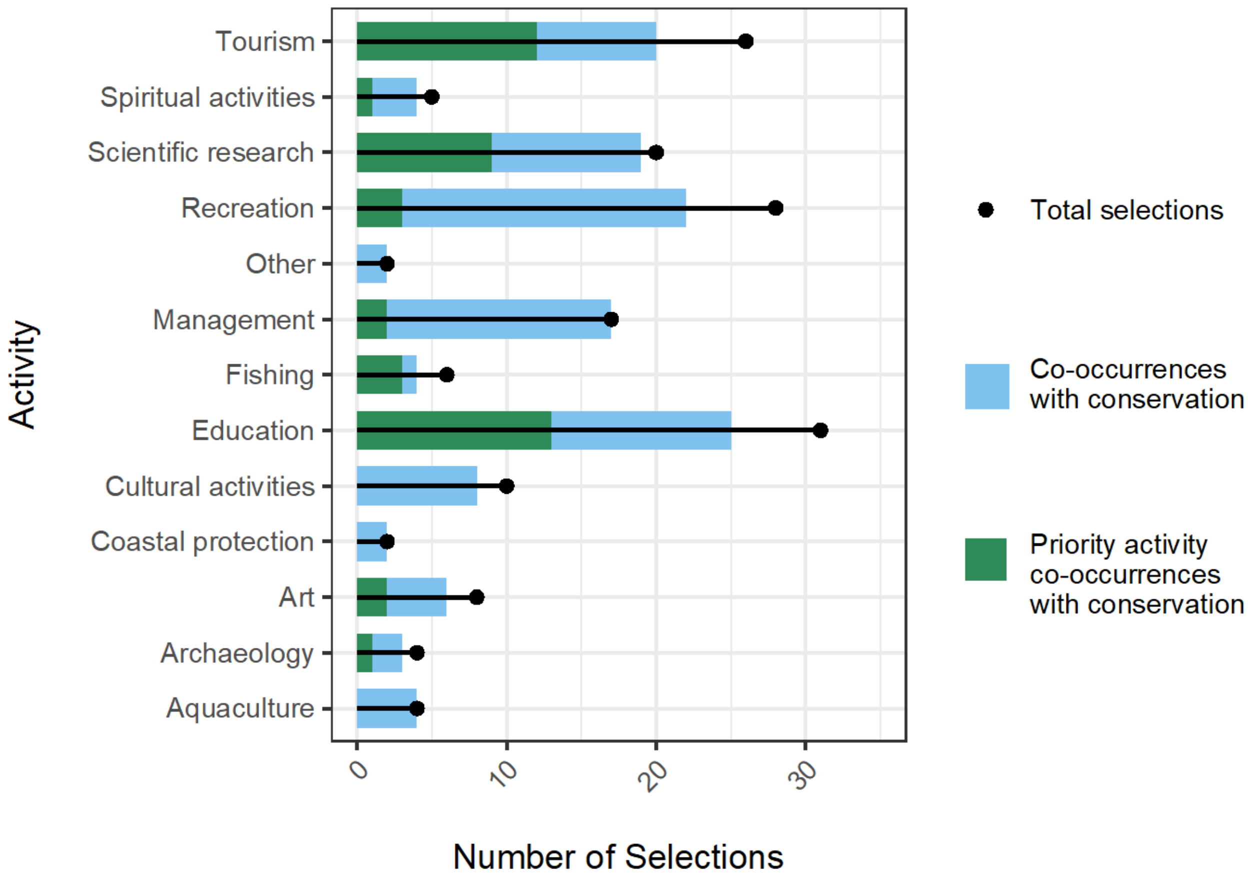


Figure 5.2 Co-occurrence of activities with conservation, as selected by participants for case study HMRs for which conservation was one of the activities selected. Dots indicate the total number of co-occurrences and bars indicate the number of co-occurrences of conservation and the given activity, overall and as priority activities. Conservation was most often selected along with education, in total and as a priority activity. Tourism and Scientific research were often selected with conservation, in total and as priority activities. Recreation and management were often co-selected with conservation, but not as priority activities.

Some activities were associated more strongly with some HMR subtypes, both in terms of primary activity and in general (Figure 5.3). Conservation, education, and tourism took place on all HMR subtypes, with scientific research and education taking place on most. Other activities, such as archaeology, aquaculture and spiritual activities, were much more limited to more specific HMR subtypes.

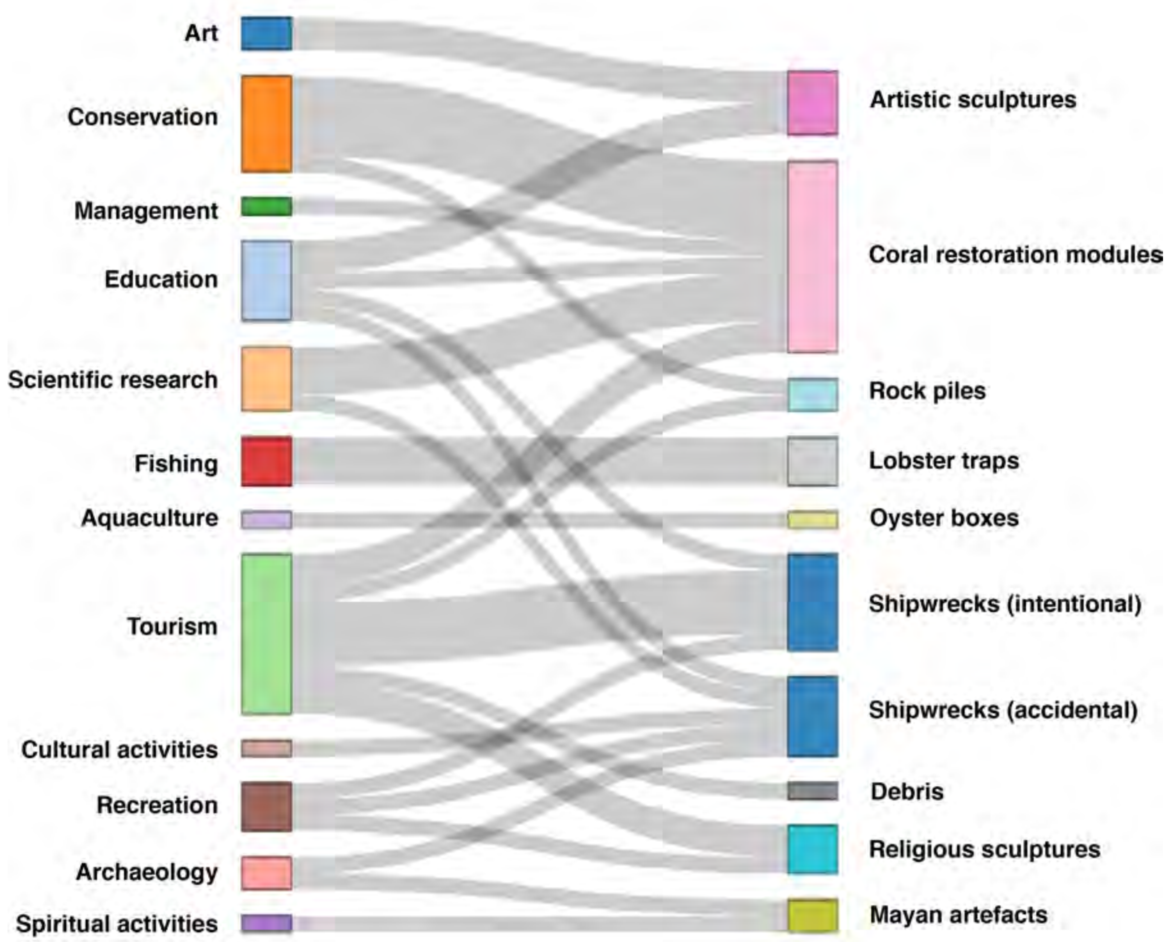


Figure 5.3 Primary activities (left) associated with HMR subtypes (right) for case study HMRs. Width of connecting line indicates the number of respondents out of 40 who selected a particular activity as their first priority with respect to a given case study subtype.

5.3.2 *Interactions with marine life*

When asked to describe the marine life actually present on their case study HMRs, all participants reported the presence of some type of marine life, and these types of marine life overlapped with descriptions of preferences in the previous sections (Figure 5.4). Almost all participants (over 95%) reported fish and mobile invertebrates as present, with reports of coral, algae and sessile invertebrates such as sponges also being very high (over 80%). Lionfish and lobster specifically were reported by almost two thirds of participants. Though participants were not asked directly about marine megafauna, 23% specifically identified megafauna in the "other" category through descriptions of rays and sharks.

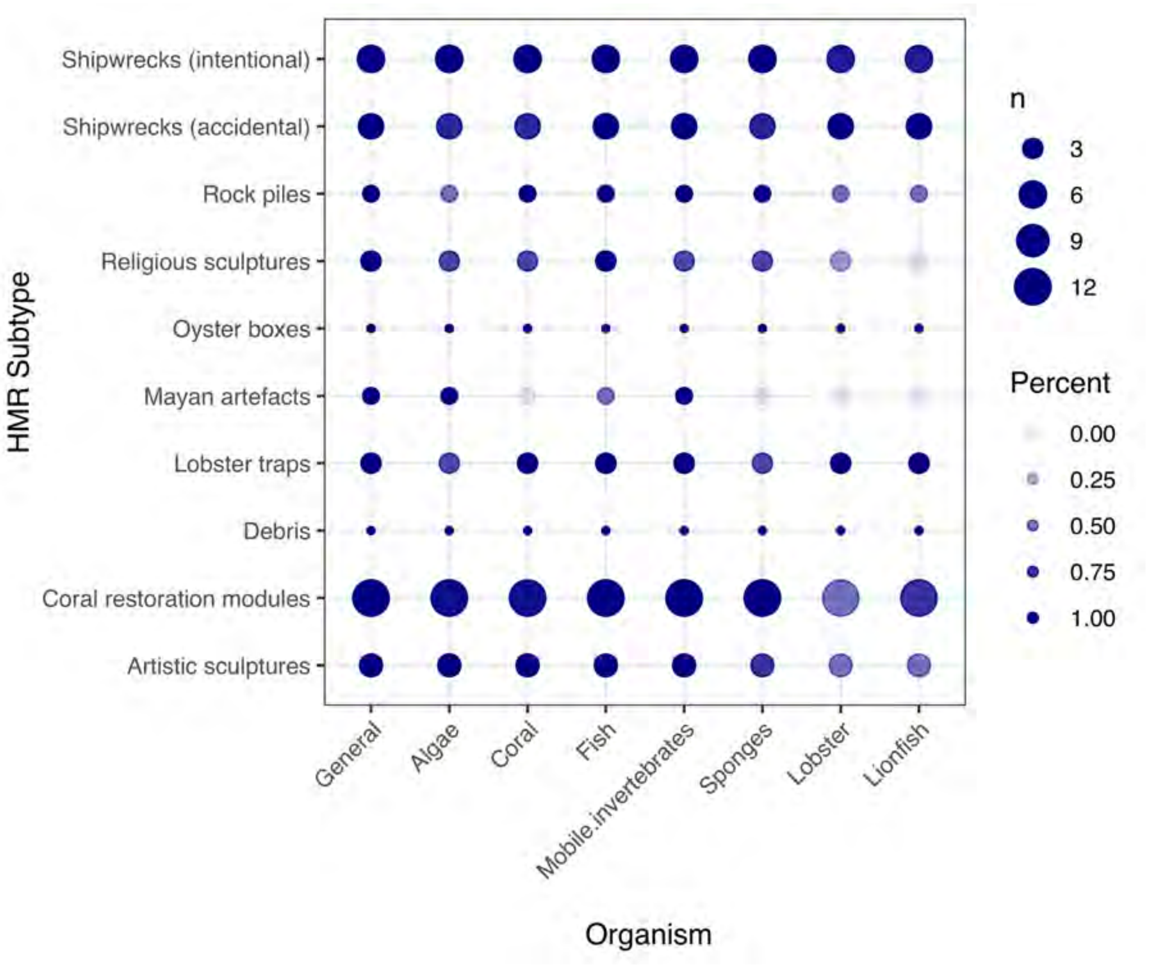


Figure 5.4 Types of marine life reported as present on case study HMRs. N= number of interviews discussing a subtype, and Percent indicates the percentage of the time an organism was labelled as present. All participants (100%) generally reported some type of marine life as present on their case study HMRs, with fish (97%) and mobile invertebrates (95%) being reported most often, followed by algae and coral (both 87%), and sponges (82%) as sessile invertebrates. Lionfish (62%) and lobster (64%), which were identified as species of management relevance by local conservation practitioners, were also reported often.

5.3.3 Attitudes to the accumulation of marine life

When questioned about the accumulation of marine life on HMRs (Figure 5.5), participants generally seemed to believe this was a positive process, with some participants believing it represented the accomplishment of a goal and others believing it added a new dimension. As one participant said, "it becomes much more spectacular, to see that change… they become living sculptures" (22-SCI). Another explained, "it's nice because it becomes more than just a statue, with what nature gives it" (03-TOU). In some cases, the structure itself became negligible because it was mostly viewed as a conduit for marine life; as one participant said, "we don't care about the structure, we want the life on top of it" (32-TOU). Integration with the surrounding environment seemed to be the gold standard for many participants, who expressed variations on the sentiment "when you can no longer perceive that it's an artificial structure, that is when you have had a complete success" (29-ENV). Several participants made reference to HMRs as the homes of marine animals, for example saying, "that octopus would travel around and it had its home near the concrete block" (04-TOU) or that "some fish took over it, or well one fish… it would defend its zone" (09-REC).

In some cases, the accumulation of marine life was seen as the result of passive accumulation, and in others as the result of human agency. This agency could be at the start of a project, with one participant saying "our intention, among other things, was to generate more marine life" (40-TOU), or as a continued input because "you need to maintain it, because if they don't like the structure then they leave" (10-FIS). There could also be a balance, with one participant saying, "You want to install it and for the sea to continue with its process" (37-AQU). In some cases, marine life was seen as an intrusion that needed to be removed, for example if it interfered with the purpose of a structure by rendering it less functional or visually attractive; as one participant said, "you can't see if it's all covered in stuff" (05-ARC).

People with different priority HMR-associated activities displayed varying patterns in preferences for the abundance of marine life (Figure 5.5). Most activities showed an overall positive relationship between accumulation of marine life and experience, with a significant difference across levels of marine life according to a Kruskal-Wallis test (Table 5.3). Conservation, fishing and management exhibited this positive relationship most strongly (though management showed no significant difference across levels of life) and education, research, recreation, tour operation and art exhibited it to a lesser degree. Some activities did not show a consistent slope or significant difference in experience across levels of marine life, such as spiritual and cultural activities, indicating that they may be relatively unaffected by the accumulation of marine life. Archaeology was unique in exhibiting an overall negative relationship between marine life and experience, where marine life appeared to consistently worsen the experience of carrying it out, though there was no significant difference detected between levels of life. Aquaculture was the only activity to demonstrate a convex shape, indicating that medium levels of marine life were optimal; however, it was only mentioned in one case so could not be verified more widely.

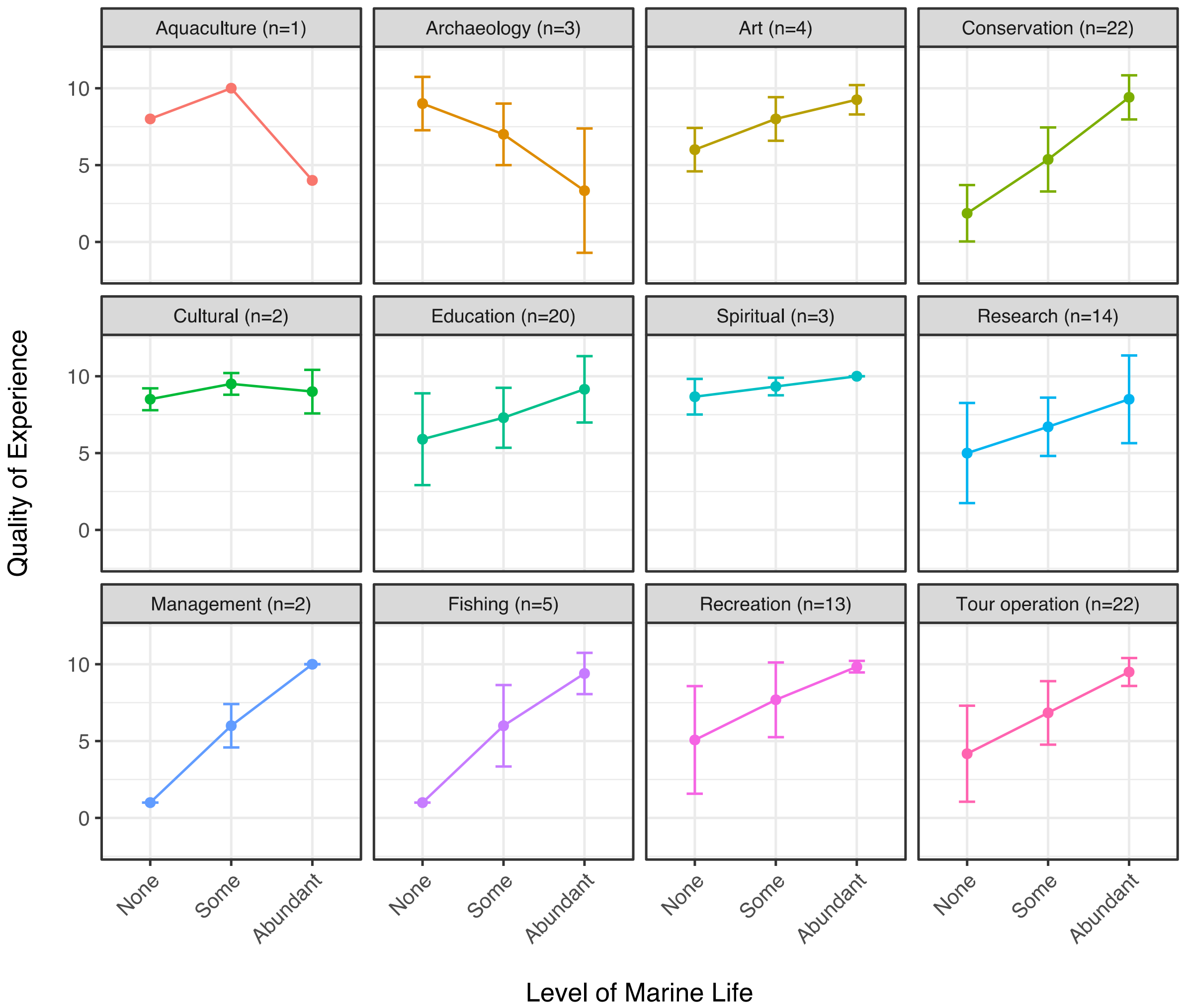


Figure 5.5 Effect of marine life accumulation on the experience of carrying out human activities on HMRs. "Quality of experience" was defined as 1 = Terrible and 10 = Excellent, and levels of marine life are as depicted in Figure 1. Participants selected between 1 and 4 priority activities they engage in on a specific case study HMR and rated their experience in reference to varying levels of marine life.

Table 5.3 Kruskal-Wallis test results for various activities assessing significant differences across abundance levels of marine life. (DF = 2).

Activity	**X^2**	**P-value**
Conservation	50.146	1.291e-11
Tourism	35.366	2.091e-08
Education	17.640	0.000148
Archaeology	3.578	0.167
Art	6.257	0.0438
Cultural activities	1.250	0.535
Fishing	11.886	0.00262
Spiritual activities	3.374	0.185
Research	9.194	0.0101
Management	4.849	0.0886
Recreation	17.127	0.000191
Aquaculture	2	0.368

5.3.3.1 Aquaculture

In aquaculture, having no marine life on an HMR (in this case, oyster boxes) was deemed good because it allowed for clear water flow. However, having some marine life was considered ideal because herbivorous organisms could help to "clean" oyster boxes and microorganisms provided "food" for oysters. An abundance of marine life was considered negative because it could decrease water flow leading to oyster mortality.

5.3.3.2 Archaeology

In an archaeological context, having no marine life was generally agreed to be ideal because it allowed ease of access to artefacts which were the focus of the activity, with easy view of details. As one participant said, "you don't have to mess with stuff that doesn't count" (30-ARC). The presence of some marine life could make HMRs harder to work with by obscuring details, though one participant indicated it depended because some organisms could have a protective effect and "we don't know if they will be good or bad" (05-ARC, see Tables 5.4 & 5.5 for more detail). The accumulation of marine life could also sometimes help to date artefacts, providing clues as to how long they had been submerged. One participant described the perfect HMR as being "complete, not too eaten up by the coral, not too destroyed by the sea" (25-ARC).

Having an abundance of marine life was referred to as "the worst" (30-ARC) because it required scraping and could "hide a lot of the information you want to extract" (25-ARC). As an example, one participant described time lost preparing "a cannon covered in accretion of marine life. I had to spend 14 days getting it out. If there hadn't been any marine life, we could have got down to it in a day" (30-ARC). Another participant presented a more nuanced view, acknowledging that with abundant marine life "it becomes very difficult but it adds a dimension" (05-ARC).

5.3.3.3 Art

In the case of art (where case studies focused on various sculptures designed to be placed underwater) participants generally believed artistic value increased with the accumulation of marine life. The marine context appeared to be a key artistic component, with one participant suggesting "you lose the notion of being in the sea" when no marine life was present (09-REC). Though participants generally agreed the HMRs themselves were attractive regardless of levels of marine life, there seemed to be a sense of unfulfilled potential when no marine life had accumulated. One participant cited concerns for marine life in this context and said, "it's good but not wow. It would be very frustrating because it would make me think it could actually be damaging for marine life and that would really mess with my head" (35-ART). When some marine life was present, experiences seemed to improve, with participants valuing interactions with marine species and one participant describing it as "very pleasant to see the experience the ocean is gifting you" (35-ART). An abundance of marine life was generally considered ideal, with one participant saying the piece could become more abstract in this way, and another explaining that even if some visual details were lost, "there was always an understanding that it was going to be covered over. I would like to register the process" (35-ART).

5.3.3.4 Conservation

The experience of doing conservation was strongly linked with levels of marine life, with one participant saying, "if there is no life, there is no conservation" (02-MGT). Various participants had emotional responses seeing no life on an HMR intended for conservation purposes, saying "it makes me sad" (18-FIS), "it would just be super deflating" (35-ART), and "the logistics are long, tiring, and maddening" (34-TOU). Many described a sense of failure, with one saying "it is not fulfilling its purpose" (15-MGT) and another saying "I'm not conserving anything, I spent half a million pesos and what am I doing with my life, [the research council] is going to hang me"

(21-SCI). Participants who described HMRs without marine life in a more positive way did so with the clear expectation that marine life would accumulate in the future, saying "it's got potential, I'm an optimist" (32-TOU) or "because we know it will have it" (33-TOU).

Once some marine life was present, reactions were more positive. Various participants making allusions to incremental success such as being "on the right path" (40-TOU), "a little grain of sand for conservation" (35-ART) or "beginning to work" (06-SCI). Some particular benefits identified were the ability to apply for further funding and to carry out research, and one participant described it as "positive and exciting but you have not yet reached your goal" (21-SCI). People who perceived having some marine life as negative continued to perceive this level of life as a disappointment, saying "you are not reaching its full potential" (26-TOU) or as a new burden of responsibility with "double work, because you need to think about how you are going to maintain that life, how it might leave" (34-TOU).

Abundant marine life was overall considered ideal, with one participant saying "the more life you have, the more success" (29-ENV). Many participants referred to success, with phrases such as "you know what you did worked" (06-SCI) and "all the objectives and plans were fulfilled" (40-TOU). Several participants mentioned themes of balance and the need to replicate structures that come to be covered in marine life. Two participants had stronger emotional reactions, with one saying "it would be amazing to see it like that" (35-ART) and another saying that taking a child to see it would be "an experience that will last their whole life, and they will never want it to be destroyed" (04-TOU). However, one participant said, "it is not different because what you want to do is keep it that way… you are always thinking about the moment when it will end or be gone" (34-TOU).

5.3.3.5 Cultural activities

When it came to cultural activities such as scuba diving on shipwrecks of historical interest, levels of marine life did not appear to impact experiences very strongly as they tended to be good regardless. When there was no marine life, there were some concerns about destruction of the HMR by humans or natural forces such as storms. However, one participant said, "it incites your imagination of what the ship might have been like… you can see it better when there is nothing on it" (19-TOU). Some marine life was linked with potential for protection of the site as well as being helpful in providing a sense of how long the shipwreck might have been there. Finally, an abundance of marine life was seen as positive for two reasons: first, because certain types of marine life could protect the shipwreck from degradation and "the more life there is, the more it is protected' (25-ARC); and second, because the presence of marine life could add a sense of atmosphere and "it is beautiful to see history embedded or anchored in nature" (19-TOU).

5.3.3.6 Education

Some participants felt education without marine life would be a bad experience because "there is nothing to show them" (17-FIS) and "you really want to talk about the species" (08-EDU). However, one participant said "where there are lemons, lemonade" (07-ENV) and others with this mindset found opportunities to discuss the design of structures, showcase the process and challenges of restoration, and observe details on the structures such as historically relevant markings. One participant described having to work harder when marine life is not present, since "you have to use your creativity to allow people to imagine future potential. You have to create an image in your students' minds as to what could potentially happen" (32-TOU). In the context of dive training, having no marine life was considered less of a problem, since HMRs could still be used to train people with buoyancy or underwater orientation, and this state was considered ideal in the context of shipwreck dive training since students can snag or hurt themselves on marine life.

Having some marine life was generally considered to improve the experience of education, because it was possible to explain more about marine species, interactions and ecological succession, and show that some restoration attempts can have a positive impact. This state was still not considered ideal, as one participant commented "it's not as good" (03-TOU) and another said "you still don't have that much to show them, just boring algae" (21-SCI). An abundance of marine life was generally considered to make for the best experience, since "people get more excited, and the instructors do too" (06-SCI) with increased interest and hope about "what might I find tomorrow" (21-SCI). Participants were glad that topics of discussion could be more varied, with the possibility of discussing diversity and the roles of species as indicators. The only perceived downsides were in the context of dive training, where instructors could face concerns about inexperienced divers damaging marine life, and in the context of historical education, where marine life could obscure important examples or information.

5.3.3.7 Spiritual activities

In the case of spiritual activities, participants generally indicated levels of marine life did not make a huge difference to their experiences, either because a religious sculpture "represents a lot" (33-TOU) on its own, or because "maybe it's not relevant" (09-REC). One participant stated that the experience would be good regardless of a lack of marine life, because of being "in a place so isolated from the everyday" (38-TOU). However, participants also indicated that an abundance of marine life "could be a representation of the unity between nature and humans" (09-REC) or provide an opportunity to "protect [the statues] from human predators" (33-TOU). Another indicated marine life could add to the spiritual dimension through observation and interaction, because "the experience is much richer… you feel like there is a connection and you are there for a reason" (38-TOU).

5.3.3.8 Scientific research

The suggested impact of marine life on researchers' experience of their case study HMR varied somewhat according to the type of research being conducted. Generally, participants seemed to believe there were research opportunities at all levels of marine life, though the topics of research would vary, as would the difficulty. One participant explained that "it depends on the context" (05-ARC) and another said "even if there is no life, it can still be valuable, since you can test materials or shapes or pHs. You can still learn" (29-ENV). A lack of marine life was associated with an ability to do better research in archaeology, whereas ecological research was more negatively impacted. Some participants suggested a lack of marine life could be associated with a positive research experience if it served as evidence that particular materials did not attract marine life. Some participants expressed a sense that this state was only the beginning of an uncertain process, since "you are still waiting to see what fauna arrives" (16-MGT) and "it's a little depressing because you don't know if it's going to work, but… it's not horrible because we know this is a slow process" (21-SCI). Others were more pessimistic and definite, saying "it did not fulfil its purpose" (03-TOU).

Having some marine life was associated with a better experience overall. It was considered more interesting by several participants because it was possible to study new interactions and track development of the community, and one participant described relief at the revelation that marine life was not rejecting the structure. However, some participants still expressed doubt in this state, since they felt uncertain about the future and it was unclear whether marine life would remain. An abundance of marine life was considered excellent from a research perspective because "you can make many comparisons" (15-MGT) and "it becomes much more complex, with different forms of life, benthic, fish, molluscs, you can obtain a lot of information" (29-ENV). Various participants noted increases in richness, success and complexity, and one participant saw this state as an opportunity to "understand the excess of life and its repercussions" (37-AQU). The exception was archaeological research, which "becomes very difficult though a new dimension is added" (05-ARC).

5.3.3.9 Management

Experiences of natural resource management were strongly linked to levels of marine life, with one participant explaining that if there is no marine life "there is nothing to manage… when you have more biodiversity, you need to manage the structure more" (02-MGT). Another participant linked the experience to levels of investment, explaining that when there is no marine life "you have to invest a lot, there are costs of operation and research" (15-MGT) but that as marine life increases, investment decreases and resources are more accessible.

5.3.3.10 Fishing

The experience of fishing on an HMR with no marine life was considered to be bad, because "you have nothing to fish" (10-FIS) and resources including time, scuba tanks and gasoline for the boat would be wasted. However, one participant indicated that even if an HMR has no marine life on it, it could still be useful as a point of reference while fishing. Another explained that lobster traps need time to work because "it needs to be covered in what is in the sea" (18-FIS) in order to attract lobsters. With some marine life present, the experience became more positive as there were organisms to fish. One participant considered this state ideal for a lobster trap, because "we want everything inside to be nice and clean so that more lobsters can fit" (18-FIS). However, most participants perceived an abundance of marine life as ideal because it was possible to be commercially successful, "you have options to choose from" (16-MGT) and it "feels cool to arrive and submerge yourself and see that it's full of lobster" (18-FIS).

5.3.3.11 Recreation

The impact of marine life on the experience of recreation appeared to be strongly affected by the type and location of HMR. If, as one participant said, "the structure itself is not attractive" (03-TOU) then the experience of recreation on it without marine life was considered bad. On the other hand, if the structure had other attributes such as being "pretty and interesting" (22-SCI), participants could point to benefits such as the "novelty of seeing a shipwreck" (11-TOU) and come to conclusions like "despite having no marine life, it was very impressive" (01-TOU). Some participants pointed to the context as key with one participant saying "the place itself, the remoteness of it and just being in a unique, isolated place" (38-TOU) could make for an excellent experience. One participant pointed to personal meaning as leading to a great experience, saying "it is something that symbolises my grandfather" (39-TOU).

Having some marine life did lead to some improvements in experience, since marine life could be entertaining and watching the process of colonisation could be interesting. One participant said, "it's emotional, it makes you excited, you say how pretty" (39-TOU). An abundance of marine life made no difference to some participants since the HMR "had always been attractive" (11-TOU) but others believed it was good when a structure looked more natural and had a lot of life associated with it. One participant said "it fulfils all expectations" (40-TOU) in this state and another said it was nice to see an HMR covered in organisms because "marine life is great, you know that now there is a place for the fish and the little animals and that there is life and colour" (39-TOU).

5.3.3.12 Tour operation

Levels of marine life had a strong impact on the experience of tour operation. Many participants described the challenges of making tourists appreciate an HMR with no marine life, and noted that a good tour guide could make a big difference. Several participants mentioned the need to integrate culture and education in this context, with one participant saying, "It's very, very difficult, but I made materials that explained that resources were going to be used for restoration. We had a lot of complaints of, 'there's nothing!'" (34-TOU). In trying to explain the tourist perspective, one participant emphasised the importance of colour and said, "What you want to see is life, colour. When it's inert, it's grey. There is no pleasure or joy" (29-ENV). Many participants explained that it felt frustrating not to have much to show tourists, and one said, "it's like an empty house, it's not very attractive" (25-ARC). In the absence of marine life, narrative became increasingly important, and one participant explained, "you can still do a story and you can still tell them it's the start of something" (08-EDU). As in recreation, an aesthetically pleasing structure or strong cultural narrative could compensate for a lack of marine life, with one participant saying "you use the cultural factor" (38-TOU) and another explaining, "it's a different kind of dive, it's historical. It's like going to a museum, but underwater" (19-TOU).

Having some marine life improved the experience of tour operation, since participants felt it was easier to call the attention of tourists, guide them to particular organisms and show off "something visually appealing" (32-TOU). Conversation flowed more easily discussing organisms tourists had seen, and the HMR looked better since "it's more nicely decorated, it has a nice feeling" (19-TOU). There also appeared to be benefits in showing a successful project, since "they can see development, they can see you are having results" (40-TOU). However, one participant said tourists could have very high expectations and "it doesn't stop being complicated. There are still comments of 'it's not enough, it's too poor, it wasn't worth it'" (34-TOU).

The experience of tour operation was generally best with an abundance of marine life, largely because tourists appeared to be more entertained and enjoy their experiences more. One participant said, "they take away better memories because they come out of the water marvelled" (31-TOU) while another described more practical benefits saying, "people will be satisfied and recommend us and we would have more economic flow" (04-TOU). Another participant described the pleasure of working with happy tourists who asked "question after question, learning and seeing" (38-TOU). In some cases, the anthropogenic aspect seemed to add cachet, with one participant saying, saying "they gawk at what we are able to create… I want another one next to it" (32-TOU). However, other participants seemed to think that the removal of obvious human presence was better, saying an abundance of marine life was ideal because "you don't perceive the artificial aspect of the structure anymore, the inertness. It is practically like looking at a natural aggregation" (29-ENV). This did appear to vary according to the cultural or spiritual component, since one participant emphasised the importance of keeping at least the hands and face of a religious structure clean. Even in ideal circumstances, the skill and interest of the guide was considered to be key in shaping the experience. One participant described the art of tour operation as "the creation of an experience, of making them say, 'wow, that was a different world, I saw everything'. But it still depends on the guide. The guide is very important" (34-TOU).

5.3.4 *What types of marine life are preferred or disliked?*

Beyond a general level of marine life, participants indicated variety in their preferences for and against particular organisms (Table 5.4, Table 5.5). As one participant explained, abundance was irrelevant if "it's not the kind of marine life that I want" (24-ART). Some organisms were almost universally liked, such as coral, and others were almost universally disliked, such as lionfish (Table 5.4, Figure 5.6). Many associations were contextual, so the same organism could be considered positive or negative in different activities or even for different reasons within the same activity (Table 5.4). Some common "positive" and "negative" characteristics of marine life on HMRs emerged across activities (Table 5.5). Some activities appeared to be associated with stronger preferences for or against marine organisms, as revealed by thematic coding of responses about which organisms impacted each activity (Table 5.4).

Several overall "positive" and "negative" characteristics emerged for organisms in relation to activities on HMRs (Table 5.5). Interestingly, overall similarity to, and difference from, coral reefs were both identified as being positive – resemblance was largely considered good in a context of coral restoration, whereas difference was considered good when it made HMRs unique and unusual. Characteristics associated with negative perceptions tended to have direct negative impacts on humans (e.g. sargassum algae being associated with skin allergies), indirect negative impacts on humans (e.g. interruption or increased difficulty of activities) or relate to a desired state for the ecosystem (e.g. disliking non-native species). Characteristics associated with positive perceptions were similarly related to the provision of direct benefits for humans (e.g. eating lobster or seeing beautiful animals), indirect benefits (e.g. ease of activities) or indications that a desired state of the ecosystem was being realised (e.g. diversity, complexity).

5.3.4.1 *Case study organisms*

I selected six organisms for further analysis as they were mentioned across several activities with a variety of positive and negative associations: lionfish, coral, lobster, urchins, algae and sharks (see Figure 5.6 for examples). These small case studies provide a sense of the complex shifting attitudes to organisms across activities and situations on HMRs. Organism categories were assigned according to the level of specificity mentioned by participants, meaning genus-level categorisation was possible for organisms such as lionfish (*Pterois sp.*) but not for coral which was often described as a group.

Lionfish were specifically identified as negative across seven activities: conservation, cultural activities, education, scientific research, fishing, recreation and tourism (Table 5.4, Figure 5.6). In a conservation context, they were identified as invasive predators feeding on small or juvenile fish and lobsters, interfering with reproduction and decreasing overall diversity. From a cultural standpoint, they were described as hiding and stinging people who were carrying out cultural activities such as diving on shipwrecks to satisfy historical or archaeological interests. In education, lionfish were described as dangerous and hidden with a painful sting, reducing biodiversity and interrupting educational activities because people no longer listen to explanations after they have been hurt. In a research context, one participant said lionfish might eat everything so there would be nothing left to study but algae. In relation to fishing, a participant explained that lionfish can take refuge in traps and prevent lobsters from entering them, as well as feeding on young lobsters. In the context of tourism, participants described general concern around ecosystem degradation with one person saying, "lionfish eat up all the fish you want to show people" (40-TOU). Lionfish had positive associations in two activities – tourism, because of being "pretty" (31-TOU), and education, where they were perceived as providing learning opportunities to explain how reefs were being damaged or to teach children not to touch dangerous animals.

Coral had positive associations across nine activities: archaeology, art, conservation, cultural activities, education, scientific research, management, recreation and tourism (Table 5.4, Figure 5.6). Coral was positively perceived in archaeology because of its role in preserving archaeological artefacts, creating a layer to protect objects from environmental damage and stop them falling apart, as well as being useful in marking artefacts and providing date estimates with coral cores. In cultural activities, coral was appreciated for burying, protecting and encapsulating material of historical interest. In art, coral was considered to be visually appealing. In conservation, coral was valued for its habitat-building properties, its ability to reproduce and create more coral, and as a symbol of conservation success. In education, coral was identified as an organism to help explain important concepts, in particular providing opportunities to showcase reef health and to measure how long it took to grow. In scientific research, coral provided an interesting opportunity to study behaviour and feeding patterns. In management it served as an "indicator species" for reef health (15-MGT). In recreation it was identified as interesting to observe. Finally, in tourism coral was appreciated for being photogenic. Coral only had negative associations in archaeology and associated scientific research, where one participant explained it could cover up delicate pieces and make them very difficult to clean or examine.

Lobsters had the most positive associations in fishing, where they were understandably described as "very helpful" (10-FIS) and several other organisms were identified as negative in relation because they could harm lobsters or stop them from entering traps. In education, lobsters were considered helpful because of being memorable, and sparking interest and further discussion; as one participant said, "people recognise them and they'll say to you, today I saw a lobster" (21-SCI). In management, lobsters were considered positive as an important commercial species which required special attention and management. In tourism, they were appreciated for being edible, cheap and delicious. Finally, in conservation lobsters were described as helpful to the ecosystem, but also had negative associations because one participant explained "they can attract illegal fishing" (34-TOU).

Urchins were divisive, receiving equal numbers of positive and negative associations across art, conservation, education, scientific research, fishing and tourism, and often being linked with reductions in levels of algae. In art, they were considered positive because of algae removal; as one participant said, "I don't like to see [my sculpture] when it's covered in algae, it makes me sad" (24-ART). In the context of education, urchins in conjunction with algae were seen as helpful in teaching about and indicating pollution and eutrophication. In the context of management, urchins were considered valuable as "herbivores" (02-MGT) fulfilling an important ecological function. In conservation, urchins were appreciated for removing algae that was seen as competing with coral. In the particular context of coral restoration where coral fragments are planted and "cleaned" every few days, urchins were seen as lightening the human workload, since one participant explained "they clean the algae so we don't have to brush" (08-EDU). However, urchins were also labelled as negative in conservation because "they indicate that something is wrong" (16-MGT) in association with high levels of algae. In tourism, urchins were negatively described as pricking or stinging people, defending their territory and being painful to touch accidentally.

Sharks were considered particularly impactful, and rated as both positive and negative in recreation and tourism. Participants acknowledged the impact of personal preference more than with any other organism, noting that some people would be afraid. However, in the context of recreation they were described as good because of being special and unusual. In tourism, sharks were judged not according to personal opinion but through projection of tourists' preferences and the need to keep them safe; one participant acknowledged this disconnect saying, "if it were me by myself, I would stay there just dumbstruck and so happy, but if I was taking tourists I would pull them out of the sea" (22-SCI).

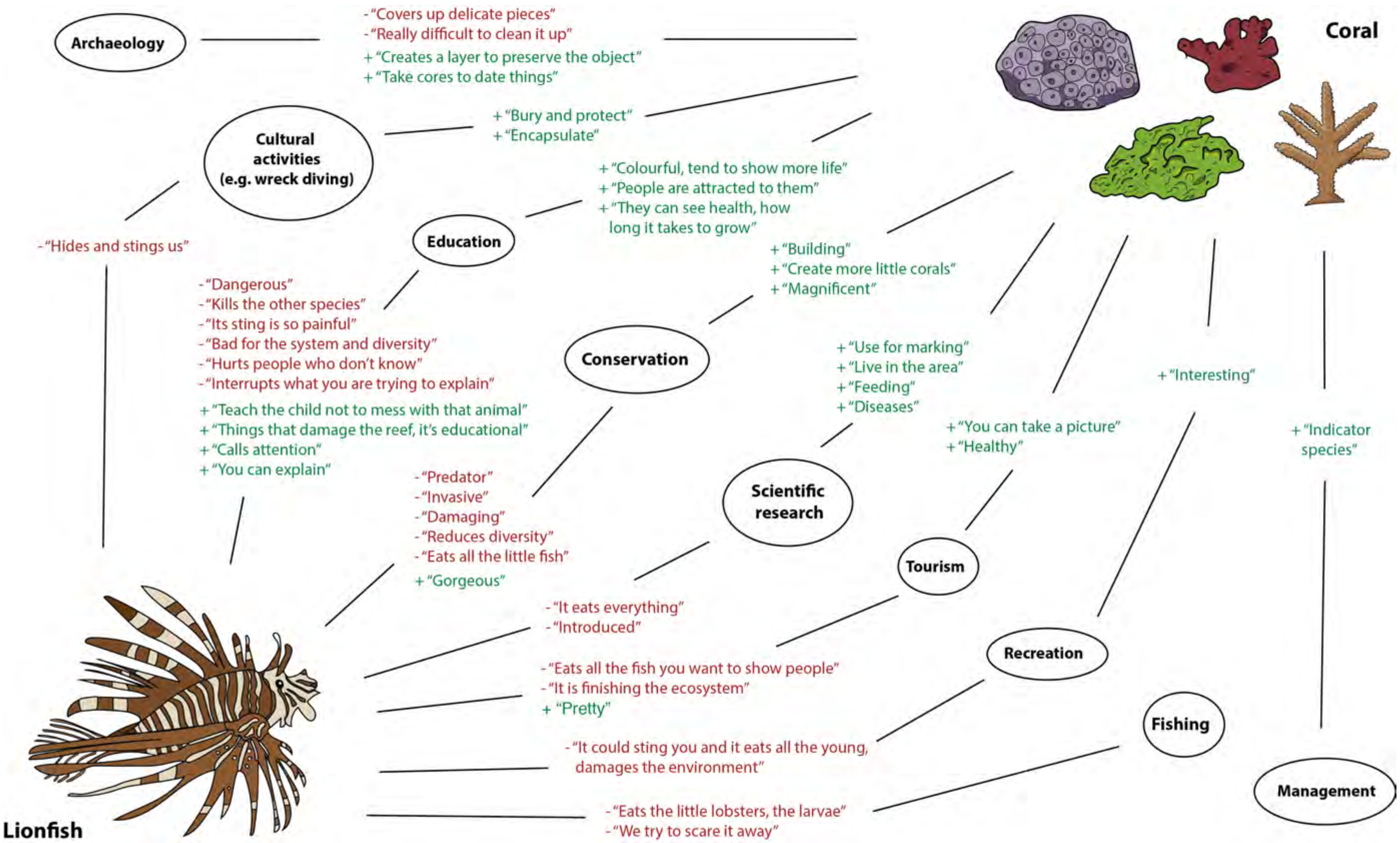


Figure 5.6 Examples of how perceptions of marine life on an HMR can vary according to the activity a person is engaged in and the organism encountered, as further analysed in Figure 5 and Tables 3 and 4. Participants could select up to four activities, and were asked to identify any organisms which could positively or negatively affect the experience of conducting each activity. ¬ Lionfish (Pterois sp., left) and coral (right) were selected as the two categories of marine organisms with the greatest number of negative and positive associations, respectively and in total, across activities. Quotes in red marked as (-) indicate statements coded as "negative" and quotes in green marked as (+) indicate statements coded as "positive".

Table 5.4 Organisms identified as having a positive or negative impact on activities taking place around case study HMRs (n = mentions in coded interviews). General categories in bold, with abundant sub-categories in italics, marked positive (+ or green) or negative (- or red) associations. Some organisms (such as lionfish and coral) impacted many activities, whereas others (such as shipworm, pufferfish and fire coral) mostly impacted one activity. Some organisms (such as lionfish and coral) could be associated with both positive and negative impacts, across different activities or even within the same activity. Additionally, some activities showed strong associations with individual organisms while others appeared not to be impacted.

	Aquaculture	Archaeology	Art	Conservation	Cultural activities	Education	Spiritual activities	Scientific research	Management	Fishing	Recreation	Tourism
Algae (+)	1	1	0	0	0	2	0	0	0	0	0	0
Algae (-)	0	0	1	6	0	2	0	3	0	0	0	5
Sargassum (-)	0	0	0	0	0	0	0	0	0	0	0	2
Fish (+)	0	0	4	6	0	7	0	1	0	2	6	11
Lionfish (+)	0	0	0	0	0	3	0	0	0	0	0	1
Parrotfish (+)	0	0	0	2	0	0	0	0	0	0	0	0
Fish (-)	0	1	0	10	1	7	0	2	0	6	1	5
Lionfish (-)	0	0	0	7	1	5	0	2	0	2	1	4
Parrotfish (-)	0	1	0	1	0	0	0	0	0	0	0	0
Pufferfish (-)	0	0	0	0	0	0	0	0	0	3	0	0
Megafauna (+)	0	0	1	0	0	0	0	0	0	0	5	5
Sharks (+)	0	0	0	0	0	0	0	0	0	0	3	2
Megafauna (-)	0	0	0	0	0	0	0	0	0	0	1	1
Sharks (-)	0	0	0	0	0	0	0	0	0	0	1	1
Mobile invertebrates (+)	0	0	1	3	0	2	0	0	2	5	1	4
Lobster (+)	0	0	0	1	0	1	0	0	1	4	0	1
Urchins (+)	0	0	1	2	0	1	0	0	1	0	0	0
Mobile invertebrates (-)	2	3	0	4	0	2	0	1	0	1	0	5
Lobster (-)	0	0	0	1	0	0	0	0	0	0	0	0
Shipworm (-)	0	3	0	0	0	0	0	0	0	0	0	0
Urchins (-)	0	0	0	1	0	1	0	0	0	0	0	3
Sessile invertebrates (+)	0	3	2	7	1	5	0	4	1	0	2	9
Coral (+)	0	3	1	6	1	4	0	4	1	0	1	5
Sponges (+)	0	0	1	1	0	0	0	0	0	0	1	3
Sessile invertebrates (-)	1	1	0	1	0	1	0	1	0	0	0	3
Coral (-)	0	1	0	0	0	0	0	1	0	0	0	0
Fire coral (-)	0	0	0	0	0	0	0	0	0	0	0	3
Sponges (-)	1	0	0	1	0	0	0	0	0	0	0	0
Total	**5**	**17**	**12**	**60**	**4**	**43**	**0**	**19**	**6**	**23**	**23**	**73**
Total/Activity mentions	***5***	***5.7***	***3***	***2.7***	***2***	***2.2***	***0***	***1.4***	***3***	***4.6***	***1.8***	***3.3***

Table 5.5 Characteristics linked to positive and negative associations with organisms on case study HMRs. Numbers indicate the number of times a characteristic was mentioned in association with a particular activity.

	Characteristics	Descriptions	Linked organisms	Linked activities
+	Visually appealing	Beautiful, pretty, big, magnificent, mobile, photogenic, colourful, eye-catching	Sponges, corals, lionfish, barracuda, crabs, lobster, fish	Art (1), Conservation (1), Education (4), Recreation (1), Tourism (8),
+	Local or native	Native, endemic, "already live there" (34-TOU), Caribbean	Corals, fish	Conservation (5), Education (1), Research (1)
+	Entertaining	Funny, friendly, inspiring, interesting, relatable, attention-calling, charismatic	Sergeant fish, eels, sea stars	Art (1), Conservation (2), Research (2), Tourism (2)
+	Edible or tradable	Delicious, cheap, "fish filets" (28-FIS), edible, commercially important	Fish, lobster	Fishing (1), Tourism (3)
+	Indicators of ecosystem health	Complex, diverse, life, variety, integrity, ecologically important, indicator species, ensemble, "big biodiversity" (08-EDU), "similar to what you see on the other coral reefs" (21-SCI)	"Everything"	Conservation (3), Education (4), Research (2), Management (2), Recreation (1), Tourism (4)
+	Helpful to other organisms (esp. desired species)	Prey, foundation species, creating habitat	Algae	Conservation (1), Fishing (1)
+	Enable human activities or decrease workload	Helpful, useful, cleaning, protecting, preserving, example, focusing, "tourists like fishes" (08-EDU)	Urchins, algae, herbivorous fish, lobster, crabs, parrotfish, corals	Archaeology (1), Fishing (2), Conservation (3), Research (3), Education (1), Tourism (2), Management (1)
+	Protecting the HMR	Enveloping, burying, encapsulating	Corals, algae	Archaeology (1)
+	Unusual	Rare, weird, special, impactful, "you see things you don't see on a coral reef" (27-TOU)	Sharks, corals	Conservation (1), Recreation (3), Tourism (1)
−	Harmful to humans	Dangerous, painful, stinging, hurts, burning, uncomfortable, skin allergies, defending	Sharks, fire coral, barracuda, sargassum, urchins, jellyfish	Education (3), Recreation (1), Tourism (9)
−	Harmful to other organisms (particularly desired species)	Smothering, competing, killing, invading, attacking, covering, doesn't allow reproduction, eating	Lionfish, parrotfish, algae	Conservation (1), Education (1), Research (1), Management (1), Fishing (3), Tourism (1)
−	Difficult to control	Difficult, voracious, predator, expensive, growing, eradicate, eats a lot, hiding	Lionfish, algae	Conservation (3), Scientific research (1), Fishing (1)
−	Non-native	Exotic, introduced, invasive	Lionfish	Conservation (6), Education (2), Research (2), Management (1)
−	Indicators of problems in the ecosystem	Imbalance, negative impact, bad for the system, reduces biodiversity	Algae, urchins, lionfish, algae	Conservation (1), Tourism (1)
−	Mood-killing	Scary, can't get near, boring, time-wasting, hard to keep optimistic	Shark, barracuda, eels, coral disease	Conservation (1), Education (2), Recreation (1), Tourism (1)
−	Interfere with human activities or increase workload	Cancel, interrupt, impact, doesn't allow, really difficult, attracts illegal fishing	Shark, coral oral, algae, lobster	Archaeology (1), Conservation (1)
−	Damaging the HMR	Degrading, destroying	Shipworms, bacteria, parrotfish	Archaeology (3)

5.3.5 Actions taken to shape marine life

Approximately half of participants (46%) described actions taking place on their case study HMRs to shape the marine life present on them. These actions included "planting" of coral fragments, "cleaning" or brushing to remove algae or sessile invertebrates, removal of rubbish or dead coral, data collection and targeted killing to remove lionfish.

Motivations for these actions – referred to as management or maintenance – were explained in a variety of ways. In some cases, a desire for a particular aesthetic was key; as one participant explained, "we cleaned it with a little brush so it would shine and look pretty" (22-SCI). In other cases, actions were justified as part of an ongoing battle with natural elements, with one participant saying "we need to keep sticking down pieces of coral because the waves unstick them" (26-TOU). Actions could be based on predicted ecological interactions affecting desired organisms; for example, one participant said "we remove the algae because we want corals and sponges to grow" (36-EDU) and another said "we remove predators like crabs" (37-AQU). Restraint could also be seen as an intervention to shape future abundance, with one participant explaining in the context of fishing, "you only remove what you can sell… it's important to leave some for future generations" (10-FIS).

Actions could also be interwoven with complex social interactions. They could relate to a sense of ownership and frustration with interference by other people; for example, one participant said about some piles of rock and coral rubble, "I kept arranging it because other people used it and they would move the things I had arranged" (31-TOU). They could be associated with a sense of personal mission and purpose; as one participant explained, "I discovered 98% of the coral I knew had died, so in that moment I planted my first coral" (06-SCI). In others, they appeared to be acts of devotion, either to the figure represented – such as religious icons – or the person who created the HMR. One participant described "systematic cleaning" in the context of "a tremendous bond of affection" with the creator of a sculpture, as well as with its subject who they considered "a model in everything" (36-EDU).

5.3.6 Conflicts and synergies with conservation

Activities on HMRs seemed to vary in their compatibility with conservation in relation to abundance of marine life (Figure 5.7). Art and conservation aligned around HMRs when a project had integrated themes of environment from the beginning, with one participant saying "it's a really exciting evolution to make habitat from a place of seeing it as living art" (24-ART). Fishing and conservation seemed to align to the extent of maintaining sustainable stocks of fish and lobster, as when a fisher explained one should "only take what is commercially important" (10-FIS). Education around HMRs often seemed to involve environmental themes, with dive instructors indicating they preferred to reduce risk to marine life on coral reefs by carrying out training with clumsy inexperienced divers on HMRs, or using HMRs to explain relevant issues such as declines in coral. Tourism and conservation goals seemed to align when business relied on having marine life to show people. As one participant said, "Hurricane Wilma devastated the reefs in the area we operated in, leaving sand and rocks and scarce marine life… the company had to take initial actions for restoration, to not distance ourselves from the affected area but be able to restore it… that place needed help, to restore it to how it had been before the hurricane" (34-TOU). However, pressure from tourism could also pose a risk to marine life, with one participant describing "snorkelers who kick, grab and pull" (36-EDU).

The relationship between conservation and archaeology seemed particularly fraught. As one participant explained, "Archaeologists and biologists do not have a good relationship. Biologists think archaeologists are destroyers, and archaeologists think biologists are ignorant with no knowledge of culture" (05-ARC). In describing an HMR in the context of archaeology, another participant said, "It's the opposite of most of these other sites, where you want to attract fish and make a habitat. We have different goals - to understand the uses, their culture, what they were doing, why they built it, how they used it, how it affected their day to day life here on the island" (30-ARC). Nonetheless, archaeologists did appreciate the protective nature of some organisms on artefacts, and one participant noted the destructive effects of ocean acidification which could point towards climate change as a common enemy.

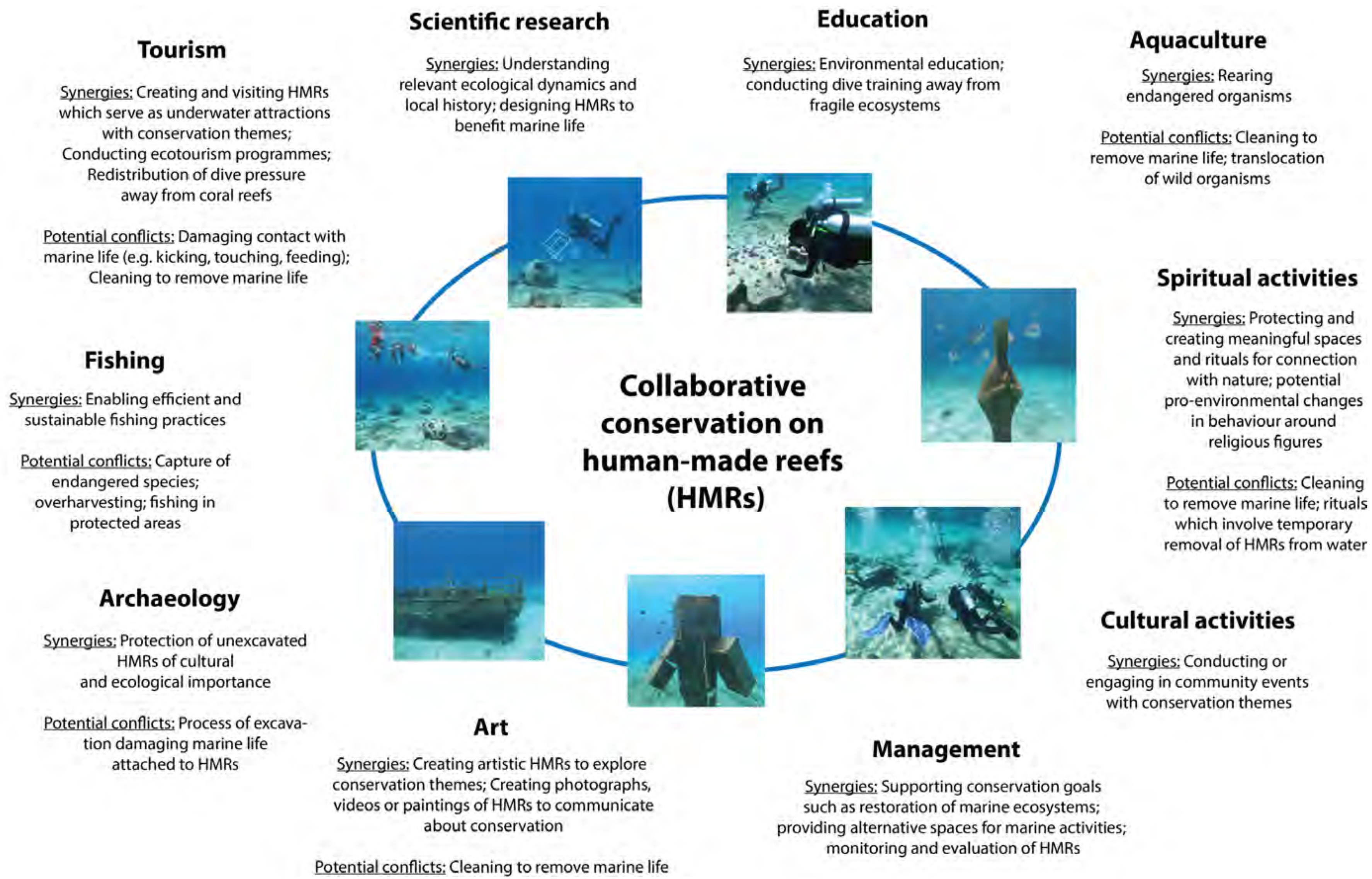


Figure 5.7 Synergies and potential conflicts identified between conservation and other activities on HMRs in Cozumel in relation to marine life.

5.4 Discussion

5.4.1 Conservation relevance

In considering the future of conservation on HMRs, it first seems important to widen the conception of "stakeholders", who are often defined by a single activity (Table 5.2, Figure 5.2). It is key to understand that many people take part in several activities around HMRs, even on a single structure, and often consider themselves to take part in conservation (Figure 5.2, Table 5.2). Despite conservation often not being selected as the primary activity, self-identification with the activity may provide valuable opportunities for cross-sector collaboration, with and between individuals who are already influential within communities relating to tourism, fishing, art, and other activities (Figure 5.7). In future research, it will be important to delve into multiple perspectives on conservation relating to HMRs, particularly with people who are not traditionally considered "conservationists". Even within traditional conservation, philosophies and intentions are known be extremely varied (Sandbrook *et al.* 2019) which suggests a need for a wider appreciation of the varied motivations for being, and self-describing as, conservationists. This could allow for a better understanding of potential synergies and what enacting different versions of conservation could look like in practice (Figure 5.7).

The variety of conservation-related activities described by participants, beyond those that might commonly be listed, could provide a roadmap of opportunities for collaboration with other stakeholders in the management of HMRs. This could facilitate the creation of "conservation partners, rather than opponents" (Teixeira *et al.* 2013 p. 245). The strength of opinions around what is right and wrong in HMR-related conservation may lead to heated exchanges, but there is also potential for this energy to be harnessed in community projects. The expansion of conservation intention beyond a specific job or type of person is a key component in the effective management of HMRs and other personally meaningful sites for conservation. However, further information is required concerning social and ecological conservation outcomes on particular structures. HMRs are clearly complex social spaces, and conservation will need to be considered in a cultural context along with the priorities and values held by multiple other stakeholders (see Chapter 3). Overall, collaborative management of HMRs for conservation will require widening perceptions of what a conservationist is and does, frank acknowledgment of situations in which goals may be opposed, and seizing of opportunities where mutual benefits exist.

One solution may be to leverage synergies and potential conflicts in different circumstances or stages, rather than seeking blanket collaborations. For example, in mapping of conservation-relevant HMRs it would be ideal to collaborate with people who have complementary expertise – such as fishers or archaeologists – but this may pose difficulties as they are sensitive about locations (Chapter 2). It may be necessary to limit collaborative detection work to situations in which mutual benefits exist. In the case of archaeology, one such situation could be in the designation of world heritage sites of mixed ecological and cultural importance (Abdulla *et al.* 2013). In contextualising and understanding HMR use, it is important to speak to people involved in various activities about the relevance of HMRs in their own fields, including archaeologists in order to understand their long-term view.

In terms of managing and interacting with marine life, some collaborations and co-locations may be easier than others. For example, collaborating with the tourism industry for coral restoration or conservation of charismatic species, or with fishers to hunt and sell invasive lionfish (Gallagher 2013), may be easier than deriving simultaneous benefits during an extractive archaeological excavation. However, technology in the field of archaeology is advancing which often allows for the gathering of information through non-destructive techniques, and *in situ* preservation is recommended in the first instance (UNESCO 2001). Additionally, the UNESCO Convention on the Protection of the Underwater Cultural Heritage (2001) contains a section on Environment, within which Rule 29 states: "An environmental policy shall be prepared that is adequate to ensure that the seabed and marine life are not unduly disturbed" (p. 28). The co-location of aquaculture and renewable energy structures has been suggested as particularly adept; however, Christie *et al.* (2014) stress the importance of legal assessment and adaptive management in assessing such arrangements.

5.4.2 Management of marine life

It does appear that people feel entitled to alter or influence the ecological communities on HMRs, either by adding desired organisms through activities such as planting of coral, or removing organisms perceived as undesirable such as lionfish and algae. This may be by virtue of the structures being human-made, which could lead to a sense that human influence has already been exerted. This coincides somewhat with the findings of Belhassen *et al.* (2017) who found that no recreational divers considered it acceptable to touch "natural" reefs but about 4% considered it acceptable to touch HMRs in their study; this attitude was borne out in practice with over twice as many disturbance events such as touching or kicking taking place on HMRs as on natural reefs. As the results around positive and negative associations with organisms show (Table 5.4), the "ideal" ecosystems associated with each activity look different, and people do appear to be taking actions to enact these ideals. Bohnsack and Sutherland (1985) suggest expanding these learnings to reef design, saying "reef designs that selectively attract or increase production of desirable species might be preferred to those that randomly attract the surrounding biota" (p. 26). While research around HMRs often explicitly takes into consideration the structural and geographic characteristics of an HMR in determining its associated ecological community (Hixon and Beets 1989; Wilhelmsson *et al.* 1998), my research suggests human activities must explicitly be taken into account as well. This could affect not only diversity and abundance at the species level, but also trophic interactions and ecosystem function, as suggested by Ferrario *et al.* (2016) who hypothesised high levels of angling and fishing at HMR sites could be leading to booms in herbivore populations grazing on a foundation species. This coincides with attitudes to urchins in this study, which appeared to be largely valued for their consumption of algae.

In terms of preferences regarding the general abundance of marine life (Figure 5.5) and characteristics associated with positive and negative associations (Table 5.5), my results on tourism and recreation aligned with the findings of Kirkbride-Smith *et al.* (2013) who found fish abundance to be the most important factor in diver satisfaction, with reef colours also being identified as important and historic value as relatively important. The results also echo those of Milon (1989) who found divers and anglers did not consider fish density on its own to be important unless accompanied by increases in "desirable species" (p. 861). Several attributes identified as important by participants in this research coincided with those in the model for diving experience developed by Stolk *et al.* (2007) including cultural historical significance, extent of colonisation, encounters with species, and diver demographics such as level of certification. Kirkbride-Smith *et al.* (2013) and Ong and Musa (2012) also found differences in preferences relating to diver experience, so this may be a crucial aspect. The attribute of being "unusual" relates to the previous identification of novelty as important in recreational diving (Bideci and Cater 2019). The overall finding that different activities are associated with particular preferences in terms of marine life is in keeping with those of Rudd and Tupper (2002) who found divers assigned value to the presence, size and abundance of particular fish species, and the assertion by

Stolk *et al.* (2007) that fishers and other stakeholders also seek out particular species. All organisms identified with positive or negative associations (Table 5.4) were identified as present on several HMRs (Figure 5.4) indicating that participants were envisaging realistic scenarios. Stolk *et al.* (2007) describes a "combination of social and natural history", which I saw echoed in terms of the trade-off that sometimes seemed to occur between the importance of marine life and cultural or historic value (p. 336). Likewise, the added value described by some participants regarding the addition of marine life to HMRs is echoed in Turner's (1961) description of an HMR designed to shelter fish: "to add to the desirability of the housing project, nature performed her own landscaping" (p. 12).

Various researchers have suggested designating HMRs for specific uses (Brock 1994; Ditton *et al.* 2002; Stolk *et al.* 2007). In the context of so many activities taking place on case study HMRs, it seems unfeasible to designate them for single uses; however, it would be necessary to assess this a case-by-case basis to consider the interplay between extractive and non-extractive uses. Though Stolk *et al.* (2007) stated these uses are incompatible because "the former is predicated on the removal of underwater attractions (i.e. marine fauna and flora) that facilitate the latter" and I did see these views reflected to some extent in my results, it may be possible to coexist at certain levels of extraction (p. 340). Negotiations of this kind would likely have to occur around fishing, archaeology and aquaculture. An example of this tension in action can be seen in a description of an archaeological project that took place in Cozumel in the 1980s, when "no coral was removed from the Cozumel guns. Therefore it was quite difficult to obtain detailed information regarding the cannon" (Albright 1987 p. 6). Further research is needed to understand conflict and coexistence, considering direct and indirect clashes. Some activities were associated with stronger preferences towards marine life in general and this could affect the feasibility of coexistence. For example, spiritual activities appeared to have no positive or negative associations with organisms and no significant difference in experience across levels of marine life, whereas activities like tourism, conservation, education and fishing seemed much more heavily impacted by levels and types of marine life. It seems likely that activities with similar preferences would co-exist better, though it strong divisions of opinion over specific organisms could remain.

Overall, this study demonstrates how crucial it is to be open-minded in seeking collaboration between conservation and other activities but also to acknowledge realistic boundaries, particularly where significant mismatches may occur, as between conservation and archaeology. There are some clear opportunities for synergy between conservation and other activities, where individuals may already be positioned across activities such as tourism and art, and in a good position to advocate for conservation practices. In several cases these collaborations appear to be occurring already. As these human-influenced ecosystems – whether "modified" or "novel" – become more common, as is the case with HMRs, further research is needed to understand the extent and ways that humans are intervening to shape the composition and abundance of organisms living on them. Exploring the role of marine conservation within broader social systems, and promoting collaboration across stakeholder groups, will be crucial to advancing conservation aims as human actions of various natures increasingly shape land and sea.

Chapter 6

Measuring diversity and abundance of marine life across a variety of human-made reefs to determine conservation potential

Schooling bluestriped grunts (Haemulon sciurus) and a lone sergeant major (Abudefduf saxatilis) swim around debris caused by Hurricane Wilma. Photo: SCT, Cozumel 2019.

6 Measuring richness and abundance of marine life across a variety of human-made reefs to determine their conservation potential

"The sea is everything… it is an immense desert,
where man is never lonely, for he feels life stirring on all sides"

- *Jules Verne (20,000 Leagues Under the Seas)*

6.1 Introduction

Human-made reefs (HMRs) are transforming marine ecosystems worldwide, increasing the availability of hard reef substrate and structural complexity available to organisms including fish and mobile invertebrates (Heery *et al.* 2017; Bugnot *et al.* 2020). HMRs have historically been created for many reasons including the extraction of resources such as fish or minerals, restoration of damaged ecosystems, and enhancement of tourism or other cultural activities (Chapters 2-5). Due in part to the proliferation of these structures, marine ecosystems are changing to the extent that Todd et al. (2019) propose that a nascent field of "urban marine ecology" has developed in heavily trafficked coastal areas.

Assessments of the diversity, richness and abundance of marine life have taken place across a variety of HMRs (Paxton *et al.* 2020), including shipwrecks (Whitfield *et al.* 2011; Consoli *et al.* 2015), piles of quarry rock, concrete shelters and automobiles (Turner *et al.* 1969), offshore infrastructure (Lindeboom *et al.* 2011; Claisse *et al.* 2014) and prefabricated modules (Ferreira *et al.* 2005). However, few have compared across more than two HMR types (Carlisle *et al.* 1963; Lemoine *et al.* 2019; Coolen *et al.* 2020) and many comparisons take place with natural reefs (Carr and Hixon 1997; Simon *et al.* 2013; Paxton *et al.* 2019). While comparisons to natural reefs have reached varying conclusions, it has become apparent that HMRs can sustain diverse and abundant communities of marine life (Carlisle *et al.* 1963; Claisse *et al.* 2014; Paxton *et al.* 2020).

Over thirty years ago, Bohnsack and Sutherland (1985) wrote: "Despite considerable enthusiasm by various government agencies, private organisations, and individuals, relatively little is known about the biology and ecology of artificial reefs" (p. 11). While much valuable information has been gathered since then, there is still much to learn about these complex ecosystems and understand their role within modern seascapes. It is necessary to consider both abiotic factors such as substrate, size, structural complexity and surrounding conditions, as well as biotic factors including abundance, diversity, richness and behaviour (Bortone and Kimmel 1991; Bortone *et al.* 2000). It is also crucial to be able to monitor biological communities across HMR types to characterise human influence as a whole and guide future decision-making in marine conservation (Chapter 2).

Specifically in relation to conservation aims, varied structures can be involved in restoration efforts (Edwards 2014; Lemoine *et al.* 2019) as well as environmental mitigation projects (Simon *et al.* 2013) and it is important to be able to make management decisions at a seascape level including decisions around decommissioning and removal of offshore infrastructure (van Elden *et al.* 2019). Currently, suggested survey methods for HMRs often require significant financial resources and expertise through the use of technology such as remotely operated vehicles (Ajemian *et al.* 2015; Consoli *et al.* 2015) or the involvement of knowledgeable divers to conduct surveys in situ (Lowry *et al.* 2012). The surveys are also designed for specific types of reefs, and therefore change according to factors such as size, shape and surrounding conditions (Bortone *et al.* 2000). Comparisons across varied HMR types raise numerous methodological questions, including how to design a survey protocol that can account for differences in size, structural complexity and materials.

In assessing HMRs, Seaman and Jensen (2000) highlight the importance of using "the right kinds of measurements at the right level of effort" due to limitations on time, money and personnel (p.13). Conservation and ecology have seen an evolution of rapid survey protocols such as the BioBlitz (Parker *et al.* 2018) which allow for the collection of relevant data in a short period of time with teams of scientists and volunteers. A citizen science programme using baited remote underwater video (BRUV) was proposed for the monitoring of fish communities on prefabricated module HMRs in Australia, given increases in their deployment (Florisson and Walker 2018). Underwater video is an increasingly popular survey tool for surveys of marine life on natural and human-made reefs, as it can make data collection more time-efficient, allow for verification when identification is uncertain or with multiple observers, reduce the impact of diver presence on sensitive species, and enable the participation of individuals without extensive training or experience (Coyer and Witman 1990; Lowry *et al.* 2012; Florisson and Walker 2018). It is therefore likely to be suitable for rapid assessments and citizen science studies of a variety of HMRs.

Given the need for ecological assessment of novel marine ecosystems to enable conservation decision-making and the lack of standardised methods to assess HMRs of various sizes, materials and origins, my objectives in this chapter were the following:

- Design and test a rapid, inexpensive, simple and replicable protocol to assess biotic and abiotic features of HMRs of various origins, sizes and materials
- Characterise ecological communities associated with a variety of HMRs around Cozumel, undertaking comparisons with natural coral and rocky reefs where appropriate
- Explore the effects of structural characteristics of HMRs on factors of conservation relevance such as species richness, abundance and ecosystem structure

6.2 Methods

6.2.1 Site and methodological overview

The island of Cozumel harbours a wide variety of HMRs in its coastal waters (Figure 6.1, Table 6.3), many of which were accessible from shore or with a short boat ride. I selected 70 structures to survey, with the aim of covering a broad range of HMRs so as to provide a robust test of the rapid survey protocol. These included purposeful shipwrecks, a planewreck, artistic and religious sculptures, infrastructure, rock piles, prefabricated coral restoration modules and debris from a hurricane (Figure 6.1, Table 6.3). All of these structures were identified during interviews with local experts (Chapters 3, 4 and 5), who often facilitated access to the structures in question.

In each survey, we measured abiotic variables (depth, size, shape, main substrate, holes, presence of internal space, GPS location) and biotic variables (presence, number, identity and behaviour of marine organisms). In designing the protocol, I drew inspiration from previous methods developed to survey coral and rocky reefs and HMRs (Coyer and Witman 1990; Bortone *et al.* 2000; Strelcheck 2001; Lowry *et al.* 2012; Folpp *et al.* 2013; Ajemian *et al.* 2015; Florisson and Walker 2018). Video and diver observations collected during the surveys were later analysed to produce both general (species richness and abundance for fish and mobile invertebrates) and targeted (presence of locally important species as identified by local conservation practitioners) metrics of marine life for individual HMRs and across subtypes. For relevant HMRs, I noted the presence of conservation-focused alterations such as coral planting and added rocks, confirmed activities with the people making the efforts, and tested for their impacts on richness and abundance of marine life. I also created generalised linear models to assess the association of HMR characteristics with richness and abundance of marine life. At one site, using a paired design, research assistants and I surveyed seven small natural reefs which were in close proximity and of a similar size to seven prefabricated concrete module HMRs, to enable a preliminary comparison between these HMRs and natural reefs. This was felt to be a valid comparison because these HMRs were created with the purpose of coral restoration. At another site, I analysed the impact of conservation alterations on prefabricated concrete HMRs, some of which had and others had not been subject to coral planting and the addition of rocks. This was in order to understand the effect of these intentional conservation actions on marine life. Finally, throughout the survey process, my research assistants and I discussed and noted reflections on the methods and protocol, identifying what worked well, problems and potential solutions.

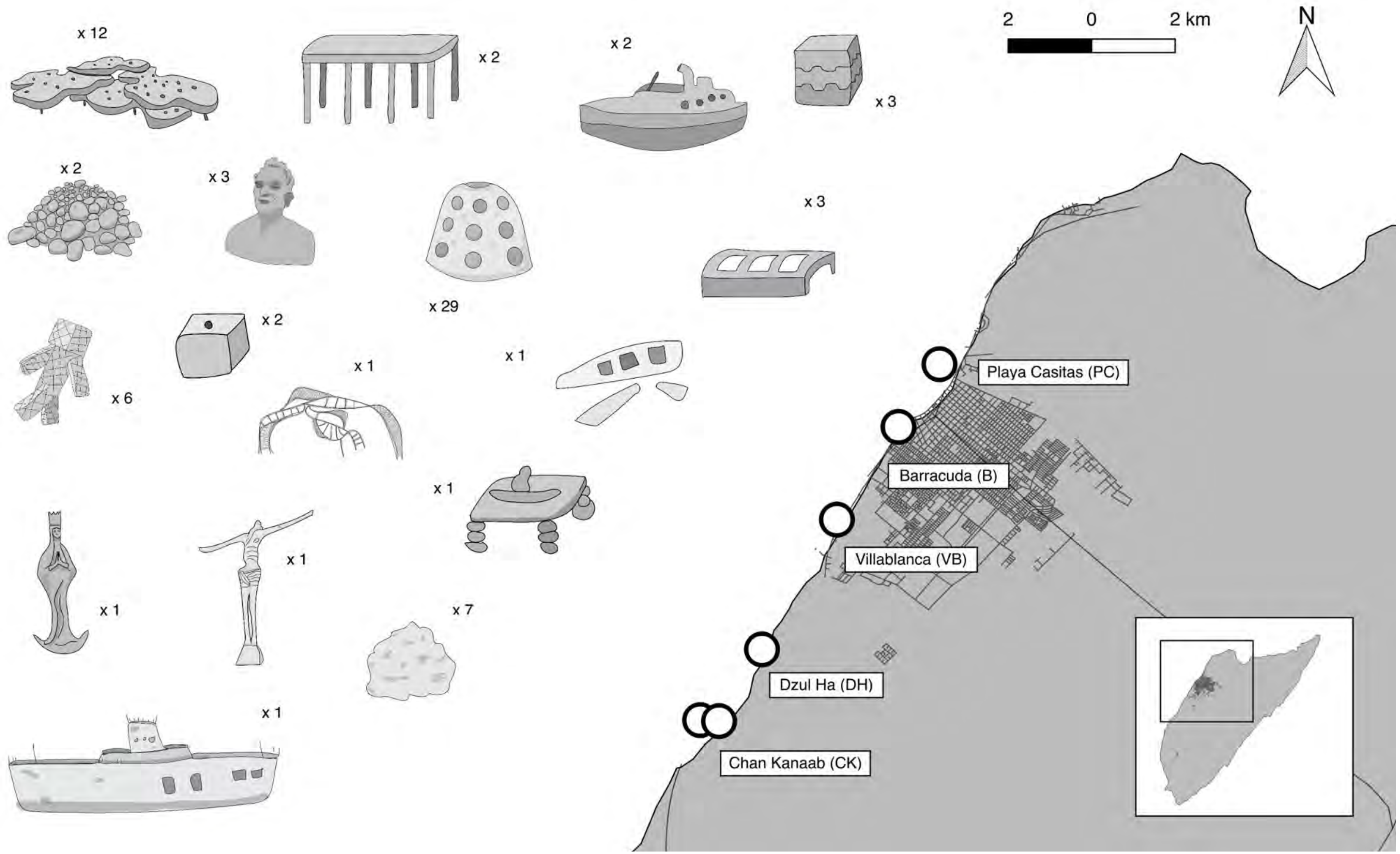


Figure 6.1 Map of HMR (n=70) and natural (n=7) structures surveyed at six sites around Cozumel, Mexico (refer to Table 3 for more detail). Natural reefs were not included in analyses of HMR abundance and richness, and only used to compare with appropriate HMRs. "X" indicates the number of structures surveyed. Drawings are not to scale and structure locations are not accurate.

6.2.2 Data collection

Diver and video surveys took place at 6 nearshore subtidal sites along the coast of Cozumel island between April and May 2019. We surveyed 77 structures, 70 of which were classified as HMRs and 7 of which were classified as "natural" coral or rocky reefs (Figure 6.1, Table 6.3). All necessary research permits (available in Supplementary Materials, ref. F00.9.DRPYCM.0005/2019 & F00.9.DRPYCM.0006/2019) were obtained from the Comisión Nacional de Áreas Protegidas (CONANP) prior to any research being conducted. Permits were laminated and carried with researchers while surveying.

All surveys followed a pre-determined research protocol (Table 6.1, Appendix 6.5.1) and took place in daylight hours between 9am and 4:30pm, and involved two divers: myself and a research assistant. At easily accessible sites, dives took place from shore, while sites that were further from the coast were accessed by a small boat provided by the local ecological research partner (Comisión Nacional de Áreas Naturales Protegidas, CONANP). Surveys followed safe diving practice (Flemming and Max 1988; PADI 2011), for example the use of a safety point contact and surface marker buoy (SMB) during all dives. Following dives, I undertook informal debriefing discussions with research assistants on what worked well during the surveys or what was complicated, in order to inform future surveys. Data collection sheets (Appendix 6.5.2, one sheet per structure) were printed on waterproof DuraRite® loose leaf paper and filled out using pencil underwater during the survey. Data were transferred to an Excel spreadsheet and all sheets were kept for future reference.

Table 6.1 Abiotic and biotic variables measured during HMR surveys. A = Abiotic, B = Biotic.

	Parameter	Method	Rationale	References
A	HMR dimensions (m)	Transect tape suspended between divers (height/length/width)	Size defines available substrate and shelter; conducted as last step in order to avoid disturbing marine life	(Baine 2001; Emslie *et al.* 2018)
A	HMR shape	Rough drawing *in situ*	Capture approximate shape in order to later calculate geometric area	(Young *et al.* 2017 & pers. comms.)
A	Main substrate (category)	Examination by diver supplemented by conversations with creators	Substrate materials and rugosity can affect structural stability and colonisation	(Carlisle 1961; Bortone *et al.* 2000; Baine 2001)
A	Holes (number and size)	Counted within size categories (<5cm, 5-10cm, 10-20cm, 20-30cm, 30-40cm, 40-50cm, 50+cm)	Presence and size of holes can affect access to internal space and therefore ability to shelter or access food in "cryptic places"	(Hixon and Beets 1989; Bortone *et al.* 2000; Wilson *et al.* 2007; Fabi *et al.* 2015)
A	Internal space (yes/no)	Presence/absence noted	Amount of internal or "void space" affects marine life that can shelter or reside within HMR	(Bortone *et al.* 2000; Lowry *et al.* 2012)
A	Visibility (m)	Transect tape suspended between two divers; one swims away holding up white dive slate, other tugs and notes distance when no longer visible	Visibility could affect ability to identify marine life in surveys	(Bortone *et al.* 2000; Fabi *et al.* 2015)
A	Location (Latitude and longitude)	Dive computer bookmarks synced with GPS device, in addition to hand drawn maps	Locate and recognise structures which have previously been surveyed and determine distance from other structures	(Collins and Baldock 2007)
A	Depth (m)	Maximum depth measured using dive computer	Depth can affect types of marine life present	(Bortone *et al.* 2000; Baine 2001; Collins and Baldock 2007)
A	Current strength (category)	Qualitative measure (low/medium/high)	May affect ability to carry out survey by researchers and behaviour of marine life	(Bortone *et al.* 2000; Lamb *et al.* 2020)
B	Species richness (number of species)	Fixed video (10 mins, 2m distance) and roving video (time scaled to size) surveys; diver observations when possible	Video surveys are often used to assess diversity and richness of species on HMRs; can verify with experts if necessary.	(Strelcheck 2001; Lowry *et al.* 2012; Ajemian *et al.* 2015; Florisson and Walker 2018)
B	Abundance (Max N individuals)	Fixed video (10 mins) and roving video (scaled to size) surveys checked for maximum individuals present in one frame	Underwater video surveys are often used to assess abundance of species on HMRs.	(Lowry *et al.* 2012; Folpp *et al.* 2013; Ajemian *et al.* 2015)
B	Fish behaviour (Yes/No in categories)	Presence/absence of behaviours by category (Swimming, Feeding, Hovering, Sheltering)	Behaviour can indicate how the HMR is being used by marine life	(Bortone *et al.* 2000; Witman *et al.* 2017)
B	Benthic community composition (% coverage)	Photo quadrats taken using quadrapod along middle band of structure and across centre of top	Benthic community composition	(Coyer and Witman 1990)

In order to minimise the impact of divers on the fish community, HMR assessments commenced with two standardised types of video surveys to quantify the abundance and richness of the fish and mobile invertebrate assemblage (Emslie *et al.* 2018). Videos were taken using a GoPro Hero 7 Black camera in a GoPro SuperSuit underwater housing, mounted on a quadrapod constructed from white plastic PVC pipes (2 cm diameter) and attached using a GoPro mount (Figure 6.3). The design of the quadrapod was based on Coyer and Witman (1990) and intended for use for both stable video and for capturing benthic quadrat photos (see Figures 6.2 & 6.3). Holes were drilled in the pipes to ensure that the quadrapod would be negatively buoyant. A 10-minute video was taken with a fixed camera two metres away from the structure lifted on the quadrapod 35cm off the benthos, facing into the current in order to avoid creating flow artefacts. A roving video was then taken by the diver, with time standardised to the horizontal length of the structure (<5m = 1 min, 5-10 m = 2 mins, 10-15 m = 3 mins, adding one minute per 5 metres of structure length). After videos were complete, a diver conducted a check of internal space to determine whether it was present and visually accessible and noting any organisms visible. On a subset of 51 structures where time allowed, one diver also wrote down all species of fish they could identify by eye, comprising a "diver observation" dataset. Two lasers were also purchased with the intent of measuring fish size, but with available materials it was not possible to maintain them in a completely fixed parallel position so they were not used.

Continuous, non-overlapping vertical benthic quadrat photographs were taken around the outside circumference of the structure using the quadrapod, in a "middle belt" based on the midpoint between the bottom and top of the structure (Figures 6.2 & 6.3). The quadrat size was 40cm x 40 cm with an area of .16m^2. The first vertical quadrat was taken from the direction of the current's flow, and quadrats proceeded clockwise. Continuous, non-overlapping horizontal benthic quadrat photographs were taken in a central line along the length of the structure. The number of vertical and horizontal quadrats varied by structure, according to how many it was possible to take along the middle belt of the structure. A Sidekick Duo® light was used to illuminate quadrats. Due to problems with variable lighting, light attachment and constraints on analysis time, these photos were ultimately not used to assess the benthic community.

The dimensions of the structure (maximum height, width, length) were measured using a transect tape and noted during the dive. The shape of the structure was recorded in *in-situ* sketch and in photographs, so that geometric shape could be used to calculate total volume. Finally, the number of holes on the structure was also documented, and holes were assigned approximate size categories based on the shortest diameter (as this was deemed to determine the minimum size of organisms that could fit through, adapted from Wilson et al. 2007). The location of surveyed structures was determined by combining data from a Garmin GPS 73 and a Suunto® Zoop Novo dive computer (method adapted from Collins and Baldock 2007). The GPS unit was secured to the SMB towed by a diver, and set to record tracks at the "smallest interval" (approximately 3 points per minute). During the dive, the diver used the "bookmarks" function on the dive computer to record the time, depth and temperature at which a particular structure was being surveyed. GPS tracks were later aligned with bookmarks and times to provide a location point for surveyed structures. Main substrate was determined by examination of the structure based on surface area and occasionally supplemented through discussions with HMR creators (Chapter 2). Temperature and maximum depth were measured using a Suunto® Zoop dive computer, with the diver placing the dive computer on the substrate for the reading. Maximum depths for structures ranged from 2.1m to 21.6m, with a mean depth of 4.8m and a median depth of 4.0m. Temperatures ranged from 27 to 28°C. In-water horizontal visibility was measured by suspending a 30m transect tape between two divers, with one diver staying in a fixed location holding a white data collection sheet and the other swimming away until the data collection sheet was no longer clearly visible, then tugging on the tape so that the stationary diver could note down the distance. On average, visibility was 27.4m, with a minimum of 25m and a maximum limit of 30m, due to the length of the measuring tape. This far exceeded the 2m distance at which cameras were placed from structures, indicating that issues of visibility did not interfere with the surveys.

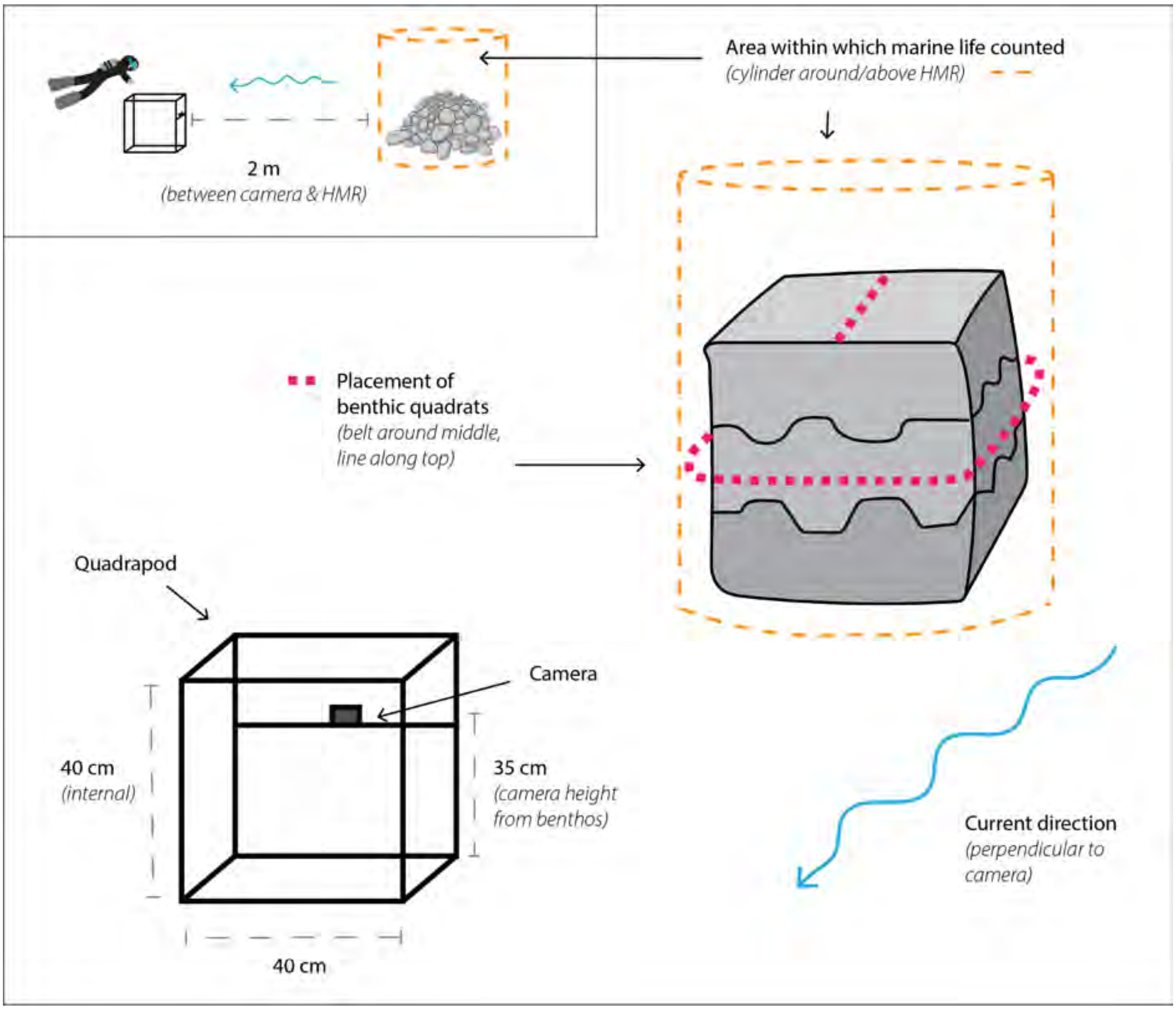


Figure 6.2 Illustration of survey methods, indicating placement of camera in relation to HMR and current as well as relevant distances and measurements.

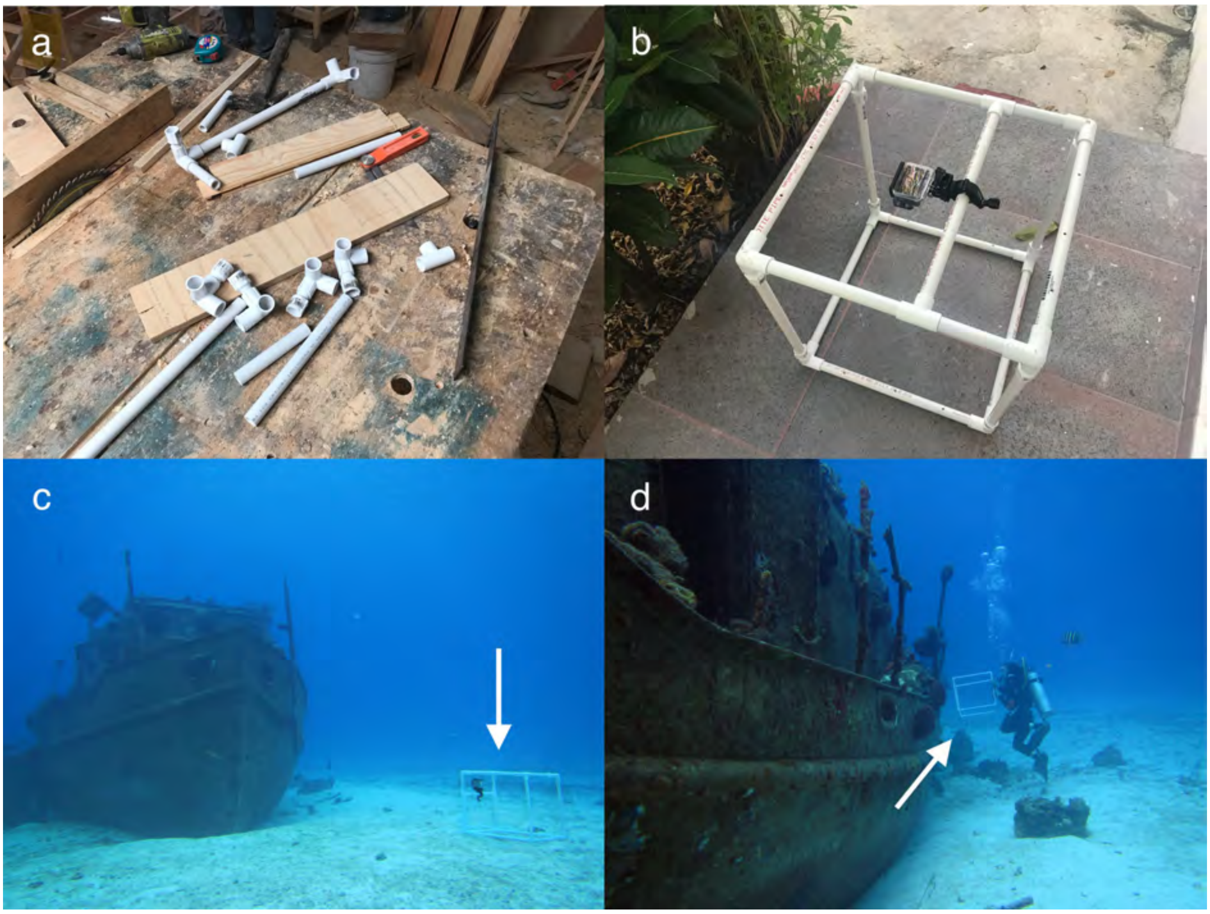


Figure 6.3 From top left to bottom right: a) PVC construction materials for quadrapod; b) Quadrapod set up with GoPro camera attached; c) Quadrapod in use to take fixed video; d) Quadrapod in use to take roving video and/or quadrats.

6.2.3 Data processing and analysis

Video data processing took place between May 2019 and February 2020. To quantify taxonomic richness, organisms were identified to species when possible, or genus or family when species level identification was not possible. To quantify fish abundance, Max N – the maximum number of species observed in a single frame – was recorded with a video timestamp (method adapted from Lowry et al. 2012; Folpp et al. 2013). Fish in different life stages were counted separately when morphology varied. Slow-moving mobile invertebrates such as urchins were counted across frames in roving video as long as they could be ascertained to be different individuals. Additionally, the first appearance of any organism was recorded with a time stamp in order to construct species accumulation curves and assess whether the data collection time was sufficient. Organisms were only counted if they were directly above, below or on the HMR, using an adapted version of the "cylinder" survey method (see Figure 6.2, method adapted from

Strelcheck 2001; Carl and Reid 2003). Four behaviours (swimming, eating, hovering, sheltering) were also noted as present or absent depending on whether they had been exhibited at any point by the species or genus during a given video. Diver observations were used to assess richness but not abundance.

Species of conservation and management relevance were identified in two ways: first, through meetings with local government partners who indicated the species they considered to be of particular local commercial (lobster, *Panulirus* sp.) and conservation (lionfish, *Pterois* sp.) relevance. As an alternative measure of conservation relevance, all fish identified to species level were cross-checked with the IUCN Red List of Endangered Species and species were classified as "Not Evaluated", "Data Deficient", "Least Concern", "Near Threatened", "Vulnerable", "Endangered", "Critically Endangered", "Extinct in the Wild" or "Extinct".

Since the majority (~90-95%) of organisms could be identified at the species level, this was the base unit used for aggregate quantification of richness, using the sum of all species present on a given structure, in a given group, or overall (e.g. detection of *Abudefduf saxatilis* + *Scarus iseri* + *Thalassoma bifasciatum* = 3 species for overall richness). Max N per species was aggregated to quantify overall abundance, using the sum of maximum number of individuals recorded in a single frame for each species on a given structure, in a given group, or overall (e.g. max 3 *Abudefduf saxatilis* + 2 *Scarus iseri* + 2 *Thalassoma bifasciatum* = 7 individual organisms for overall abundance). When organisms could not be identified to species, but were the only individuals present in their genus, they were included in species-level analyses and labelled at genus level (e.g. *Kyphosus sp.*).

All data analysis was conducted using R running on RStudio version 1.2, "Orange Blossom", using the packages *dplyr* and *ggplot2*. I used aggregate metrics to measure overall richness and abundance found on HMRs using data from video surveys and diver observations as well as using only data from video surveys to compare richness and abundance across various subgroups (HMR subtypes, HMR alterations, and comparison with natural coral/rocky reefs in one site where they were of comparable sizes). I created generalised linear models (Gaussian family for richness, Poisson family for abundance) to determine impacts of HMR characteristics. I created species accumulation curves to assess the validity of timing for surveys using the packages *vegan* and *lubridate*. Maps were created using QGIS version 2.18 (Las Palmas).

6.3 Results

6.3.1 Abundance and richness of marine life

Across video surveys and diver observations on 70 HMRs of various types including purposeful shipwrecks, prefabricated modules, artistic and religious sculptures, infrastructure and rock piles (Table 6.3, Figure 6.1) we detected 83 species, 60 genera and 37 families of fish and mobile invertebrates (Table 6.2, Appendix 6.5.3).

Table 6.2 Total numbers of families, genera and species identified across 70 HMRs through video surveys and diver observations (detailed information on common names, families, genera and species available in Appendix 6.5.3 & 6.5.4).

Category	Families	Genera	Species
Fish	33	55	78
Mobile Invertebrates	4	5	5

Some organisms were widespread, with surgeonfishes (*Acanthurus sp.)*, parrotfishes (*Scarus sp.* and *Sparisoma sp.*), wrasses (*Thalassoma sp.*, *Halichoeres sp.* and *Clepticus sp.)* and damselfishes (*Abudefduf sp.*, *Stegastes sp.*, *Microspathadon sp.* and *Pomacanthus sp.*) being detected on over 80% of structures (Figure 6.4, Appendix 6.5.4). Others were only detected on one or two structures. Abundance also varied, with some organisms including grunts (*Haemulon sp.*), damselfishes (*Abudefduf sp.*), chromis (*Chromis sp.*), sea chubs (*Kyphosus sp.*), sweepers (*Pempheris sp.*), wrasses (*Clepticus sp.*) and urchins (*Diadema sp.*) spotted in aggregations of 30 or more individuals on a single structure, though the majority of genera (~70%) were detected as solitary individuals or in small groups with fewer than 5 individuals (Figure 6.5).

Richness and abundance varied across HMR types and subtypes, with the most species being detected on coral restoration modules, shipwrecks and artistic sculptures and the highest abundances of organisms being found on docks, shipwrecks and rock piles (Figure 6.6). As the largest structures in the data set and only three structures surveyed, shipwrecks were likely under-sampled, so the richness and abundance of associated marine life may be even greater (Table 6.3, Figure 6.7, Figure 6.12).

6.3.2 Species of conservation and management relevance

Of the 78 fish identified to species, 71 (91%) were categorised as "Least Concern" (LC), while three (4%) were categorised as "Data Deficient", two (3%) were categorised as "Near Threatened", and two were unlisted. The two "Near Threatened" species were *Balistes vetula* or "Queen Triggerfish", seen on the C53 shipwreck, and *Lutjanus synagris* or "Lane Snapper", seen on Reef Balls and concrete debris. No endemic species to Cozumel were found, as defined by Millet-Encalada and Álvarez-Filip (2007). Of the species identified as important by local conservation practitioners, invasive lionfish (*Pterois volitans)* were observed by a diver on a coral restoration module on one occasion, but not identified in any video surveys.

Table 6.3 Morphological details of structures surveyed. Longest side was used to class structures into size categories. Types are taken from Chapter 2.

Type	**Subtype**	**Descriptions**	**Main substrate**	**Depth (m)**		**Longest side (m)**		**Total**
				Mean	*SD*	*Mean*	*SD*	
Artworks	Artistic sculptures	Busts	Metal	3.7	0.4	0.8	0.1	3
		Minecraft mesh sculptures	Biorock	5.6	0.8	2.4	0.6	6
		Zoë abstract sculpture	Biorock	3.4	-	4.8	-	1
		Crocodile	Rock or concrete	6.0	-	1.8	-	1
	Religious sculptures	Christ	Metal	7.3	-	4.3	-	1
		Virgin	Metal	5.1	-	2.3	-	1
Prefabricated modules	Coral restoration modules	Reef Balls	Concrete	3.8	0.9	0.9	0.3	29
		Fractals	Concrete	4.3	1.2	2.4	0.4	12
		HAMs	Concrete	11.0	0.7	4.4	0.2	3
Sunken artefacts	Intentional shipwrecks	C53 Navy Boat	Metal	21.6	-	56.0	-	1
		Patrol boats	Metal	10.1	0.1	20.0	7.1	2
	Sunken plane	Small sunken plane	Metal	7.1	-	10.1	-	1
	Debris	Concrete blocks	Concrete	6.1	0.3	4.1	1.4	3
Infrastructure	Infrastructure	Dock pilings	Concrete	2.8	0	2.8	0	2
		Anchor bases	Concrete	3.6	0.4	0.6	0	2
Traditional structures	Rock piles	Rock piles	Rock	3.5	0.6	12.3	1.6	2
Natural reefs	Coral/rocky reefs	Small outcrops of coral/rocky reefs	Coral/rock	2.9	0.3	1.1	0.3	7
			Overall	*4.8*	*2.8*	*3.3*	*7.2*	*77*

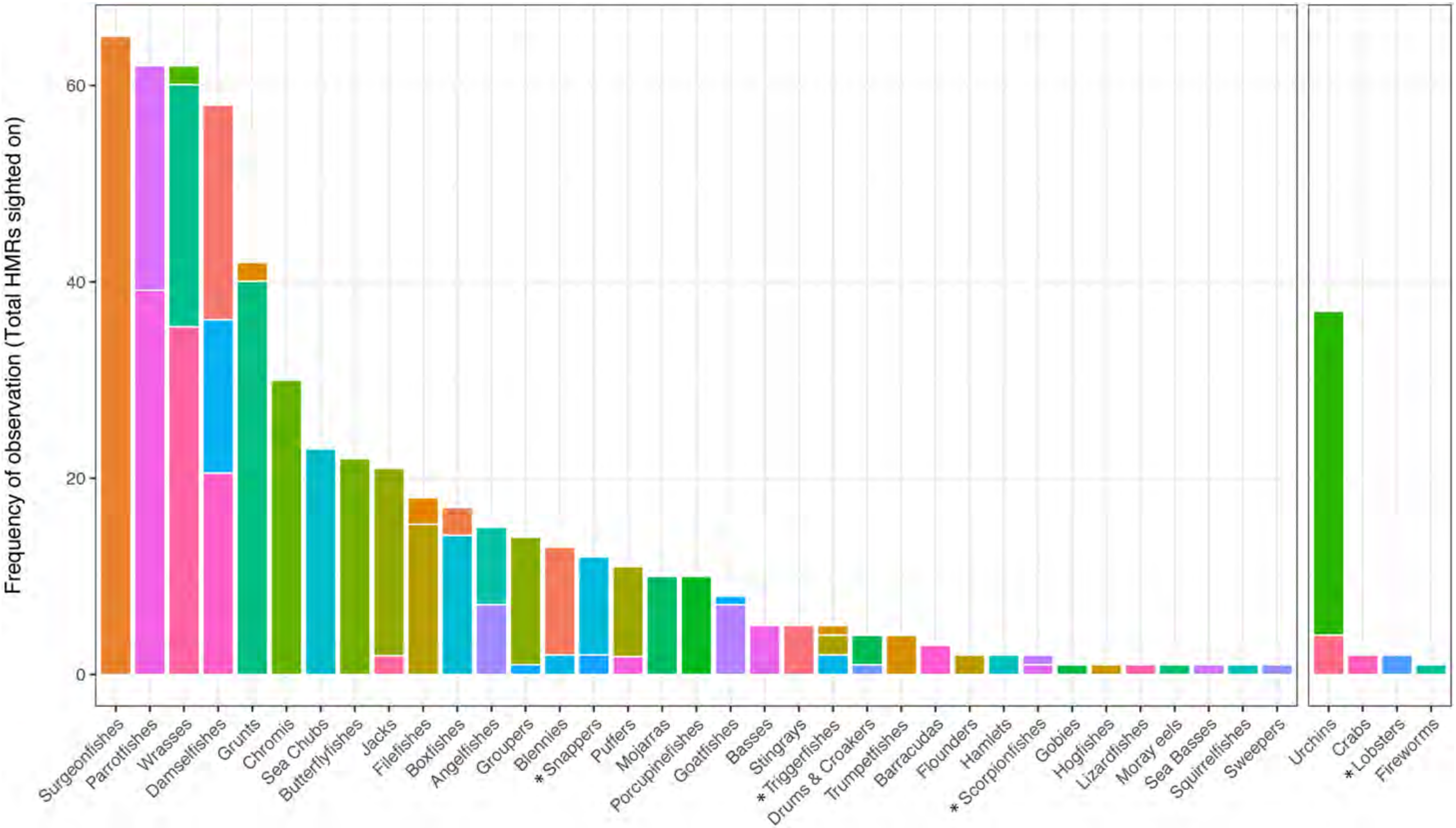


*Figure 6.4 Richness of fish and mobile invertebrates identified in all video surveys and diver observations of 70 HMRs in Cozumel, grouped by common name. Height of bar indicates total observation frequency (number of HMRs a group was found on) and coloured segments show the proportion of observations (%) made up by different genera. Use of * indicates that the group contains a species of conservation and management relevance (identified by local conservation practitioners or IUCN status of "Near Threatened").*

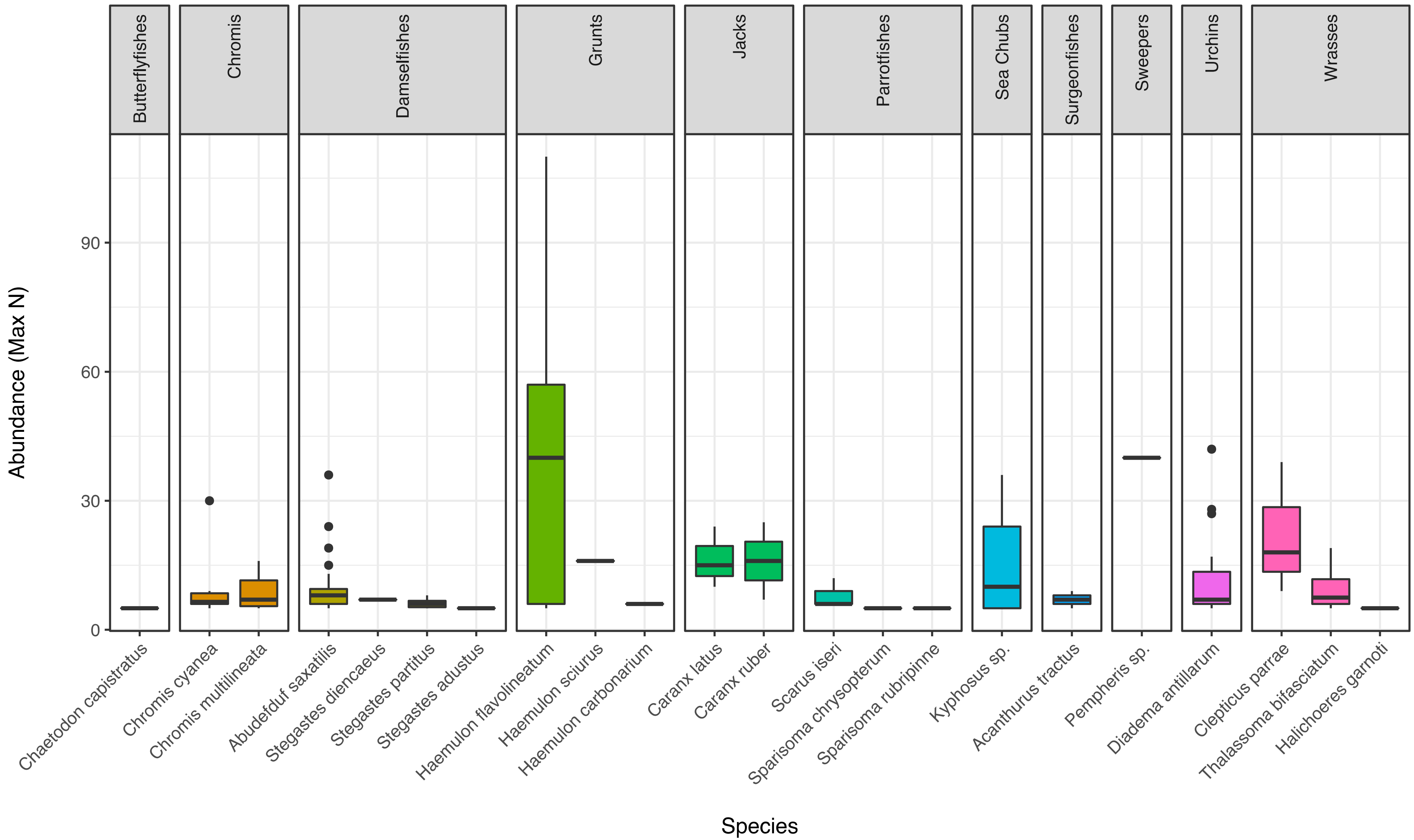


Figure 6.5 Abundance across HMRs for all species of fish and mobile invertebrates with a Max N ≥ 5. Common name indicated in grey boxes above.

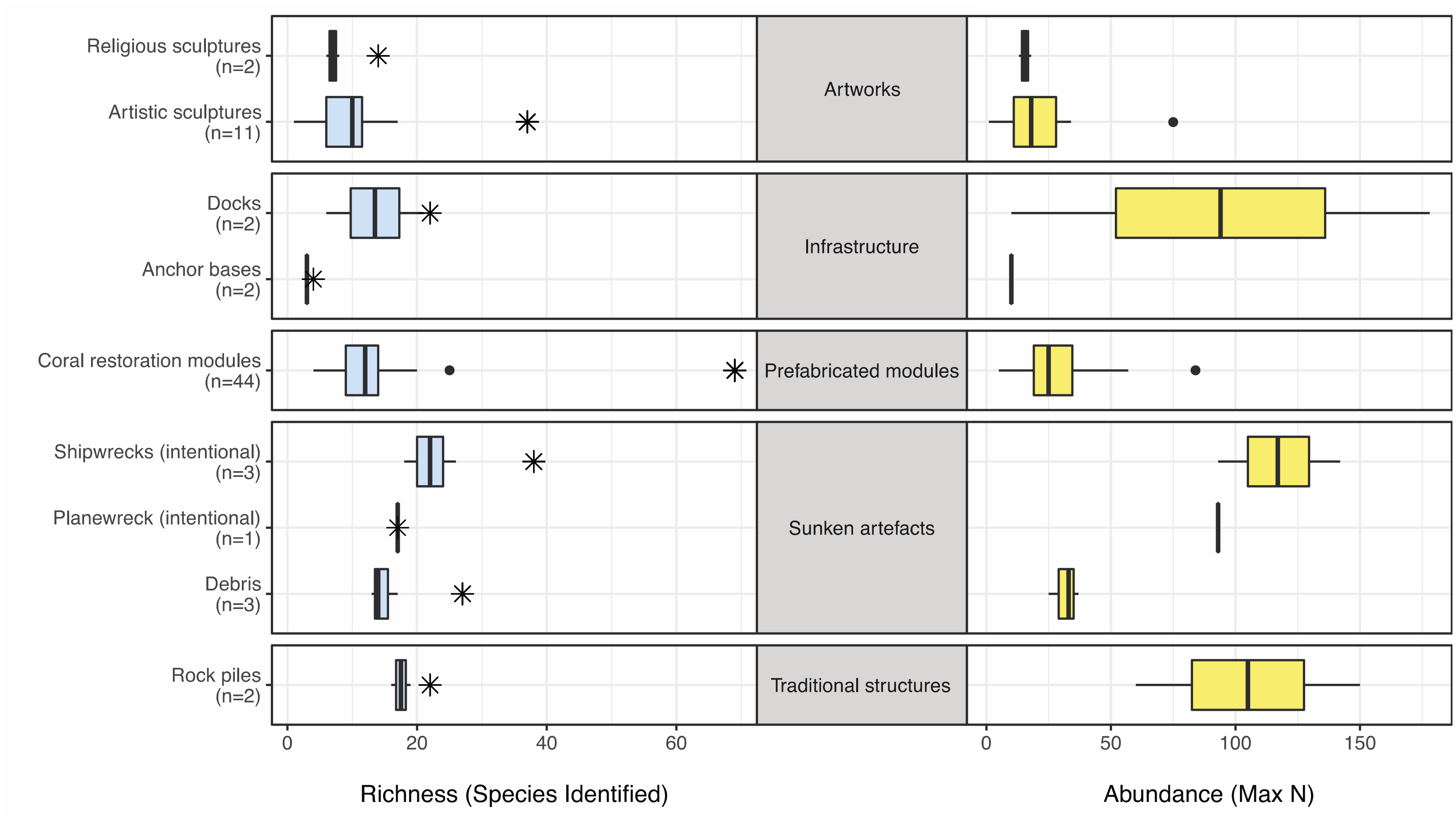


*Figure 6.6 Aggregates of species richness and abundance of organisms identified on HMR types and subtypes. Richness boxplots describe variation in numbers of species identified on individual structures, while * indicates total species found across the entire subtype. Abundance boxplots describe variation in aggregate numbers of organisms (sum of max N for each species) counted on individual structures within the subtype.*

6.3.3 Effects of HMR characteristics on marine life

Generalised linear models constructed to assess the impact of structural characteristics of HMRs on marine life indicated higher abundance and richness of organisms on structures which were deeper, larger and contained more holes and internal space (Figure 6.7). These effects were particularly clear in terms of abundance, but also applied to richness. Structure age was not included as a variable because it could not be verified for all structures. Additionally, the process of cleaning was considered disruptive since it could potentially "reset" the structure, especially in cases where they are periodically removed from the sea as is known to be the case with the statue of the Virgin (Chapter 4). Therefore I did not consider age to be a particularly meaningful ecological parameter for this analysis of HMRs in this context, because many of them are periodically either cleaned or scraped of marine life by hurricanes.

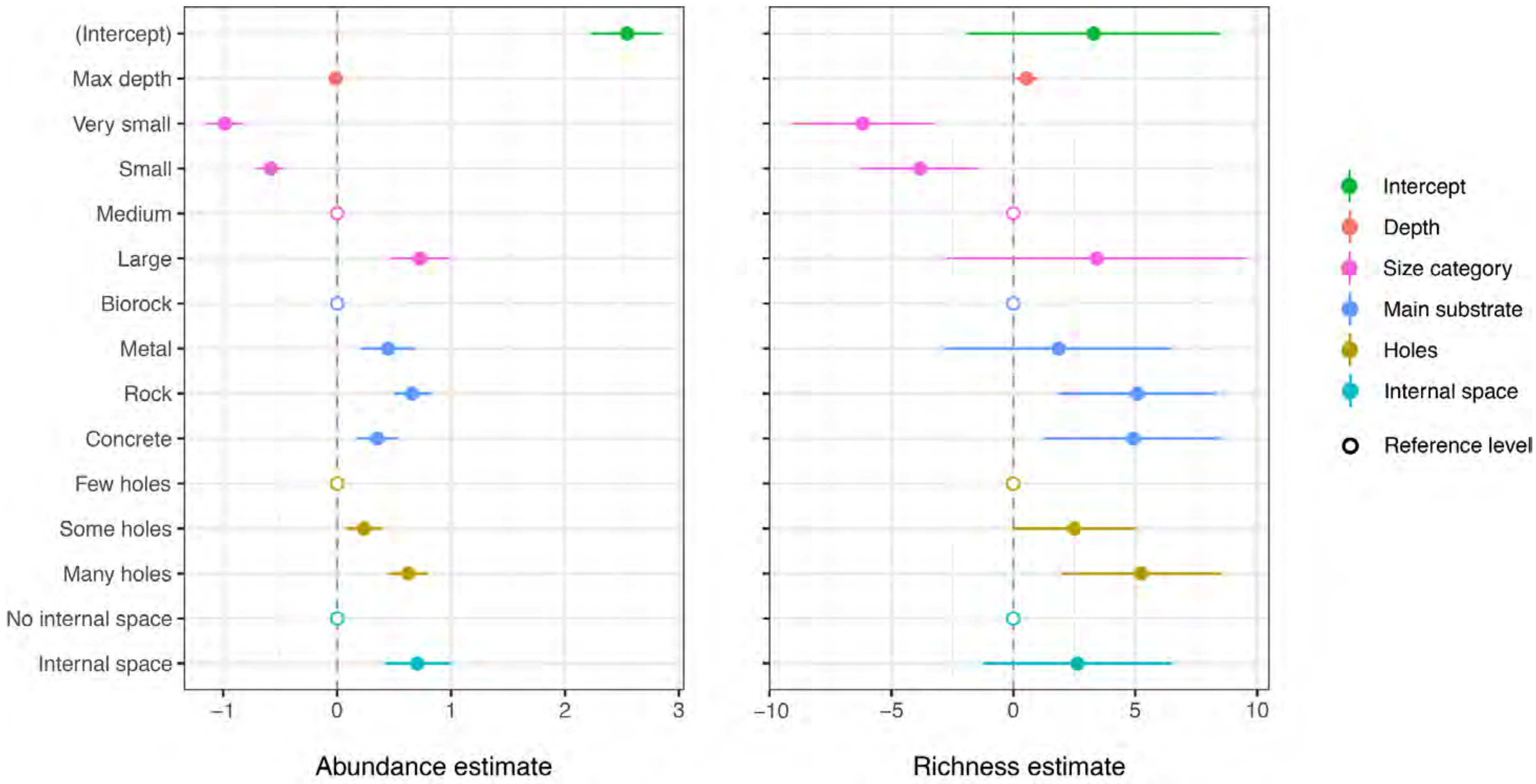


Figure 6.7 Association of structural characteristics of HMRs with abundance and richness of organisms across 70 HMRs in Cozumel, Mexico. Age was not included as a variable as it could not be verified for all structures. Size categories defined by longest side: Very small (0-1m), Small (1-3m), Medium (3-15m), Large (15-60m). Holes categories: Few (0-4), Some (5-19), Many (20+). Abundance data was assessed using a GLM (Poisson family) whereas richness was assessed using a GLM (Gaussian family). Estimate uncertainty is presented in 95% confidence intervals. Model output tables available in Appendix 6.5.5.

6.3.4 *Impact of conservation-focused alterations*

An assessment of the impact of conservation-focused alterations to two types of prefabricated concrete modules in one site (Figure 6.8) found no significant difference in species richness (W = 13.5, p-value = 0.5167) or abundance (W = 16, p-value = 0.8092) associated with coral gardening (a practice which involves attaching coral fragments to HMRs) and no significant difference in richness associated with adding rocks around the prefabricated modules (W = 84.5, p-value = 0.1206). However, the addition of rocks did lead to a significant increase in the abundance of organisms detected around a structure (W = 107, p-value = 0.0025).

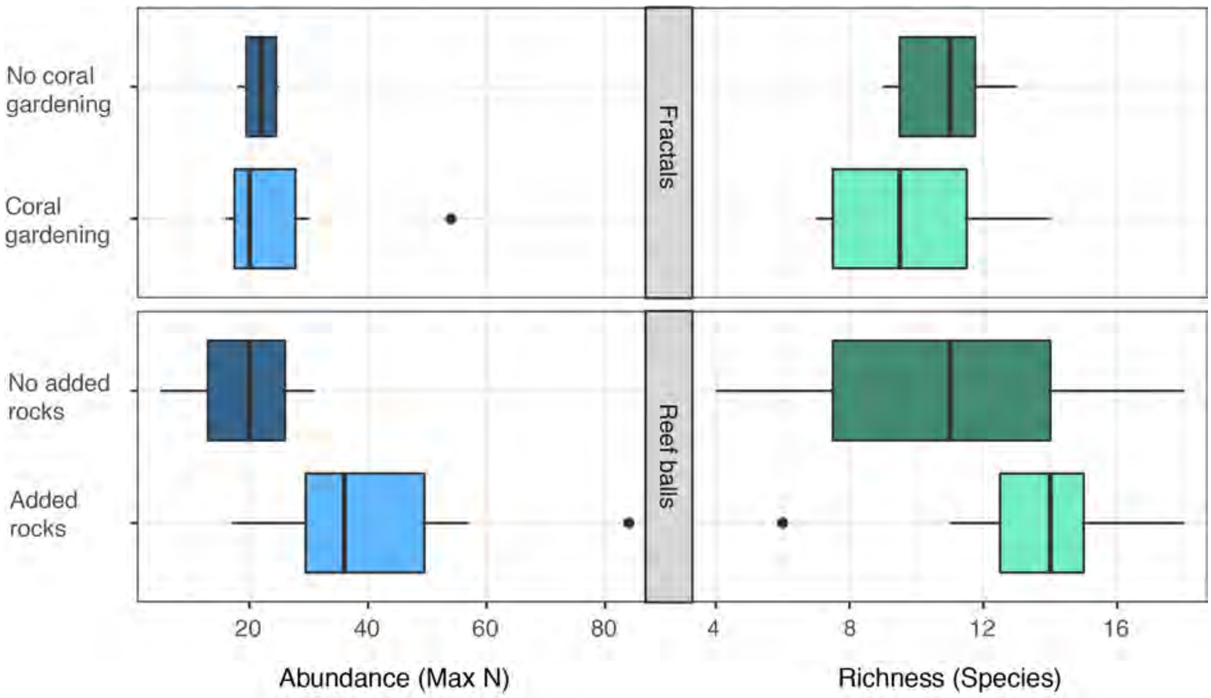


Figure 6.8 Impact of conservation alterations on richness of marine life on concrete prefabricated modules (n=22 small and medium Reef Balls with 11 in each subgroup, n= 12 fractals with 6 in each subgroup). Mann-Whitney U tests showed a significant difference in abundance of organisms when rocks were added to Reef Balls (bottom left, W=107, p-value=0.0025) but not in abundance or richness with other alterations.

6.3.5 Comparison with natural coral/rocky reefs

A comparison between seven prefabricated concrete modules (Reef Balls) and seven natural coral/rocky reefs of matched sizes in one site with Mann Whitney U tests revealed no significant difference in terms of overall species richness (Figure 6.9, W = 12.5, p-value = 0.1364) or abundance (W = 14, p-value = 0.2003). Further analysis at the species level using metrics from FishBase (Froese and Pauly 2000, 2021; Faith *et al.* 2004; Cheung *et al.* 2005) revealed no significant difference in mean trophic level (W = 2326, p-value = 0.9418), vulnerability to extinction (W = 2296.5, p-value = 0.9634), or phylogenetic diversity (W = 2285.5, p-value = 0.8543). One fish species (*Stegastes planifrons*, "Threespot damselfish", Least Concern on IUCN Red List) was detected on two natural coral/rocky reefs but not on any HMR. Some species of damselfish could be difficult to distinguish in the videos because requisite details were not visible, which may have impacted the detection of *Stegastes planifrons*.

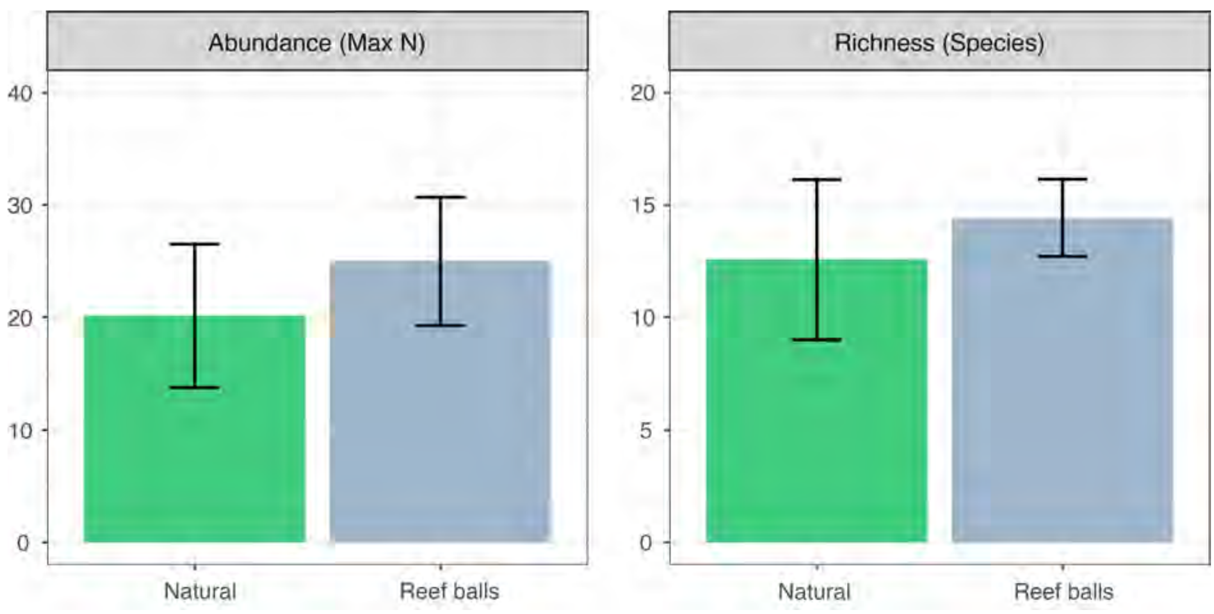


Figure 6.9 Comparison of mean abundance and richness (with standard deviation as error bars) across 14 comparably sized HMRs (n=7 Reef Balls) and natural reefs (n=7) at one site in Cozumel.

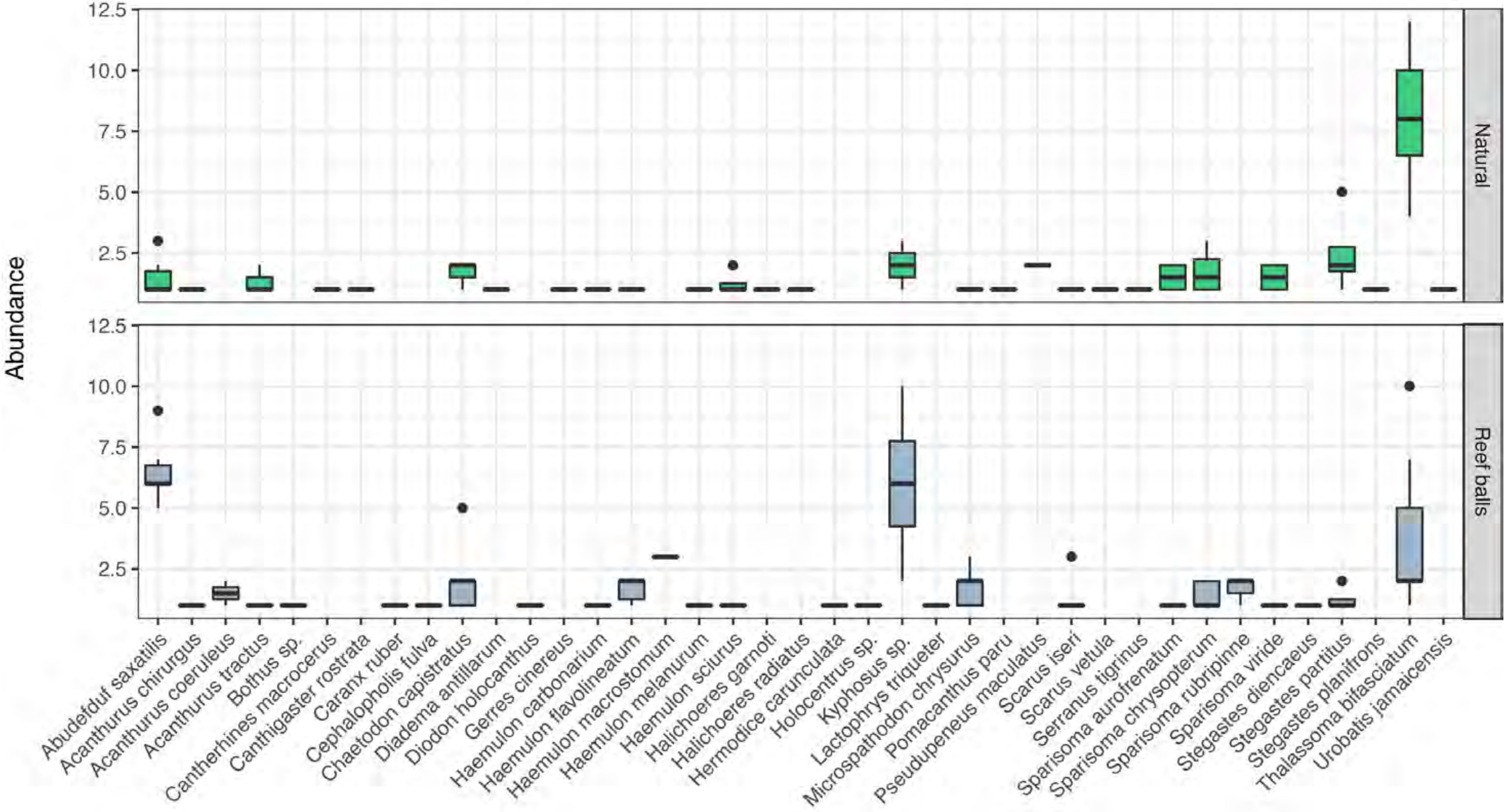


Figure 6.10 Comparison of abundance at the species level across natural reefs and HMRs (Reef Balls) created for coral restoration.

6.3.6 Fish behaviour on HMRs

Categorisations of behaviour suggested that fish are using a variety of HMRs for shelter and feeding as well as swimming by them or hovering near them (Figure 6.10).

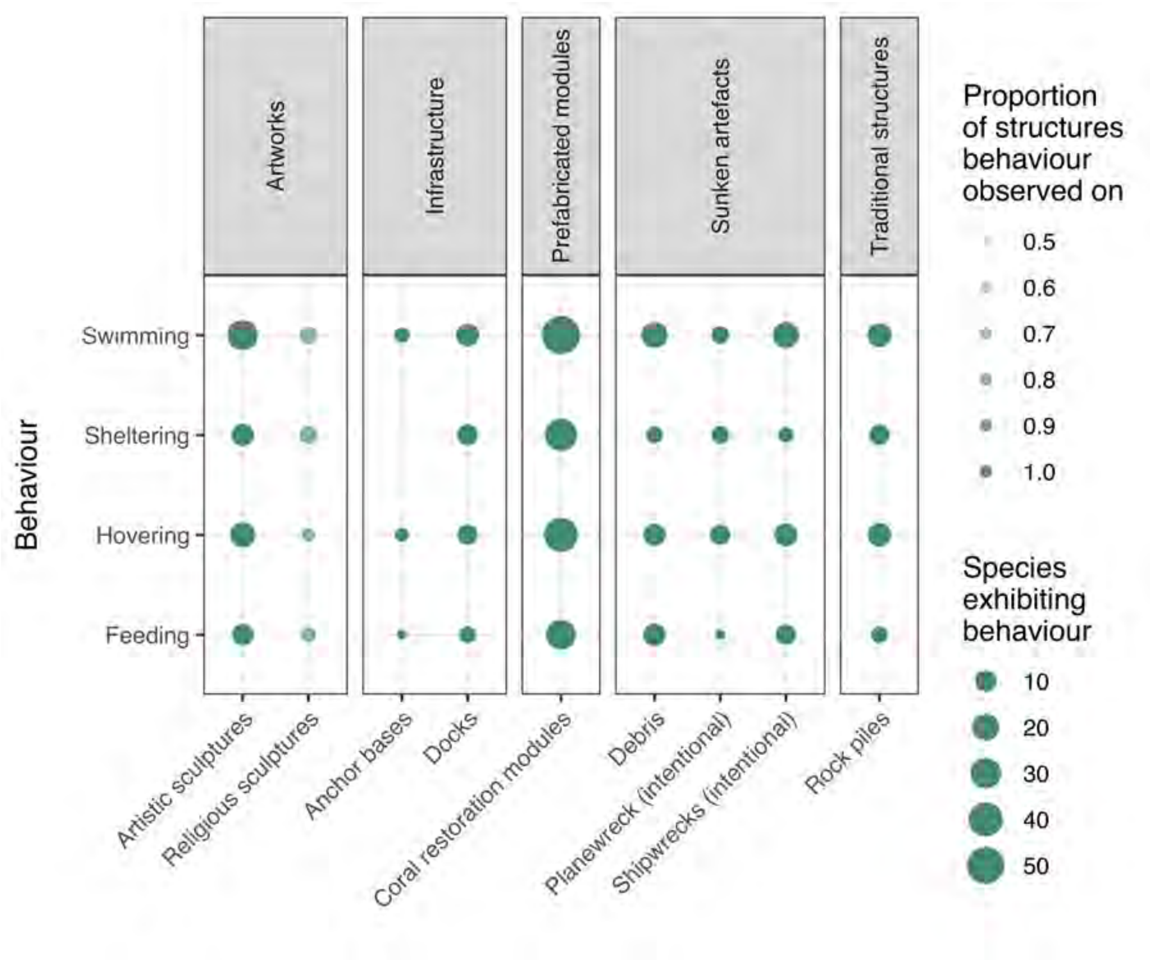


Figure 6.11 Behaviours exhibited by fish on HMRs. Shading indicates the proportion of HMRs within the subtype where the behaviour was observed. Dot size indicate the number of species observed exhibiting the behaviour within the subtype.

6.3.7 Evaluation of survey methods

A comparison of richness across fixed and roving video surveys and diver observations indicated that each method may detect organisms differently (Figure 6.11). Fixed videos – recorded from a single vantage point over a period of 10 minutes – uniquely picked up on flounders, moray eels and sea basses but did not detect basses or drums and croakers when both other methods did. Fixed video did appear to be the most consistent method; once organisms were detected, they were identified on the most structures. Roving videos – assessing the entire structure and lasting between 1 and 12 minutes based on HMR size – uniquely detected sweepers, but did not detect filefishes, snappers, squirrelfishes, triggerfishes or trumpetfishes when both other methods did. Diver observations uniquely detected barracudas, blennies, gobies and scorpionfishes, and did not detect mojarras when both video methods did. Damselfishes, wrasses, puffers, chromis, groupers and stingrays were detected relatively equally across data collection methods, while there was no clear pattern in detection across methods for other organisms.

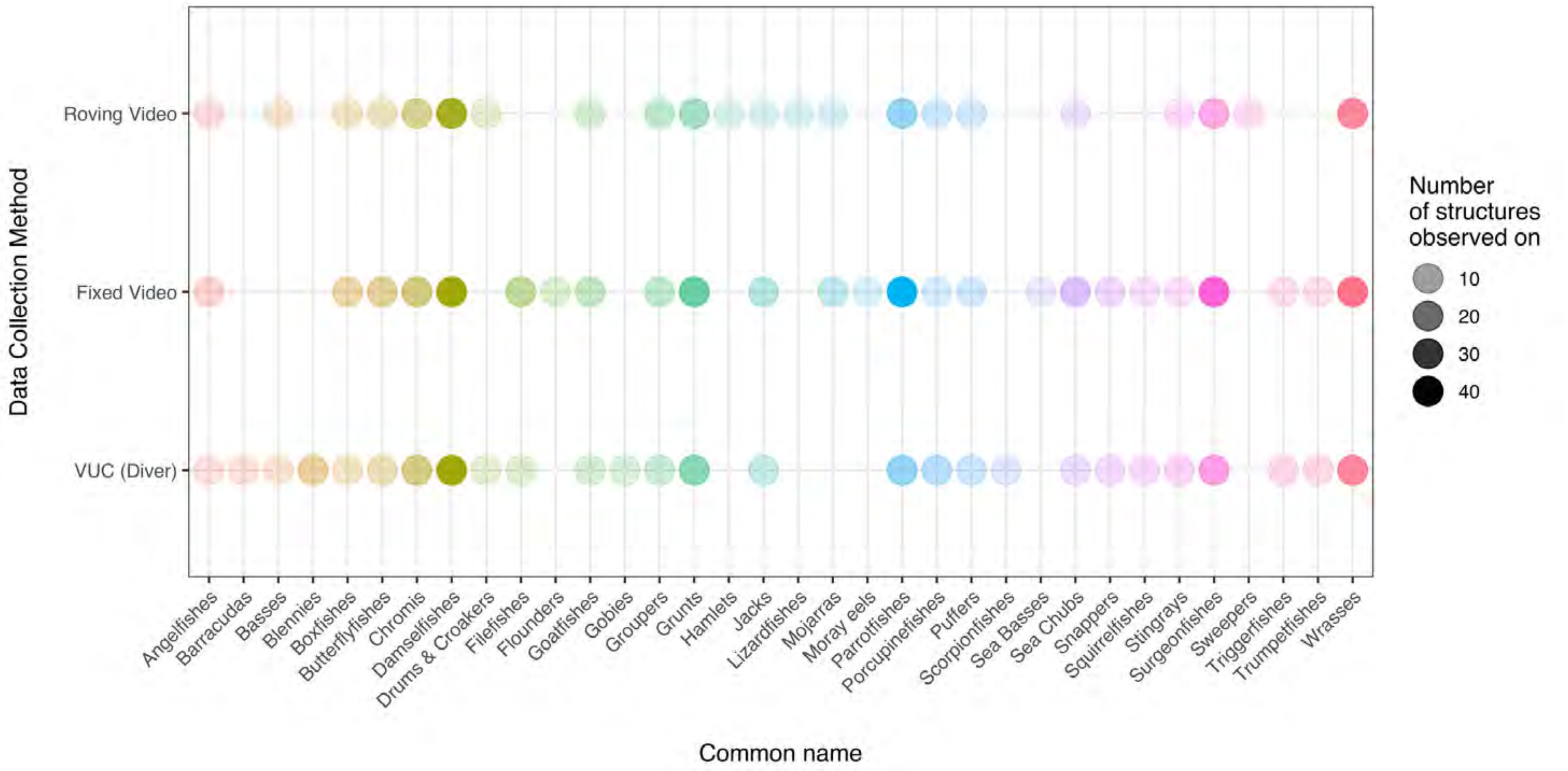


Figure 6.12 Fish identified on subset of 44 HMRs where fixed video, roving video and diver observations took place. Coloured dots indicate the detection of an organism and opacity indicates number of structures on which organisms were spotted in each survey type.

Analysis of species accumulation curves over the time of video surveys (Figure 6.12, Appendix 6.5.6) indicated that 10 minutes were sufficient for fixed video surveys, as detection curves mostly all levelled off around seven minutes. Curves did not fully level off for roving videos, especially on large structures, indicating more time would be beneficial to ensure the capture of all species present using this method.

Considerations of the benefits, challenges and potential solutions emerging from enactment of the tested survey methods (Table 6.4) revealed several opportunities for learning and improvement. These included practical considerations around ideal survey equipment and conditions including good lighting and low current, as well as suggestions on how to improve survey protocols such as the need for longer roving videos and ways to measure structural complexity. Often, an increase in accuracy or information would require trade-offs with time and money. Some problems encountered, such as the measurement of marine life inside HMRs, could not be resolved in a way that allowed for standardisation across variable structures.

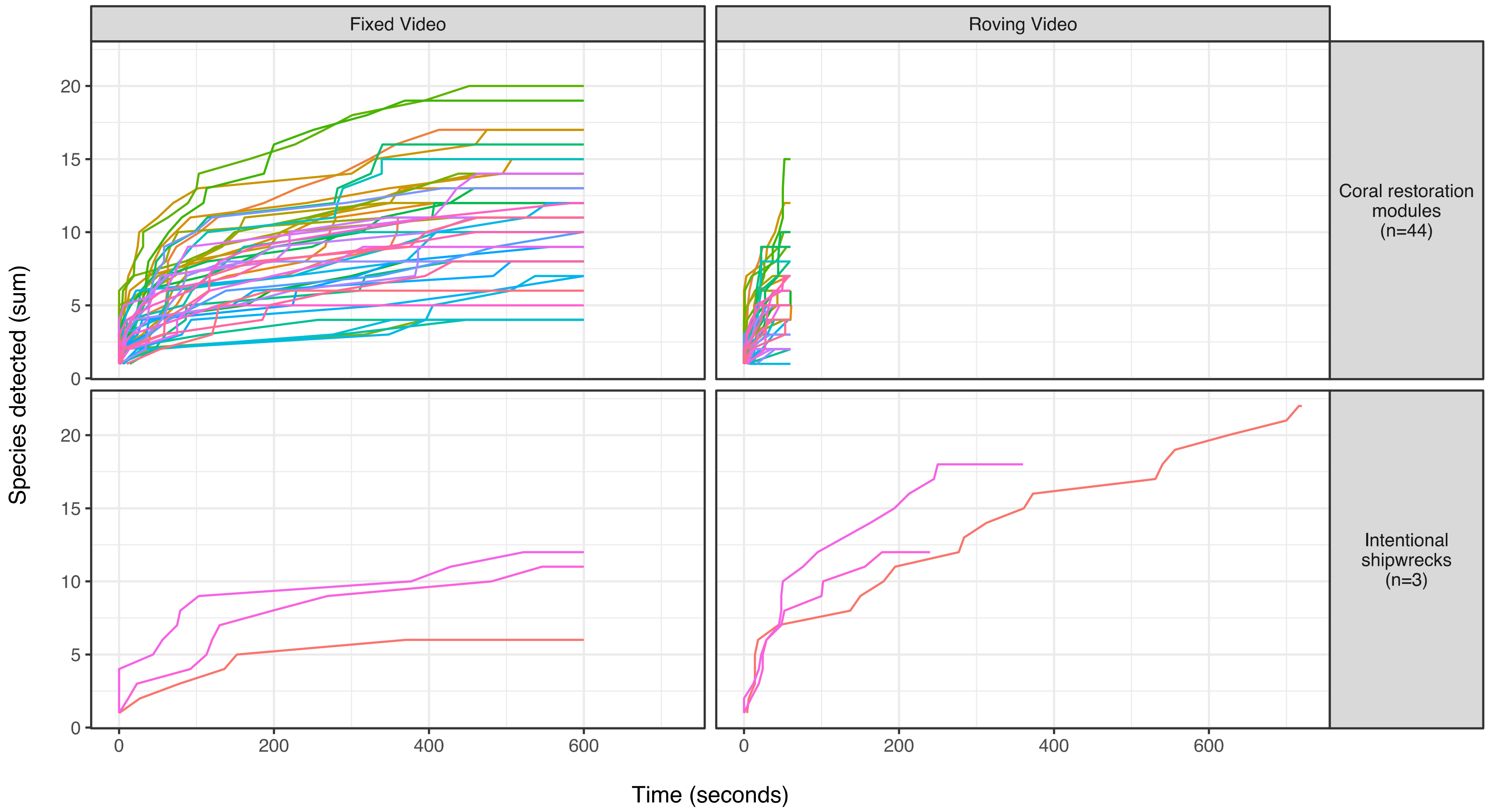


Figure 6.13 Two examples of species accumulation curves for fixed and roving video surveys on coral restoration modules (n=44) and intentional shipwrecks (n=3) selected to highlight comparison across HMR sizes. Each coloured line represents one HMR structure. All fixed video surveys had a duration of 10 minutes/600 seconds. For roving video surveys, time was scaled according to the size of the structure, with an additional minute added on for every 5 metres of structure length (with surveys lasting from 1 minute/60 seconds to 12 minutes/720 seconds). Species accumulation curves for all structures available in Appendix 6.5.6.

Table 6.4 Evaluation of survey methods and key parameters, considering what worked well, challenges and potential solutions encountered with survey methods. (A=Abiotic, B=Biotic, O=Other). For descriptions of how parameters were measured see Table 1 & Appendix 6.5.1.

	Parameter	Worked well	Problems encountered	Potential solutions
A	HMR dimensions	• Time-efficient method • Easy to survey small structures • Requires minimal equipment and two divers • Size categories	• Current could stretch out tape measure, esp. on larger structures • Tape measure (30m) was not long enough for largest structures, requiring "relay" • "Longest side" did not account for expanding area	• Whenever possible, measure structures in low-current conditions • Use transect tape of appropriate length for relevant structures (trade-off between length and bulkiness)
A	HMR shape	• Quick to draw underwater • Reduces potential damage to benthic communities from alternative method (i.e. chain measurement)	• Some structures were so irregularly shaped it was not possible to assign a geometric shape	• Could use 3D photogrammetary modelling technologies (Young *et al.* 2017) or sonar, but expensive
A	Main substrate	• Selecting dominant substrate by surface area • Verifying construction materials with creators	• Difficult to determine if surface is overgrown	• Incorporate short social surveys with HMR creators to understand origins and verify materials
A	Holes	• Measuring smallest side of hole as limiting factor (some fish rotate to fit) • Not assuming similarity across prefabricated HMRs; hole sizes could vary due to deterioration and colonisation by organisms such as sponges • Using categories of "few", "some", "many" in model	• Time-consuming to count and measure all holes • Sometimes difficult to ascertain whether a gap was leading to internal space • Calculation of number of holes in some cases (e.g. mesh) was fraught and likely irrelevant	• Use categorical complexity metric for numbers of holes and distribution of hole sizes that could be quickly assessed e.g. "few holes of one size category" or "many holes of many size categories" (Bortone *et al.* 2000); or count on random part of HMR (Wilson *et al.* 2007) but probably not representative
A	Location (GPS)	• Aligning points between dive computer bookmarks and GPS track (Collins and Baldock 2007) • Securing GPS device to pouch in surface marker buoy (additional safety benefits in highly trafficked areas)	• Additional software needed to analyse GPS points • If moved on quickly or had GPS on slow point collection mode, did not get usable GPS points • Not always possible to distinguish different locations within small areas	• Keep buoy/GPS in position for at least 1 min; use fastest point collection mode to compatibility with dive computer bookmark • Use dive weight to place buoy/GPS next to HMR • Use of underwater GPS such as Garmin Descent (but 6-7x more expensive)
A	Depth	• Using dive computer to assess approximate depth (Collins and Baldock 2007)	• On large structures, difficult to know where the exact deepest point was	• Only survey HMRs within safe diving limits (which we did)
A	Internal space	• Simple and quick to check whether internal space existed and note down visible fish or invertebrates	• Could not estimate volume of internal space • Could not conduct "systematic search" for organisms within all structures (Lowry *et al.* 2012) since interiors could be dark or inaccessible	• Place fixed cameras with flashes inside, or trained wreck divers could enter large HMRs, or use flashlight to peer through holes, but inconsistent access & disturbance • Rough estimates of "void space" by volume (e.g. Bortone *et al.* 2000)
B	Richness	• Fixed video timing seemed to capture richness present (as	• Roving videos may have needed more time (Fig. 6.12)	• Calculate timing for roving videos with area not length (but hard to estimate *in situ*)

		indicated by accumulation curves, Figure 11 and Appendix 6.5.6)	• Small and cryptic species difficult to identify; some confusion with juvenile and adult life stages	• Awareness of morphology across life stages • Combine diver observations and video surveys wherever possible (Lowry *et al.* 2012)
B	Abundance	• Max N as conservative measure of abundance (Lowry *et al.* 2012) • Use of video in slow motion to count large schools of fish	• Difficult to count large schools of fish	• N/A
B	Fish size / Biomass	• N/A	• Could not secure lasers in a fixed parallel position with available materials • Fish were sometimes attracted to the lasers	• Build inexpensive mounting rig for laser photogrammetry (Rohner *et al.* 2011)
B	Fish behaviour	• Presence/absence of behaviours was simple to detect with clear definitions	• Behaviour may differ at night; sometimes sheltering organisms could not be ID'd as they were in shadow	• For detailed information on feeding behaviour, could count fish bites in videos (Witman *et al.* 2017)
B	Benthic composition	• Easy to manoeuvre quadrapod • In good lighting conditions, photos were of high quality • Roving video could be used to gain different perspectives for benthic ID	• Difficult to select appropriate quadrat size with variable size of HMRs • Difficult to take consistent quadrats with irregular shapes • Lighting varied with depth; light required adaptation to attach and malfunctioned, requiring replacement	• Use new GoPro light attachment which is designed for this camera • Have extra lights on hand in case one malfunctions • Vary quadrat size according to HMR dimensions
O	Camera placement	• Quadrapod functioned well as stable camera base (Coyer and Witman 1990) • Not using bait as fish were accustomed to feeding by tourists and would flock toward food which could affect results	• Current sometimes changed, so eddy effects may have occurred despite efforts • 2m distance could encapsulate partial or entire structure • Quadrapod could float/be unstable until holes drilled	• Could use multiple cameras for larger structures but price/time would go up • Make sure to drill holes in PVC pipes to avoid floating • Add weights to quadrapod to enhance negative buoyancy
O	Order of activities in protocol	• Balance of responsibilities between divers • "Piggy-backing" between HMRs to run video and measure abiotic variables	• Had to estimate approx. size to set roving video length, as size measurements took place at the end to avoid disturbing fish	• Measure structures and carry out video surveys on different dives • Take longer video and cut off analysis when necessary
O	Data analysis	• Counting only organisms in close proximity to HMR (Strelcheck 2001)	• Some visibility problems with strong current, lighting, suspended sediment	• Conduct surveys in low-current and well-lit (e.g. midday) conditions whenever possible
O	Equipment costs	• Quadrapod materials: PVC pipes, connectors, glue ($272 or £10.36) • GoPro materials including camera, underwater housing, mount, SD card (£365.48 each x 2)	• Camera light which malfunctioned ($99.99 or £78), lasers were functional but I was not able to use them ($99.99 or £78 each)	• N/A
O	Time	• Approx. 20 mins to survey for small HMRs, 30-40 mins for larger HMRs • Approximately 30 mins to analyse videos per HMR • In-person knowledge of species for quicker ID	• N/A	• N/A

6.4 Discussion

In this study, I tested the use of a set of procedures for the replicable ecological assessment of conservation potential of HMRs. Using these methods, I estimated the degree of marine life on these structures in terms of "general" metrics such as abundance and richness and "targeted" metrics such as presence of species on the IUCN Red List or prioritised by local conservation practitioners. I then modelled the association of these metrics with characteristics of varied HMRs created for different purposes (Chapter 2).

6.4.1 *Ecological assessment and conservation potential of HMRs in Cozumel*

The identification of over 30 families, 50 genera and almost 80 species of fish indicates that HMRs in Cozumel can harbour significant richness of marine life, on structures created with and without conservation intention (Table 6.2, Figures 6.4 & 6.6, Appendix 6.5.3). These numbers represent over a third of the 87 families of fish known to inhabit coral reefs in Cozumel, as well as a quarter of the 211 known genera and just under a fifth of the 427 known species (Millet-Encalada and Álvarez-Filip 2007). The fact that none of the species found on HMRs were listed as vulnerable, endangered or critically endangered, while two were listed as "near-threatened", may suggest that the fish living on HMRs are largely common. On the other hand, rare and endangered species are difficult to detect due to their low abundance and so data from our study could simply reflect limited sampling, though our accumulation curves do indicate appropriate sampling intensities for fixed videos at least. Many of our surveys took place at shallow depths in sites with high levels of human activity, and all took place during the day, so any nocturnal, particularly sensitive or deeper-dwelling species were unlikely to be detected even if they could viably live on these structures.

The selection of lionfish as important by local conservation practitioners is logical given the magnitude of their impact on marine ecosystems in the Caribbean (Green *et al.* 2012) and their identification as an important species with strong positive and negative associations for various HMR stakeholders in Cozumel (Chapter 5). Our low detection rates for lionfish are similar to those found by Gress et al. (2018) and may be explained by the established practices of culling by recreational divers as well as local fishing and consumption. A study on stakeholder perceptions in Cozumel found 100% of diver-fishermen were interested in participating in a lionfish removal programme, as well as 80% of restaurant owners and 92% of fish consumers, whereas 100%, 100% and 77% of these groups respectively were willing to consume it (Carrillo-Flota and Aguilar-Perera 2017). Lionfish is a popular item on restaurant menus in Cozumel which is often sold out (pers. obs.) and populations may be suppressed at the studied depths in a way they are not in other parts of the Caribbean.

Analyses of fish behaviour indicated that they are actively using HMRs, engaging in ecologically important behaviours such as feeding and sheltering rather than simply swimming (Figure 6.10). This could indicate that they are "resident" or "semi-resident" (Turner *et al.* 1969) though such a determination would require further analysis. Fish are generally known to aggregate around hard structures and HMRs, which Carlisle et al. (1963) attribute to "thigmotropism" or an attraction to solid objects and has also been more widely attributed to the availability of food and shelter (Turner *et al.* 1969; Carr and Hixon 1997; Fowler *et al.* 2018). Behaviours and ecological interactions may be different on HMRs than natural reefs, with (Ferrario *et al.* 2016) reporting stronger herbivory and grazing pressure on HMRs as compared to rocky reefs. The oft-raised question of attraction vs. production is not one I could address in this study given the limited time period and survey design (Smith *et al.* 2015).

The articulation of clear goals at the outset of HMR projects is unfortunately rare, but can be extremely valuable in monitoring their success and guiding the creation of future projects (Becker *et al.* 2018). In general, comparisons between HMRs and natural coral or rocky reefs should only take place when their initial purpose makes such a comparison valid or necessary, as otherwise such comparisons can be misleading, lack standardisation across key variables, or contribute to a notion that coral reefs are replaceable (Chapter 2). In this case, such a comparison was valid because the Reef Balls in question were established for the purpose of coral restoration, making a comparison with similarly sized natural coral reefs, interspersed with the HMRs, valid to assess outcomes in relation to initial goals. The lack of a significant difference in richness or abundance between comparably sized natural reefs and HMRs in the same location (Figure 6.9) aligns with the results of a recent meta-analysis of 39 studies which found no significant difference in diversity, abundance, richness or biomass between natural coral and rocky reefs and HMRs (Paxton *et al.* 2020). In an experimental study designed to overcome differences in size, age and isolation, Carr and Hixon (1997) found higher species richness and abundance on natural coral reefs though they did not detect substantial differences in species composition. Assessment of the benthic community would have been extremely valuable, as coral restoration was a central goal beyond similarity in fish and mobile invertebrate communities; however, I was not able to conduct this analysis due to logistical constraints (Table 3.4).

6.4.2 Effects of HMR characteristics on ecological communities

In addition to measuring performance in relation to *a priori* goals, modelling associations between HMR characteristics and richness and abundance can help to identify factors which lead to desired outcomes across a variety of HMRs with different initial goals (Figure 6.7). Notably, "Biorock" substrate, which is often deployed specifically with a conservation intention, appeared to have the lowest abundance and richness associated with it. However, it should be noted that the "Biorock" structures may have been under-sampled due to surrounding mesh which meant the main structure was further from the camera and fish may have been harder to detect. Concrete has previously been identified as a substrate which attracts substantial numbers of fish; however Carlisle (1961) suggested its financial and logistical costs may outweigh the relatively small difference with rocks, which may be more suitable overall due to availability. Additionally, the carbon emissions of construction with concrete should be considered when low-emission and low-cost materials such as rocks are easily available locally (Müller *et al.* 2013; Fox *et al.* 2019).

6.4.3 Robustness of survey techniques and recommendations for improvement

The comparison of survey methods (Figure 6.11) indicates that they are best used in a complementary manner to assess richness, as they each appear to detect organisms differently. This is to be expected to some degree; as Watson et al. (2010) write, "No single technique is suitable for providing information on all fish species" (p. 1237). Lowry et al. (2012) also recommend using diver and video surveys together, since small, rare and cryptic species are particularly hard to detect in video surveys and this can lead to under-sampling (Strelcheck 2001). It is fairly well established that the presence of divers can spook fish (Watson *et al.* 2010; Emslie *et al.* 2018) so another idea could be have divers set up cameras at the end of a dive and pick them up on the next dive (Witman *et al.* 2017). However, it is important to note that most of the HMRs we surveyed are in highly trafficked tourist areas, so divers are present on a regular basis and the organisms which do use these structures are likely to be acclimatised to these levels of human activity. The species accumulation curves (Figure 6.12, Appendix 6.5.6) indicate that longer roving videos would better capture richness, so I would initially recommend doubling these times for another trial. It may also be beneficial to set up various fixed cameras on larger structures, to ensure that organisms are captured in different places on the structure. It would also be good to develop a metric that incorporates both hole size and number of holes, as variation in both of these determines shelter availability for fish of different size categories (Hixon and Beets 1989). The incorporation of metrics for biomass and benthic composition would add greatly to understanding of how marine life assemblages vary across HMRs, and the incorporation of standardised metrics for human use – such as cleaning frequency and diver presence – could help to inform understanding of HMRs as social-ecological systems.

The survey presented in this chapter is a "snapshot" or Type 1 survey, and indicates the state of some types of marine life on HMRs at one point in time (Seaman and Jensen 2000). It would be ideal to repeat these surveys at a larger scale and over time in order to track changes and understand seasonal and spatial variation (Bortone *et al.* 2000; Becker *et al.* 2017). However, this initial trial of replicable survey protocols was crucial to fuel learning and gather descriptive data on interactions between HMRs and marine life. Ultimately, established and replicable protocols are of great value because they can be scaled up to enable monitoring and comparison across time and place (Rogers *et al.* 1994). In the words of Seaman and Jensen (2000) "we seek to create a basis for research worldwide that may yield data that are more directly comparable" (p. 16). I also hope that a protocol such as developed here could allow for the participation of individuals who are highly invested in HMRs but have limited scientific training, as several local stakeholders approached us with interest while we were conducting the ecological surveys (Rogers et al. 1994; Florisson and Walker 2018, pers. obs.). I consider the survey materials to be cost-effective as costs were lower than those in a citizen science project with similar goals, particularly in terms of materials and labour (Florisson and Walker 2018).

The understanding of context and connections between people and HMRs which I gained during social surveys that accompanied this fieldwork (Chapters 2, 3, 4) was extremely helpful for the ecological surveys (Table 6.4). In some cases, it allowed for the location of and access to surveyed structures, and in others it allowed for the confirmation of key variables such as substrate when it was overgrown or the confirmation of intentional conservation alterations such as coral planting (Figure 6.8). It was the only way that some parameters could be verified across HMRs, including age, though the validity of this parameter came into question given cleaning practices on some structures which could "reset" colonisation and the sourcing of different materials. For example, how to allocate an age to rearranged rocks which were already underwater? Biodiversity on HMRs will probably need to be managed by considering them as dynamic structures, considering aspects of disturbance ecology as exemplified by work on boulder fields which are variably disturbed by storms (Sousa 1979). In an analysis of steel offshore infrastructure, Coolen et al. (2020) found that age and cleaning were non-significant in predicting species richness. The association I found between added rocks and an increased abundance of marine life reflected the anecdotal observations of the individuals who made these alterations (Chapter 4 & 5). Fox et al. (2019) also found rock piles to be an effective and inexpensive restoration method in assessments of coral cover, indicating they could provide a viable nature-based solution for coral restoration efforts (Seddon *et al.* 2020). Although I did not find a significant difference in fish and mobile invertebrate species richness between HMRs with and without rock piles, this metric does not necessarily reflect its primary purpose given that planting in particular intended for coral restoration; assessment of benthic communities would therefore provide a crucial benchmark for comparison. Nonetheless, coral "gardening" is growing in popularity with projects such as the Cozumel Coral Reef Restoration Program (ccrrp.org), coralgardeners.org and the involvement of coral planting activities in ecotourism (Schmidt-Roach *et al.* 2020), so assessing the impact of this activity on marine life more broadly would be useful.

Figure 6.14 Photo of a diver using a brush to clean a concrete coral restoration module which has been "planted" with coral (SCT, Cozumel 2019).

The social-ecological approach taken here has been found to be successful in other conservation contexts, such as fire management in community forestry (Sheridan *et al.* 2015). In addition to providing logistical benefits in our study, the parallel deployment of social and ecological surveys allowed for trust-building within the community and may facilitate the communication of results to feed into adaptive management. In the development and measurement of conservation potential, an understanding of the social context can be crucial; for example, while religious sculptures displayed low richness and abundance of marine life, they provided spiritual value and may even foster pro-environmental behaviour (Figure 6.6, Chapter 3).

Overall, the results of these surveys indicate that HMRs in Cozumel host diverse and abundant communities of marine life, making them of high conservation relevance despite and because of their anthropogenic origins. The implementation of a rapid survey protocol may be of great use in assessing conservation interventions and shaping future HMR projects as they continue to crop up in oceans worldwide.

6.5 Appendices

6.5.1 Survey protocol

Before diving (boat/shore)

1. Collect equipment
   - .16m² PVC Quadrapod with attached GoPro camera and fresh battery (have extra batteries in safe site on shore/boat for subsequent dives) (RL)
   - Dive slates with multiple appropriate sheets on either side (RL, RA)
   - Transect tape and small measuring tape (RL, RA)
   - Buoy with lead line and GPS tied to inside (make sure it is on and tracking) (RA)
2. Perform safety checks (BWRAF)

While diving **RL: Research leader *RA: Research assistant*

1. Get bearings, swim to 1st structure, note on map* (RL)
2. Measure visibility
   - RL: hold base of transect tape
   - RA: swim away holding up white slate
   - RL: once white slate is no longer visible, tug 2 times on tape and mark distance
3. Determine where current is coming from by dangling transect tape, note strength of current (RL)
4. Bookmark location of structure using dive computer to match up with GPS later (RL)
5. Measure 2m upcurrent from structure
   - RA: hold tape next to structure
   - RL: hold base of transect tape, swim away from structure
   - RL: adjust tape until 2m away from structure
   - Place quadrapod on seafloor facing downcurrent, ensure structure is in centre of the frame with bottom clearly in view
   - Allow 1 min for sediment to settle, then turn on camera
   - Begin recording fixed video (RL, 10 mins). RA notes down species observed.
6. Conduct roving video survey
   - Swim around structure with camera to carry out roving video find cryptic species (RL)
     i. Confirm with RA by showing minutes on fingers
     ii. 1 min for structures with <5 m length, 2 mins for structures 5-10 m diameter, 3 mins for structures 10-15 m diameter…
   - Keep time, tap on tank or nudge RL when survey complete (RA)
7. Benthic quadrats
   - Take up to 20 evenly spaced, non-overlapping .16m² benthic quadrats along the middle belt of the structure, starting with point that faces upcurrent and moving clockwise (RL)
8. Structural characteristics
   - Structure size – height, length, width, distance to closest structure (RL/RA)
     i. RL holds base of transect tape
     ii. RA swims to end of structure and tugs 2 times
     iii. RL notes down measurement
   - Measure holes (RA)
     i. RA counts approximate number of holes in each size category (<5cm, 5-10cm, 10-20, 20-30, 30-40, 40+)
     ii. RA notes down materials
   - Meanwhile, check internal space (RL)
     i. Visually accessible?
        1. Y/N/Partial
     ii. Fish inside?
        1. Y/N
        2. Species seen
     iii. Inverts inside?
        1. Y/N
        2. Species seen
9. Move onto next structure, repeat steps 3-9

6.5.2 Data collection sheet

HMR Ecological Survey – Data collection sheet

Date: ________________ **Dive #:** _____ **Site name/code:** _________________________________

Checklist	Safety checks (BWRAF)	Quadrapod w camera	GPS in buoy (on)
	Transect tapes	Measuring tape	Dive slates	Lasers

Visibility: ______ m   Surrounding substrate type: ____________________________________

Current strength *(low/medium/high)*: __________ Other divers seen: _______________________

Structure type: ____ Structure number: __________

Max depth at structure (m): ________ Temp at structure (°C): __________ GPS Bookmark: ______

Structure size category _____________ Materials: ___________________________________
(<5m, 5-10m, 10-20m, 20-30m, 30+m)

Fish video length: _________________   Roving survey length: ________

Quadrats (.16m^2): *# Vertical:* _______ *Bookmark:* _____ *# Horizontal:* ______ *Bookmark:* _______

Drawing of structure, current and placement of fixed video/benthic quadrats:

Internal space visually accessible?   Yes   No   Partial view

Fish inside?   Yes   No   Don't know   *Mobile inverts inside?*   Yes   No   Don't know

Height: _____________m   Length: _____________ m   Width: _____________m

Distance to nearest structure: _____________m

Holes (minimum diameter): *<5 cm:* ______ *5-10 cm:* _______ *10-20 cm:* _______

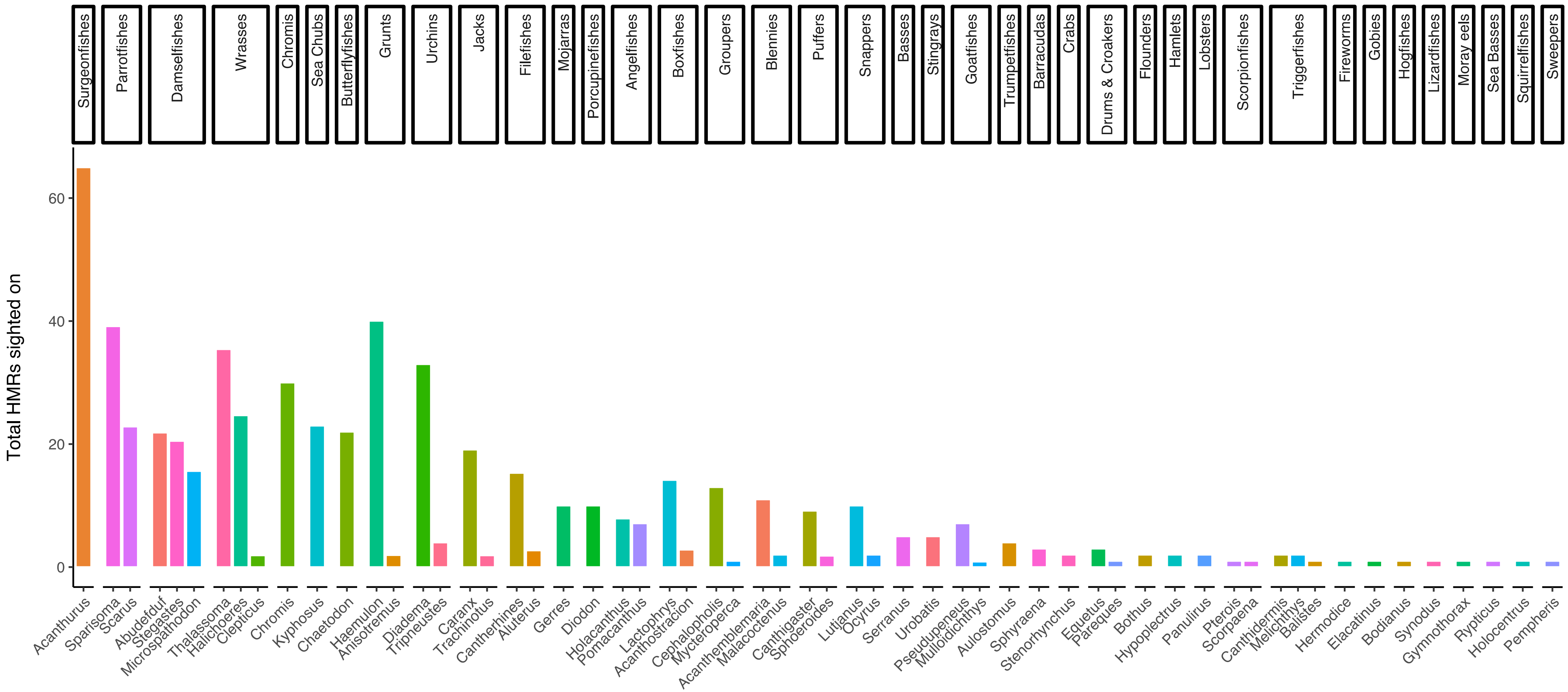
20-30 cm: _______ *30-40 cm:* _____ *40-50 cm:* _______ *50+ cm:* ______

6.5.3 *Fish and mobile invertebrates identified to family, genus and species level in video surveys and diver observations on 70 HMRs in Cozumel.*

Category	**Common name**	**Family**	**Genus**	**Species**	**IUCN Status**
Fish	Angelfishes	Pomacanthidae	Holacanthus	Holacanthus ciliaris	LC
Fish	Angelfishes	Pomacanthidae	Holacanthus	Holacanthus tricolor	LC
Fish	Angelfishes	Pomacanthidae	Pomacanthus	Pomacanthus paru	LC
Fish	Angelfishes	Pomacanthidae	Pomacanthus	NA	-
Fish	Barracudas	Sphyraenidae	Sphyraena	Sphyraena barracuda	LC
Fish	Basses	Serranidae	Serranus	Serranus tabacarius	LC
Fish	Basses	Serranidae	Serranus	Serranus tigrinus	LC
Fish	Blennies	Chaeonopsidae	Acanthemblemaria	Acanthemblemaria spinosa	LC
Fish	Blennies	Labrisomidae	Malacoctenus	Malacoctenus triangulatus	LC
Fish	Boxfishes	Ostraciidae	Acanthostracion	Acanthostracion polygonius	LC
Fish	Boxfishes	Ostraciidae	Lactophrys	Lactophrys triqueter	LC
Fish	Butterflyfishes	Chaetodontidae	Chaetodon	Chaetodon capistratus	LC
Fish	Butterflyfishes	Chaetodontidae	Chaetodon	Chaetodon ocellatus	LC
Fish	Butterflyfishes	Chaetodontidae	Chaetodon	Chaetodon striatus	LC
Fish	Chromis	Pomacentridae	Chromis	Chromis cyanea	LC
Fish	Chromis	Pomacentridae	Chromis	Chromis multilineata	LC
Fish	Damselfishes	Pomacentridae	Abudefduf	Abudefduf saxatilis	LC
Fish	Damselfishes	Pomacentridae	Microspathodon	Microspathodon chrysurus	LC
Fish	Damselfishes	Pomacentridae	Stegastes	Stegastes adustus	LC
Fish	Damselfishes	Pomacentridae	Stegastes	Stegastes diencaeus	LC
Fish	Damselfishes	Pomacentridae	Stegastes	Stegastes partitus	LC
Fish	Damselfishes	Pomacentridae	Stegastes	Stegastes variabilis	-
Fish	Damselfishes	Pomacentridae	Stegastes	NA	-
Fish	Drums & Croakers	Sciaenidae	Pareques	Pareques acuminatus	LC
Fish	Drums & Croakers	Scianidae	Equetus	Equetus punctatus	LC
Fish	Filefishes	Monacanthidae	Aluterus	Aluterus scriptus	LC
Fish	Filefishes	Monacanthidae	Cantherhines	Cantherhines macrocerus	LC
Fish	Filefishes	Monacanthidae	Cantherhines	Cantherhines pullus	LC
Fish	Flounders	Bothidae	Bothus	NA	-
Fish	Goatfishes	Mullidae	Mulloidichthys	Mulloidichthys martinicus	LC
Fish	Goatfishes	Mullidae	Pseudupeneus	Pseudupeneus maculatus	LC
Fish	Gobies	Gobiidae	Coryphoterus	NA	-
Fish	Gobies	Gobiidae	Elacatinus	NA	-
Fish	Gobies	Gobiidae	NA	NA	-
Fish	Groupers	Epinephelidae	Cephalopholis	Cephalopholis cruentata	LC
Fish	Groupers	Epinephelidae	Cephalopholis	Cephalopholis fulva	LC
Fish	Groupers	Epinephelidae	Mycteroperca	Mycteroperca tigris	LC
Fish	Grunts	Haemulidae	Anisotremus	Anisotremus surinamensis	DD
Fish	Grunts	Haemulidae	Haemulon	Haemulon album	DD
Fish	Grunts	Haemulidae	Haemulon	Haemulon carbonarium	LC
Fish	Grunts	Haemulidae	Haemulon	Haemulon flavolineatum	LC
Fish	Grunts	Haemulidae	Haemulon	Haemulon macrostomum	LC
Fish	Grunts	Haemulidae	Haemulon	Haemulon melanurum	LC
Fish	Grunts	Haemulidae	Haemulon	Haemulon parra	LC
Fish	Grunts	Haemulidae	Haemulon	Haemulon sciurus	LC
Fish	Grunts	Haemulidae	Haemulon	NA	-
Fish	Hamlets	Serranidae	Hypoplectrus	Hypoplectrus puella	LC
Fish	Hogfishes	Labridae	Bodianus	Bodianus rufus	LC
Fish	Jacks	Carangidae	Caranx	Caranx latus	LC
Fish	Jacks	Carangidae	Caranx	Caranx ruber	LC
Fish	Jacks	Carangidae	Trachinotus	Trachinotus goodei	LC
Fish	Lizardfishes	Synodontidae	Synodus	Synodus intermedius	LC

Fish	Mojarras	Gerridae	Gerres	Gerres cinereus	LC
Fish	Moray eels	Muraenidae	Gymnothorax	Gymnothorax moringa	LC
Fish	Parrotfishes	Scaridae	Scarus	Scarus iseri	LC
Fish	Parrotfishes	Scaridae	Scarus	Scarus taeniopterus	LC
Fish	Parrotfishes	Scaridae	Scarus	Scarus vetula	LC
Fish	Parrotfishes	Scaridae	Scarus	NA	-
Fish	Parrotfishes	Scaridae	Sparisoma	Sparisoma aurofrenatum	LC
Fish	Parrotfishes	Scaridae	Sparisoma	Sparisoma chrysopterum	LC
Fish	Parrotfishes	Scaridae	Sparisoma	Sparisoma rubripinne	LC
Fish	Parrotfishes	Scaridae	Sparisoma	Sparisoma viride	LC
Fish	Parrotfishes	Scaridae	Sparisoma	NA	-
Fish	Porcupinefishes	Diodontidae	Diodon	Diodon holocanthus	LC
Fish	Porcupinefishes	Diodontidae	Diodon	Diodon hystrix	LC
Fish	Puffers	Tetraodontidae	Canthigaster	Canthigaster rostrata	LC
Fish	Puffers	Tetraodontidae	Canthigaster	NA	-
Fish	Puffers	Tetraodontidae	Sphoeroides	Sphoeroides spengleri	LC
Fish	Scorpionfish	Scorpaenidae	Pterois	Pterois volitans	-
Fish	Scorpionfish	Scorpaenidae	Scorpaena	NA	-
Fish	Sea Basses	Serranidae	Rypticus	NA	-
Fish	Sea Chubs	Kyphosidae	Kyphosus	Kyphosus vaigiensis	LC
Fish	Sea Chubs	Kyphosidae	Kyphosus	NA	-
Fish	Snappers	Lutjanidae	Lutjanus	Lutjanus griseus	LC
Fish	Snappers	Lutjanidae	Lutjanus	Lutjanus mahogoni	LC
Fish	Snappers	Lutjanidae	Lutjanus	Lutjanus synagris	NT
Fish	Snappers	Lutjanidae	Ocyrus	Ocyurus chrysurus	DD
Fish	Squirrelfishes	Holocentridae	Holocentrus	NA	-
Fish	Stingrays	Urotrygonidae	Urobatis	Urobatis jamaicensis	LC
Fish	Surgeonfishes	Acanthuridae	Acanthurus	Acanthurus chirurgus	LC
Fish	Surgeonfishes	Acanthuridae	Acanthurus	Acanthurus coeruleus	LC
Fish	Surgeonfishes	Acanthuridae	Acanthurus	Acanthurus tractus	LC
Fish	Surgeonfishes	Acanthuridae	Acanthurus	NA	-
Fish	Sweepers	Pempheridae	Pempheris	NA	-
Fish	Triggerfishes	Balistidae	Balistes	Balistes vetula	NT
Fish	Triggerfishes	Balistidae	Canthidermis	Canthidermis sufflamen	LC
Fish	Triggerfishes	Balistidae	Melichthys	Melichthys niger	LC
Fish	Trumpetfishes	Aulostomidae	Aulostomus	Aulostomus maculatus	LC
Fish	Wrasses	Labridae	Clepticus	Clepticus parrae	LC
Fish	Wrasses	Labridae	Halichoeres	Halichoeres bivittatus	LC
Fish	Wrasses	Labridae	Halichoeres	Halichoeres garnoti	LC
Fish	Wrasses	Labridae	Halichoeres	Halichoeres maculipinna	LC
Fish	Wrasses	Labridae	Halichoeres	Halichoeres radiatus	LC
Fish	Wrasses	Labridae	Halichoeres	NA	-
Fish	Wrasses	Labridae	Thalassoma	Thalassoma bifasciatum	LC
Mobile invertebrates	Crabs	Inachoididae	Stenorhynchus	Stenorhynchus seticornis	-
Mobile invertebrates	Lobsters	Palinuridae	Panulirus	Panulirus argus	DD
Mobile invertebrates	Fireworms	Amphinomidae	Hermodice	Hermodice carunculata	-
Mobile invertebrates	Urchins	Diadematidae	Diadema	Diadema antillarum	-
Mobile invertebrates	Urchins	Toxopneustidae	Tripneustes	Tripneustes ventricosus	-

6.5.4 Number of HMRs each genus was sighted on, with common names displayed above grouped genera.



6.5.5 *Model output tables for GLMs to assess association of structural characteristics with richness and abundance of organisms on HMRs.*

```
MODEL INFO:
Observations: 70
Dependent Variable: div
Type: Linear regression

MODEL FIT:
χ²(10) = 1310.57, p = 0.00
Pseudo-R² (Cragg-Uhler) = 0.71
Pseudo-R² (McFadden) = 0.20
AIC = 364.41, BIC = 391.39

Standard errors: MLE
```

	Est.	S.E.	t val.	p
(Intercept)	2.86	2.46	1.16	0.25
Max.depth	0.52	0.22	2.42	0.02
Size.cat.2Large	2.60	2.92	0.89	0.38
Size.cat.2Small	-3.59	1.15	-3.13	0.00
Size.cat.2Very small	-5.93	1.38	-4.30	0.00
Main.substrateConcrete	4.73	1.73	2.74	0.01
Main.substrateMetal	2.17	2.20	0.99	0.33
Main.substrateRock	4.82	1.54	3.14	0.00
HolesMany	5.26	1.55	3.39	0.00
HolesSome	2.63	1.18	2.22	0.03
Internal.spaceYes	2.70	1.83	1.47	0.15

Estimated dispersion parameter = 8.99

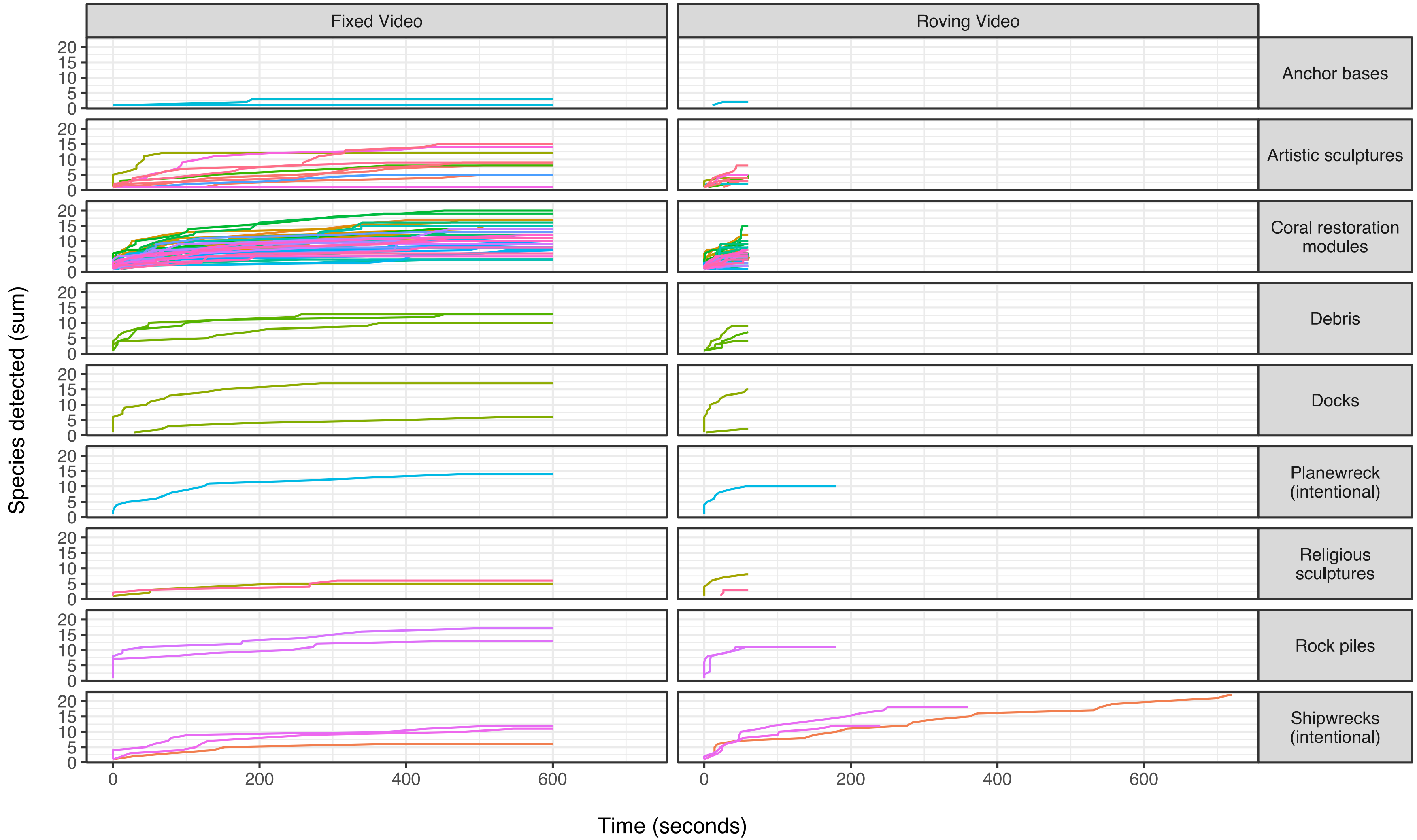
```
MODEL INFO:
Observations: 70 (7 missing obs. deleted)
Dependent Variable: totalmaxn
Type: Generalized linear model
  Family: poisson
  Link function: log

MODEL FIT:
χ²(10) = 1151.06, p = 0.00
Pseudo-R² (Cragg-Uhler) = 1.00
Pseudo-R² (McFadden) = 0.59
AIC = 835.75, BIC = 860.48

Standard errors: MLE
```

	Est.	S.E.	z val.	p
(Intercept)	2.54	0.16	16.06	0.00
Max.depth	-0.01	0.01	-1.36	0.18
Size.cat.2Large	0.73	0.13	5.57	0.00
Size.cat.2Small	-0.58	0.06	-9.98	0.00
Size.cat.2Very small	-0.98	0.08	-12.01	0.00
Main.substrateConcrete	0.35	0.09	3.74	0.00
Main.substrateMetal	0.45	0.12	3.66	0.00
Main.substrateRock	0.66	0.08	8.00	0.00
HolesMany	0.62	0.09	7.07	0.00
HolesSome	0.24	0.08	2.93	0.00
Internal.spaceYes	0.70	0.15	4.80	0.00

6.5.6 *Species accumulation curves for fixed and roving video surveys. Each coloured line represents one HMR structure. All fixed video surveys had a duration of 10 minutes/600 seconds. For roving video surveys, time was scaled according to the size of the structure, with an additional minute added on for every 5 metres of structure length (with surveys lasting from 1 minute/60 seconds to 12 minutes/720 seconds).*



Chapter 7

Discussion

Divers undergo training for a community coral restoration project near rock piles. Photo: SCT, Cozumel 2019.

7 Discussion

"I came to explore the wreck.
The words are purposes.
The words are maps.
I came to see the damage that was done
and the treasures that prevail."

– Adrienne Rich (Diving into the Wreck)

In this chapter, I reflect upon the contribution to knowledge offered by this thesis and analyse several cross-cutting themes which emerged throughout. Within each theme, I discuss applicable previous research and consider how it relates to my findings in Chapters 2, 3, 4, 5 and 6. I occasionally include extracts from my research logs to show how my thinking developed during the research process. Finally, I discuss recommendations for future research and priorities.

7.1 Contribution to knowledge

In this thesis, my aims and objectives were to 1) develop new approaches and frameworks to assess the prevalence, variety and conservation potential of HMRs from a social and ecological standpoint, and 2) enable decision-makers to navigate trade-offs and synergies between different uses and understandings of HMRs, balancing the needs of multiple human stakeholders and the marine ecosystem.

The first objective has been met through the development of an original framework for social and ecological conservation assessment of HMRs (Chapter 2) as well as its enactment at a case study site in Cozumel, Mexico (Chapters 3-6). Novel elements of the framework comprise the inclusion of a wide variety of structures within the definition of an HMR, the suggestion to decouple intention and outcome when assessing conservation opportunities regardless of original intention (Chapter 2), and the assertion that HMRs are distinct novel ecosystems which have social and ecological value independent of any comparison to natural reefs. The social and ecological assessment of various HMR types in Cozumel included factors such as location and conservation intention (Chapter 3), attitudes and ecosystem service provision (Chapter 4), activities and preferences of different stakeholders including potential overlaps with conservation (Chapter 5) and richness and abundance of marine life on HMRs of various origins, sizes and materials (Chapter 6).

The second objective has been met through an in-depth exploration of the points of view of multiple stakeholders and their uses of HMRs at a case study site (Chapters 3-5), as well as the gathering of information on richness, abundance and local and global conservation importance of marine life on HMRs to help guide future decisions (Chapters 5 & 6). The broader results of this analysis, such as the identification of several modes of encounter, barriers to access, challenges in creating a database, potential cultural importance and factors to consider in the creation of HMRs, may well apply in other places and contribute to marine conservation management more widely.

This thesis was conceptualised in response to a global lack of information around the locations, origins, uses and impacts of HMRs, and an increasing need to consider the role of novel marine ecosystems in conservation as the Anthropocene takes hold. Key knowledge advances include the conceptualisation of a wide variety of anthropogenic structures in the ocean as conservation-relevant "human-made reefs" (HMRs) regardless of origin, and the development of social and ecological methods to assess their conservation potential. Sociocultural analysis reveals the complex roles played by HMRs as novel marine ecosystems, exploring the benefits and limits of applying the ecosystem services concept to human-influenced or -created ecosystems and shedding light on the relationships and preferences expressed by different stakeholders. This will inform future collaborative conservation efforts. Finally, the design and application of a standardised rapid ecological assessment protocol gives indications of the HMR characteristics that foster richness and abundance of marine life.

7.2 Cross-cutting themes

7.2.1 Navigating novelty in nature

In the early 19th century, the poet William Wordsworth wrote, "Little we see in nature that is ours". The opposite now seems true, as human influence has spread throughout the planet

(Vitousek *et al.* 1997) and into the oceans (Jones *et al.* 2018). The acknowledgment of human influence brings both challenges and opportunities; as environmental journalist Emma Marris suggested in an interview, "getting rid of our obsession with the past is going to help us have a relationship with the nature of the present" (Nelson 2011). However, the simultaneous positioning of humans as destroyers, saviours and neutral participants in environmental change is difficult to navigate, especially within conservation. As barriers between "people and nature" have increasingly broken down, the consideration of relationships that are "difficult to conceptualise, let alone to measure" has led to enormous complexity in defining conservation goals (Mace 2014 p. 1559). This becomes especially true when conceptions of what nature "should" ultimately look like are questioned through the introduction of concepts such as novel ecosystems (Hobbs *et al.* 2013) and the rejection of traditional measures such as ecological integrity (Rohwer and Marris 2021).

HMRs provide fertile ground to interrogate the role of conservation in modern ecosystems, with their ambiguous status – created and used by humans, colonised by marine life – requiring clarification before appropriate management can be instigated. They raise questions of agency, ownership, accountability, desirable levels of human influence, definitions and consequences of success or failure, and what currently qualifies as "nature". By virtue of being underwater and not fitting the categories of "wild" or "pristine" (Jones *et al.* 2018), these unconventional ecosystems can be forgotten or ignored; the expression "out of sight, out of mind" is often applied to marine problems (Riera *et al.* 2014) and may apply particularly here. This potential to examine larger ethical questions in addition to practical concerns in an understudied environment is one of the reasons I was drawn to this project; an early entry in my research log reads: "Human influence is pervasive in the ocean, but in so many cases it is fleeting, difficult to measure and imagine… HMRs as structures are permanent evidence of our presence and influence" (pers. obs., 4 May 2017).

HMRs occupy a strange position on the continuum of "nature" to "artifice", and interview participants often brought these elements up when explaining their attitudes to a given structure or to HMRs in general (Chapter 3). I struggled similarly, as can be seen in this research log entry from 17 August 2017 which also outlines my reasoning for keeping these observations in a log (pers. obs.):

> "Today was my first dive on an [HMR]… Seeing the corals thriving on concrete blocks

> made me think… I'm glad someone took the time to put them here, glad they're healthy and here – but there's something depressing about seeing it, something that hints at their glory and tells you how short this falls… The boats felt totally different. They felt fascinating and real and like themselves. Covered and filled with life – like something had been added to make them even better. They didn't feel quite as 'artificial' somehow, and it was fun that they put my imagination to work thinking of the way people occupied these spaces before fish did. They evoked more of a sense of wonder in me, somehow? … it might seem out of place to write about how I felt in these places, to reflect on that as a scientist rather than on the makeup of the benthos. But I think my experience is a porthole onto other people's, and the feelings that arise around these structures define how people treat and value them – as well as the associated species."

In navigating this tension between human and natural elements, I ultimately found it helpful to regard HMRs and natural coral or rocky reefs as socially and ecologically different, with HMRs engendering complex social dimensions due to their human origins (Chapter 3). Some ecologists compare HMRs to rocky reefs rather than coral reefs because the structure itself is non-living and does not contribute directly to energy flows, rather collecting and channelling energy, so this comparison may be more apt from an ecological standpoint (Bortone *et al.* 2000, Chapter 6). Except in appropriate circumstances where restoration was the initial goal (such as the example with concrete coral restoration modules above), or when using specific metrics to inform regional management (Chapters 2, 5 & 6), comparisons with coral reefs are best avoided (Chapter 2).

It may also be useful to consider HMRs as marine gardens: initiated or tended by humans, composed of natural elements, and shaped by varied interactions between the two. This notion is not new; ancient clam gardens serve as a clear example of a resilient and varied "management portfolio" within a social-ecological system (Jackley *et al.* 2016). The presence of "nature" need not be binary; rather, as marine life accumulates, perceptions may shift and concepts such as nature-based solutions could come into play (Seddon *et al.* 2020). In a description of one project undertaken by the California Department of Fish and Game, Carlisle (1958) wrote: "With great hopes the department is taking a bold step into the future. The goal? To transform underwater 'deserts' into lush 'gardens' where the ocean angler can reap a brand new harvest" (p. 3) The parallel between gardens and HMRs is apt in several ways. First, the garden has been used as a metaphor more widely to describe human involvement in modern nature and novel ecosystems, with Marris (2011 p. 7) suggesting:

> "We are already running the whole Earth, whether we admit it or not. To run it consciously and effectively, we must admit our role and even embrace it. We must temper our romantic notion of untrammelled wilderness and find room next to it for the more nuanced notion of a global, half-wild rambunctious garden, tended by us."

The wide use of the terms "coral gardening" and "planting" of coral fragments in restoration efforts, both by interview participants in my study and in the literature, suggests that this framing is already in place, even if subconsciously (Chapters 4-6). In 20,000 Leagues Under the Sea, Jules Verne makes reference to an HMR overtaken by marine life, describing "all objects from the wrecked ships, now carpeted with living flowers". In a TED talk, artist Jason DeCaires Taylor describes his work as "an underwater museum, with over 500 living sculptures. Gardening, it seems, is not just for greenhouses" (DeCaires Taylor 2015). Finally, the description of preferences for certain types of marine life on HMRs and actions undertaken to make these a reality (such as cleaning, planting, and attempting to make structures appealing to target organisms) indicates a level of involvement akin to gardening. The intensity of intervention is likely to vary across structures; in cases where structures are "off the radar" (Chapter 3) or activities are not really impacted by marine life (Chapter 5), approaches may be non-existent or more hands-off.

7.2.2 The many faces of conservation

HMRs are commonly and purposefully being used as conservation tools in Cozumel and beyond to restore coral (Fox *et al.* 2019; Bayraktarov *et al.* 2020), reduce user pressure on beleaguered coral reefs (Leeworthy *et al.* 2006), and enhance fish communities (Dupont 2008; Lemoine *et al.* 2019). Conservation intention was attributed to a wide variety and high proportion of HMRs identified in Cozumel (Chapter 3). Even when conservation was not the primary purpose at the point of construction, they can deliver a variety of social and ecological conservation benefits (Chapters 2-6) which have also been attributed to structures such as oil rigs, wind turbines and shipwrecks in other places (Claisse et al. 2014; Schläppy and Hobbs 2019). Nonetheless, doubts about the compatibility of HMRs with conservation remain. For example, Rendle (2015) states:

"Altering a natural ecosystem, no matter how apparently barren, is not considered appropriate by conservationists" (p. 35). Given the plurality of actors and intentions involved in HMR creation, the idea of conservationists as a singular group who approve or disapprove of a new structure or its management seems reductive (Chapters 3-5). Instead, Sandbrook's (2015) definition of conservation as "actions that are intended to establish, improve or maintain good relations with nature" seems fitting as it incorporates the possibility of a wide range of stakeholders and motivations (p. 565).

The potential for constant and varied human influence is a key point to consider in the management of HMRs for conservation. Particularly in public-facing news, HMRs are often described as being "abandoned" or "dropped", implying that human influence ends at the point of creation and the structure is then overtaken by marine life (Hogan 2020; Gerretsen 2021). In an interview, New York Governor Andrew Cuomo explained, "we are dropping rail cars, old ships that are no longer of use, we're dropping a turbine, we're dropping significant structures because these will last a long time" (Hogan 2020). However, most synergies and conflicts that arise between different activities on HMRs, including conservation, will occur because the structures are in constant use and stakeholders disagree over appropriate management (Chapter 5).

The variety of perspectives held by different stakeholders may complicate conservation management of HMRs, because the lenses through which they see the same structures can be wildly different. I first realised this during a meeting on my scoping trip in which two experts and I discussed a rock pile believed to be the remnants of a Mayan HMR used for fishing in another part of Mexico. I wrote the following in my research log on August 15, 2017:

> "I find it amazing how 3 different people from 3 different professions (fisheries specialist, archaeologist, biologist) can look at a pile of rocks and see different things. [One] saw a potential fishing technique, [another] saw the shape and structure of a wall that used to be there, and… how it might have been used by the people who lived there. I wanted to know what animals might have been associated with the rocks, imagined what might have taken refuge or grown there."

By analysing people's descriptions of the sea, Engel et al. (2021) found that mental images and understandings of the sea can shape their relationships to it and influence pro-environmental behaviours. Analyses in this thesis identify stakeholder differences in awareness of types and locations of HMRs, understandings of their history, attitudes, perceived provision of ecosystem services and preferences regarding marine life (Chapters 3-5). Hare et al. (2018) describe conservation behaviours as "interspecific cooperation" and suggest humans "maximize their inclusive fitness returns by selectively affecting the success of members of other species" (p. 7). Through this lens, it makes sense that individuals with different activities, needs and requirements may choose to conserve different organisms or have different approaches to conservation (Chapter 5).

As Parsons et al. (2017) state, "conservation is people" (p. 3). In the course of my research, many individuals exhibited a clear emotional and logistical investment in the HMRs they use, putting energy into creation, upkeep and achieving certain outcomes (Chapters 4 & 5). They also articulated several versions of conservation intention within varied realms such as fishing, tourism, art, education, research and aquaculture (Chapter 3). Therefore, synergies and conflicts between different perspectives need to be considered when carrying out conservation on these structures and considering avenues for collaboration (Chapter 5). Highly invested individuals with different primary activities could be strong advocates and partners, as indicated by their unprompted self-determination as conservationists and their widespread and specific knowledge of HMRs (Chapters 2 & 5). However, if conceptualisations and goals of conservation differ, this could create problems. It would therefore be important to determine priorities and definitions of conservation for different stakeholder groups prior to commencing any collaboration. Rather than imposing pre-defined notions, this could include asking all stakeholders questions such as, "What does conservation mean to you?"; "What are your needs and goals in relation to this HMR (access, uses, ideal levels and types of marine life)?"; and "What resources (time, money, expertise, networks) are you willing to put towards achieving these goals?" It may then be possible to see the extent to which these goals and ideals overlap with those of a community- or research-based conservation project and determine how and whether a collaboration could proceed.

7.2.3 An HMR of one's own

People who create and use HMRs can develop a strong sense of ownership which may raise the stakes of any encounter with others who may also feel a sense of ownership (Chapter 5). The cultural models of property described in Thompson's (2007) work on shoreline conflicts can serve to illuminate sensitivity and the sense of ownership around the uses and locations of HMRs (Table 7.1, Chapter 5). Thompson explains that people enact property based on expectations formed by shared cognitive models, or cultural models, which serve as "simplified representations of the world that highlight only selected features of our biophysical and social environments" (p. 213). He describes seven cultural models of property – sovereignty, community, landscape, ecology, commodity, moral order and productivity – and posits that conflict emerges when expectations are not sufficiently shared. These cultural models of property apply clearly to HMRs in Cozumel (Table 7.1) as well as to descriptions of HMRs in the wider literature, with for example the productivity model being clearly expressed in the statement "perhaps man can help to bring some of this richness of life to the unsheltered, relatively barren areas" (Carlisle 1958 p. 3).

Despite strong feelings of ownership, no individual can legally claim private property in federally managed marine and coastal areas in Mexico, such as those containing HMRs. The governance of such spaces is determined in the 27th article of the Mexican Constitution, which was written after the 1917 revolution and establishes natural resources including coastal and marine waters as "propiedad de la nación" or "property of the nation" (Artículo 27 Constitucional). This determination was a matter of practical ownership and symbolic national pride in the wake of centuries of imperialist and colonial rule (Brañes 2018; Souza Bosch 2021). In some cases, people are granted federal concessions which allow them to use and – following an environmental impact assessment, with appropriate permits – modify a given area, for example by constructing HMRs. However, they cannot legally exclude other people or control their use of the HMR because these areas and resources are considered to be within the public dominion, freely accessible to all individuals. This can result in significant tensions, with notions of private and common property becoming confused, as can so often occur in the ocean, and resentments rising (Cole and Ostrom 2012; Souza Bosch 2021). Thus, the cultural models of property in a particular setting can take on great relevance in understanding stakeholder conflicts.

I did see many examples of people enacting perceived property rights through barriers to access (Chapter 3) such as selective sharing of knowledge, or reacting to perceived property rights with social discomfort along HMR access routes. The most striking instance I saw was a rope fence strung around underwater sculptures at a beach club; any diver could easily swim over it, and it seemed like a highly terrestrial statement of belonging. The implications of perceived ownership over HMRs are vast, with agency and responsibility emerging as important themes in attitudes to

HMRs (Chapter 4) and playing a significant role in conflicts and synergies between stakeholders, with problems arising if their goals are not aligned (Chapter 5). In some cases, this sense of ownership could be extreme, as when one participant referred to an HMR as “my baby”, or when the creators of structures invested a lot of time, care and money in maintenance (Chapter 5). However, other participants could also distance themselves from ownership, for example when conducting environmental consulting projects, as they seemed to see the origin of the project as beyond their control. In his TED talk, artist DeCaires Taylor (2015) seemed to believe ownership is nullified by the growth of marine life, through the creation of a sense of the structure belonging to nature:

> “the greatest thing about what we do, the really humbling thing about the work, is that as soon as we submerge the sculptures, they're not ours anymore, because as soon as we sink them, the sculptures, they belong to the sea. As new reefs form, a new world literally starts to evolve, a world that continuously amazes me”

While creating an HMR can give people a sense of satisfaction, it also comes with a responsibility which statements such as the quote above ignore (Chapters 4 & 5, Moore 2016). Management and maintenance of HMRs is no small feat, nor is their removal when things do not go as planned. In the case of a tyre reef in Florida, the removal costs were about $2 million USD in 2007, and the costs of decommissioning offshore infrastructure has been estimated at $210 billion USD. Many structures, including accidental shipwrecks, are simply left in place even when they might be leaking pollutants because recovery operations are logistically onerous and even dangerous. In many cases, the creator of an HMR cannot be identified or held liable. Macdonald (1994) expresses concern over the accumulation of such structures, stating “we are creating a seafloor consisting of waste… it must be on a limited scale” (p. 108). De Alessi (1997 p. 141) sees private ownership as a solution to some of these problems, suggesting:

> “one of the most promising areas for underwater ownership lies in the creation of artificial reefs… even partial ownership encourages protection and innovation… Allowing exclusive ownership of artificial reefs, or ownership of the right to fish at such reefs, would provide even greater encouragement for reef creation and maintenance.”

While this level of ownership is not currently an option in the Mexican context, it may be worth considering elsewhere. When it comes to conservation, the sense of ownership people feel over HMRs is a double-edged sword. In some cases, it may blind them to objective assessments of conservation outcomes as a potential "IKEA effect" kicks in and "labour leads to love" (Chapter 3, Norton *et al.* 2012 p. 453). A sense of investment and willingness to expend effort could be harnessed for mutual benefit when conservation goals are aligned, but may present significant roadblocks when goals are not aligned. Likewise, people may be keen to assert ownership when outcomes are good but shirk any association when problems arise. Therefore, some form of traceable responsibility for the creation of HMRs (if not outright ownership), as instigated through permitting processes, could help minimise damage and maximise benefits.

Table 7.1 Cultural models of property as defined by Thompson (2007) and relevance to HMR research in this thesis. Numbers in parentheses indicate referenced chapters.

From Thompson (2007)		**Applications to HMRs**			
Cultural model	*Focus*	*Activities*	*Ecosystem services*	*Trends noted in my research*	*Examples from Cozumel*
Sovereignty	Individual control, boundaries, exclusion, privacy	All	All	Unwillingness to share location information (3); Sense of ownership after "discovering" or creating an HMR (3, 4); Creation or maintenance of barriers to access (3); Stakeholder conflicts over management of marine life on HMRs (5)	Installation of sculpture of Virgin Mary to prevent theft and property destruction (4); Concealing Mayan artefact by hovering above it on guided tour (3); Enforcement against illegal fishing on HMRs (4); Social discomfort around accessing HMRs through beach clubs (3)
Community	Social interaction, proper behaviour, sense of place	Tour operation, Recreation, Cultural activities, Art, Conservation	Social relations, Sense of place, Cultural heritage, Recreation & tourism, Education	Meaningful experiences in guided encounters of HMRs (3); Desire to improve marine ecosystems for future generations (4); Sense of HMRs as landmarks which shape local identity (4)	Annual gathering, ritual and parade around the "Virgin of Cozumel" (4); United opposition to damage of corals in construction of cruise ship dock (4); Condemning "theft" of anchors frequently visited by community members (3)
Landscape	Visual consumption	Tour operation, Recreation, Art, Conservation	Recreation & tourism, Inspiration, Sense of place	Aesthetic concerns over HMR design and placement (4); Disapproval of visual disruption of natural spaces (4, 5)	Disposal of hurricane rubble and debris underwater (3, 4); Designation of artistic sculptures as "ugly" or "beautiful" (4); Preference for designed HMRs which mimicked natural shapes (4)
Ecology	Ecosystem functions and ecological connectivity	Conservation, Scientific research, Coastal protection, Erosion regulation	Habitat, Genetic resources, Knowledge systems	Comparisons to "natural" coral and rocky reefs (4); Use of HMRs for coral restoration or coastal protection (3, 4, 5); Use of HMRs to understand ecological processes (4, 5, 6)	Use of coral restoration modules to rebuild previous ecosystems (3, 4, 5); Scientific work using HMRs to study community succession (4, 5)

From Thompson (2007)		**Applications to HMRs (cont.)**			
Cultural model	*Focus*	*Activities*	*Ecosystem services*	*Trends noted in my research*	*Examples from Cozumel*
Moral order	Awe, humility, wonder and proper order	Spiritual and religious activities, Conservation, Art, Education	Spiritual & religious, Inspiration, Knowledge systems, Education	Preference for careful planning and aversion to "sinking to sink" (4); Desire to create HMRs and contribute to recovery of nature (4); Dichotomies between "natural" and "artificial" (4); Use of art and education to build awareness of and galvanise action for environmental crises (4)	Installation of sculpture of Jesus Christ to encourage pro-environmental behaviour (4); "Cleaning" to remove marine life on HMRs (5); Creation of artworks to pay tribute to environmental heroes (3, 4, 5)
Commodity	Selling for the highest market value	Fishing, aquaculture, tour operation	Fishery, ornamental resources	Concern over profit as a dangerous or immoral motivation (3, 4); Disagreements over who should bear costs for maintenance (4, 5)	Use of lobster traps and oyster boxes to maximise saleable product (4, 5); Concerns over "looting" and sale of archaeological artefacts (4, 5); Criticism, suspicion or resentment of individuals who financially profit from HMR creation (3, 4, 5)
Productivity	Putting resources to use for the betterment of society	Aquaculture, Conservation, Tour operation, Inspiration	Education, aesthetic value, fishery, habitat	Sense of agency in transforming marine spaces to make them more usable by humans and marine life (3, 4, 5); Context of environmental destruction making interference more palatable (4)	Maximising attractiveness of sandy areas for tourism by building HMRs (4, 5); Practice of coral "gardening" (4, 5)

7.2.4 Conservation assessment of HMRs

Determinations of conservation value or "potential" change over time as social conditions and conceptions of conservation change, but usually include at least two elements: benefits that can be derived by humans and the existence value of organisms (Margules and Usher 1981). In this thesis, benefits were largely measured through the provision of ecosystem services (Chapter 4), and the richness and abundance of marine life served as a proxy for the organisms present (Chapter 6). The complexities of relationships between people and nature were further explored through an analysis of perceptions, attitudes, synergies and conflicts (Chapters 3-5).

HMRs are often referred to as "tools" to achieve different ends and shape marine ecosystems in some way (Pitcher and Seaman Jr 2000; Dupont 2008), in keeping with their role as agents of transformation to enact human will in the marine environment (Chapter 4). In Cozumel, levels of comfort with human agency varied widely, with some people "happy to put their little grain of sand" and contribute to positive environmental change through the creation or maintenance of HMRs, and others resenting any human interference in natural systems. Often, a sense of appropriate purpose was what seemed to enable acceptance of HMRs, while "sinking to sink" was derided (Chapter 4). The social and ecological assessment of HMRs in conservation management is paramount, as many projects cite or predict conservation benefits but few monitor or record them. Early on in the project, I noted in my research log while reading through permit applications and news stories that there was abundant "conservation rhetoric but in what ways are… [HMRs] living up to that?" (pers. obs., 22 July 2017).

Assessment of conservation benefits of HMRs can take two forms, both of which were trialled in this thesis: comparison to original goals; and assessment of targeted and general conservation-relevant outcomes regardless of original goals (Chapters 2-6). Bortone et al. (2000) suggest "no artificial reef should be built without some intended purpose", encouraging specificity in goals (p. 134). This statement is echoed in some form by the majority of scientists studying HMRs, and yet many structures are created without articulating clear goals (Becker *et al.* 2018). Requiring HMR creators to articulate goals is likely to be useful in two ways: first, the process could serve as a gatekeeping strategy, engendering focus and reflection and helping to ensure structures are only created for specific purposes by individuals or groups who can be held responsible. Second, it can provide a benchmark to measure success in relation to original goals. However, it is important to acknowledge that purpose is not singular, binding, or a guarantee of results. Conservation intention can be present even when it is neither primary nor envisaged at the point of creation (Chapter 2). Multiple intentions can be present simultaneously, and even conservation intentions can include a wide range of purposes (Chapters 3 & 5). The example of conservation-focused alterations such as adding rocks around Reef Balls or dock pilings to provide habitat for marine life (Chapters 3 & 6), or the repurposing of a decommissioned oil rig in a "rigs-to-reefs" scenario (Fowler *et al.* 2018) are clear examples of how a structure's purpose can be transformed.

In assessing the relevance and potential of HMRs for conservation, the combination of social and ecological surveys seems crucial, due to human influence in their creation and use (Chapters 2-6). This holistic approach can help conservationists to understand how structures associated with low levels of marine life may provide value to conservation in other ways (e.g. religious sculptures which have low richness and abundance but also hold cultural and spiritual value that can enhance people's relationships with nature in ways that may change their behaviour and attitudes in other contexts; Chapters 4-6). Taking a holistic approach to researching HMRs can prompt the gathering of contextual information, such as on the creation of structures (e.g. confirmation of materials used) as well as their uses and maintenance (e.g. diver disturbance, cleaning practices) and even enable ecological surveys to occur (e.g. by informal discussions revealing locations and access routes). The process of conducting social surveys may allow conservationists to identify and easily share results with key stakeholders and build trust and understanding. Conversely, ecological surveys can inform the results of social surveys and guide policy based on the diversity and abundance of marine life present. In some cases, it may be possible to empower non-scientists to monitor structures and feed into adaptive management since they are often present and highly invested in outcomes (Chapter 6). Anecdotally, many people came up to ask about my project while I was conducting ecological surveys, and the people who created or worked around the HMRs were very curious to know the results. When I gave a short talk about my research at a beach club, one individual approached me afterwards and expressed frustration and resentment at not being included in monitoring efforts. This made me think there was real potential for these techniques to enable HMR creators to monitor their structures in a way that could be used by scientists to help determine conservation benefits and shape best practice. Marine biodiversity monitoring by tourists is already a widespread activity throughout the world, with programmes such as Reef Check (https://www.reefcheck.org/) contributing to conservation management and scientific research.

One moment in which I realised the importance of assessing the interplay between human and marine life on HMRs was during a video survey, when a group of divers swam by the structure I was filming. I felt annoyed and concerned that it would affect the results of my ecological survey, given the well-documented effects of divers on reef fish communities (Emslie *et al.* 2018). The structures were built and managed for tourism by a nearby beach club, and the manager was allowing me space to store my equipment and easy access via their stairs, so it seemed highly unreasonable to ask them to keep tourists out of the water for weeks on end. I debated whether I could perform my surveys at times when tourists would not be in the water, but this would drastically cut down the amount of time I could spend surveying daily and I was on a tight schedule. Then I reasoned that the presence of these tourists was normal for the fish who had chosen to use those structures; if anything, conducting my surveys without people present would represent an abnormal situation. I continued with the surveys and noted the presence of divers when it occurred. This experience made me think that the constant interaction with, and shaping of, ecosystems needs to be studied more, taking the range of human activities such as diving, cleaning or planting into account in assessments of biodiversity. Most immediately, this could take the form of metrics such as "cleaning frequency" or formal noting of conservation alterations such as the addition of rocks and coral planting (Chapter 6). However, it could also translate into further research on human-wildlife interactions, as some research has shown that animals can have differential responses to human activities (Papworth *et al.* 2013) which could ultimately shape ecosystem dynamics.

In order to enable holistic conservation assessment, social and ecological data could be combined to determine the conservation potential of varied HMRs within a single geographic area. This could help managers to prioritise resources and conduct appropriate monitoring and maintenance, as well as make decisions about which HMR projects to fund or create. For example, ecological data on diversity and abundance and presence of species of conservation importance (Chapter 5) could be combined with social data on provision of ecosystem services (Chapter 3) and perceived conservation intention (Chapter 2). Uniting simplified versions of these conservation-relevant data in a tick-box matrix could provide a holistic picture of the conservation importance of a given HMR and allow for comparison between existing and potential HMRs in an area (Table 7.2). It could also be aggregated to indicate real-world conservation potential as suggested in the matrix of conservation opportunities Chapter 1 (schematic in Figure 7.1).

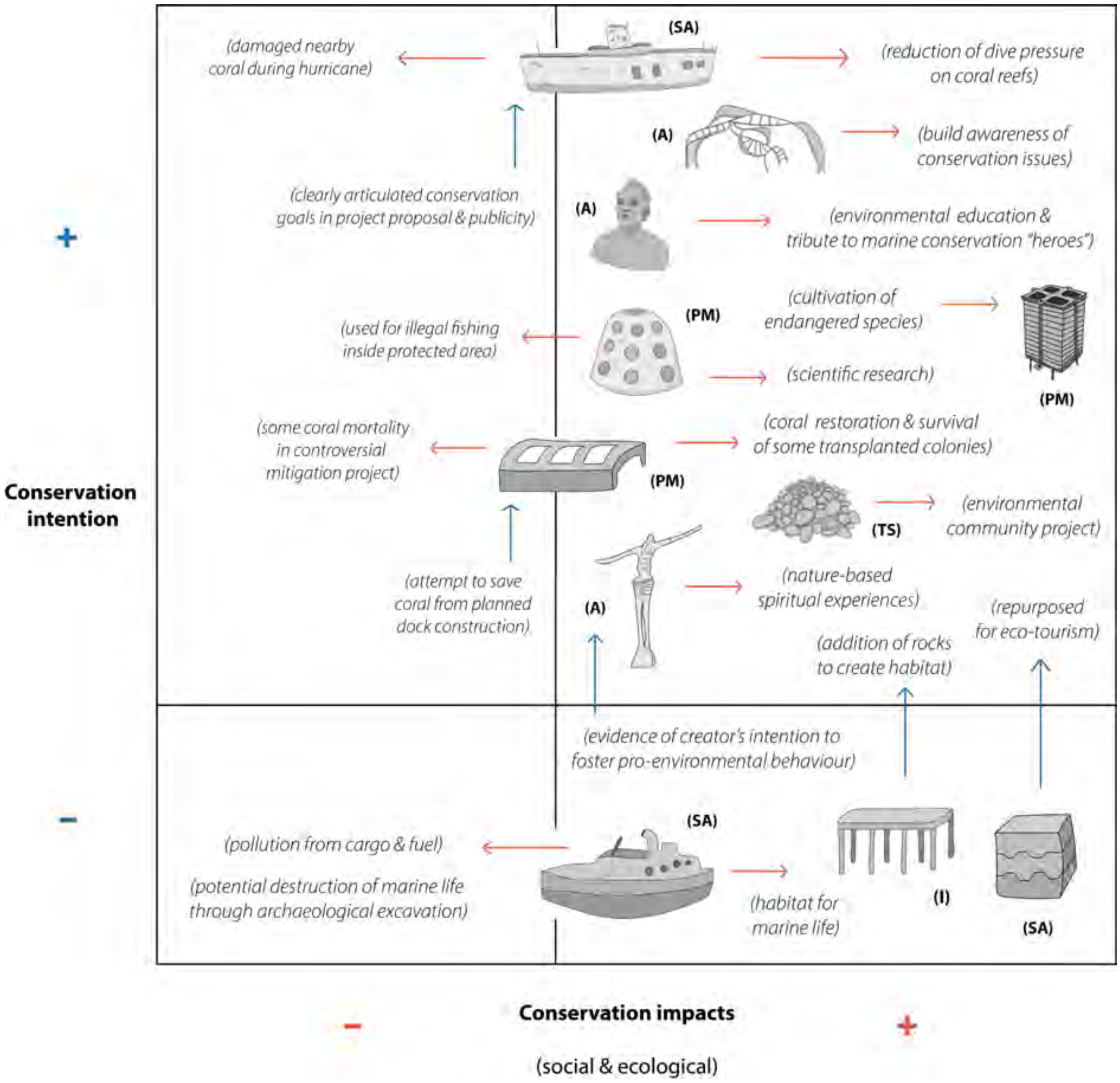


Figure 7.1 Updated matrix of conservation intention and conservation impacts (Chapter 2) indicating examples of conservation intention (blue) and social and ecological conservation impacts (orange) from analyses of case study (Chapters 3-6). Featured HMRs include sunken artefacts (SA) such as shipwrecks and debris, prefabricated modules (PM) such as oyster boxes and concrete coral restoration modules, traditional structures (TS) such as rock piles, and artworks (A) including artistic sculptures and religious sculptures. Examples are for illustrative purposes and impacts or intentions may apply beyond the HMRs shown.

Table 7.2 Example of factors to consider in HMR creation (Chapter 3) and conservation benefits (Chapters 4, 5, 6) with additional factors based on an environmental impact report prepared by Secretaría de Pesca (2005). Green indicates a conservation-relevant factor and blue indicates a metric of conservation benefit. Preliminary indications for two HMR types included as examples.

Category	**Factor**	**Explanation**	***Rock pile***	***Shipwreck (intentional)***
Materials	Availability	✓ = locally available	✓	✓
	Toxicity	✓ = non-toxic	✓	NA
	Durability	✓ = durable	✓	✓
	Costs	✓ = cheap (or within budget)	✓	✓ (donation)
Design	Aesthetic appeal	✓ = visually appealing	✓	✓
	Conservation intention	✓ = present	✓	✓
	Stability	✓ = unlikely to be displaced	✕	✕ (displaced in hurricane)
	Technology	✓ = locally available	✓	NA
Installation	Labour costs	✓ = cheap (or within budget)	✓	NA
	Experience	✓ = local expertise	✓	NA
	Transport (terrestrial & marine)	✓ = minimal transport	✓	✕
	Anchoring	✓ = secure	NA	NA
	Submersion process	✓ = simple	✓	✕
	Machinery required	✓ = locally available	✓	NA
	Community involvement	✓ = involved, ✕ = excluded	✓	✓
	Environmental impact assessment	✓ = no concern, ✕ = high concern	NA	NA
Maintenance & monitoring	Costs (labour & materials)	✓ = cheap (or within budget)	✓	NA
	Experience	✓ = local expertise	✓	NA
Prevention	Removal costs	✓ = cheap (or within budget)	✓	NA
	Logistics of removal	✓ = simple	✓	✕
Sociocultural (ES)	Education	✓ = present	✓	✓
	Spiritual & religious	✓ = present	✕	✓
	Inspiration	✓ = present	✓	✓
	Cultural heritage	✓ = present	✕	✓
	Recreation & Tourism	✓ = present	✓	✓
	Social relations	✓ = present	✓	✓
	Sense of place	✓ = present	✓	✓
	Knowledge systems	✓ = present	✓	✓
	Aesthetic value	✓ = present	✓	✓
	Fishery	✓ = present	✓	✓
	Genetic resources	✓ = present	✕	✕
	Ornamental resources	✓ = present	✕	✓
	Coastal protection	✓ = present	✕	✕
	Erosion regulation	✓ = present	✕	✓
	Habitat	✓ = present	✓	✓
Marine life	Overall richness	✓ = richness (# species)	16	29
	Overall abundance	✓ = Max N	137	128
	Local Target Species 1 (positive)	✓ = present (e.g. keystone)	NA	NA
	Local Target Species 2 (negative)	✓ = absent (e.g. invasive)	✓	✓
	Endangered species (Red List)	✓ = present	✕	✓

7.2.5 *Conservation potential, intentions and benefits: how much "good" is enough?*

Once social and ecological impacts have been measured and potential conservation benefits have been identified, the question then becomes where the line is in terms of providing "sufficient" benefits to merit investment or penalties from a conservation perspective. Though outcomes are often framed in a binary way – for example, with Bohnsack and Sutherland (1985) stating "many artificial reefs have failed" (p. 20) – it may be more beneficial to consider HMRs as dynamic structures which can be managed adaptively (Figure 7.2). Both benefits and costs can emerge when things do not go according to plan, and by reframing this process it may be possible to learn from previous outcomes and realise "the failures of the past have not been complete: there have been partial successes" (Berkes *et al.* 2003 p. xix). By compiling stories of conservation outcomes at different stages, it may be possible to guide present and future HMRs toward creating as many benefits as possible through conscious intervention. For example, it may help to curb damaging behaviours or enable standardised monitoring. Similarly, it may help managers to recognise when a structure needs to be removed, as well as identify key risks and avoid the creation of HMRs which are well-intended but unlikely to deliver conservation benefits. The regular use of a "reef performance scale" such as that suggested by Baine (2001), considering original objectives and unintended positive and negative outcomes, could help to track an HMR's state and aid in management decisions over time.

It is also important to consider the origin of conservation intentions, and how these might be driven by other emotions or values. For example, one sense in which people appear relatively united is in the use of HMRs for restoration following some kind of natural disaster or transformation. This was a persistent theme in the interviews, with participants usually indicating that they approved of the use of HMRs to restore a previous state, but being much more selective about the creation of perceived change (Chapter 4). In the case of Cozumel, these disasters were destructive hurricanes which impacted coral communities, leading to the creation of several HMR projects to restore the ecosystem and prospects for tourism (Álvarez-Filip *et al.* 2009; Santander *et al.* 2012). The desire to return to this previous state could be combined with strong emotions and attachment to a sense of place, such as when one participant indicated that he wanted his children and grandchildren to be able to enjoy the same environment he had (Chapter 4). Klein (2007) explains something similar to this impulse, saying "Most people who survive a devastating disaster want the opposite of a clean slate: they want to salvage whatever they can and begin repairing what was not destroyed; they want to reaffirm their relatedness to the places that formed them" (p. 8). This sentiment may apply more generally in a time of climate change, partially explaining the emotional desire to create HMRs and salvage some version of what is lost. However, this must be balanced with the awareness that the creation of HMRs represents a new type of transformation.

It should be noted that the London Convention Guidelines for the Placement of Artificial Reefs, which apply to HMRs clearly state, "artificial reefs should not be constructed in areas prone to hurricanes or other storm events" (London Convention and Protocol/UNEP 2009 p. 3). Concerns around the anchoring of structures are particularly prevalent in an area such as Cozumel, where unsecured HMRs could conceivably become mobile during a storm and crash into natural coral or rocky reefs or cause other types of damage. Even when anchored, the 56m-long C53 shipwreck shifted during Hurricane Wilma (Category 5) and pushed into a nearby natural reef, sustaining and causing damage. As much as possible, these occurrences must be foreseen and planned for when HMRs are created, rather than dealing with the fallout after it occurs. To some extent, it is necessary to acknowledge that "ecosystems are always changing, whether humans are involved or not" (Marris 2011 p. 10) – but also to avoid creating further damage, even with the best intentions.

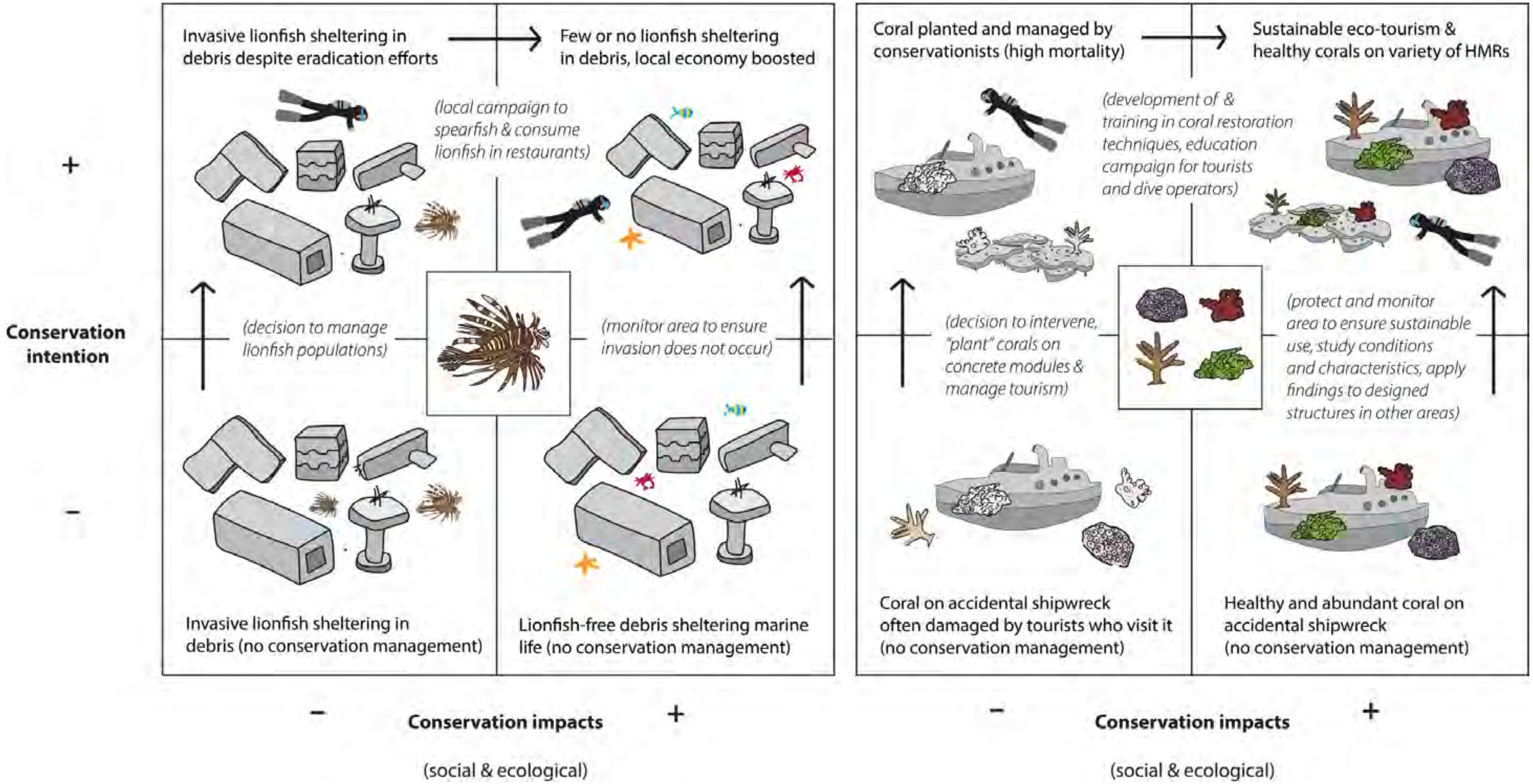


Figure 7.2 Examples of potential adaptive management for conservation on HMRs based on simplified examples of marine life preferences for coral and lionfish (Chapter 6). Situations are highly simplified and organisms are not drawn to scale.

7.2.6 *The application of ecosystem services*

The application of the ecosystem services framework to HMRs in their own right – rather than as replacements for coral reefs (Schut 2013) – raised several questions of wider relevance to novel ecosystems. While the use of this framework integrates well with the consideration of ecosystem services and associated benefits in conservation policy and potential mitigation projects, it also raises questions around situations in which the benefits being provided by nature are set in motion by, and later realised by, humans themselves (and to what extent this origin makes a difference). Collier (2014) suggests that "some novel ecosystems may provide ecosystem services that were minimal or perhaps absent from their original form" (p. 166). During fieldwork, in my research log, I noted curiosity about "the way people interpret ecosystem services or activities – like how structures used for education can be for dive training or environmental awareness, or spiritual uses range from structures as posthumous tributes to just generally feeling at one with nature while diving to representations of religious icons" (pers. obs., 23 February 2019).

Particularly in the case of cultural ecosystem services, the range of examples people identified went far beyond those normally attributed to coral reefs, even in the Anthropocene (Hicks *et al.* 2013; Woodhead *et al.* 2019). After being given a definition of the ecosystem service, participants applied it in ways I would not have expected; for example, saying that retrieving "treasure" from a shipwreck was an ornamental resource. Some of the services seemed more open to interpretation or even strangely falsifiable; for example, when I wrote in my research log, "LOLLL – someone heard a dive guide telling tourists on a similar site that these [concrete modules] were 'Mayan structures' – which of course the tourists were thrilled with. So maybe imagination can be applied to good effect there too" (pers. obs., 17 August 2017). I chose to keep these explanations and nuances because they seemed valid in the context of the question and a clear example of how people and nature have become so intertwined, perhaps exceeding the scope originally intended for the ecosystem services framework.

7.2.7 *Databases*

The creation of local and global databases of HMRs (Chapters 2 & 3) would be a valuable contribution to marine conservation, enabling holistic management and understanding of the state of the seascape. However, the creation of such databases should proceed with caution given the high sensitivity of HMR locations and the sense of emotional connection and protection many stakeholders may feel (Chapters 3, 4, 5). Gaius Petronius Arbiter once wrote, "Si recte calculum ponas, ubique naufragium est" – "if you reckon correctly, shipwreck is everywhere". The quote applies in two ways. The discovery of so many more HMR sites than I expected in Cozumel (Chapter 3), coupled with measures of their global extent (Halpern *et al.* 2008; Bugnot *et al.* 2020), suggests that HMRs are abundant and spreading fast. But their management is incredibly sensitive, and their successful use in conservation will require careful navigation of relationships with different stakeholders and cautious data management.

In creating and managing databases, and particularly when including GPS points, I would recommend that individual informants be made fully cognizant of the potential consequences of sharing information, and it should not necessarily be made publicly available. Some data are already available in existing local open access databases, in which case administering it could be less of a problem. Options for data management could include an independently managed "data trust" where data are kept securely and managed or shared according to a pre-established ethical framework (Zarkadakis 2020). In any case, a GPS point is not a guarantee; in a government-led project in the Mexican state of Tamaulipas, Reef Balls were set down 600m away from a beach and then lost for ten years because it turned out the points had either not been taken correctly or the structures had moved; they were later found by a team of divers (Huerta 2018). Even without exact GPS points, information on the existence and characteristics of HMRs can be incredibly useful in understanding their variety and spread.

In cases where individuals feel location data is sensitive, a ballpark process such as that employed in Chapter 3 could be useful. This would allow managers to gain a sense of approximate numbers and locations of HMRs without compromising their exact locations, which may be appropriate in cases where sites hold significant cultural or ecological value and require some sort of protection (Frank *et al.* 2015). Remote sensing technology may soon allow the detection of HMRs in shallow water, as it is already being used to map coral reefs facing similar logistical challenges (Asner *et al.* 2020). In the case that this occurs, careful consideration should be given to how and when data should be shared. The compilation of relevant data can contribute to local and regional marine and coastal management, as HMR creation can have landscape-level effects on processes such as coastal erosion (Zepeda-Centeno *et al.* 2019).

7.2.8 *Creating guidelines for HMR creation and management*

Ultimately, the collection of information on HMRs at a local, regional and global scale can feed into guidelines for HMR creation and management from a conservation perspective. In this respect, there is something of a vacuum because in many places it remains unclear who should be in charge of monitoring and management of HMRs (Pickering *et al.* 1998; Rendle 2015). Even when the chain of command is clear, inputs to decision-making may not be; as Rendle (2015) states, "Quite often a country's stance on artificial reef deployment is based on opinion rather than reliable research" (p. 52). While local government agencies often field permit applications, there is a gap between regulation and action. Often, when an HMR is not creating significant harm (and even sometimes when it is), the decision is taken to simply leave it. The logistical and financial costs of installation lead to significant path dependency, compounded by the "out of sight, out of mind" dynamics that often govern ocean issues. In an unregulated environment, the powerful motivation "to make a difference" in conservation (Papworth et al. 2019) or assert "environmental virtue" (Sandler 2013) can easily override evidence around the functionality of particular HMRs.

While people may derive a strong sense of meaning from creating or managing HMRs with conservation intention, feeling good is not necessarily enough. As Parsons et al. (2017) suggest, "Conservation needs to be more than just "being busy" or "feeling" that we are having an impact" (p. 1). This point took one particular relevance for me one morning in Cozumel near the end of my fieldwork, when I ran into an acquaintance on the way back from a beach clean-up. They told me excitedly about a project they were considering; they would work with a local artist and use the rubbish to create and submerge a sculpture, creating an HMR to call attention to marine conservation issues. I said the intention seemed laudable, but asked what they thought might happen to the structure over time. They did not appear to have considered this aspect, but after a short conversation we concluded the disintegration of the structure might prove counterproductive. This moment, among others, made me reflect on the need to channel good intentions through best practice guidelines and permitting processes. In turn, these permitting processes would ideally be informed through data on various types of HMRs.

In a conversation with a government worker somewhere else in Mexico, they described frustration over the lack of information around what "worked" or didn't with HMRs for conservation purposes, expressing a desire for tools to help guide their decisions. Some helpful examples of such guidelines already exist, but they do not consider a full range of HMR types or social and ecological parameters (London Convention and Protocol/UNEP 2009; Fabi *et al.* 2015). Additionally, the reality of success is likely to be different in different contexts, requiring some level of assessment at a local level. The consideration of multiple social, logistical and ecological factors in the creation and regulation of a wide variety of HMRs (Table 7.2) could inform construction at a wider scale, helping to ensure that good intentions are realised. In the context of general guidelines, empowering rapid assessment of HMRs at a local level through scalable and affordable tools can help foster locally appropriate decisions, subject to applicable law.

7.3 Overarching reflections

7.3.1 Strengths and weaknesses

Strengths of this thesis include the diversity of HMRs and stakeholders considered and the concurrent application of varied methods to assess these systems in which social and ecological processes are inextricably linked. In addition, I believe the deep exploration of cultural engagement with HMRs, including emotional and utilitarian relationships, can help to inform conservation efforts across disciplines. By engaging with the understudied topics of HMRs and novel marine ecosystems, this thesis fills a unique and increasingly relevant niche.

While constraints on time and funding and the small nature of my study site prevented me from surveying more people and HMRs, this would ideally have occurred. Nonetheless, I believe the conclusions of the thesis are robust within its parameters, given saturation in the social interviews and the widespread coverage of HMR types and sizes in the snapshot ecological surveys. With that said, I recommend further sampling across time and space to inform any future interventions, particularly when considering a different site or type of HMR not included here. In order to understand the impacts of HMRs more broadly, analysis of benthic communities as well as mobile fish and invertebrates would provide insight at a community level and be of particular use in coral restoration.

7.3.2 Wider implications

Wider implications of this thesis centre largely around the treatment of novel ecosystems and incorporation of multiple stakeholders in marine and terrestrial conservation. While the co-creation of spaces where human and non-human life exist is far from new, the validity of active human influence seems to be perceived differently in novel ecosystems such as HMRs. This may bring into relief a changing contract between people and nature, where the depth and complexity of relationships with nature – both emotional and utilitarian – take on a new form. The dynamic nature of these interactions is crucial, as some interventions may be long-standing, strong and involve several stakeholder groups while others may be fleeting, indirect or non-existent. A strong sense of ownership and desire to manage natural spaces was found, despite this not being something which is often associated with the sea. This sense can take several forms including the wish to protect specific features like HMRs from external forces, a sense of stewardship, or a feeling of entitlement to exert positive or negative impacts on HMR-associated marine life and create a microcosm in which one's preferences are realised. Therefore, in planning conservation in these uncharted waters, with multiple interested parties who may feel strongly, there is a strong need to under understand different definitions of conservation and idealised visions of nature. Conceptualisations of "good biodiversity" are varied and context-dependent, meaning that conservation collaborations will benefit from a clear delineation of priorities and ideal or acceptable future scenarios, in order to be conscious of tradeoffs as they occur. Finally, a proactive approach to these complicated questions will pay dividends; as nature at sea and on land is transformed by people (actively or passively), the opportunity to shape this influence for the benefit of both people and nature must be seized.

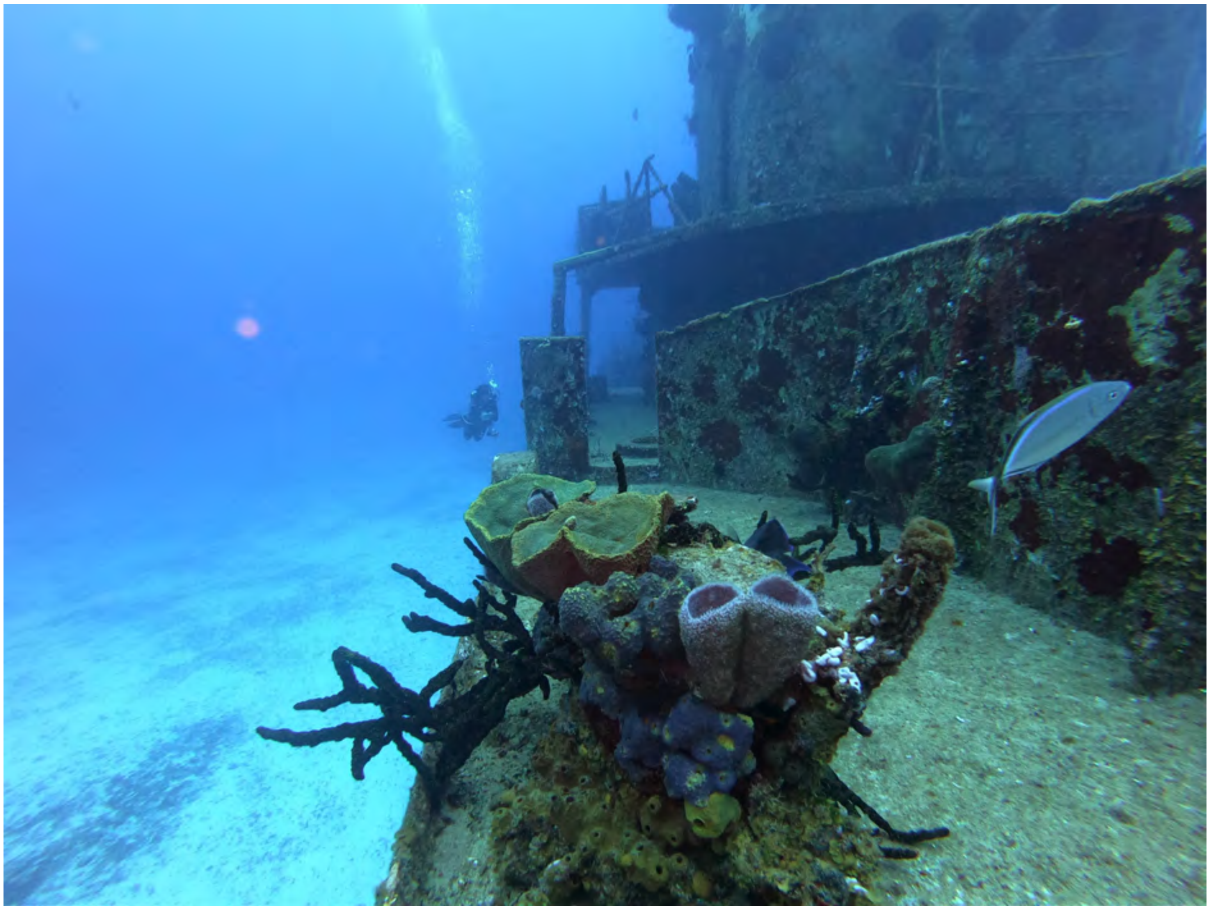
7.3.3 Further research

With the long-term aim of understanding how coastal ecosystems are being shaped by people and marine life in the Anthropocene, and of shaping human influence in an optimal direction, I would recommend the replication of social and ecological surveys on HMRs over time and in different circumstances. Focused case studies on specific HMR types which affect multiple stakeholders, such as offshore wind turbines or units placed to prevent coastal erosion, could inform site-based and broader management strategies which incorporate conservation concerns. Cross-cutting assessments of multiple HMR types within one site or region could shape understanding of their impacts and best uses, enabling a conscious "portfolio"-style management of structures which balances their uses across the seascape. A greater understanding of stakeholders' needs and preferences regarding HMRs and how these may be balanced with conservation, as well as the real-world will to do so beyond stated intention, will be crucial to garnering action. It would also be essential to study other locations to understand the potential for conservation collaboration through HMRs, as people in the case study site of Cozumel are well acquainted with conservation already, being surrounded by three marine protected areas. More widely, the incorporation of novel ecosystems into marine conservation planning will require a clearer delineation of social and ecological conservation priorities, in order to allow assessment of the extent to which HMRs and other novel ecosystems can contribute to these aims.

7.4 Conclusion

Over the last four years, the question I have fielded most often when describing my PhD project is some version of, "but actually, just tell me, are HMRs good or bad?" I have often prevaricated with a long-winded response, but perhaps a shorter one is possible: HMRs can be both good and bad. We need more information to amplify the good and minimise the bad. In carrying out this project, I have seen surprising examples of positive and negative impacts, and my outlook on marine conservation has been greatly expanded. I now realise that in deciding how to employ HMRs consciously, responsibly and for the benefit of people and marine life, any answer is unlikely to be "one-size-fits-all". Rather, making these decisions will require conservationists of all kinds – managers, scientists, artists, fishers and others – to decide what their ideal world looks like, and how much energy they are willing to put toward creating it. Making and maintaining HMRs requires significant investment; campaigning for their removal or undertaking an extraction takes even more. The development of tools to enable and reflect on the creation and management of HMRs is crucial to avoid a steady build-up of structures in marine environments that no one cares about enough to remove.

At a time when marine life is facing myriad threats, well-intentioned projects need to be shaped at the outset or transformed to meet expectations. As Unger (1966) wrote in a review of HMRs over fifty years ago, "We have a long way to go, but we have made a good beginning… [to] profit from both the failures and successes of past experience and carry this aspect of a comprehensive marine conservation program a further step along the way" (p. 4). In order to continue on this path, further information is needed to understand what HMRs are present in today's oceans and how their social and ecological impacts are playing into conservation goals. The case study in this thesis demonstrated key principles on one island. However, meta-analyses suggest humans are appropriating ever more of the seabed, through the construction of HMRs to generate power and provide steady sources of food and entertainment (Bugnot *et al.* 2020). As the human footprint continues to grow on the sea floor, scaling our understanding of HMRs across cultures and ecosystems can help channel marine conservation efforts, enabling us to build towards flourishing seascapes filled with human and marine life.



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Supplementary materials

DEPARTMENT OF ZOOLOGY
Zoology Research & Administration Building
11a Mansfield Road
Oxford OX1 3SZ

Dimensiones sociales y ecológicas de arrecifes antropogénicos en Quintana Roo

Referencia del comité de ética: R60895/RE001

Muchas gracias por su participación en este proyecto de investigación. Si tiene alguna pregunta o preocupación sobre cualquier aspecto del proyecto, por favor hable con la investigadora pertinente, quién hará lo possible por responder a su pregunta:

Sofia Castelló y Tickell, Estudiante de doctorado, Universidad de Oxford
Correo: sofia.castelloytickell@zoo.ox.ac.uk
Tel: +44 7917 274 385 / +52 1 55 4591 8588

También puede contactar a su asesora, la Profesora EJ Milner-Gulland, en el siguiente correo: ej.milner-gulland@zoo.ox.ac.uk.

Si desea retirarse del studio, por favour notifíquenos antes del 15 abril 2019, y sus datos no serán incluidos.

La investigadora deberá reconocer el asunto dentro de 10 días hábiles, y darle una indicación de cómo se puede resolver. Si sigue consternado/a o desea registrar una queja formal, por favor contacte a la persona relevante en el comité de ética en la Universidad de Oxford, quién buscará la forma de resolver el asunto:

Chair, Oxford Tropical Research Ethics Committee; Email: oxtrec@admin.ox.ac.uk. Address: Research Services, University of Oxford, Wellington Square, Oxford OX1 2JD

Para ver más información sobre sus derechos como participante, acuda a esta página:
http://www.admin.ox.ac.uk/councilsec/compliance/gdpr/individualrights/

Researcher record of consent template

Interviewee Name or Number (if anonymous participant):

Date:

Location (City / Region):

Project Explained (Yes/No):

Interview recorded or Notes Taken:

Participant agreed to quotes which would not identify them? (Yes/No):

Participant is not to be quoted at all (Yes/No):

Signature of Researcher [Sofia Castello y Tickell]

(Signed in the presence of the
interviewee to confirm oral consent):

Signature of participant (if written consent):

Cuestionario

 # Entrevista: ____________

Fecha:

Entrevistador(a):

En el contexto de este proyecto, estamos definiendo los arrecifes hechos por humanos como estructuras persistentes sumergidas hechas por humanos en el medio marino, ya sea a propósito o por accidente. Pueden incluir naufragios, barcos hundidos, proyectos de restauración de coral, esculturas, estructuras de ingeniería costera, sitios de buceo, y otros tipos de estructuras sumergidas.

SECCIÓN A. Conocimiento de estructuras sumergidas

1. Cuénteme un poco sobre su experiencia con las estructuras sumergidas.

2. ¿En qué actividades relacionadas a las estructuras sumergidas toma parte usted?

   Seleccione todas las que aplican….

   Pesca Acuacultura Operación de turismo Investigación científica Manejo

   Arqueología Protección costera Recreación Arte Educación

   Conservación de la naturaleza Actividades espirituales Actividades culturales

   Otra (por favor especifique): ____________

Si tuviera que escoger solo una actividad, ¿cuál refleja su prioridad más alta en el uso diario/cotidiano? *[anotar en lista]*

3. ¿Con qué frecuencia interactúa con estas estructuras sumergidas?

   Diario   Semanalmente   Mensualmente   Anualmente   En raras ocasiones   Nunca

4. ¿Usted alguna vez ha sumergido una estructura legal?   *Sí / No / Prefiero no decir*

   En caso que sí, ¿por qué y cuándo? ¿Qué tipo de estructura era?

5. Por favor señale su opinión general sobre la creación de las estructuras sumergidas a propósito en los ecosistemas marinos. ¿Por qué?

Muy en desacuerdo	*En desacuerdo*	*Ni de acuerdo ni en desacuerdo*	*De acuerdo*	*Muy de acuerdo*
-2	-1	0	1	2

SECCIÓN B. Mapeo y tendencias

Nos interesa crear una base de datos con un mapa que identifica las estructuras sumergidas que existen en Quintana Roo. La mayoría de estas estructuras se encuentran debajo de la superficie del mar y pueden ser difíciles de localizar. Por lo tanto el conocimiento local es muy valioso en determinar sus ubicaciones. La idea es crear un mapa con una variedad de estructuras, así que podría incluir naufragios, barcos hundidos, proyectos de restauración de coral, esculturas, estructuras de ingeniería costera, sitios de buceo, y otros tipos de estructuras sumergidas.

¿Estaría dispuesto/a a ayudarme con este mapa, compartiendo su conocimiento sobre estructuras sumergidas locales?

*Puede utilizar esta línea de tiempo para recordar más o menos cuando se crearon las estructuras sumergidas. Si la miramos juntos, ¿eso le ayuda a definir aproximadamente cuándo se crearon o destruyeron las estructuras sumergidas que mencionó? (Dado que los huracanes son eventos importantes, los hemos puesto en la línea de tiempo como referencia)

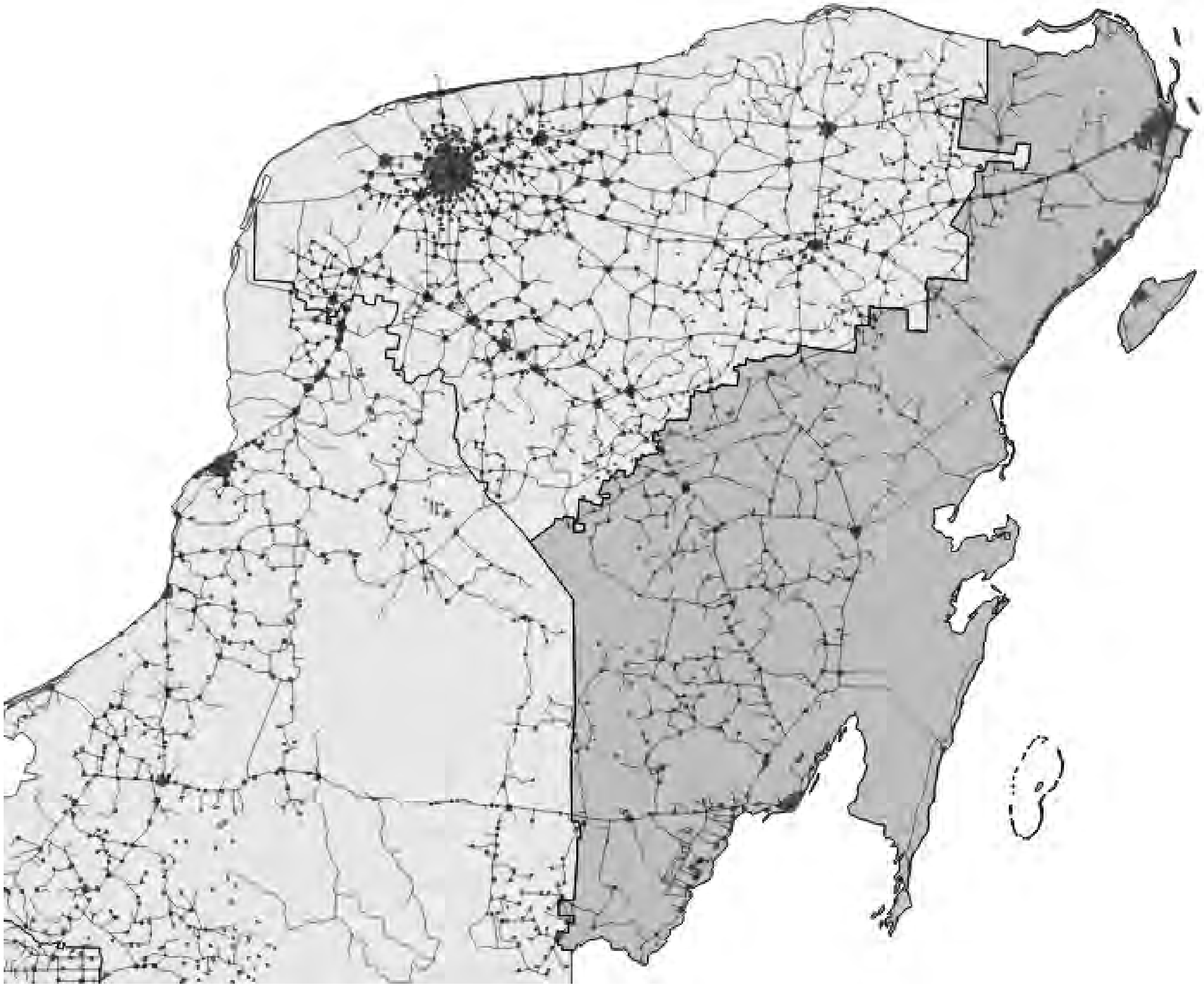
6. Por favor mire este mapa de su área local.

   ¿Podría dibujar en este mapa la ubicación aproximada de los sitios que describió?

   ¿Podría darme algún punto de referencia para encontrar el sitio, o tiene la ubicación en GPS?

7. Más generalmente en Quintana Roo, ¿puede marcar los sitios donde sabe que hay estructuras sumergidas?

Descripción/Tipo de estructura(s)	Unidades	Prof	Materiales	Grupo creador	Año de creación (aprox)	Razones de creación	Intencional? Conservación?		Usos	Usuarios	Ubicación / código en mapa



[Mostrar fotografías que representan servicios ecosistémicos]

Estas fotos representan algunos de los beneficios que pensamos que podría obtener la sociedad a través de las estructuras sumergidas. Me interesa su percepción de los beneficios que las estructuras sumergidas crean en [su área local] y sus preferencias personales en torno a estos beneficios.

8. Por favor seleccione todas las fotografías que representan los beneficios que obtiene la sociedad de las estructuras sumergidas en [su área local].

   Pesca Recursos ornamentales Recursos genéticos Medicinas

   Regulación de erosión Protección contra tormentas Hábitat Sentido de lugar

   Experiencias espirituales y/o religiosas Inspiración Educación Valor estético

   Legado cultural Recreación y turismo Sistemas de conocimiento Relaciones sociales

9. *Si existen múltiples beneficios:* Por favor escoja los tres más importantes para usted personalmente y póngalos en orden de importancia. *[anotar junto a las selecciones]*

Ahora me gustaría escuchar sobre su percepción de cómo han cambiado las estructuras sumergidas con el tiempo en [su área local]. Vamos a mirar a través de la historia…

10. ¿Hace cuantos años piensa que empezaron a sumergir estructuras en [su área local]?

    ____

11. ¿Y la cantidad ha cambiado con el paso del tiempo? *Sí / No / No sé*
    Vamos a intentar verlo por décadas… *Incrementado / Disminuido / Igual*

Década	No se sumergieron estructuras	Se sumergieron algunas estructuras	Se sumergieron muchas estructuras	Desconozco si se sumergieron estructuras
1950's				
1960's				
1970's				
1980's				
1990's				
2000's				
2010's				

12. ¿Ha notado un cambio en el tipo de estructuras que se colocan? *Sí / No / No sé*

    ¿Cuál ha sido el cambio?

13. ¿Piensa que las estructuras sumergidas han creado beneficios en su área local? *Sí / No / No sé*

¿Y costos o impactos negativos? *Sí / No / No sé*

14. ¿Piensa que hay circunstancias en las que es bueno crear estructuras sumergidas?

Sí / No / No sé

¿Cuáles son?

15. ¿Piensa que hay circunstancias en las que NO es bueno crear estructuras sumergidas?

Sí / No / No sé

¿Cuáles son?

16. ¿Cuáles son los factores que se deberían de considerar en la construcción intencional de una estructura sumergida?

17. ¿En su experiencia, hay prácticas que pueden ayudar a que las estructuras sumergidas tengan un impacto positivo en los ecosistemas marinos?

    Sí / No / No sé ¿Cuáles son?

18. ¿Y hay prácticas que contribuyen a que las estructuras tengan impactos nocivos?

    Sí / No / No sé

    ¿Cuáles son?

19. ¿Piensa que se las ESs pueden comparar con los arrecifes "naturales" coralinos o rocosos?

    Coralinos *Sí / No / No sé* Rocosos *Sí / No / No sé*

    ¿Cómo piensa que se comparan con los arrecifes coralinos o rocosos?

20. ¿Piensa que la creación de estructuras sumergidas puede tener un impacto los arrecifes "naturales" coralinos o rocosos?

    Positivo: Sí No No sé *Negativo: Sí No No sé*

    ¿Por qué?

SECCIÓN C. Estudio de caso

Basado en la lista que preparamos al principio de la entrevista, por favor escoge una estructuras sumergida con el que interactúa a menudo y descríbalo.
[Si es caso de estudio, puede ser predeterminado]

Tipo: ______________________ Descripción:
Código en el mapa: __________________

21. ¿Qué sabe sobre la historia de esta estructura sumergida?

    ¿Si fue creado legalmente, usted tuvo parte en su creación? *Sí / No / Prefiero no decir*

22. ¿En qué formas interactúa usted con esta estructura sumergida?

    Pesca Acuacultura Operación de turismo Investigación científica Manejo

    Arqueología Protección costera Recreación Arte Educación

    Conservación de la naturaleza Actividades espirituales Actividades culturales

    Otra (por favor especifique): ____________

    Si tuviera que escoger solo una actividad, ¿cuál refleja su prioridad más alta en el uso diario/cotidiano?

    _________________________________ ¿En qué orden pondría las demás?

23. ¿Con qué frecuencia interactúa con la estructura sumergida?

    Diario Semanalmente Mensualmente Anualmente En raras ocasiones Nunca

24. ¿Cuándo fue la última vez que visitó la estructura?

¿Por cuánto tiempo la ha conocido?

¿Cuál era su propósito principal? ¿Se cumplió? *Sí* / *No* / *Prefiero no decir*

25. Por favor señale su opinión sobre la creación de esa estructura sumergida en este ecosistema marino.

Muy en desacuerdo	*En desacuerdo*	*Ni de acuerdo ni en desacuerdo*	*De acuerdo*	*Muy de acuerdo*
-2	-1	0	1	2

26. ¿Quién tiene acceso a esta estructura sumergida? ¿Hay grupos de gente que lo utilizan de formas diferentes?

`

27. *Si no se incluyó en la base de datos...*

¿De qué materiales está hecho la estructura sumergida?

¿De qué tamaño es?

¿Cuántas unidades tiene?

¿Profundidad?

28. ¿Hay organismos marinos que viven en esta estructura sumergida? *Sí / No / No sé*

Si es el caso, ¿de qué tipo? Por favor seleccione todos los que aplican.

Algas *Sí / No / No sé*

Coral duro *Sí / No / No sé*

Coral blando *Sí / No / No sé*

Peces *Sí / No / No sé*

Invertebrados móviles *Sí / No / No sé*

Esponjas *Sí / No / No sé*

Algas coralinas *Sí / No / No sé*

Cuerno de ciervo *Sí / No / No sé*

Cuerno de alce *Sí / No / No sé*

Cherna *Sí / No / No sé*

Abadejo *Sí / No / No sé*

Pez león *Sí / No / No sé*

Langosta *Sí / No / No sé*

Otro: ______________________

29. ¿Sabe de acciones de manejo que se estén llevando a cabo en esta estructura sumergida? (por ejemplo mantenimiento, limpieza, plantación de corales u otros organismos, etc)

Sí / No / No sé

30. ¿Ha visto que esta estructura sumergida genere beneficios o impactos positivos?

Sí / No / No sé

¿Cuáles? ¿Para quién?

¿Ha visto que esta estructura sumergida genere costos o impactos negativos?

Sí / No / No sé

¿Cuáles? ¿Para quién?

31. ¿Qué efecto cree que tenga esta estructura sumergida en los siguientes factores, y por qué?

	Muy negativo	*Negativo*	*Ni negativo ni positivo (neutro)*	*Positivo*	*Muy positivo*	
Abundancia y diversidad de vida marina						*No sé / Prefiero no decir*
Protección costera						*No sé / Prefiero no decir*
Captura de pesca						*No sé / Prefiero no decir*
Turismo acuático (snorkel y buceo)						*No sé / Prefiero no decir*
Bienestar de arrecifes coralinos o rocosos cercanos						*No sé / Prefiero no decir*

32. ¿Piensa que hay algo que podríamos aprender de esta estructura que se podría aplicar a la creación de estructuras en el futuro?

Sí / No / No sé

33. Por favor seleccione todas las fotografías que representan un beneficio proveído por esta estructura.

Pesca   Recursos ornamentales   Recursos genéticos   Medicinas

Regulación de erosión   Protección contra tormentas   Hábitat   Sentido de lugar

Experiencias espirituales y/o religiosas   Inspiración   Educación   Valor estético

Legado cultural   Recreación y turismo   Sistemas de conocimiento   Relaciones sociales

34. Por favor escoja las tres más importantes para usted personalmente y póngalos en orden de importancia.

¿Por qué escogió estos?

Biodiversidad y actividades

35. Quiero entender cómo se afectan las actividades cuando llegan a vivir todo tipo de organismos marinos en las estructuras – desde los animales y plantas más chicos hasta los grandes, incluyendo algas y corales y peces y todo tipo de organismos marinos que habitan en [su área local].

    Así que vamos a imaginar la estructura con diferentes niveles de vida, y pensar en cómo cambiaría la calidad de experiencia de las actividades que escogió, en cada nivel. Vamos a calificar cada experiencia del 1-10, con el 1 siendo la experiencia más negativa, 5 neutra, y 10 la más positiva.

Actividad:	*Calidad de experiencia (1-10)*	*¿Por qué?*
Estructura no tiene vida marina		
Estructura tiene alguna vida marina		
Estructura tiene una abundancia de vida marina		

¿Cuál sería su nivel ideal de vida marina en la estructura para esta actividad?

¿Hay algunas especies en particular que ayudan o perjudican en esta actividad?

Actividad:	*Calidad de experiencia (1-10)*	*¿Por qué?*
Estructura no tiene vida marina		
Estructura tiene alguna vida marina		
Estructura tiene una abundancia de vida marina		

¿Cuál sería su nivel ideal de vida marina en la estructura para esta actividad?

¿Hay algunas especies en particular que ayudan o perjudican en esta actividad?

Actividad:	*Calidad de experiencia (1-10)*	*¿Por qué?*
Estructura no tiene vida marina		
Estructura tiene alguna vida marina		
Estructura tiene una abundancia de vida marina		

¿Cuál sería su nivel ideal de vida marina en la estructura para esta actividad?

¿Hay algunas especies en particular que ayudan o perjudican en esta actividad?

36. ¿Hay algo más que quiera agregar?

¿Piensa que hay algo que no hemos considerado?

¿Se le ocurre alguien más que sepa de los temas que platicamos y que tal vez pueda entrevistar?

Información demográfica

37. ¿Cuál es su edad? _________

38. ¿A qué se dedica? _______________

    ¿Cuántos años lleva trabajando en esto? _______________

39. ¿Cuál es su género? __________

40. Actualmente, ¿vive en Quintana Roo? Sí / No

    - ¿Dónde vive? ____________
    - ¿Cuántos años tiene viviendo en ese lugar? ________
    - Si no vive en QR, ¿cuánto tiempo ha pasado en el estado (años)? _____

41. ¿Cuál es su nivel de escolaridad más alto? _____________

    ¿Y qué estudió? ________________

Muchísimas gracias por su tiempo.

Questionnaire (English translation)

Date:

Interviewer:

In the context of this project we are defining human-made reefs as persistent structures created or submerged by humans in the marine environment, accidentally or on purpose. This may include shipwrecks, coral restoration projects, sculptures, coastal infrastructure, dive sites and other types of submerged structures.

SECTION A. Knowledge of human-made reefs

1. Tell me about your experience with human-made reefs.

2. What activities related to human-made reefs do you take part in? Select all that apply.

   Fishing, Aquaculture, Tour operation, Scientific research, Management, Archaeology, Coastal protection, Recreation, Art, Education, Nature conservation, Spiritual activities, Cultural activities, Other (please specify)

   If you had to choose only one activity, which reflects your highest priority in daily life?

3. How frequently do you interact with human-made reefs?

   Daily, Weekly, Monthly, Annually, Rarely, Never

4. Have you ever legally submerged a human-made reef? *Yes, No, Prefer not to say*

   If so, when and why? What type of structure was it?

5. Please indicate your general opinion on the purposeful creation of human-made reefs in marine ecosystems. Why is this the case?

Completely disagree	*Disagree*	*Neither agree nor disagree*	*Agree*	*Completely agree*
-2	-1	0	1	2

SECTION B. Mapping and trends

We are interested in creating a database with a map that identifies human-made reefs that exist in Quintana Roo. Most of these structures are below the surface of the ocean and can be difficult to find. Therefore, local knowledge is very valuable in determining their locations. The idea is to create a map with a variety of structures, so it could include shipwrecks, coral restoration projects, sculptures, coastal infrastructure, dive sites and other types of human-made reefs.

Would you be willing to help me with this map, sharing your knowledge about local human-made reefs?

*You can use this timeline to remember more or less when human-made reefs were created. If we look at it together, does that help you to define approximately when the human-made reefs you mentioned were created or destroyed? (Given that hurricanes are important local events, we have put them on the timeline as references).

6. Please look at this map of your local area (Cozumel).

   Could you draw on the map the approximate location of the sites you described?

   Could you give me some reference point to find the site, or do you have the GPS location?

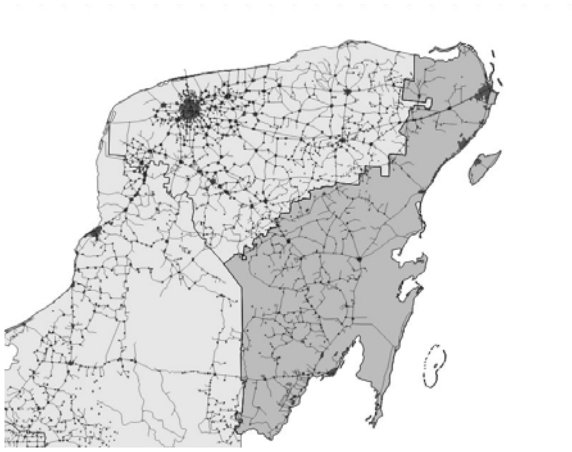
7. More generally in Quintana Roo, can you mark any sites you know of where human-made reefs are present?

Database categories:

Description/Type	Units	Depth	Materials	Creating group	Year of creation

Reasons for creation	Intentional?	Conservation intention?	Uses	Users	Location/Code on map

Map of Cozumel (small version)



Map of Quintana Roo (small version)

These photos represent some of the benefits that we believe society may obtain from human-made reefs [*show cards indicating ecosystem services*]. I am interested in your perception of the benefits that human-made reefs may provide in your local area (Cozumel) and your personal preferences relating to those benefits.

8. Please select all of the photos that represent benefits obtained by society from human-made reefs in your local area (Cozumel).

   Fishing, Ornamental resources, Genetic resources, Medicines, Erosion regulation, Storm protection, Habitat, Sense of place, Spiritual and/or religious experiences, Inspiration, Education, Aesthetic value, Cultural legacy, Tourism and recreation, Knowledge systems, Social relations

9. *If multiple benefits have been identified*: Please choose the three most important benefits for you personally and rank them in order of importance.

Now I would like to hear about your perception of how human-made reefs have changed over time in your local area (Cozumel). Let's look back through history…

10. How many years ago did human-made reefs start to be created in your local area (Cozumel)?

11. Has the amount changed with time? *Yes / No / Don't know*

    Increased / Decreased / Stayed the same

    Let's think in terms of decades…

Decade	No HMRs submerged	Some HMRs submerged	Many HMRs submerged	I don't know if HMRs were submerged
1950's				
1960's				
1970's				
1980's				
1990's				
2000's				
2010's				

12. Have you noticed a change in the type of structures that are being submerged?
    Yes / No / Don't know

    If so, what has the change been?

13. Do you believe human-made reefs have created benefits in your local area? If so, what are they?
    Yes / No / Don't know

    Do you believe human-made reefs have created costs in your local area? If so, what are they?
    Yes / No / Don't know

14. Do you believe there are circumstances in which it is good to create human-made reefs?
    Yes / No / Don't know

    If so, what are they?

15. Do you believe there are circumstances in which it is NOT good to create human-made reefs?

Yes / No / Don't know

If so, what are they?

16. What are the factors that should be considered in the intentional construction of a human-made reef?

17. In your experience, are there practices that can help human-made reefs have a positive impact on marine ecosystems?
    Yes / No / Don't know

    If so, what are they?

18. In your experience, are there practices that contribute to human-made reefs having a negative impact on marine ecosystems?
    Yes / No / Don't know

    If so, what are they?

19. Do you believe HMRs can be compared to "natural" coral or rocky reefs? How?

    Coral: *Yes/No/Don't know*   Rocky: *Yes/No/Don't know*

20. Do you believe the creation of HMRS can have an impact on "natural" coral or rocky reefs? Why?

    Positive: *Yes/No/Don't know*   Negative: *Yes/No/Don't know*

SECTION C. Case study

Based on the list we prepared at the beginning of the interview, please select one human-made reef you interact with frequently and describe it.

Type:

Description:

Code on map:

21. What do you know about the history of this human-made reef? If it was legally created, did you have a role in its creation?
    Yes/No/Prefer not to say

22. In what ways do you interact with this human-made reef? Select all that apply.

    Fishing, Aquaculture, Tour operation, Scientific research, Management, Archaeology, Coastal protection, Recreation, Art, Education, Nature conservation, Spiritual activities, Cultural activities, Other (please specify)

    If you had to choose only one activity, which reflects your highest priority in daily life? In what order would you put the rest?

23. How frequently do you interact with this human-made reef?

    Daily, Weekly, Monthly, Annually, Rarely, Never

24. When is the last time you visited it? How long have you known it? What was its primary purpose? Do you think this purpose has been fulfilled?
    Yes / No / Prefer not to say

25. Please indicate your opinion on the creation of this human-made reef in this marine ecosystem. Why is this the case?

Completely disagree	*Disagree*	*Neither agree nor disagree*	*Agree*	*Completely agree*
-2	-1	0	1	2

26. Who has access to this human-made reef? Do different groups of people use it in different ways?

27. *If not included in the database…*

    What materials is this HMR made of?

    How big is it?

    How many units does it have?

    Depth?

28. Do marine organisms live on this human-made reef? *Yes/No/Don't know*

    If so, what types? Please select all that apply.

    General: Algae, Hard coral, Soft coral, Fish, Mobile Invertebrates, Sponges, Coralline algae

    Specific: Elkhorn coral, Staghorn coral, Grouper, Haddock, Lionfish, Lobster, Other _____

29. Do you know of management actions that are taking place on this HMR? (for example maintenance, cleaning, planting of coral or other organisms, etc). If so, what are they?

Yes/No/Don't know

30. Have you seen this human-made reef generate benefits or positive impacts? Which ones? For whom?

Yes/No/Don't know

Have you seen this human-made reef generate costs or negative impacts? Which ones? For whom?

Yes/No/Don't know

31. What impacts do you think this human-made reef has on the following factors, and why?

	Very negative	*Negative*	*Neither positive nor negative (neutral)*	*Positive*	*Very positive*	*Don't know / prefer not to say*
Abundance and diversity of marine life						
Coastal protection						
Fishing capture						
Aquatic tourism (snorkel and diving)						
State of nearby coral or rocky reefs						

32. Do you believe there is something we could learn from this structure that could apply to the creation of human-made reefs in the future? If so, what?

Yes/No/Don't know

33. Please select all the photographs that represent a benefit provided by this structure.

Fishing, Ornamental resources, Genetic resources, Medicines, Erosion regulation, Storm protection, Habitat, Sense of place, Spiritual and/or religious experiences, Inspiration, Education, Aesthetic value, Cultural legacy, Tourism and recreation, Knowledge systems, Social relations

34. Please choose the three most important ones for you personally and arrange them in order of importance. Why did you choose these?

Biodiversity and activities

35. I want to understand how activities are affected when all kinds of marine organisms come to live on human-made reefs – from the smallest plants and animals to the largest, including algae and corals and fish and all kinds of marine organisms that inhabit your local area (Cozumel).

So we are going to imagine a structure with different levels of life, and think about how that would change the quality of the experience of the activities you undertake, at each level. We are going to "grade" the experience from 1-10, with 1 being the most negative experience, 5 being neutral, and 10 being the most positive.

Diagram used to indicate levels of life (no/some/abundant marine life)

(repeated 3x for priority activities)

Activity:	Quality of experience (1-10)	Why?
No marine life on HMR		
Some marine life on HMR		
Abundant marine life on HMR		

What would be your ideal level of marine life on the HMR for this activity?

Are there particular species that help or impair this activity?

36. Is there anything else you would like to add?

    Is there anything we haven't considered?

    Can you think of anyone else who knows about the topics we discussed and I may be able to interview?

Demographic information

37. What is your age?

38. What is your occupation? For how long have you done this?

39. What is your gender?

40. Do you currently live in Quintana Roo? *Yes/No*

    Where? For how many years have you lived in this place?

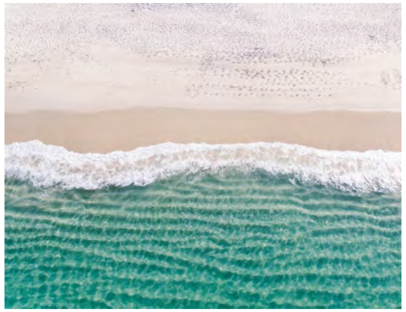
    If you don't live in Quintana Roo, how much time have you spent in the state? (years)

41. What is your highest level of education? What did you study?

Thank you so much for your time.

SM2. Illustrations used to explain ecosystem services

Pesca	**Acuacultura**	**Recursos ornamentales**	**Recursos genéticos**
			
Pesca de organismos silvestres.	La provisión de alimento u otros productos marinos a través de la acuacultura.	Productos derivados de organismos marinos que se usan como decoración.	Información genética que se puede utilizar para reproducción de organismos o biotecnología.

Químicos, medicinas naturales y farmacéuticos  Medicinas, químicos o productos de salud derivados de ecosistemas marinos.	**Regulación de la erosión**  Retención de arena/sedimento y playas	**Protección contra tormentas**  Regulación de los impactos de tormentas	**Hábitat**  Proporción de hábitat donde pueden vivir organismos marinos
Legado cultural  Mantenimiento de sitios y especies de importancia histórica y cultural	**Recreación y turismo**  Oportunidades de recreación y negocios de turismo.	**Sentido de lugar**  Reconocimiento de lugares a través de	**Experiencias espirituales & religiosas**  Experiencias de importancia espiritual y/o religiosa

Sistemas de conocimiento  La creación de diferentes tipos de conocimiento en la sociedad	**Relaciones sociales**  Facilitación de relaciones sociales a través de actividades	**Valor estético**  Belleza en lugares u organismos.	**Educación**  Oportunidades para educación
Inspiración  Fuentes de inspiración para el arte, ideas, símbolos nacionales, cuentos, arquitectura, etc.	**Inspiración**  Fuentes de inspiración para el arte, ideas, símbolos nacionales, cuentos, arquitectura, etc.	**Educación**  Oportunidades para educación	

SM3. Ethical approval from the Oxford Tropical Research Ethics Committee

Oxford Tropical Research Ethics Committee

University of Oxford
Research Services, University Offices
Wellington Square, Oxford OX1 2JD
Tel. +44 (0)1865 (2)82106
E-mail: oxtrec@admin.ox.ac.uk

Ms Sofia Castelló y Tickell
Department of Zoology
University of Oxford

12 December 2018

Dear Ms Tickell

Full Title of Study: Sunken worlds: Social and ecological dimensions of anthropogenic reefs in Quintana Roo, Mexico

Reference: R60895/RE001

I am pleased to confirm that approval has now been granted for this study. This is valid for the first five years and is subject to receiving the local ethical approval (if this approval has not yet been received).

The documents approved for this study are as follows:

Documents:
CUREC 1a form
Fieldwork risk assessment form
Questionnaire
PIS
Consent form

Any subsequent changes to the application must be submitted to the Committee as an Amendment. This should include a letter to give the reasons for the proposed modifications and all revised documents with changes tracked.

Please ensure that you submit a completed Annual Report form on every anniversary of this approval and a final End of Study Report. The relevant forms can be found on the OxTREC website: https://researchsupport.admin.ox.ac.uk/governance/ethics/apply/oxtrec.

Finally, please note the following **important information**:

Data safety—all studies
It is the responsibility of the PI to ensure that all data collected during the course of the study is stored and transferred safely and securely. Further guidance and advice is available from the Research Data Team.

Tel: +44 (0)1865 (2)82106
Email: oxtrec@admin.ox.ac.uk
Web: https://researchsupport.admin.ox.ac.uk/governance/ethics

Studies that will involve storing human tissue samples in Oxford
As you are planning to import the samples into England, you will need to make arrangements before the samples are transferred to store them under the governance of a Human Tissue Authority (HTA) licence. It is a legal requirement that any tissue or fluid made up of or containing human cells to be used for the purpose of research is stored on premises licensed by the HTA unless covered by an exemption. OxTREC approval is not a recognised exemption. Further information may be found on the University's human tissue governance web pages: https://researchsupport.admin.ox.ac.uk/governance/human-tissue.

Yours sincerely

Dr Rebecca Bryant
Research Ethics Manager, OxTREC

SM4. Letter of support confirming ethical review from local partner (ECOSUR).

ECOSUR

Área Académica
Conservación de la Biodiversidad

4 December 2018

Mrs. Claudia Kozeny-Pelling
Research Ethics Manager (Social Sciences and Humanities)
Research Services
University of Oxford, University Offices
Wellington Square, Oxford, OX1 2JD, United Kingdom

Dear Mrs. Kozeny-Pelling,

I am writing to you regarding the matter of local ethical review for the doctoral research proposed by Sofia Castelló y Tickell in the Zoology department in Oxford. I am a professor and researcher at the Graduate School and Research Centre ECOSUR in Mexico, and I am co-supervising Sofia's project along with Professor EJ Milner-Gulland. We are a part of the National Research Council (CONACYT).

The ethical approval procedure for research at ECOSUR allows for a supervisor to state that procedures in the handbook have been followed, in which case the project does not require further approval from the central ethics committee. I have worked closely with Sofia to make sure her surveys will not collect unnecessary personally information and protects in all sense people; all her surveys will be preceded by a locally appropriate informed consent as requested in our ethical handbook. I can confirm that Sofia's research fits within the criteria of our university's ethics code, which is attached to this letter and can also be found online here: https://sitios.ecosur.mx/intranet/wp-content/uploads/sites/13/2018/11/Gui%CC%81a-para-la-incorporacio%CC%81n-de-aspectos-e%CC%81ticos-en-los-protocolos-de-investigacio%CC%81n-.pdf

Regarding the concern of making surveys in "illegal" artificial reefs, please make sure that we will just work with those reef that were placed legally after the environmental legislation regulated its creation (1994). Before that, it was not illegal to establish artificial reefs at people's discretion (or accidentally in case of the Shipwrecks) and some of them date back centuries. Not for that are currently illegal. Historical artificial reefs will also be surveyed by Sofia's work.

If you have further questions, please do not hesitate in contacting me.

Thanking in advance your time and attention, please receive my best regards.

Andrea Sáenz-Arroyo, PhD.
Profesora/Investigadora Titular

EL COLEGIO DE LA FRONTERA SUR
San Cristóbal º Tapachula º Chetumal º Villahermosa º Campeche
Carretera Panamericana y Periférico Sur s/n. CP 29290
San Cristóbal de LasCasas Chiapas. Apartado Postal 63,
TEL: (967) 674 90 00 http://www.ecosur.mx

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COMISIÓN NACIONAL DE ÁREAS
NATURALES PROTEGIDAS
DIRECCIÓN PARQUE NACIONAL
ARRECIFES DE COZUMEL
Oficio No. DPNAC/021/2019
Folio SIRCA: F00.9.DRPYCM.00065/2019
Cozumel, Quintana Roo a 25 de enero de 2019

"2019, Año del Caudillo del Sur, Emiliano Zapata".

SOFIA MARIA TERESA CLARA CASTELLO Y TICKELL
ESTUDIANTE DE DOCTORADO
UNIVERSIDAD DE OXFORD
PRESENTE

Asunto: No objeción de investigación sin colecta

Hago referencia a su escrito con fecha 10 de enero del presente año y recibido en esta Dirección el 14 del mismo mes y año, mediante el cual ingresó el trámite CNANP-00-008 denominado "Aviso para realizar investigación sin colecta o manipulación de ejemplares de especies no consideradas en riesgo en Áreas Naturales Protegidas". Lo anterior a efectos de llevar a cabo actividades de investigación del proyecto "Dimensiones sociales y ecológicas de los arrecifes antropogénicos en Quintana Roo, México", dentro del Parque Nacional Arrecifes de Cozumel (PNAC).

Al respecto y de conformidad con lo dispuesto en los artículos 2 fracción I, 17, 18, 26 y 32-Bis fracciones I, II, III, VI, VII, y XXXIX de la Ley Orgánica de la Administración Pública Federal; 44, 45 fracción I, II, III y IV, 46 fracción III, 50, 51, 64, 75 Bis, 79, 80 fracción I y 83 de la Ley General del Equilibrio Ecológico y la Protección al Ambiente; 85 y 88 del Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en Materia de Áreas Naturales Protegidas; 41, 42, 43, 70, 71 fracción IX y 80 fracción XIX del Reglamento Interior de esta Secretaría; el artículo quinto del Decreto por el que se declara Área Natural Protegida con el carácter de Parque Nacional Arrecifes de Cozumel y la Regla 40 del Programa de Manejo del PNAC; comunico que esta Dirección NO tiene objeción en que usted SOFIA MARIA TERESA CLARA CASTELLO Y TICKELL, ingrese al Parque Nacional Arrecifes de Cozumel para realizar actividades de investigación sin colecta o manipulación de ejemplares no consideradas en riesgo.

LAS ACTIVIDADES SE DEBERÁN LLEVAR A CABO DE LA SIGUIENTE FORMA:

1.- La presente ampara las actividades de investigación que se lleven a cabo única y exclusivamente dentro de los límites del PNAC, debiendo respetar la zonificación y actividades establecidas en el Decreto de creación del ANP y su programa de manejo.

2.- La presente tendrá una vigencia del 25 de enero al 31 de mayo de 2019.

3.- Antes de iniciar sus actividades y con al menos 3 días hábiles de anticipación deberá establecer comunicación con el M. en C. Cristopher Arturo González Baca, Director del Parque Nacional, con correo electrónico: cristopher.gonzalezb@conanp.gob.mx o bien a la M. en C. Blanca Alicia Quiroga García con correo electrónico blanca.quiroga@conanp.gob.mx con la finalidad de registrar su estancia e informar de las actividades específicas que se llevarán a cabo. Así mismo, al término de las mismas deberán informar de su salida.

Calle 4 Norte entre 15 y 20 Ave. Col. Centro, Cozumel, Q. Roo C.P. 77600
Tels. (01) 987 872 45 80 y 872 42 78, anpcozumel@conanp.gob.mx
www.gob.mx/conanp

Página 1

4.- Respetar en todo momento las disposiciones aplicables que rigen la vida jurídica de las Áreas Naturales Protegidas.

5.- Durante los trabajos de investigación en el ANP no podrán permanecer más personas de las autorizadas.

6.- Durante la realización de las actividades de investigación se deberá de acatar las siguientes prohibiciones establecidas en el artículo 87 del Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en materia de Áreas Naturales Protegidas y las demás establecidas en el programa de manejo del PNAC:

I.- Molestar, capturar, remover, extraer, retener o apropiarse de vida silvestre o sus productos;
II.- Remover o extraer material mineral;
III.- Utilizar métodos de pesca que alteren el lecho marino;
IV.- Trasladar especímenes de poblaciones nativas de una comunidad biológica a otra;
V.- Alterar o destruir por cualquier medio o acción los sitios de alimentación, anidación, refugio o reproducción de las especies silvestres;
VI.- Alimentar, tocar o hacer ruidos intensos que alteren el comportamiento natural de los ejemplares de la vida silvestre;
VII.- Introducir plantas, semillas y animales domésticos;
VIII.- Introducir ejemplares o poblaciones silvestres exóticas;
IX.- Dañar, cortar y marcar árboles;
X.- Hacer un uso inadecuado o irresponsable del fuego;
XI.- Interrumpir, desviar, rellenar o desecar flujos hidráulicos o cuerpos de agua;
XII- Abrir senderos, brechas o caminos;
XIII.- Arrojar, verter o descargar cualquier tipo de desechos orgánicos, residuos sólidos o líquidos o cualquier otro tipo de contaminante, tales como insecticidas, fungicidas y pesticidas, entre otros, al suelo o a cuerpos de agua;
XIV.- Utilizar lámparas o cualquier fuente de luz para aprovechamiento u observación de ejemplares de la vida silvestre;
XV.- Usar altavoces, radios o cualquier aparato de sonido, que altere el comportamiento de las poblaciones o ejemplares de las especies silvestres o que impida el disfrute del área protegida por los visitantes, y
XVI.- Hacer uso de explosivos
XVII.- Modificar la línea de costa, remover o modificar de alguna forma playas arenosas y/o rocosas y dunas costeras.
XVIII.- Realizar actividades de dragado o de cualquier otra naturaleza que generen la suspensión de sedimentos o provoquen áreas con aguas fangosas o limosas dentro del área protegida o en zonas aledañas.
XIX.- Instalar plataformas o infraestructura de cualquier otra índole.

7.- En caso de requerir apoyo con vehículos del ANP, deberá sujetarse a la disponibilidad de personal, así como de las condiciones climáticas y de seguridad.

8.- El autorizado deberá sujetarse a las siguientes disposiciones de carácter administrativo:

I. Atender las indicaciones que haga el personal del PNAC, referentes a la protección del ecosistema y sus recursos naturales.
II. Otorgar el apoyo necesario al personal comisionado oficialmente por las dependencias federales que, en su caso, realicen actividades de supervisión, censo y/o que participen en labores de inspección y vigilancia.
III. Reportar ante las autoridades competentes cualquier anomalía que se presente en el área durante el desarrollo de las actividades.

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IV. Con la finalidad de garantizar la seguridad de los investigadores y participantes, es necesario contrate embarcaciones autorizadas para prestar el servicio para realizar actividades acuático-recreativas dentro del ANP, toda vez que estos cuentan con los seguros correspondientes.

V. Responsabilizarse de todos aquellos daños provocados a los ecosistemas y a la infraestructura por las actividades realizadas durante su estancia.

VI. La Secretaría de Medio Ambiente y Recursos Naturales se libera de cualquier responsabilidad que corresponda por los daños que sufran en sus bienes, equipos o persona, miembros del grupo de investigación o aquellos causados a terceros durante su estancia y desarrollo de las actividades que ampara la presente dentro del ANP.

VII. La presente es intransferible por lo que el responsable de las actividades de investigación, deberá portar en todo momento la presente en un lugar visible y deberá mostrarse cuantas veces sea requerido por las autoridades competentes que lo soliciten para efectos de supervisión y vigilancia.

VIII. La presente autorización no ampara la colecta botánica de cualquier especie de flora o fauna silvestre dentro de las ANPs, por lo que estas deberán contar, en su caso, con el permiso que para tal efecto emita la autoridad competente.

IX. La presente se otorga sin perjuicio de las demás que en el ámbito de su competencia corresponda otorgar a otras dependencias de la Administración Pública Federal, relacionadas con la actividad a que se refiere la presente.

X. Al término de sus trabajos, remitan los resultados obtenidos, con el fin de enriquecer la información técnica que se tiene en esta ANP.

XI. Proporcionar los créditos correspondientes a la Secretaría de Medio Ambiente y Recursos Naturales en la edición final de las actividades. Así mismo, destacar que los sitios donde se realizaron las actividades de investigación corresponden a un área natural protegida sujeta a manejo especial y decretada como tal por el Gobierno Mexicano, para preservar los recursos naturales.

XII. La presente se revocará, en su caso, en términos de lo establecido en el Artículo 104 del Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en Materia de Áreas Naturales Protegidas.

XIII. La presente no exime de responsabilidades legales a los solicitantes, por las sanciones a las que se hagan acreedores de no ser acatadas las restricciones antes mencionadas.

Sin otro particular por el momento, reciba un cordial saludo

ATENTAMENTE

M. en C. CRISTOPHER A. GONZÁLEZ BACA
DIRECTOR
PARQUE NACIONAL ARRECIFES DE COZUMEL

C.c.p. Archivo

BHH/BCG

"Con fundamento en lo establecido por el artículo 84 último párrafo del Reglamento Interior de la Secretaría de Medio Ambiente y Recursos Naturales, publicado en el Diario Oficial de la Federación el 26 de noviembre de 2012, en suplencia por ausencia del director del Parque Nacional Arrecifes de Cozumel y Encargado del Área de Protección de Flora y Fauna Isla de Cozumel, en correlación con el OFICIO NO. F00.9.DPNAC./014/2019 de fecha 21 de enero de 2019, firma el presente"

SUBDIRECTORA
M. en C. BRENDA HERNÁNDEZ HERNÁNDEZ

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COMISIÓN NACIONAL DE ÁREAS
NATURALES PROTEGIDAS
ÁREA DE PROTECCIÓN DE FLORA Y FAUNA ISLA DE COZUMEL

Oficio No. APFFIC/ 03/2019
Folio SIRCA: F00.9.DRPYCM.00006/2019
Cozumel, Quintana Roo a 25 de enero de 2019

"2019, Año del Caudillo del Sur, Emiliano Zapata".

SOFIA MARIA TERESA CLARA CASTELLO Y TICKELL
ESTUDIANTE DE DOCTORADO
UNIVERSIDAD DE OXFORD
PRESENTE

Asunto: No objeción de investigación sin colecta

Hago referencia a su escrito con fecha 10 de enero del presente año y recibido en esta Dirección el 14 del mismo mes y año, mediante el cual ingresó el trámite CNANP-00-008 denominado "Aviso para realizar investigación sin colecta o manipulación de ejemplares de especies no consideradas en riesgo en Áreas Naturales Protegidas". Lo anterior a efectos de llevar a cabo actividades de investigación del proyecto "Dimensiones sociales y ecológicas de los arrecifes antropogénicos en Quintana Roo, México", dentro del Área de Protección de Flora y Fauna Isla de Cozumel (APFFIC).

Al respecto y de conformidad con lo dispuesto en los artículos 2 fracción I, 17, 18, 26 y 32-Bis fracciones I, II, III, VI, VII, y XXXIX de la Ley Orgánica de la Administración Pública Federal; 44, 45 fracción I, II, III y IV, 46 fracción III, VII 50, 51, 54, 64, 75 Bis, 79, 80 fracción I y 83 de la Ley General del Equilibrio Ecológico y la Protección al Ambiente; 85, 88 y 105 del Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en Materia de Áreas Naturales Protegidas; 41, 42, 43, 70, 71 fracción IX y 80 fracción XIX del Reglamento Interior de esta Secretaría; el artículo 5,6, 8 y 14 del Decreto por que se declara Área Natural Protegida con el carácter de Área de protección de flora y fauna, la porción norte y la franja costera oriental, terrestres y marinas de la Isla de Cozumel y la Regla 11 del programa de manejo del APFFIC, comunico que está Dirección de ANP NO tiene objeción en que usted SOFIA MARIA TERESA CLARA CASTELLO Y TICKELL, ingrese al APFFIC para realizar actividades de investigación sin colecta o manipulación de ejemplares no consideradas en riesgo.

LAS ACTIVIDADES SE DEBERÁN LLEVAR A CABO DE LA SIGUIENTE FORMA:

1.- La presente ampara las actividades de investigación que se lleven a cabo única y exclusivamente dentro de los límites del APFFIC, debiendo respetar la zonificación y actividades establecidas en el Decreto de creación del ANP y su programa de manejo.

2.- La presente tendrá una vigencia del 25 de enero al 31 de mayo de 2019.

3.- Antes de iniciar sus actividades y con al menos 3 días hábiles de anticipación deberá establecer comunicación con el M. en C. Cristopher Arturo González Baca, Director del Área de Protección de Flora y Fauna, con correo electrónico: cristopher.gonzalezb@conanp.gob.mx o bien a la M. en C. Blanca Alicia Quiroga García con correo electrónico blanca.quiroga@conanp.gob.mx con la finalidad de

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registrar su estancia e informar de las actividades específicas que se llevarán a cabo. Así mismo, al término de las mismas deberán informar de su salida.

4.- Respetar en todo momento las disposiciones aplicables que rigen la vida jurídica de las Áreas Naturales Protegidas.

5.- Durante los trabajos de investigación en el ANP no podrán permanecer más personas de las autorizadas.

6.- Durante la realización de las actividades de investigación se deberá de acatar las siguientes prohibiciones establecidas en el artículo 87 del Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en materia de Áreas Naturales Protegidas y las demás establecidas en el programa de manejo del PNAC:

I.- Molestar, capturar, remover, extraer, retener o apropiarse de vida silvestre o sus productos;
II.- Remover o extraer material mineral;
III.- Utilizar métodos de pesca que alteren el lecho marino;
IV.- Trasladar especímenes de poblaciones nativas de una comunidad biológica a otra;
V.- Alterar o destruir por cualquier medio o acción los sitios de alimentación, anidación, refugio o reproducción de las especies silvestres;
VI.- Alimentar, tocar o hacer ruidos intensos que alteren el comportamiento natural de los ejemplares de la vida silvestre;
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XIV.- Utilizar lámparas o cualquier fuente de luz para aprovechamiento u observación de ejemplares de la vida silvestre;
XV.- Usar altavoces, radios o cualquier aparato de sonido, que altere el comportamiento de las poblaciones o ejemplares de las especies silvestres o que impida el disfrute del área protegida por los visitantes, y
XVI.- Hacer uso de explosivos
XVII.- Modificar la línea de costa, remover o modificar de alguna forma playas arenosas y/o rocosas y dunas costeras.
XVIII.- Realizar actividades de dragado o de cualquier otra naturaleza que generen la suspensión de sedimentos o provoquen áreas con aguas fangosas o limosas dentro del área protegida o en zonas aledañas.
XIX.- Instalar plataformas o infraestructura de cualquier otra índole.

7.- En caso de requerir apoyo con vehículos del ANP, deberá sujetarse a la disponibilidad de personal, así como de las condiciones climáticas y de seguridad.

8.- El autorizado deberá sujetarse a las siguientes disposiciones de carácter administrativo:

I. Atender las indicaciones que haga el personal del PNAC, referentes a la protección del ecosistema y sus recursos naturales.
II. Otorgar el apoyo necesario al personal comisionado oficialmente por las dependencias federales que, en su caso, realicen actividades de supervisión, censo y/o que participen en labores de inspección y vigilancia.
III. Reportar ante las autoridades competentes cualquier anomalía que se presente en el Área durante el desarrollo de las actividades.

IV. Con la finalidad de garantizar la seguridad de los investigadores y participantes, es necesario contrate embarcaciones autorizadas para prestar el servicio para realizar actividades acuático-recreativas dentro del ANP, toda vez que estos cuentan con los seguros correspondientes.

V. Responsabilizarse de todos aquellos daños provocados a los ecosistemas y a la infraestructura por las actividades realizadas durante su estancia.

VI. La Secretaría de Medio Ambiente y Recursos Naturales se libera de cualquier responsabilidad que corresponda por los daños que sufran en sus bienes, equipos o persona, miembros del grupo de investigación o aquellos causados a terceros durante su estancia y desarrollo de las actividades que ampara la presente dentro del ANP.

VII. La presente es intransferible por lo que el responsable de las actividades de investigación, deberá portar en todo momento la presente en un lugar visible y deberá mostrarse cuantas veces sea requerido por las autoridades competentes que lo soliciten para efectos de supervisión y vigilancia.

VIII. La presente autorización no ampara la colecta botánica de cualquier especie de flora o fauna silvestre dentro de las ANPs, por lo que estas deberán contar, en su caso, con el permiso que para tal efecto emita la autoridad competente.

IX. La presente se otorga sin perjuicio de las demás que en el ámbito de su competencia corresponda otorgar a otras dependencias de la Administración Pública Federal, relacionadas con la actividad a que se refiere la presente.

X. Al término de sus trabajos, remitan los resultados obtenidos, con el fin de enriquecer la información técnica que se tiene en esta ANP.

XI. Proporcionar los créditos correspondientes a la Secretaría de Medio Ambiente y Recursos Naturales en la edición final de las actividades. Así mismo, destacar que los sitios donde se realizaron las actividades de investigación corresponden a un Área natural protegida sujeta a manejo especial y decretada como tal por el Gobierno Mexicano, para preservar los recursos naturales.

XII. La presente se revocará, en su caso, en términos de lo establecido en el Artículo 104 del Reglamento de la Ley General del Equilibrio Ecológico y la Protección al Ambiente en Materia de Áreas Naturales Protegidas.

XIII. La presente no exime de responsabilidades legales a los solicitantes, por las sanciones a las que se hagan acreedores de no ser acatadas las restricciones antes mencionadas.

Sin otro particular por el momento, reciba un cordial saludo

ATENTAMENTE

M en C. CRISTOPHER A. GONZÁLEZ BACA
ENCARGADO DE LA DIRECCIÓN
ÁREA DE PROTECCIÓN DE FLORA Y FAUNA
ISLA DE COZUMEL

"Con fundamento en lo establecido por el artículo 84 último párrafo del Reglamento Interior de la Secretaría de Medio Ambiente y Recursos Naturales, publicado en el Diario Oficial de la Federación el 26 de noviembre de 2012, en suplencia por ausencia del director del Parque Nacional Arrecifes de Cozumel y Encargado del Área de Protección de Flora y Fauna Isla de Cozumel, en correlación con el OFICIO NO. FOO.9.DPMAC./ de fecha 21 de enero de 2019, firma el presente

SUBDIRECTORA
M. en C. BRENDA HERNÁNDEZ HERNÁNDEZ

C.c.p. Archivo

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