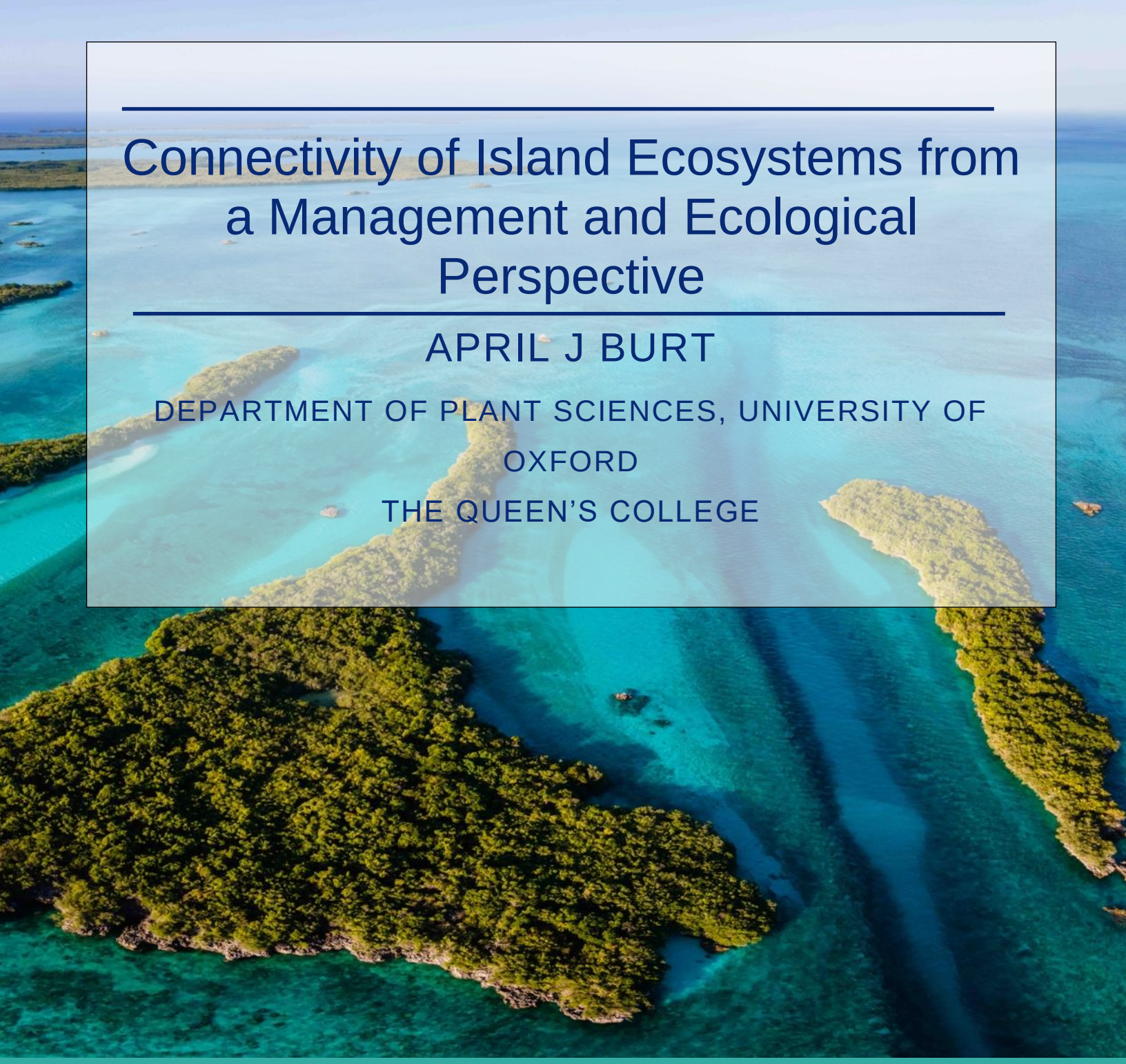


Connectivity of Island Ecosystems from a Management and Ecological Perspective

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I dedicate this thesis to the many hardworking conservation and management practitioners I have had the honour of working with and learning from, and whose conversations helped spark the questions I have addressed in this work.

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Thesis Abstract

In total, two-thirds of the world's countries are, or include, islands or archipelagos, directly supporting 10% of the world's population. These islands also support around 20% of global biodiversity but are where 61% of all known extinctions have occurred. Despite their isolation, islands *can* exhibit high levels of ecological connectivity, or host similar, but genetically distinct, groups of species. The similarity between island ecosystems and the threats they face provides an opportunity to achieve more effective management through management connectivity, for example by sharing lessons learned, pooling dataset and working together to manage threats. Often, however, this management connectivity is lacking. This thesis aims to better understand and enhance the level of management connectivity, and increase management effectiveness of island ecosystems by: (1) exploring current barriers to island ecosystem management; and (2) generating information addressing two threats that are common to island ecosystems in the Seychelles archipelago and elsewhere.

I found a raft of barriers which prevent practitioners from meeting their conservation and management goals, most of which existed at organization level (55%), followed by national (24%) and site/project level (21%). We found that the three most common barriers preventing practitioners from achieving more effective management are: insufficient staff capacity; difficulties turning data into useful information for management (including lack of data analysis capacity and time to analyse); and lack of a research strategy. In addition, numerous barriers to collaboration hinder management connectivity between relevant actors. However, these more common barriers

are not the most important in forming respondents' perceptions about management effectiveness. Instead, their opinion of national level management effectiveness was mostly associated with their perception of governance issues, the presence/absence of research and management strategies and their experience of collaboration outcomes.

To inform management of plastic pollution in the Seychelles I estimate that to remove 1 tonne of litter costs $8,900 and that to clean up the ca 500 tonnes on Aldabra will cost $4.68 million and require 18,000 person-hours of labour. Given that this is one island and that plastic pollution is continuously arriving into island ecosystems in the Seychelles, a more coordinated approach to this issue is required in additional to a great deal of funding. To inform management of the coral reef system in Seychelles I have mapped genetic connectivity across the inner and outer islands of Seychelles, showing the first evidence of gene flow between reefs, especially between Aldabra and the Mahé area. With this new evidence of the importance of the outer islands for regional reef persistence in the face of climate change I recommend management actions to increase reef resilience are targeted at Aldabra, being the largest reef system in the outer islands.

Increasing management connectivity has the potential to greatly enhance overall management effectiveness at local and national levels, whether by understanding the impacts and costs involved in marine plastic pollution to generate funding and guide actions, or identifying important larval source reefs to inform management of coral reefs. But to achieve sustained management connectivity requires greater local collaboration, greater transparency in success/failure, higher levels of data pooling, stronger

alignment of local-level efforts with national targets and overall greater sharing of knowledge and information between practitioners, government, and scientists. All of which can be achieved through targeted actions at site, organization and national level.

CHAPTER 1



1.0 Thesis Introduction

1.1 Island Ecosystems

In total, two-thirds of the world's countries are, or include, islands or archipelagos, directly supporting 10% of the world's population[1]. These islands also support around 20% of global biodiversity but are where 61% of all known extinctions have occurred[2]. The geological origins of islands – either split from continents or raised from the ocean – has shaped the evolution of biodiversity and given islands their uniquely high levels of endemism. As such, Islands have made substantial contributions to our understanding of biogeography. Despite their isolation, islands *can* exhibit high levels of ecological connectivity, or host similar, but genetically distinct, groups of species. This ecological connectivity continues to play a major role in the evolution of biodiversity at these critical sites but increased human-induced connectivity to islands has led to increased anthropogenic threats to island biodiversity, and these require active management.

The similarity between island ecosystems and the threats they face provides an opportunity to achieve greater management effectiveness through management connectivity. Management connectivity (i.e. coordinated efforts between sites) can potentially reduce costs of protecting biodiversity and

improve the efficient allocation of limited conservation resources[3–7]. Often, however, this management connectivity is lacking. This thesis aims to better understand and enhance the level of management connectivity, and increase management effectiveness of island ecosystems by: (1) exploring current barriers to island ecosystem management; and (2) generating information addressing two threats that are common to island ecosystems in the Seychelles archipelago and elsewhere.

1.2 Biodiversity Loss and Islands

The average rate of vertebrate species loss over the last century is up to 100 times higher than the background rate, indicating that the 6th mass extinction is already underway[8]. Conserving biodiversity as a moral obligation for nature is a compelling argument for conservation[9] but has less support and emphasis than the focus on conserving biodiversity for the contribution nature makes to human health and wellbeing[10]. These contributions are known as ecosystem services and this monetization and commodification of biodiversity has enhanced political support for conservation[11]. Ecosystems provide four types of service: provisioning (e.g. food), regulating (e.g. water quality regulation and pollination), cultural (e.g. recreation) and supporting (e.g. nutrient cycling)[11].The loss of biodiversity is impacting ecosystem service provision and consequently human well-being, particularly among island ecosystem communities who are heavily reliant upon healthy ecosystems and yet are also living in extinction hotspots. Historic drivers of biodiversity loss on islands include hunting, habitat loss and the introduction of invasive alien species which accompanied prehistoric settlement[12]. More

recent threats include the impacts of climate change[13] and plastic pollution[13–15].

1.3 SIDS and Climate Change

Of those island nations most vulnerable to both biodiversity loss and the impacts of climate change are Small Island Developing States (SIDS). SIDS face similar challenges, being both ecologically fragile and economically vulnerable[16]; factors that influence their ability to respond to these global environmental challenges. As a result SIDS have played a leading role in advocating for stronger ambition to limit global warming through the United Nations Framework Convention on Climate Change (UNFCCC)[17]. Despite resource limitations, one SIDS that has been leading in climate change adaptation strategies[18] and pioneering efforts towards establishing a blue economy[19] is the Republic of Seychelles.

1.4 The Seychelles Archipelago

The Seychelles archipelago is situated in the Western Indian Ocean (WIO) and comprises 155 islands stretching over 1.4 million km^2 of ocean. The islands gained independence from the British in 1976 after a long colonial history and exploitation of natural resources. Exploitation slowed post-independence and the legislating of the National Parks and Nature Conservancy Act established the country's first protected areas, the largest of which was Aldabra Atoll situated over 1000 km south from the main granitic islands of Seychelles. This marked a new era of conservation in Seychelles, with numerous and substantial efforts to restore island ecosystems that were previously exploited[20–22].

1.5 Seychelles Conservation

Collectively the Seychelles has achieved many important conservation success stories, largely as a result of local NGOs, dedicated individuals and the government's recent commitments to meet global targets. For example, nesting marine turtle populations have rebounded[23–25], native habitat has been restored on several islands[21,22], endemic landbirds have been brought back from the brink of extinction[26–30] and there have been many successful invasive alien species eradications, including species that have not been eradicated elsewhere[31–33]. More recently (2000s onwards), there has been growing emphasis on marine conservation, especially after widespread coral mortality in the 1998 global bleaching event[34]. Coral reef monitoring programmes are now standard practice in marine protected areas and there has been increasing emphasis on and funding for active coral reef restoration, with the development of pioneering coral gardening techniques[35]. National capacity and human resources were strengthened with the establishment of the University in Seychelles (UniSey) in 2009 and the Blue Economy Research Institute (BERI) in 2015. In 2014, the Seychelles Marine Spatial Planning (MSP) Initiative commenced following goals set by the Seychelles government to protect 30% of the Exclusive Economic Zone (EEZ).

1.6 Major Obstacles to More Effective Management

Despite these clear and positive moves towards conserving biodiversity, there are two overarching obstacles to more effective management of both marine and terrestrial island ecosystems (and indeed all ecosystems). These

are the lack of: (1) evidence-use in management and policy decision making (i.e. the knowledge–action boundary) and; (2) evidence required to inform both management and policy decisions (i.e. knowledge gaps). Within the Seychelles context, the combined threats already impacting Island ecosystems coupled with the additional constraints of SIDS and their greater economic reliance upon healthy ecosystems, makes the need to overcome these obstacles even more urgent.

1.6.1 Lack of Evidence-Based Decision-Making

The lack of evidence-based decision making in conservation management is a recognised and much discussed obstacle to the effective management of biodiversity worldwide[36–40]. Very few protected area agencies or natural resource management programmes can quantify their conservation outcomes or modify their management reactively[41]. Research quantifying the extent to which conservation practitioners use evidence-based knowledge to support their management shows that personal experience is more prominent than scientific evidence in forming decisions, even in developed countries where scientific knowledge and evidence should be more accessible. A detailed review of the conservation management of over 1000 protected areas in Australia found around 60% of conservation management decisions relied on observational or anecdotal data from conservation practitioners rather than knowledge derived from research, monitoring, and/or formal assessment[39]. Similarly, at a high profile conservation site in the UK, 77% of decision-making sources were anecdotal, whereas only 2% were based upon verifiable scientific evidence[38]. Experience can contribute substantially to the development of expertise and should not be undervalued

as a source of knowledge, especially where evidence is lacking and practitioners must make rapid decisions, however the lack of evidence-based knowledge to support decision making is nevertheless worrying and the issues arising from relying on experience alone are numerous[38,42].

The causes behind this lack of evidence uptake[43] have been explored; when practitioners in the UK were asked why they generally do not access primary literature to help them in their decision-making, the most frequent response was that this literature is too time-consuming to locate and access (65%), followed by the literature is too time-consuming to read (60%) and 25% said primary literature is too technical and difficult to interpret in the context of their decision-making or that they rely on advisors or expert groups to feed information to them from the primary literature[40]. These responses suggest that the platform of scientific literature is not accessible enough for most practitioners. Furthermore, the lack of scientific evidence-based decision making highlighted in these well-resourced, developed nations, makes it likely that the situation for practitioners in the developing world, and especially in SIDS – where many of the biodiversity hotspots are located – is considerably worse, although there are no studies to date to verify this.

1.6.2 Lack of Scientific Evidence to Inform Decision-Making

Despite £42 billion annually going into the monitoring of biodiversity and natural resources at conservation sites worldwide[44] and over half of resources in threatened species conservation plans being allocated to research and monitoring[45], there is still a lack of evidence to guide management and policy decisions[39]. Evidence/information is often generated by species/ecosystem monitoring programmes which, if effective,

can form an integral role in conservation management by providing the evidence-based science to support adaptive management. ‘Effective’ in this context means well-conceived, designed and implemented biodiversity monitoring, with clear aims and protocols, which can [46–48]:

- **(i)** deliver reliable information on trends in key aspects of biodiversity (e.g. population changes);
- **(ii)** provide early warning of problems (e.g. population crashes, introduction or spread of invasive alien species, disease) that might otherwise be difficult or expensive to reverse;
- **(iii)** generate quantifiable evidence of conservation successes (e.g. species recovery following management) and failures;
- **(iv)** highlight ways to make management more effective;
- **(v)** provide information on return on conservation investment;
- **(vi)** evaluate ecological responses to disturbances, including natural (such as weather events or coral bleaching), or human-induced disturbances (such as from experimental manipulations or management interventions);
- **(vii)** generate new and important questions that enable adaptive management;
- **(viii)** provide empirical data for testing ecological theory and models.
- **(ix)** be easily analysed by staff on the ground or in a long-term collaboration

Data is being collected in the name of conservation management all over the world, but evidence suggests that despite the vital role many monitoring programmes play in meeting global biodiversity targets, too often, they fail to deliver[49–54]. The value of these monitoring efforts is often diminished by a

lack of rigour in analysing, reporting and responding to the results of data collected[49], but the specific barriers to these need exploring further at practitioner level. If monitoring programmes fail to deliver information that is critical to management, then they are ineffective and a waste of valuable resources and conservation potential.

1.7 Defining and Bridging the Barriers to Effective Management of Island Ecosystems

These barriers to generating and applying knowledge are likely to be caused by or interlinked with a raft of other day-to-day barriers that are impacting practitioners, scientists and policy makers. Uncovering and defining these barriers is the first step towards overcoming them. The second step is identifying which solutions will have the biggest impact on bridging these barriers. Overcoming such barriers has the potential to improve management connectivity between island practitioners and across the science-policy interface, and by doing so, improve the effectiveness of island ecosystem management. As such, chapter two of this thesis aims to define the main barriers (and their causes) impacting the ability of island ecosystem management practitioners to meet their conservation and management objectives. Chapter three builds on and broadens the scope of chapter two to quantify the most prolific barriers on a global scale, and explore which barriers most influence practitioner perceptions of management effectiveness and lastly, to determine which solutions for bridging these barriers have the most support from practitioners.

1.8 Bridging Information Gaps in Seychelles

There are key gaps in the knowledge needed to implement more effective management of threats currently impacting island ecosystems within the Seychelles. It is important to differentiate between the information which could be used for local (at a particular site/island) management and that which is needed to inform national management of island ecosystems via policy, and to recognise that often local-scale information can also be used to inform national policy decisions. One example of this was the coral reef mapping project implemented by the Seychelles Islands Foundation at Aldabra Atoll, which initially aimed to inform local-level management of the Aldabra Marine Protected Area (MPA) but ended up being used to inform the Seychelles Marine Spatial Plan (MSP) and the extension of the Aldabra MPA under national legislation[55].

1.9 Knowledge Gaps Identified for Aldabra Atoll UNESCO World Heritage Site

Aldabra Atoll is managed by The Seychelles Islands Foundation (SIF), a public trust set up by presidential decree in 1979. Aldabra's legal protection commenced in 1981 when the atoll was declared a special reserve under the Seychelles National Parks and Nature Conservancy Act. The atoll was then inscribed on the UNESCO World Heritage list the following year. Since then, Aldabra has been declared an Important Bird Area (1998; BirdLife International), a RAMSAR Wetland Site of International Importance (2010), an Indian Ocean-South-East Asian (IOSEA) Marine Turtle Site Network site (2014), and Important Marine Mammal Area (2019) and was recently recognised as an outstanding marine protected area and awarded a Blue

Park platinum-level designation (2019). In 2018, the protected area was expanded from 439 km² to 2599 km², to include newly discovered areas of coral reef[55].

Aldabra is situated 1120 km southwest of Mahé (09°25′S and 46°21′E), the main inhabited island of Seychelles. The closest inhabited land is Madagascar, 407 km to the south, and Tanzania 700 km due west. Aldabra, at 34 × 14 km, is among the largest raised coral atolls worldwide and consists of four main islands: Grande Terre (108 km^2), Malabar (26 km^2), Picard (8.75 km^2) and Polymnie (1.9 km^2) and separated by narrow channels (<20 m depth) enclosing a shallow tidal lagoon (196 km^2). The lagoon coastline is fringed by mangrove forest (12.8 km^2)[56] and coral reef surrounds the outer coastline of the atoll (53 km^2) and cover 19.3 km^2 of the lagoon where it is interspersed with seagrass beds. Aldabra's 155.5 km^2 land area is composed of limestone karst[57] and dominated by a mixed scrub of high density woody plants (42.3 km^2), pemphis scrub (35.8 km^2) and open mixed scrub of woody plants and tortoise turf (25.4 km^2)[58]. The atoll is home to the last remaining population of giant tortoises in the Indian Ocean (the largest population of giant tortoises worldwide[59]) as well being one of the largest breeding sites for endangered green turtles in the Indian Ocean[24].

The conservation of Aldabra presents numerous challenges due to the isolation and size of the reserve. A team of 10–16 SIF staff are present year-round at the research station on Picard. The team cover all the monitoring, research, surveillance and logistics on the atoll and their presence also acts as a deterrent for poaching. In addition to the research station there are field camps located at key locations around the atoll to facilitate atoll-wide

monitoring programmes and other research. SIF has a strong track record of conducting research to inform local management, especially in their management of invasive alien species[29,31,32,60].

Of all the threats to biodiversity there are two whose impacts cannot be directly addressed via site protection; pollution and climate change[61]. These two threats are having negative impacts on the ecosystems of Aldabra and the wider Seychelles; specifically (1) marine plastic pollution and (2) increased frequency and duration of sea surface temperature anomalies as a consequence of climate change. The former is accumulating in vast quantities along the coastline of Aldabra[62], the latter has caused widespread hard coral mortality[63] in several global coral bleaching events. Consequently, SIF has identified knowledge gaps associated with these two threats and proposed key research questions that, if tackled, would generate information to inform both local and national level management and/or policy of these issues.

1.9.1 Example of Local Level Management Information Gap: Plastic Pollution

The accumulation and impacts of marine plastic pollution[64–69] is one of the growing threats to marine ecosystems worldwide. Eight million tonnes of plastic enters the ocean annually[64] – largely as a result of mismanaged waste – with an estimated 269,000 tonnes of plastic in surface waters across the world[70]. A study of the world's waste management shows that the Indian Ocean is fringed by countries with 100% mismanaged waste[64]. In fact, 86% of total ocean plastic pollution comes from rivers in Asia[65] and there is an estimated 59,130 tonnes of surface plastic in the Indian Ocean[71]. This plastic is transported by currents and wind, persisting for decades and breaking into

increasingly smaller pieces as a result of physical abrasion from wave action and photodegradation[69]. The end point for some of this plastic includes remote islands[72–75] like Aldabra.

This poses several threats to the atoll's ecosystems, not least the direct impact of entanglement, ingestion and smothering on a wide range of animals[66,75,76]. In addition, once plastic pollution accumulates along coastlines it creates a barrier to critical habitats, like turtle nesting beaches. Lastly, and perhaps the biggest threat of all, is the potential for marine pollution to act as a vector for the arrival of non-native species, as has been recorded elsewhere[77–79]. In 2017 SIF prioritised research that could help inform local-level management of this threat and therefore priority research questions were co-developed between SIF and myself. Specifically, how much plastic pollution there was, where was it coming from and the resources needed to remove it. These questions are addressed in chapter four of this thesis.

1.9.2 Example of National-Level Management Information Gap: Coral Reef Connectivity

The Seychelles EEZ covers a vast area and is in one of the world's richest biodiversity hotspots[80]. Seychelles is greatly dependent on this area to support the two pillars of its economy: tourism and fisheries. The two sectors directly account for 34% of GDP, 37% employment and close to 100% of exports[81]. So, economic growth and development must be coupled with sustainable resource management and protection of the nation's biodiversity on which it depends, especially on its coral reef ecosystems. Like other SIDS, Seychelles is concerned about the impacts of climate change on coral

reef ecosystems and the species they support, especially as these are paramount in safeguarding ecosystem health and food security in the region. Ensuring coral reef persistence is therefore a top priority for Seychelles and one that will be hard to deliver, given the increasing threats they face.

Climate change poses imminent threats to the long-term persistence of coral reef ecosystems[82,83], and El-Niño-induced coral bleaching is among the most rapidly-growing and devastating of these[84] . The 2014-2017 El Niño caused a multi-year global coral bleaching event which impacted reefs worldwide[84–91] and even well-protected sites like Aldabra saw 52% reduction in hard coral cover[63]. The frequency of strong El-Niño events is projected to increase with climate change[92,93] and regionally coral is estimated to collapse within 50 years[94]. These projections are bleak, hence the urgent need to understand drivers of reef resistance and resilience[95–99] and coral reef connectivity[100–102], and to use this information in management to maximize the chances of reef persistence.

As such, the Blue Economy concept has been adopted by the Seychelles government to implement and maintain sustainable management of these vast marine resources for present and future generations. Under the Marine Spatial Planning initiative, 30% of the Seychelles EEZ has been designated under protected area status. This process brought together existing scientific data, local expert knowledge and stakeholder input. However, a knowledge gap identified in this process was local-scale information about coral reef connectivity. Similarly, SIF identified the need to better understand the role of Aldabra's reefs in the region's coral reef connectivity, especially as evidence of Aldabra's importance in regional coral reef resilience would lend

greater support to SIF's mission to eradicate rats and cats from the atoll, a costly management action but one that has been proven to positively impact coral reef ecosystems[103,104]. Therefore, based on this initial gap identification, the research proposal was co-developed between SIF, the Ministry of Environment and myself. Chapter five of this thesis therefore aims to establish the first understanding of coral reef connectivity in Seychelles using a genomics approach to inform national management and policy of Seychelles coral reef ecosystems. Mapping connectivity among major reefs across Seychelles and using this map to determine keystone reefs – defined as highly connected sites that potentially supply larvae to many other reefs in the region – will fill this gap in current knowledge. These sites are likely to be critical for recolonization following disturbance events like bleaching and so identifying and protecting these keystone reefs will be an important management tool for Seychelles: allowing conservation resources (time, money, legislation) to be better targeted.

1.10 Statement of authorship

The chapters of this thesis are published or draft manuscripts. I led all of the work and the contributions of co-authors, alongside the details of publication or planned manuscript submission, are given at the start of each chapter.

1.11 Thesis Overview

Table 1.1: Summary of data chapters 2–5

Chapter	Title	Aims	Method/s	Status
2	Defining and bridging the barriers to more effective conservation of island ecosystems: A practitioner's perspective	Identify the barriers practitioners face in meeting management objectives and their causes. Generate ideas to strengthen and support island ecosystem management and discuss ideas for follow-up actions.	Semi-structured Interviews	Published in *Conservation Science and Practice*
3	A global assessment of the barriers influencing the effectiveness of island ecosystem management	Identify the most common barriers that island practitioners experience. Investigate how the prevalence of particular barriers shape views of overall management effectiveness of islands. Identify which of the proposed solutions have the highest support.	Online questionnaire (Social Science)	In review in *People and Nature*
4	The costs of removing the unsanctioned import of marine plastic litter to small island states	Estimate the total amounts and types of marine plastic litter on Aldabra. Identify the source(s) of the problem. Estimate the financial and human resource costs of a clean-up effort for the entire atoll.	Visual transects, fieldwork time and cost calculations.	Published in *Scientific Reports*
5	Genome-wide SNP genotyping of coral *Porites* sp. identifies key source and sink reefs in the Seychelles archipelago	Identify population structure of *P. lutea* in the Seychelles archipelago. Calculate gene flow between reef sites to identify which sites are key sources for coral persistence in the region.	Genome-wide single nucleotide polymorphisms analysis	Combining with Oceanographic modelling results and submit to *Marine Biology* or similar journal

CHAPTER 2:

Defining and bridging the barriers to more effective conservation of island ecosystems: A practitioner's perspective



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“There is a pleasure in the pathless woods,

There is a rapture on the lonely shore,

There is society, where none intrudes,

By the deep sea, and music in its roar:

I love not man the less, but Nature more”

— Lord Byron

2.1 Introduction

Despite efforts to halt the accelerating loss of biodiversity[8], the Aichi Biodiversity Targets for 2010 and 2020 were not met at a global level[105,106]. The reports outlining these failures do not detail why they have occurred except to say that “*national targets are generally poorly aligned with the Aichi Biodiversity Targets, in terms of scope and the level of ambition*”[106]. If future failures are to be avoided, a better understanding of current barriers to biodiversity management and conservation success is needed[107], especially at sites with disproportionally high levels of biodiversity loss, such as islands[108]. This will be key to implementing more ambitious and effective national level biodiversity efforts.

Two major barriers to achieving global biodiversity targets are well addressed in the literature. The first is financial limitations[109,110]. It is estimated that to protect and effectively manage sites of global conservation significance will require conservation funding to increase by at least an order of magnitude[109]. The second is the documented lack of evidence-based

decision-making in conservation management[36,111–113 36,111–113]. Practitioners manage species and ecosystems through a combination of active management[114] (e.g., enforcing site protection, habitat restoration, invasive alien species eradications), research[115] and monitoring[53], with the latter two generating the evidence on which decisions can be made about the former. Therefore, if monitoring and research are well conducted, the information generated can play a vital role in achieving effective management and meeting biodiversity conservation objectives[46,47]. However, such programmes often do not deliver[50,53]. While financial limitations and lack of evidence-based decision-making undoubtably contribute to missed targets, there are likely a raft of other barriers operating at multiple levels across the management landscape that are not so clearly defined or addressed.

The ability of a country to meet national targets (and so contribute to global targets) depends on the combined efforts of a diverse group of practitioners working across sectors and scales. While this diversity offers an opportunity to capture the breadth and depth of different considerations, knowledge and experience, spatial and temporal mismatches and barriers to collaboration are likely to hinder conservation success[116,117]. For example, the scale of management ranges from single sites and species to national governance of whole ecosystems and natural resources. Practitioners include those working within and for government, who enact land/sea use designation, develop appropriate policy, and implement and enforce legislation. Outside government, practitioners include those working in non-governmental organisations[118] and private companies, as well as researchers and consultants who work with these organisations to generate information useful for management. Management at local level usually aims to achieve

site- or taxon-specific conservation goals and collectively these site-level successes or failures influence national targets. Ideally there should be synergies between national and local level; whereby government departments define and coordinate national targets linked to local organisation/project objectives and, in turn, government decisions are guided or prompted by the information generated from these smaller management bodies. However, significant barriers often prevent these important interactions between national and local level from happening[43].

There is little detailed understanding of the day-to-day barriers to success and where precisely they occur: for example, whether at project/site, organisational or national level, and whether they result from institutional issues (such as lack of expertise and staffing), poor governance, lack of societal support and social complexities[119], or other factors. Although several studies have described barriers to effective biodiversity conservation, these have mostly focused on specific barriers and have not fully considered practitioners, or have focused on the perspectives of senior practitioners in upper management[15,120]. To obtain a more complete picture we need to understand the views of practitioners across seniority levels and sectors, especially those at the very frontline of tackling biodiversity loss.

Nowhere has biodiversity loss been so acute as in island ecosystems[121], where invasive alien species[122,123], habitat loss[121] and climate change[124] have all had major impacts, causing extinctions and reducing surviving populations to critical levels. Despite major conservation progress and the development of pioneering techniques, such as invasive alien species management[31,125], translocations[30,126] and *in situ* species management[127],

these pressures are compounded in island nations – especially Small Island Developing States – which are highly dependent on biodiversity for their economic and social wellbeing[128]. However, capacity and resource constraints (human, institutional, and financial) can often hinder national and regional responses [16].

Identifying barriers based on past experience can be an important step towards achieving success (e.g [129]). Therefore, here we focus on Western Indian Ocean islands (where the lead and senior authors are based), including the Small Island Developing States (SIDS) of Seychelles and Mauritius. We interviewed practitioners across sectors and seniority levels who are involved in island ecosystem management and compiled the first in-depth case-study on the barriers to more effective management of island ecosystems from a practitioner's perspective. Our aims are to: (1) identify the barriers practitioners face in meeting management objectives and their causes; and (2) generate ideas to strengthen and support island ecosystem management and discuss ideas for follow-up actions.

2.2 Methods

Study area

The study focuses on island ecosystem management and conservation practitioners in the Western Indian Ocean (WIO), which is a global biodiversity hotspot[80] and identified as a key area to prioritize for the conservation of global marine biodiversity[130]. This region is characterised by islands which vary greatly in size, culture, socio-economic context and political status[131]. The islands have unique environmental origins (volcanic,

granitic or coralline) as well as cultural (settlers from various origins; African, Arabic, European, Indian, and Chinese). The cultural heritage of the islands is heavily defined by their colonial history (especially French) and the slavery which accompanied that. Despite these differences, the islands within this region share natural heritage, including the rich terrestrial biodiversity unique to the islands and extensive marine biodiversity which forms the basis of the region's economy[132]. This natural heritage is threatened by over-exploitation, destruction of habitat, invasive alien species and pollution.

Most interviews were conducted with practitioners from the Republic of Seychelles (where the lead and senior authors work), an archipelago of 115 islands stretching across an exclusive economic zone of 1.4 million km^2 with *ca* 98,000 citizens[133], three-quarters of whom live on the main island of Mahé. Other interviewees were based in Mauritius, La Réunion (France) and Madagascar.

Interviewee selection

We recognize that there are many roles associated with island ecosystem management. We therefore included not only staff working within conservation organizations but also conservation practitioners working on privately managed islands, government staff, consultants within the region who have many years of experience working with different organisations, and academics and researchers who have worked with conservation organisations to implement and achieve conservation and management objectives. Within organisations, where appropriate, we requested to interview staff from across seniority levels, for example CEOs, managers, and field staff. A criteria for participation was that practitioners, as part of

their work, aimed to manage, conserve or restore biodiversity to the island ecosystems within their jurisdiction, including playing a role in data collection and/or processing (either directly or through partnerships) to obtain information that would inform their management decisions or those of higher-level entities, such as government. All interviewees also needed to have a minimum of two years' experience in their current or a related role in island ecosystem management to participate.

Prospective interviewees were identified firstly by listing all island management and conservation bodies for the islands in the study region, either through consultation with people working there or through informal internet searches. Then perspective interviewees (or organisations where individual contact details were not available) were contacted via email to explain the project and request an interview. To enrol an appropriate number of interviewees representing a wide range of experiences while avoiding potential sampling biases due to researchers' personal networks and perceptions about the issues[134], we also employed respondent-driven sampling; this approach involves requesting those directly contacted to recruit additional participants among colleagues, peers and other organisations. A total of 68 individuals were contacted via email and asked for an interview (Table 2.1).

Table 2.1 *Information about the 32 interview respondents: (a) The number of interviews conducted for each of the countries in the Western Indian Ocean region included in this study; (b) The number of interviewees per role description; (c) The number of participants per place of work.*

(a)	Island/Archipelago (Country)	# Interviewed
	Madagascar	1
	Mauritius and Rodrigues (Republic of Mauritius)	6
	La Réunion (France)	2
	Seychelles (Republic of Seychelles)	23
	Total	32
(b)	Role of participant	
	Conservation officer/coordinator/site manager	12
	Researcher/academic	9
	CEO/director	5
	Field assistant/warden/ranger	4
	Local consultant	3
(c)	Place of work	
	NGO	14
	Academic institute	6
	Public trust/parastatal	4
	Government	3
	Private island	3
	Consultant/self-employed	2

Survey design and data collection

The survey design was approved by the University of Oxford Social Sciences and Humanities Interdivisional Research Ethics Committee (Ref No: R62246/RE001). Interviews were conducted whenever possible in person (34%) and, when this was not feasible or preferred, via Skype (32%) or written (34%) via email exchange and took place between April–December 2019. Consent for participation was obtained before each interview. Interviews used a semi-structured approach, following discussion guidelines that combined open-ended questions, more direct questions and 'organic questions' that arose from interviewee responses (see Fig. 2.1 for overall structure and supplementary material section 4 for the full interview outline); this is particularly useful to gather more in-depth personal perspectives on challenges faced by specific respondents [134]. The pre-determined topics were generated based on the authors' personal experiences of working in island conservation management and a review of literature around the current understanding of factors that drive and influence effective management of biodiversity[36,47,51,135–139]. The topics, however, remained broad to prevent biasing interviewees. The interview started by asking the interviewee "Tell me about your role in island ecosystem management" and continued as outlined in Figure 2.1, prompting the interviewee for additional information or particulars where necessary and adding follow-up questions to new ideas the interviewees introduced. Towards the end of the interview, interviewees were asked to make suggestions for what would be most impactful in improving their ability to fulfil management objectives.

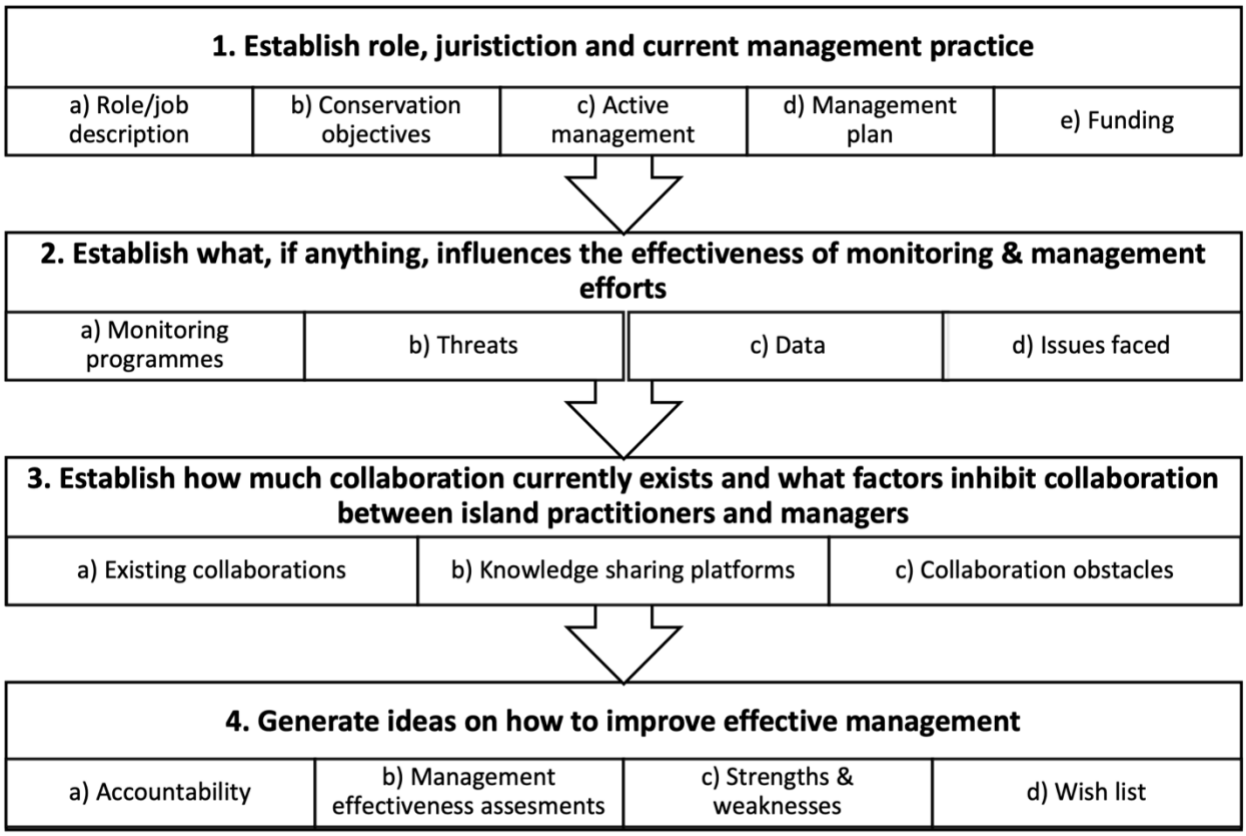


Figure 2.1: Schematic representation of the semi-structured interview employed

Data analysis

The interviewee responses were transcribed directly during interviews, which prevented interviewee wariness that could arise during recorded interviews when discussing other organisations or using specific examples. The downside of this method was that consequently, some of the transcripts were abridged in sections, though the main points and their meanings were all documented. Each transcript was then reviewed to develop a conceptual framework from qualitative data using a hybrid approach of inductive and deductive coding[140]. All coding was done initially by researcher AJB.

Deductive coding was used firstly by grouping barriers mentioned by practitioners based on the pre-determined topics developed when designing the interview, resulting in the following initial codes of barrier themes expected in the interviewee responses: data management and analysis; collaborations & communication; management objectives and resources. Inductive coding was used when a barrier was discussed that did not belong to a pre-determined topic and was therefore assigned/coded to a new topic. New topics added to the coding framework were: education; government capacity and coordination; policy and legislation; national research strategy; staffing; organisation leadership; knowledge exchange and communication forums; and site/project management & leadership. This resulted in 12 topics (Figure 2.2a), four which were pre-determined, and eight which arose organically.

While coding the barriers under main topics, it became clear that the topics could also be categorised based on their provenance (i.e. at which level they arose within the management system), for example if a practitioner described ‘lack of coordination by government’ then it was clear that this barrier needed to be addressed not by individual organisations or projects but at national level. Conversely if a practitioner described ‘no time for data analysis’ this was clearly a barrier operating at individual site/project level. Each topic with its associated barriers was therefore coded most logically to: (a) national level (e.g. policy and legislation); (b) organisation level (e.g. staffing/resources); and (c) site or project level (e.g. data management; Figure 2.2, Table S2.1).

Based on participants' comments about specific barriers we could also assign one or more causes to the barriers (Table S2.2). We therefore listed causes for each barrier, for example, poor database design could be attributed to lack of data management skills/capacity. Other barriers were self-explanatory, for example, low capacity in data analysis. From this exercise six major causal links emerged: (1) limited capacity; (2) poor leadership; (3) lack of government coordination; (4) interpersonal issues; (5) lack of incentives; and (6) limited resources. Within the scope of this study, we refer to the term 'capacity' strictly in relation to skill capabilities rather than the broader term which may also encompass resources. The networkD3 package in R Core Team (2020) was used to map these causes in a Sankey network diagram (Figure 2.3) to show the underlying causes of the barriers raised by practitioners at each level (national, organisational and project/site).

2.3 Results

Of the 68 (30 female, 38 male) practitioners invited for an interview, 32 interviews were conducted (20 female [67% response rate], 12 male [32% response rate]) from four countries and four islands in the WIO region (Table 2.1a), an overall response rate of 47%. Interviews lasted from 35 minutes to 2 hours with mean interview length of ca. 1 hour. The seniority level of interviewees varied from high-level management positions and government officials to on-site field staff (Table 2.1b). The organisations to which interviewees belonged included: privately-owned islands; NGOs that manage one or more islands or parts of islands; government employees in Ministry for the Environment roles; and researchers from educational

institutes that work closely with organisations on conservation and management projects (Table 2.1c).

Barriers to effective management

We identified 33 barriers under 12 topics that practitioners raised during the interviews in regard to meeting conservation and management objectives. Table S1 lists these specific barriers and key illustrative quotes lifted from the interviews. The majority of barriers described by interviewees existed at organisation level (55%; Figure 2.2a), followed by national level (24%) and site/project level (21%). The themes under which practitioners described the most barriers were ‘collaboration’, ‘staffing’ and ‘data management and analysis’ (Figure 2.2a). The number of barriers grouped in each topic reflects the variety of barriers, not the frequency with which they were mentioned. The most frequently mentioned barriers were lack of data analysis and management capacity (21 of 32 practitioners mentioned this; Figure 2.2b), lack of local collaboration (13), interpersonal relationships interfering with conservation/working relationships (12) and no time for data analysis (11).

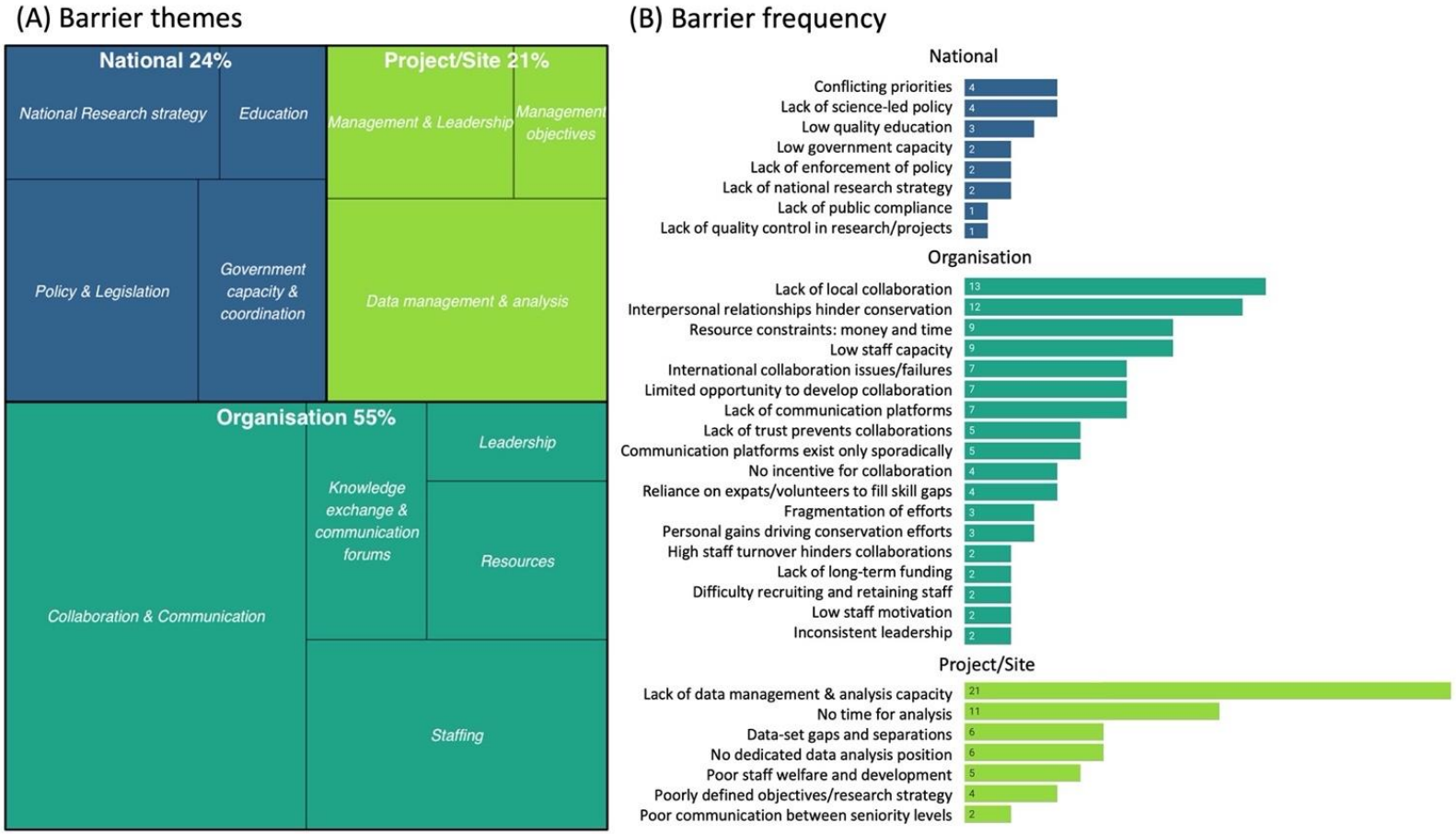


Figure 2.2: (a) Treemap plot presenting the proportion of barriers for each of the 12 main topics discussed during interviews, organized by the provenance level associated with each of the barriers showing the percentage of barriers that fall into each level. Each block size is proportionate to the number of barriers that topic represents. (b) Bar chart showing the number of practitioners who mentioned each barrier from the 32 interviews.

Cross-cutting causes

Of the 33 barriers described by practitioners, the most frequently associated cause was limited capacity (23.5%; Figure 2.3) followed by lack of government coordination (21.6%), limited resources (21.6%), lack of incentives (11.8%), poor leadership (11.7%), and finally interpersonal issues interfering with progress (9.8%). The contribution of causes to barriers varied between levels (Figure 3). The majority of national-level barriers were caused by limited capacity (43%) and lack of government coordination (36%). The organisation-level barriers had a wider set of causes, dominated by lack of government coordination (23%), limited resources (23%), lack of incentives (19%), limited capacity and interpersonal issues (each with 15%). Finally, at project and site level the majority of barriers were caused by poor leadership (45%), followed by limited capacity and limited resources (each with 18%), lack of incentives (9%), and interpersonal issues (9%). Note: some of the actual barriers listed became causal links, e.g. capacity was listed in several barriers and became a causal link.

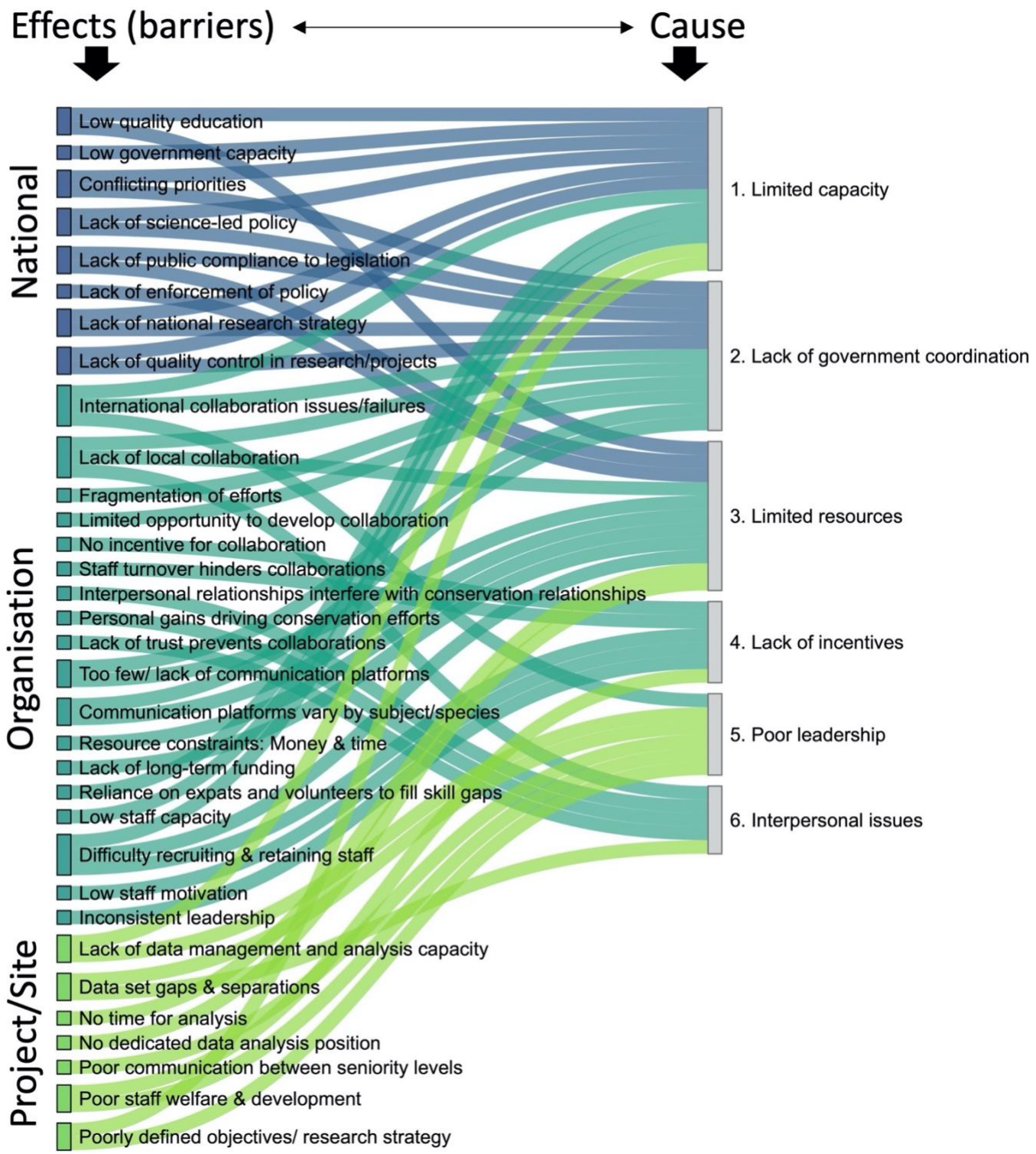


Figure 2.3: A Sankey diagram linking barriers from each provenance level (National, Organization, Project/Site) to the main causes. One barrier may stem from one or more causes

Improving effective management

Practitioners suggested 14 solutions (Table S2.3) that would most enhance their ability to achieve more effective island ecosystem management and conservation, and we have linked their suggestions (where possible) to the most closely linked cause (Figure 2.4). Interestingly, there were no proposed solutions for dealing with interpersonal issues. The most frequently suggested solution centred around the need for more funding (Figure 4), though few of these suggested how funding streams could be enhanced, other than to extend project funding beyond the standard 2–3 years. Following this was the suggestion that there should be enhanced transparency and accountability around the outcomes of actions and funding.

As 12 of the 33 barriers were entirely or partially attributed to limited capacity, five of these solutions were centred around recruiting and retaining a high-capacity staff team. This included the recruitment of additional personnel, such as a database manager or an internal researcher to ensure standardised data collection that was analysed properly and used to inform management. Another suggestion was to ensure long-term inducement in the form of pay increments and giving staff chances to progress via training opportunities and career development.

To enhance coordination of efforts, one practitioner suggested that an annual, government-coordinated symposium become a compulsory event for appropriate ministers, practitioners, and researchers; each organisation could present their work, which would be open to scrutiny by peers,

facilitating a more transparent model for conservation at the national level. In addition, it was proposed that each organisation have a clear set of management objectives incorporated into a plan and that this is linked with a national research strategy.

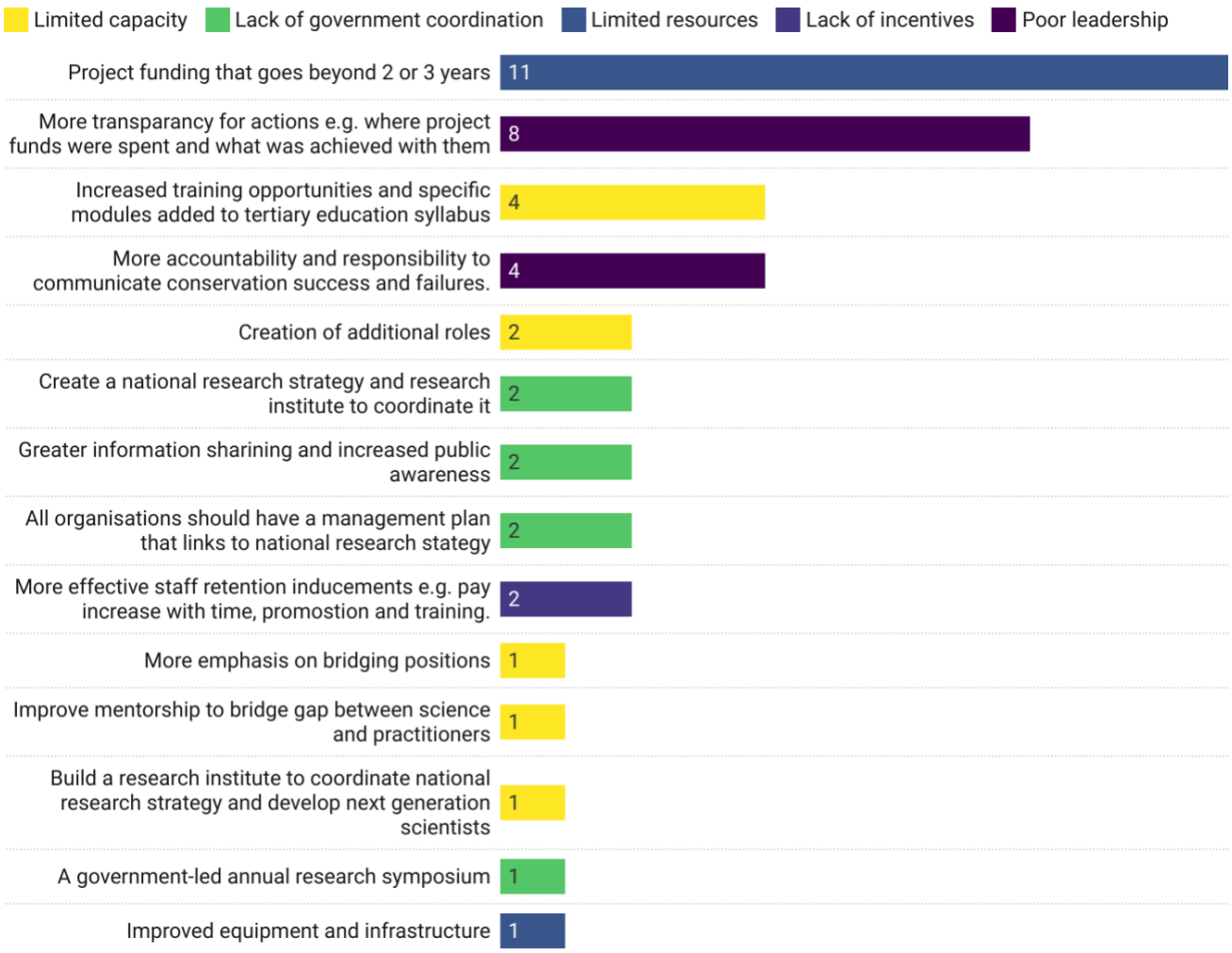


Figure 2.4: The frequency with which each solution was proposed by practitioners, grouped based on the main barrier cause they most relate to

2.4 Discussion

Organisations, government departments, private companies and research institutes are channelling vast resources[109] into the conservation and management of biodiversity. If these efforts are effective, this would collectively translate into national level conservation and management achievements and subsequently contribute towards meeting global biodiversity targets. Our research has uncovered a raft of barriers operating across management levels, stemming from six main causal links, which interfere with the ability of practitioners to achieve local and national conservation objectives in the Western Indian Ocean (WIO).

Causal link 1: Limited capacity

The term 'limited capacity' is frequently described as an issue within environmental conservation[141,142], but often without reference to what specific type of 'capacity' is lacking. In our study, staff capacity limitations were identified as a key barrier but also a cause of several other barriers described by practitioners.

Many skill-sets are required by an organization to meet conservation targets, as outlined by Salafsky et al. (2002)[144]. Our survey has identified which skills are lacking in conservation and management of island ecosystems in the WIO region. At the national level, practitioners perceived capacity gaps in the skills/abilities to: (1) coordinate national efforts and develop a national research strategy (*"It's the blind leading the blind"*); (2) critically review projects and their scientific rigour; and (3) implement scientifically sound conservation and management of island ecosystems. At organisation and

project levels, skills perceived to be lacking were: (4) leadership and management; (5) data management and analysis; and (6) the ability to define research and monitoring objectives that effectively inform management. The lack of these skills was attributed to in-country tertiary education standards (*"Most students are not getting the core skills needed or to a standard that's required to progress in any conservation research or management role"*) and a lack of internal training opportunities and skill development through skill exchange and/or mentorship. With relatively few graduates and even fewer with post-graduate education (who remain in-country) there is little basis for in-country capacity to fulfil the attribute list for successful conservation, which has created a reliance on international staff and volunteers. One practitioner described how their organisation have combated this issue by developing strong links with external researchers and institutions whereby their overall capacity and outputs were enhanced. Another practitioner pointed out that while overall capacity was lacking, certain organisations have developed very strong capacity (in some cases world-leading) in certain niche areas, such as invasive species eradication and species translocations.

One capacity-driven barrier described by practitioners was the perception of poorly defined objectives, whereby practitioners spend resources (time, money) collecting data of little apparent value (*"…[Feels like we are] collecting data forever without a reason why or any end goal"*). Monitoring programmes must be motivated by a clear management question or problem, with well-defined objectives on how the programme will answer this question or provide critical information. Without this fundamental step, design and implementation problems are likely, and consequently the data are unlikely to achieve anything meaningful[47]. The conception, design and

implementation of a successful monitoring programme requires critical thinking, sound scientific understanding, good knowledge of past work, and consideration of a broad range of factors, as well as regular assessment of the data collected[51]. In our survey, practitioners described how data is not analysed frequently enough to detect such problems, which can mean that data are collected for years or even decades before problems are uncovered and addressed (*"the major bottleneck is one of time"* or analysis is *"very basic & incomplete"*). Such delays seriously impinge the effectiveness, relevance and value of monitoring programmes and prevent their use in adaptive management[145]. Previous studies suggested that building technical capacity is not insurmountable, especially if funders drive this requirement through selection of projects which demonstrate clear outcome-focused objectives coupled with transparency and accountability[36]. But the need to strengthen capacity has long been recognised in the region[146], and 'capacity building' *is* therefore already often a requirement for funding consideration. Whether or not these funder-driven capacity-building initiatives are effective requires further investigation; other studies highlight the need for dedicated funding to support knowledge exchange *beyond* the lifetime of such projects to develop real and lasting *institutional* capacity[111].

Our interviewees suggested several solutions to these capacity-driven barriers, including establishing new roles such as data manager and, specifically, acknowledging the need for and development of 'bridging' positions within organisations (*"Having a resident researcher at each site would be hugely beneficial"*). These bridging positions could be created for high-capacity post-graduates or practitioners who partner more closely with scientists to clarify conservation objectives, develop research strategy,

design projects/programmes and ultimately ensure the information being generated feeds back into management – and research and monitoring objectives are driven by management needs – through rigorous analysis and interpretation. Other suggestions centred around the education system, e.g. introducing specific modules to existing courses that better equip students for work in the conservation management sector, or the need for an overall shift at government level to develop a research culture through the allocation of resources, e.g. "*Build a research institute whose mandate is just to do research to inform management"* and by *"Investing in schemes to develop next generation conservation scientists"*.

Our study shows that, despite some perceived improvement in capacity, there is still a vacuum whereby the value of practitioners' efforts is compromised due to limited capacity. Bridging these gaps in core skills will require further assessment of specific capacity needs at national, organisational and project/site level, coupled with a long-term collaborative investment in people development across government and organisations to develop the next generation of conservation practitioners capable of *increasing* effective management.

Causal link 2: Lack of government coordination

Lack of government-led coordination of conservation and management efforts was the second major causal link across barriers at all levels. This lack of coordination results in a "*fragmentation of efforts*", whereby practitioners have "*no idea what is happening on other islands*", and are "*all doing the same thing, in slightly different ways but not sharing lessons learned*". This lack of connection and collaboration makes it difficult to track

and synthesise project outcomes, compile national data, identify successful (and unsuccessful) actions and ultimately to maximise resource use and effective management: "[There is a] *lack of platforms for 'cross-pollination'…Stronger leadership is needed to outline what data is needed and where funds should be allocated vs where they are going to waste*". This view was shared by practitioners both outside and within government: "*There are workshops and occasional symposiums, as much as possible ministry staff attend these, but there is no annual forum*".

Government ministries/departments were perceived to be in the best position to harness the collective power of non-governmental organisations and thereby create synergies between national and local level efforts. The solutions suggested by practitioners align with this need for government-led coordination of efforts, for example by creating a national research strategy and mandating that conservation management of island ecosystems is transparent and accountable, i.e. by clearly stating their core aims at regular intervals, how they are achieving these aims, and crucially, how these aims support the national research and conservation strategy (*"Regular self-reporting should be mandatory for all to report on management plans - how is management being conducted and is it successful? We should be held to account and prove ourselves to Cabinet once a year, for both government and the public"*). A key suggestion, and one that could be relatively easy and cost-effective to implement, was a government-led annual research symposium. This would help to strengthen synergies across levels, reduce fragmentation of efforts, encourage knowledge exchange, and potentially lead to increased collaboration. More than one practitioner mentioned instances where non-governmental organisations often step into the breach

to ensure knowledge exchange and communication between practitioners. One example provided was of an NGO who coordinates annual meetings for focus groups on seabirds and one of the long-term endemic land bird species recovery programmes, despite no-longer receiving project funds to do this.

Government coordination of island ecosystem management inevitably varies in approach across the countries represented in our interviews, and although the majority of interviewees were from a single country, we suggest that the issues outlined are likely to be representative or common to many such nations, and perhaps especially to Small Island Developing States.

Causal link 3: Limited resources

Resource constraints are well documented for both conservation of biodiversity[109] and for Small Island Developing States such as Seychelles [16,147], so it is unsurprising that resource limitations were identified as a major cause of the barriers described in this study and that 'more funding' was the most frequently suggested solution. Overall, limited resources were a direct cause of 11 of the 33 barriers described by practitioners. Even within government, lack of resources (human, institutional and financial) was identified as limiting what was possible and the effectiveness of actions: *"[The ministry] do what is possible with the low resources".* Outside government departments, financial support for many of the conservation organisations comes directly from eco-tourism. These tourism revenues often support the basic running of operations (staffing costs and monitoring activities), and additional conservation actions normally rely on external project funding through grants. One practitioner described how one of the strengths to national conservation efforts had been the high level of

international funding which had facilitated some of the country's biggest conservation successes. However overall, practitioners felt that project funding, although crucial, does not support long-term objectives and often doesn't allow specific funds for staffing projects appropriately: *"Conservation of threatened species and the associated habitat rehabilitation is not a sprint; it is a marathon that requires years of work, not 2 – 3 years which is the general length of project funding".*

Innovative ways of funding conservation and management of island ecosystems in the region have been developed; for example, in the Seychelles, the world's first sovereign blue bond was introduced in 2015 – a pioneering financial instrument designed to support sustainable marine and fisheries projects. Proceeds from the bond supports grants and loans issued through the Blue Grants Fund and Blue Investment Fund. This initiative is shaping the research and conservation landscape in Seychelles by exclusively funding projects that are of national importance to the blue economy and climate adaptation. Now, with the impacts of Covid-19 de-stabilising conservation worldwide[148,149], it is more important than ever to ensure that the available resources are being used in the most efficient and effective way. Bridging these barriers is therefore essential for success.

Causal link 4: Lack of incentives

Six of the 33 barriers described in this study were linked to a lack of incentive for staff. Practitioners described how high staff turnover was a major barrier to achieving effective conservation due to the loss of long-term perspective, resulting in each new staff member "*reinventing the wheel*" by altering methods, shifting research focus, starting new databases etc. Staff turnover

was a cause of other barriers, such as data management and consistency issues, loss of collaborations and poor management. As one practitioner put it, the solution to many of the barriers faced would be to "*ensure you have the A-team in place*". The specific incentive issues described in this study included low pay, lack of career development opportunities, in some cases no formal contract or financial incentive for contract renewal or reward for loyalty (e.g. *"I have lots of responsibilities as project leader but no contract"*).

The lack of employment contract mentioned by a couple of the interviewees, while not illegal, is unlikely to reassure employees or lead to long-term retainment. The issue of pay is not so easy to address because while 'better pay' and financial rewards to continued employment in a role are almost certainly likely to lead to increased staff retention, there simply may not be the money to do this. But arguably it is better to do less but do it better by investing more in staff than ineffective efforts towards achieving management objectives. Clearly, funding is a major factor in the development of incentive schemes but serious considerations should go into balancing resource allocations to enable incentives, given the clear evidence for their success in other sectors[150,151]. There are also other inducements for staff than financial ones, such as increasing holiday allowance, facilitating skill and career development, promotion, and work/life flexibility. For example, one practitioner described how their organisation had become more flexible to staff needs to retain key staff, which has enabled the core management team to have remained stable for the past ten years.

Causal link 5: Poor leadership

Practitioners identified several barriers that were attributed to poor leadership. Ultimately it is effective leadership that most supports effective management; effective leaders need the knowledge, skills, and attitudes to boost organisational capability and performance to tackle environmental and institutional challenges[152]. Leaders are therefore pivotal in making or breaking efforts to achieve management objectives but the specific skills needed to be a good leader are broad and available training does not necessarily cover the key skills required for effective leadership (e.g.*"[For managers] day-to-day they are dealing with anything from staff sickness/HR issues to planning and science, these people need to be great drivers, diplomatic, and have strong communication and management skills"*).

In a study of effective leadership skills, the skills deemed essential were not those targeted in academic and professional development[152], i.e. post-graduate degrees do not provide leadership skills. Some practitioners acquire these 'soft skills' through learning from others (good/bad mentorship) but a lack of specific training within academia and at organisation level greatly reduces leadership potential and therefore the effective management of ecosystems. The huge disparity between the emphasis on improving leadership within the business/financial sectors versus the environmental sector is acknowledged[153], but it is imperative that environmental conservation leadership catches up if we are to address the biodiversity crisis.

Causal link 6: Interpersonal issues

Among the most frequently cited recommendations in the scientific literature for protecting biodiversity is improving regional coordination among practitioners[154], i.e. collaboration. The overall response of practitioners interviewed in this study to collaborations (local and international) was recognition of their value (all 32 respondents), a general feeling that there is "*more collaboration these days*" but acknowledgement of numerous barriers to collaboration: nine of the 33 barriers identified were grouped under the collaboration theme. Among those barriers to local collaborations most frequently mentioned (12 of 32 practitioners) was the issue of interpersonal relationships between managers impacting the likelihood and success of collaborations. Despite recognising that collaborations have the potential to increase conservation effectiveness ("*one person could do all datasets to save time and resources*"), egos, interpersonal conflicts within high level management and a lack of trust were frequently perceived as problems ("*People politics comes before conservation*" and "*Historic 'egos' govern organisations from a top-down approach*"). These barriers manifest themselves through blocking of data-sharing agreements, unwillingness to support or participate in knowledge or skill exchange activities, competitiveness, or sense of ownership over a species, dataset or site (as described by one practitioner, "*some people will keep data to the grave*"). Despite no explicit solutions proposed by practitioners to bridge these type of barriers, the frequency with which they arose during our interviews suggests that they have a larger influence on management effectiveness than has been previously recognised; these issues are only briefly touched on in a handful of studies[120,153] and so further investigation could be important for defining and implementing solutions.

2.5 Conclusion

It is important to recognise that despite the barriers outlined in this study, there is a huge amount of crucial and successful conservation work being carried out by practitioners in the region. Many of which have already recognised certain barriers and are proactively dealing with them; for example, by creating data management positions or by developing collaborations with research institutes to facilitate data analysis. Despite such efforts, multiple barriers existed for all practitioners within this study and fixing any one of these barriers will not address the entire problem. For example, if practitioners in the field are struggling with data management and a solution is implemented, there are still more hurdles to navigate, i.e. data analysis, data interpretation and report writing. If practitioners fall at one of these hurdles, they have little chance of achieving their ultimate objectives further down the line (Figure 2.5). Some barriers have simple fixes, some require individual organisations to act, while others require national level action and coordination to tackle them. It will therefore be essential to identify the trade-offs between solutions that are the most achievable, the cheapest and the most effective. However, by identifying the main causes of barriers, and implementing solutions to *these*, we will have a better chance of bridging multiple barriers at once.

While our study was focused on the Western Indian Ocean region and is restricted to practitioners mostly representing two small island developing states (SIDS), the barriers they described are likely to be representative of those operating in SIDS worldwide and perhaps even more broadly within biodiversity conservation and management. Further research to quantify

which barriers are most prevalent and most decisive, and which solutions will most increase the effectiveness of island ecosystem management would be greatly beneficial. By defining these barriers through systematic research, they can be brought forward for discussion between practitioners across management levels. Finding meaningful solutions relies on us being honest, realistic and self-critical of our work, but implementing these solutions will require national level investment. Only by doing so can we increase the effectiveness of our management efforts across local and national levels and maximise our chances of actually achieving global biodiversity targets.

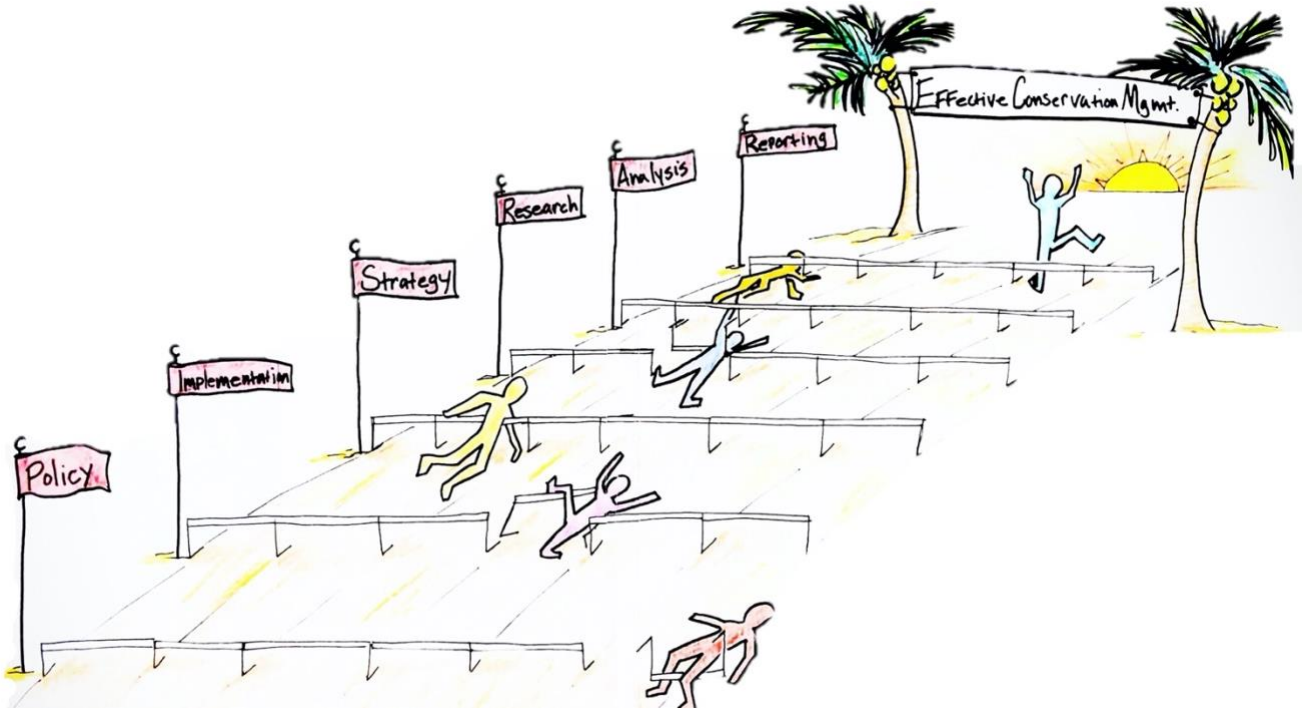


Figure 2.5: A practitioner's hurdle race to achieving effective conservation management

2.6 Chapter Acknowledgements

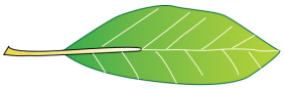
Our sincere thanks to all those practitioners who took their precious time to participate in the interviews, most of whom wished to remain anonymous. Thanks specifically to Vikash Tatayah from the Mauritian Wildlife Foundation and to Steve Goodman from the Field Museum of Natural History for their time. Also, thanks to Erin Bullen for producing Figure 5.

Author Contributions

April J. Burt and Nancy Bunbury: Conceived the study. April J. Burt and Nancy Bunbury: Developed the methodology. April J. Burt: Conducted the interviews, analyzed the data under guidance of Ana Nuno, prepared the figures and tables and wrote the first draft of the manuscript. April J. Burt, Nancy Bunbury, and Ana Nuno: Contributed substantially to refining further drafts of the manuscript.

CHAPTER 3:

A Global Assessment of the Barriers Influencing the Effectiveness of Island Ecosystem Management



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"Those who contemplate the beauty of the earth find reserves of strength that will endure as long as life lasts. There is something infinitely healing in the repeated refrains of nature -- the assurance that dawn comes after night, and spring after winter."

— Rachel Carson, Silent Spring

3.1 Introduction

Collectively, the world's islands host around 20% of global biodiversity and yet have suffered 61% of recent extinctions [108]. Today, islands vary greatly in their developmental and geopolitical status, which has implications for their vulnerability and response to the direct drivers and indirect drivers of biodiversity loss (IPBES Chapter 2.1, Balvanera et al., 2019). This is especially true for Small Island Developing States (SIDS), which are disproportionately impacted by environmental pressures, yet have less resources or capacity for managing them [16,17,156]. Regardless of these differences, conservation and sustainable management of island ecosystems is a priority for island nations, whose populations rely on the services they provide [128]. As such, practitioners worldwide work to manage island ecosystems through active conservation and sustainable management. Despite many successes, these efforts are hindered by a raft of barriers operating from site/project level up to national level, impeding practitioners from achieving conservation and management goals [157].

So far national and global biodiversity targets have been missed by a wide margin and these failures have been attributed in part to inadequate national policy responses [105,106]. Many factors are likely to be contributing to failures and therefore understanding what barriers are perceived to be impacting national level management effectiveness is crucial to informing the effective design and implementation of the post-2020 Global Biodiversity Framework (GBF; Xu et al., 2021). The effectiveness of management at site level may be minor in the outcome of global targets, but cumulatively, site level actions, such as species protection, setting fishery quotas, habitat restoration and invasive alien species removal, if effective, ought to play a role in achieving *national* targets. However, this is rarely the case, with site-level management lacking the basic requirements to operate effectively (Leverington et al. 2010).

To identify which barriers practitioners face in achieving effective management, various interviews and surveys of frontline staff have been conducted (e.g., Bottrill, Hockings, & Possingham, 2011; Burt et al., 2021; Forster, Lake, Watkinson, & Gill, 2011; Sanders, Miller, Bhagwat, & Rogers, 2019). The practitioners in these studies described barriers operating at different levels of management, but with some clear and consistent themes. At site/project level these include skill gaps in data management and analysis, poor monitoring or research design and inadequate staffing or roles to achieve objectives [15,50,157]. At organisation level they include staffing and resource limitations and limited collaboration and communication between practitioners and organisations/institutions [15,120,157]. More broadly, at the national level, practitioners have described barriers caused by poor education, governance issues, institutional capacity and limited coordination

of efforts [15,135,157,158]. Whilst these surveys have helped to define what barriers exist and highlight the need to bridge them, their focus on single geographic regions hinders our ability to identify patterns and draw recommendations at wider scales. In addition, understanding not only which barriers are faced (as most previous studies focused on) but also their prevalence can help us set priorities and inform the development of collaborative efforts towards addressing them [159].

Furthermore, knowing which barriers are most commonly experienced does not necessarily reveal which ones most strongly shape a practitioner's overall view of management effectiveness. For example, if all practitioners in a survey identify insufficient funding as a major barrier to effective management, but some still perceive management to be effective in spite of this, we would have to look elsewhere to explain variation in their overall views of management effectiveness. Limited attention has been given, however, to understanding the relative importance of specific barriers on management effectiveness. Understanding which barriers play a greater role, and identifying which solutions practitioners believe could most effectively bridge these, should provide much-needed insights into the potential levers for improving management effectiveness.

In this study we developed an online survey based on barriers previously described by island ecosystem management practitioners from island nations in the Western Indian Ocean [157]. The survey was circulated through international networks of practitioners and engaged people working in island ecosystem management. The survey was designed to address three key questions: (1) what are the most common barriers that island practitioners

experience in working to meet island ecosystem management and conservation objectives?; (2) how does the prevalence of particular barriers shape practitioner views of national and organisation level management effectiveness of island ecosystems?; and (3) which of the proposed solutions to bridging these barriers have the highest support from practitioners? By identifying the most important barriers that currently impede effective island conservation and management, we can streamline investment to focus on cost-efficient interventions that better reflect realities on the ground and the need to address barriers under substantial time and budget constraints [107,109,160].

3.2 Methods

Data Collection

Survey approach and design

Survey approach and design

This study is informed by a preceding series of exploratory semi-structured interviews with 32 conservation and management practitioners from island nations in the Western Indian Ocean [157]. This was done as a scoping exercise to identify the type of day-to-day barriers that practitioners face in their efforts to meet conservation and management objectives. The interviews identified 33 barriers under 12 overarching themes across national, organisation and project/site level (see Table S1 for details). In this study, we used these findings to inform the structure and content of a more detailed questionnaire to quantify the prevalence of these barriers at broader

scales and explore their overall impact on perceptions of management effectiveness.

The survey (English version in supplementary material 1) consisted of 35 questions divided into 12 sections (Fig. S1). Sections 1–4 aimed to gather information about the practitioners themselves, their main management objectives and the type and severity of threats they encounter at the site(s) they work with. Sections 5–7 aimed to quantify the barriers practitioners are facing at national, organisation and project/site level based on barriers identified during scoping interviews. In these sections the term ‘low staff capacity’ refers to specific staff skill-sets rather than to insufficient staff numbers, which is listed as a separate barrier in this section. Sections 8–10 were included due to their frequent mentions in the scoping interviews, with sections 8 and 9 focused more intently on barriers to collaboration and data management and analysis, and section 10 aiming to quantify how many practitioners had access to scientific literature and whether there are barriers to their engagement with scientific evidence. In addition, section 11 aimed to quantify which solutions and skills would most enhance effective management, with these also being based on suggestions by practitioners in scoping interviews [157]. Lastly, section 12 aimed to quantify practitioners’ overall perception of management effectiveness. Not all sections and questions were relevant to all practitioners; for example, if a practitioner had mostly positive experiences of collaborations, they would skip the barriers to collaboration section, likewise if a practitioner was not involved in data management, they would skip the data management and analysis section. A variety of question types were used, including single-answer, multiple-choice, and open-ended questions, but the majority of questions could be

answered using grid-like responses and Likert-type scales. These allow responses from a range of ordinal options to achieve a semi-quantitative assessment of the issues [161].

Survey administration

The online survey was piloted to 30 practitioners in March 2020 (these were not included in the final data set), revised, and launched on 30th July 2020, and closed on 31st Jan 2021. On average, the survey duration was around 15 minutes per participant.

We ran the survey in eight languages (English, French, Spanish, Portuguese, Arabic, Indonesian (Bahasa), Japanese and Malaysian), chosen to maximise participation throughout the global island practitioner community. To minimise bias towards the researchers' personal networks we circulated the questionnaire in four stages: (1) the survey was seeded to global networks of island conservation and management practitioners via mailing lists. These included the IUCN Island Ecosystem Specialist Group, Global Island Partnership, UNESCO Marine World Heritage site managers' network and Island Biology Society; (2) once the survey had circulated through global networks, we targeted more specific, niche groups, including Coral-list, Aliens-list, Flora & Fauna International, Birdlife International and the Royal Society for the Protection of Birds; (3) we sent emails to colleagues and personal networks, specifically targeting regions that had a low number of early respondents (e.g. New Zealand); and finally (4) we posted the survey on social media, tagging additional network groups, some of whom then shared the post. Throughout each stage we employed respondent-driven

sampling; this involves requesting those directly contacted to recruit additional respondents by sharing the survey within their networks of island ecosystem conservation and management practitioners. In total there were 360 respondents: 80 responses in stage 1; 110 in stage two; 130 in stage 3; and 40 in stage 4.

This study was approved by the University of Oxford Social Sciences and Humanities Interdivisional Research Ethics Committee (Ref No: R62246/RE002). The survey was administered only after obtaining the consent of each participant and asking them to confirm they were over 18 years old. Participants were informed about the purpose of the project, the voluntary nature of their participation, the right to terminate the questionnaire at any time, and that any data disclosed in reports, scientific publications or presentations would be completely anonymous. Participants were also asked to respond based on their experience over the last three years and focusing on the organisation(s) or site(s) they have direct experience with. This was done to ensure our respondents were still active practitioners, clarify the timescale they had in mind when answering questions and ensure they had specific site(s) or project(s) in mind from which they were drawing their direct experience.

Data analysis

Study participants

The non-English surveys were back-translated to English using google translate. Data from Sections 1 and 2 of the survey were compiled to summarise descriptive information about the study participants, their role,

and the organisation(s) they work for. To assess the coverage of our circulation efforts we compared respondents' country of origin and country in which they have most experience of island ecosystem management, creating a new variable: national/non-national. This is important both for ensuring our survey reached local practitioners and because we felt there could be differences in perceptions between these two respondent groups. We also used 'country of work' to create two new variables which grouped respondents by region and by their socio-economic and political characteristics (for brevity we therefore used the categorisation 'Global North' or 'Global South' (see Table S2 for details). We included these variables because they may be important when considering respondent perceptions of island ecosystem management effectiveness, given the likely differences in resource and capacity levels between regions of differing economic status.

Descriptive results

To summarise the survey data, the responses were collated to quantify the number of respondents for each statement response (Supplementary material S3.1). These were then condensed further to simplify interpretation in the main results, for example respondent responses were grouped into two categories; the responses 'always', 'often' and sometimes were grouped and the responses 'rarely' and 'never' were grouped. Therefore, the frequency that a barrier was identified/experienced across respondents was assessed – rather than its importance as a barrier *per se.* Additionally, for most questions the respondents were given the option to add additional comments and these comments have been used to illustrate points made in the discussion. In the solutions section, additional written responses were

grouped based on the content theme (e.g. funding or capacity) and the frequency each theme was mentioned was tallied (Table 1).

Investigating which barriers are predictors of practitioner perceptions of island ecosystem management effectiveness

In the final section of the survey we asked respondents to rate the effectiveness of management at (a) national level and (b) within the organisation they work with/for. We particularly wished to explore these based in part on the statement in the CBD report that “biodiversity targets have been missed due to inadequate national policy responses”. We have obtained a unique set of data from practitioners and wished to use this to explore what might be the factors influencing the perception of management effectiveness. Especially as perceptions are considered an indispensable form of evidence on how to improve conservation success[162].

The response variables (overall perception of management effectiveness at national and organisation level) were ordered; e.g. respondents were asked to register a rating for management effectiveness (very poor; poor; fair; good; excellent). While it is reasonable to assume that all participants will view the rank order of these potential answers in the same way, we can’t make assumptions about the distance between categories or their distribution. We thus used ordinal logistic regressions to explore relationships between the response variables and all potential explanatory variables.

We compiled a list of potential explanatory variables (see Table S3.1 for justification of inclusion) created from the survey responses which were

considered to be potentially important factors in forming a practitioner's view on management effectiveness. For example, are practitioners who have experienced more governance issues more likely to perceive national management to be less effective.

We used the MuMIn package v.1.42.1 [163] to fit ordinal regression models with all the explanatory variables included for each response variable (the global models). We used the MuMIn function 'dredge' to generate a model selection table of models with combinations (subsets) of explanatory variables from the global models. We then used the 'subset' function to filter out models with Akaike's information criterion ≥4 (AIC ≥4 indicating considerably less support for the model [164]) leaving the most parsimonious models among all possible combinations. We then obtained the model average across the remaining candidate models using the model.avg function. Statistical analyses were conducted in R version 4.0.2 [165].

Treatment of categorical variables

Categorical variables (see table S3.1) were re-coded into a set of binary variables within the R MuMIn package v.1.42.1 [163]. Therefore, categorical variables with more than two levels were re-coded so each level was compared to a single reference level. For example, for the categorical variable 'Region' there were five levels (Africa, Asia/Pacific, Europe, North America, South/latin America) and the reference level was Africa, so all other levels were compared to this reference level.

Condensing Likert statements

Some Likert statements measured the same latent variable, for example, there were eight statements which measured a practitioner's perception of monitoring programme issues (e.g. lack of monitoring aims, lack of protocols). To create one variable which summarised the extent to which a practitioner had experienced monitoring programme issues we condensed these variables. To do this we converted Likert responses into numerical scale (e.g. Always=5, Often=4, Sometimes=3, Rarely=2, Never=1), and to verify the internal consistency across the statements we used Cronbach's Alpha (Psy package V1.1; Tavakol & Dennick, 2011). A high Cronbach's alpha score (>0.7) affirms a correlation in the responses across these statements and therefore they can be averaged to form one variable; we therefore proceeded with condensing variables if Cronbach's Alpha was >0.7.

3.3 Results

The survey respondents, sites and perceived threats

A total of 360 respondents completed the online survey (41 in the non-English versions). Not all participants answered all sections, so sample size varies per question, and is reported throughout. Respondents identified 77 different countries as their main country of work (Fig. 1) of 107 countries which are, or have, islands. More than half (57%) of the respondents were nationals of that country and 61% were working in countries categorised as belonging to the Global South. The top ten countries of response were Seychelles (43), United States (40), Mauritius (19), Australia (17), New

Zealand (17), Portugal (13), United Kingdom (13), Saint Helena, Ascension and Tristan da Cunha (10), Spain (10) and Indonesia (8). Regional coverage ranged between 44 and 96 respondents per region, except for the Middle East (one respondent) and other Arab states (four respondents – see supplementary material 3). We also had relatively equal coverage across the different roles within island ecosystem management, with the highest number of respondents identifying their role as a 'science officer/coordinator' (33%), followed by 'researcher/academic' (26%) and 'manager/CEO' (18%; Fig. S2). Respondent experience varied across role type (Fig. S2); overall 46% of respondents had >10 years of experience.

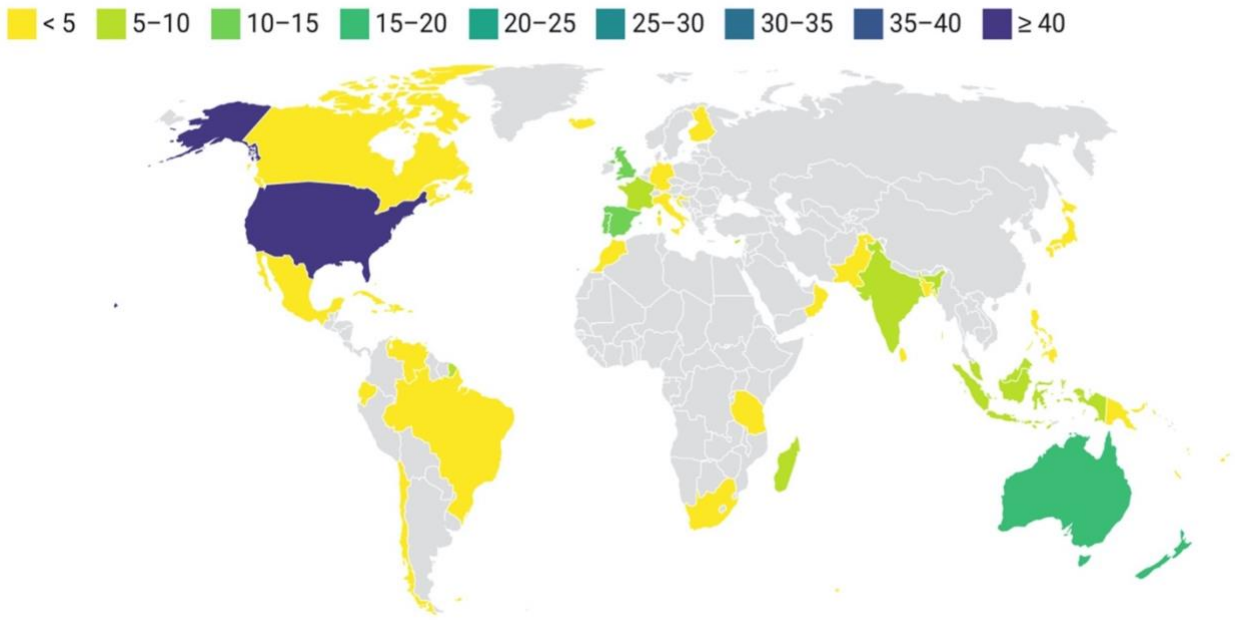


Figure 3.1: Online survey coverage of respondent's country of work in island ecosystem management and conservation, based on 360 practitioners. NB: Countries with high number of respondents but not seen on the map due to their size include Seychelles and Mauritius, for a full list of countries and the number of respondents see supplementary data file 1.

Respondents mostly worked with more than one type of site or area (70%; Fig. S5) but overall, the main site type that respondents worked with was protected areas (82%) and national parks (41%). Most respondents worked with multiple sites that varied in remoteness (46%), with 14% of respondents working in sites >100 km from mainland areas (Fig. S6). The most common management objectives for the organisation(s) that respondents worked with were: monitoring species and ecosystems (68%; Fig. S3) and habitat restoration (65%), followed by research to inform management (58%) and site protection (55%; an interesting result considering 82% of practitioners worked with protected areas). Slightly less than half (46%) of respondents worked with multiple types of organisations, while 25% worked solely with non-governmental organisations and 20% worked solely with government-led authorities (Fig. S4).

Invasive alien species were perceived to be the biggest threat to the site(s) (Fig. S7) with 56% of respondents ranking this threat as severe, followed by coral bleaching and mortality (36% of the 235 respondents whose sites included marine ecosystems, although important to note that not all these islands will have coral reef ecosystems), native habitat destruction for development (34%), plastic pollution (32%) and tourist impacts (25%). Threats perceived to have the most impact on management resources were invasive alien species (59%), habitat destruction (40%), illegal activities (28%), tourist impacts (27%), plastic pollution (23%) and coral bleaching and mortality (19% of the 235 respondents whose sites included marine ecosystems; Fig. S8).

Barriers faced to fulfilment of management objectives.

The most frequently experienced barrier overall was ‘low staff capacity’ (85% experienced this either always, often or sometimes; Fig. 2a and Figs. S9–S12) with 82% of respondents having to recruit volunteers to fill skill gaps within the organisation/s they work for. Following this were ‘lack of data analysis capacity’ and ‘difficulties with turning data into information that can be used for management’ (74% experienced these always, often or sometimes), and ‘lack of time to analyse data’ (72%). In addition, 70% of respondents experienced a ‘lack of research strategy’ and 61% experienced a ‘lack of management objectives’. At national level the most common barriers were ‘poor enforcement of conservation law’ (64%) and ‘poor conservation policy implementation’ (61%).

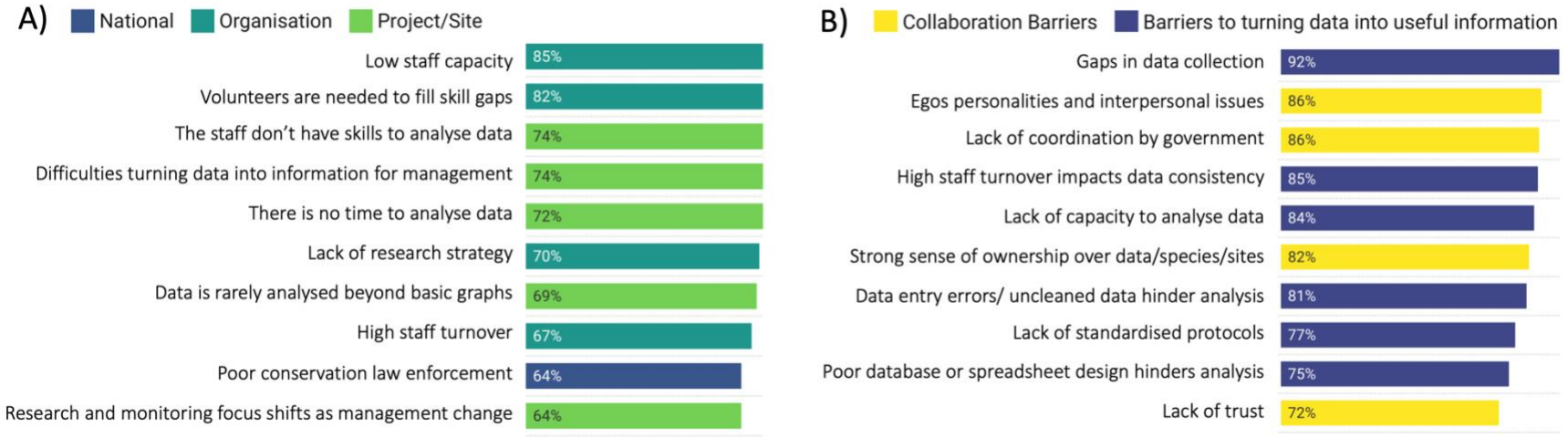


Figure 3.2: The top ten most frequently experienced barriers to: (A) the fulfilment of management, conservation, or research objectives at national level (respondents were asked to tick all that apply), organisation level and project or site level (percentage of respondents whose likert responses were 'Always' + 'Often' + 'Sometimes'; Based on 360 respondents) and (B) to collaboration (Likert responses 'strongly agree' + 'agree') and barriers to turning data into useful information for management (Likert responses 'Always' + 'Sometimes'). For the full results see Figures S9–S12.

Collaboration outcomes and barriers

When asked how frequently collaborations had positive outcomes, 55% of respondents felt that local collaborations often had positive outcomes and 50% felt that international collaborations often had positive outcomes (Fig. S13). Respondents were also asked if collaborative reports or data sharing was rare, to which 59% of respondents agreed or strongly agreed (Fig. S14).

The 139 respondents who felt that local collaborations only sometimes or rarely had positive outcomes were then asked to what extent they agreed with the eleven potential barriers to collaboration that we listed (Fig. 2b and Fig. S15). The most widely perceived barriers to local collaboration were ‘egos, personalities and interpersonal Issues’ and ‘lack of coordination by government’ (86% of respondents either agreed or strongly agreed with both), followed by ‘strong sense of ownership over data, species, or sites’ (82%) and ‘lack of trust’ (72%). Of note, over half of respondents (55%) had previously had ‘bad experiences of collaboration’ (Fig. 2b).

Data analysis barriers

A total of 341 respondents (97%) were directly involved in data management or analysis. Of the 12 potential barriers to data analysis and management we listed in the survey (Fig. 2b and Fig. S16), 42% of respondents had experienced ten or more of these at least some of the time. The most frequently experienced barriers were ‘gaps in data collection’ (92%); ‘high staff turnover impacting data consistency’ (85%); and ‘lack of capacity to analyse data’ (84%). Over half (>53%) of practitioners had experienced the remaining listed barriers at least some of the time, with the exception of ‘staff have been known to falsify data’, which 24% of respondents had

encountered sometimes or always (see Figs. S16b–c for breakdown by country and role).

Access to scientific literature

Just under half (46%) of respondents agreed or strongly agreed there was a lack of in-country access to scientific research articles (Fig. S17) and 61% agreed that there was not enough time to read research articles, with 37% agreeing that scientific articles are difficult to understand.

Overall perspective of island ecosystem management effectiveness

When asked at which level (national, organisation or project/site) respondents perceived the main barriers to effective conservation and management of island ecosystems occurred, 62% of respondents identified national, 25% organisation and 13% project/site level (Fig. S18 – S19).

When asked to rate the current level of management effectiveness both nationally and within their organisation(s), 51% of respondents perceived that management effectiveness within their organisation was good or excellent; 32% considered it fair; and 14% perceived it as poor or very poor (Fig. S20a). Those who perceived management to be very poor were mainly within government or consultants (Fig. S20b). At national level, 14% perceived management effectiveness to be good or excellent, 39% perceived it to be fair and 42% of respondents perceived it to be poor or very poor.

Predictors of perceptions of management effectiveness

After modelling respondent's perception of management effectiveness at national level against a series of potential explanatory variables (Table S2), the most important predictors were their experience or perception of 'governance issues', 'collaboration' and the presence/absence of a national 'research and management strategy' (Fig. 3a). In addition, whether they are from countries categorised as Global South or Global North, the region they are from, and their main management focus (marine or terrestrial, or both) were important in shaping their perception of national management effectiveness (Fig. 3a, Table S3). Perception of national management effectiveness was more positive in the global north and where the management focus was mainly on terrestrial ecosystems (Fig. 3b).

When considering the perspective of respondents on overall management effectiveness within the organisation(s) they work for/with, the most important factors were the presence/absence of a 'research and management strategy' within the organisation and their experience of 'issues with monitoring programmes', 'staffing issues' and 'collaboration' (Fig. 3a; Table S4). Their perception of organisational management effectiveness was less positive where practitioners perceived more issues with monitoring programmes, a lack of research and management strategy and if they experienced more staffing issues (Fig. 3b).

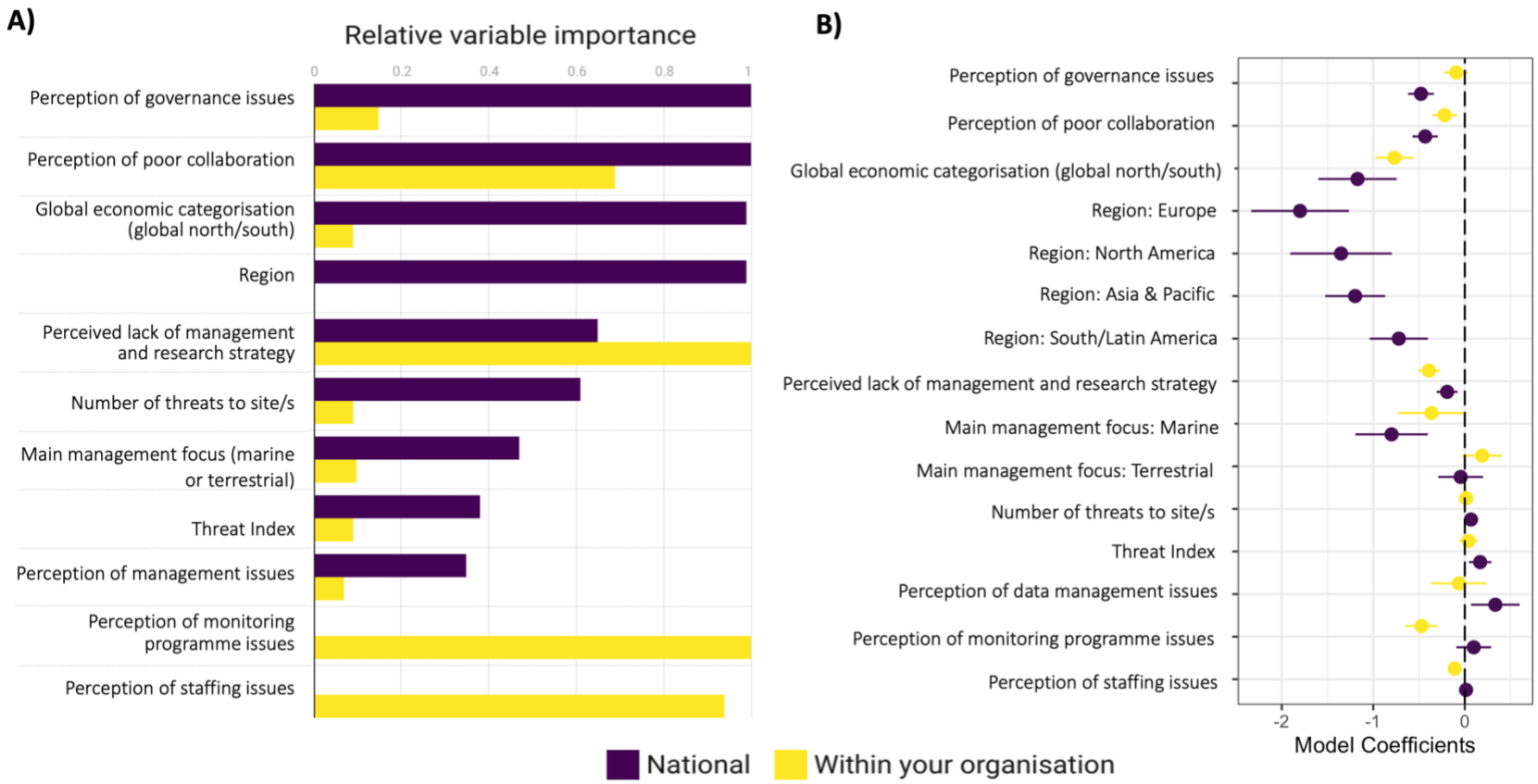


Figure 3.3: *Model outputs obtained by averaging overall models in the top model set from the averaged ordered logistic regressions fitted to respondent's perception of management effectiveness (very good, good, fair, poor, very poor) both nationally and within their organisation. (A) Relative variable importance of predictor variables (expressed as the sum of the Akaike weights for the variables included in the averaged models), and (B) Model parameter unconditional estimates; If the coefficient >0, then it results in an improved perception of management effectiveness (if <0, more negative perception). If the bars*

overlap zero, then you cannot confidently assess whether the variable dictates a more positive or negative perception but the variable itself might still be important. Note: Categorical variables were recoded into a set of binary variables within the R MuMIn package v.1.42.1 [163]*. For data see tables S3–4.*

Support for potential solutions and training needs

Overall, 276 respondents (77%) completed the solutions section of the online survey. Of the 19 listed potential solutions, the greatest support from respondents was for ‘longer funding cycles’ and ‘additional staff’ (90%; Figs. 4a, S21–S23), followed by ‘better training opportunities for staff’ (88%) and ‘incentives to keep high-capacity staff long-term’ (87%). The skills perceived to be most lacking by practitioners but that are needed to achieve management objectives were data analysis/statistics (61%), data management and database design (51%), leadership and supervision skills (50%), spatial analysis and GIS (48%) and critical thinking (48%; Figs. 4b, S24).

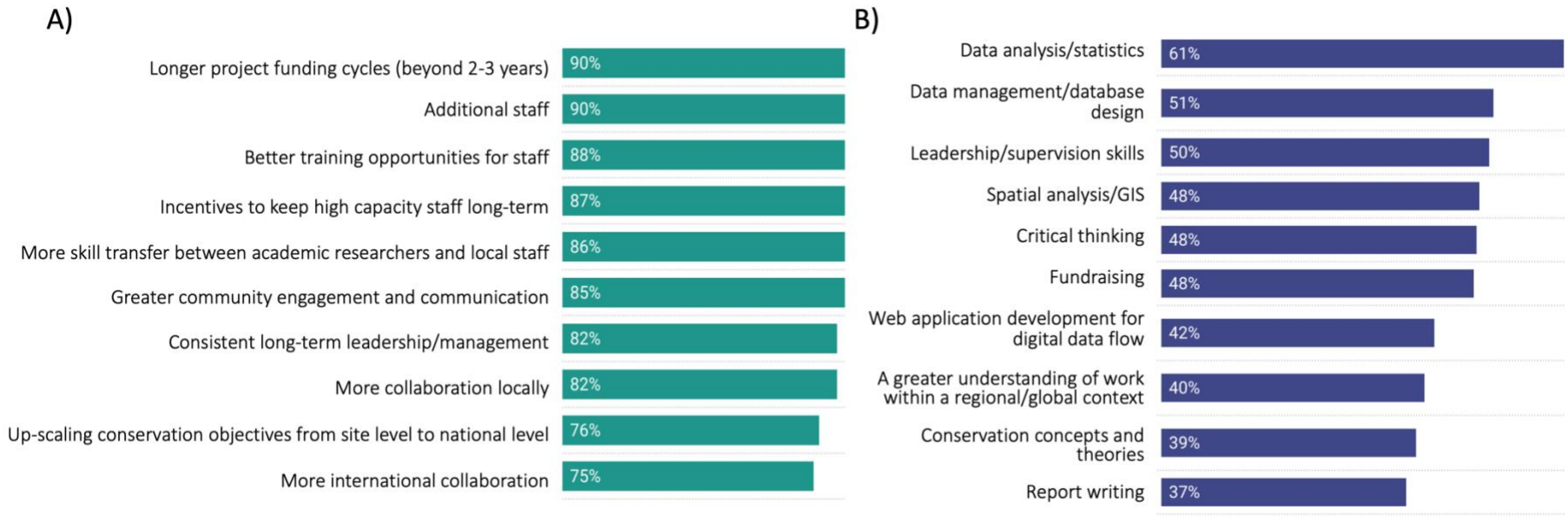


Figure 3.4: The top ten: (A) potential solutions listed that respondents felt would most improve management effectiveness of the site/s they work with (percentage of respondents whose likert responses were: 'greatly improve' + 'Moderately improve'). Based on a sub-sample of 276 respondents and; (B) skills and training needs that respondents felt would assist in achieving management objectives. For the full results see Figures S21–24.

Additional suggestions for improving management

Respondents were given the opportunity to elaborate on or add thoughts around potential solutions to improve effective management. The most commonly discussed solutions were the need for additional funding, greater diversification of funding streams and more staff (Table 1). A new idea not listed in the survey but raised by practitioners included the need for greater gender diversity and equality.

Table 3.2: Selected additional suggestions or comments from 52 respondents under the solutions section, ranked by the number of times they arose. New ideas not listed in the survey are in bold.

Solution	# Practitioners	Example quote(s)
Additional/diversification of funding	22	*"ANY project funding, never mind 'beyond 2-3 years'!"* *"All of the above are key to carrying out effective management, developing a diverse revenue funding strategy would also help maintain consistency in these areas."*
More staff/staff consistency	12	*"Hiring of appropriate and most qualified staff for specific positions."*
Longer funding cycles	4	*"Further, all grants available are short term (</=3 years) and do not address long-term conservation issues (tree conservation, ecosystem restoration)."*
Higher education standards	4	*"Improvement in university level education standards and training variety to produce AND RETAIN high calibre LOCAL graduates."*
Greater political will and conservation prioritisation	2	*"Political prioritization of conservation" and "National level support for conservation research and actions feels low, despite quite dedicated local staff and researchers."*
More community involvement	2	*"More community-based management, training local communities, and provide funding for capacity building & employment"*
Management scrutiny	2	*"Remove incompetent managers and directors. Grants and projects are written with vague objectives and deliverables"*
Improved legislation and policy	2	*"Improved legislation and policy. Climate change policies that are effective and beneficial to conservation."*

Greater gender diversity and equality	1	*“Greater gender diversity and safer places for females”*
Training & mechanisms to deal with sexual harassment	1	*“1. Creating mechanisms to report sexual harassment in the field to the organization funding the research, and 2. training on sexual harassment awareness for all member of a research team going into the field, as well as 3. training to improve awareness of the impact of power dynamics for leaders going into the field with research teams”*
Greater mentorship opportunities	1	*“Learning on the job with good mentors helps with critical thinking and decision making”*
Enforcement	1	*“A strong commitment to enforce management plans”*

3.4 Discussion

We have found that the three barriers most commonly experienced by island ecosystem management practitioners are: insufficient capacity of staff; difficulties turning data into useful information for management (mostly due to lack of data analysis capacity and time constraints); and lack of a research strategy. In addition, a raft of barriers to collaboration hinders management connectivity between relevant actors. Importantly, the majority of practitioners had experienced most of the barriers listed in the survey at least sometimes. Our survey also reveals that these more common barriers are not the most important in forming practitioners' perceptions about management effectiveness. Instead, their opinion of national level management effectiveness was mostly associated with their perception of governance issues, the presence/absence of research and management strategies and their experience of collaboration outcomes. The latter two factors were also important in shaping their perception of management effectiveness within the organisation(s) they worked with, along with their experience of staffing and monitoring programme issues. These findings paint a bleak picture; building on from previous studies which defined barriers experienced by practitioners within specific regions (e.g. (Burt et al., 2021; Forster et al., 2011; Sanders et al., 2019), our results clearly show us that the majority of people undertaking frontline conservation of island ecosystems worldwide struggle to reach their potential as a result of barriers operating at multiple levels.

The aim of this survey was to specifically quantify the day-to-day barriers experienced by practitioners. We therefore did not include survey sections

which relate to those less measurable underlying causes of barriers, which are outlined in the IBPES report (Balvanera et al., 2019), and broadly summarised as the factors behind the human choices that affect nature (e.g. governance, demographic, technological and economic). However, the respondents themselves highlighted them extensively (and passionately) within the additional comments sections throughout the survey, in particular the role that issues such as inequality, corruption, conflicting priorities, illegal activities, extreme poverty and neo-colonial pressures play in their ability to work effectively. Due to the differences in vulnerabilities to such issues, it is not surprising that we found that those respondents working in island ecosystem management in Global South countries were less likely to perceive national level management to be effective. With these underlying causes in mind, but with a desire to highlight more immediate and local level potential interventions, we discuss the main barrier themes and what can reasonably be done to bridge them, given appropriate resources.

Governance

Practitioners overwhelmingly felt that the main barriers to effective management were at national level. As the majority of the respondents were working outside of government (only 13 within) this perception may arguably represent a bias or general shifting of blame. However, whilst our survey represents only the perceptions of practitioners, which are open to bias, practitioner perceptions are recognised as an indispensable form of evidence on how to improve conservation success (Bennett, 2016). We therefore argue that these perceptions are a valid and clear insight into where island practitioners feel the problems lie. Additionally, our analysis did not find respondent role (i.e. whether a respondent worked within

government or NGO etc) to be an important variable in determining respondent's perception of management effectiveness. We acknowledge that with a greater proportion of respondents working within government this result may have been different.

Within the national context, the most commonly cited obstacle was 'poor conservation policy implementation and law enforcement', with over 60% of practitioners experiencing this as a barrier to their work. This finding corroborates the idea that Aichi targets have been missed due to inadequate national policy responses (Xu et al., 2021) ; i.e. that National Biodiversity Strategies and Action Plans (NBSAPs) are poorly implemented or implementation is not sufficiently translated into actions and results visible to practitioners. To integrate the Aichi targets, governments must translate them into appropriate national targets, develop a strategy (i.e. the NBSAPs) to meet them, communicate this strategy and coordinate actions to meeting strategy objectives via collaboration across departments and sectors. Yet, we have found that numerous barriers impede this process; from lack of nationally coordinated research and conservation objectives to low staff capacity and unsuccessful local and international collaborations.

Going forward, these implementation issues need to be addressed to meet future targets (Phang, 2020). How this can best be done is an urgent topic and requires a systems change approach (Chan et al., 2020; Obura et al., 2021; Phang, Failler, & Bridgewater, 2020; Rice, Sowman, & Bavinck, 2020), but we argue that a first step should be a structured consultation with those tasked with developing and implementing NBSAPs to understand exactly what is lacking/needed on a case-by-case basis coupled with targeted

international funding to assist island nations in strengthening this process. Stronger national coordination of efforts, once achieved, will have a positive knock-on effect to many of the barriers to collaboration that practitioners have experienced.

Collaboration

Collaboration is the glue that strengthens and pulls together individual efforts required to achieve national biodiversity targets. Whether between or across government, the private sector, NGO's or academic institutions, the aim of collaborations is to achieve common objectives, solve problems, share resources and expertise, exchange knowledge and utilise skill sets. This requires strong central coordination to bring a variety of voices to the table and ensure information flows freely. Our results show that half of our respondents experienced a lack of national research coordination and that one of the major barriers to collaboration is lack of coordination by governments. Often practitioners/organisations are working to manage one or more sites – in this study over half of practitioners work with one organisation to manage specific areas – and within a country there could be hundreds of practitioners working to achieve similar objectives (e.g., 67% of practitioners in our survey shared the management objective of restoring native habitat). Without working groups that include government officials and practitioners, efforts are isolated and may not align or translate into national objectives.

Ideally, governments would create platforms for each target sector (e.g. fisheries, coral reefs, native forests etc) bringing all relevant practitioners together, to ensure individual management objectives link to national

objectives. This also requires that progress towards achieving these targets is regularly assessed and reported, not only for the sake of fulfilling national obligations under various conventions but to develop a meaningful adaptive management cycle that informs, ensures feedback and requires action from government and practitioners. This should also include the use of programmes and user-friendly formats that are specifically designed to measure the success/failure of actions. In addition, such platforms would create an environment to stimulate knowledge and skill exchange and create a sense of joint endeavour, where the goals are clear and where the contribution of each actor is transparent and measurable. Such forums could also identify gaps in knowledge and action, which could highlight priority research and action areas to be promoted via regional funding bodies. How to establish this 'ideal' vision, however, is less clear, especially if governments with already stretched resources and human capacity, have little attention to direct to coordinating these efforts. In some instances, NGOs have stepped in to facilitate these forums and this has led to more collaboration and streamlining of efforts (Burt et al., 2021). With this in mind we suggest that funders should consider including the creation of forums for open data and knowledge sharing under their project calls. This suggestion goes hand-in-hand with the need for longer project funding cycles, which was the solution with the highest support from respondents.

Of other barriers that prevent effective collaboration, the most common in a local context was egos and interpersonal issues (84%). This issue has had very little coverage and yet appears to play a major part in preventing effective local collaboration. Our results suggest that our inability to put aside egos and overcome interpersonal issues hinders conservation efforts

worldwide. The scoping interviews with practitioners highlighted the kind of effects that unrestrained egos may create, such as the blocking of data-sharing agreements and unwillingness to support or participate in knowledge or skill exchange activities, but did not suggest potential solutions (Burt et al., 2021). Overall, solutions to this barrier are less tangible than for others but, as with all problem-solving, the first step is to define the problem and raise awareness of the issue. Doing so will potentially promote a culture where such issues are less accepted and more readily 'called out' and this could assist practitioners who feel that they have: "no power to prevent/mitigate bad behaviour, especially by senior/permanent staff".

Human Capacity

Capacity issues are a well-documented barrier to effective management (Gill et al., 2017; Gustafsson, Díaz-Reviriego, & Turnhout, 2020; Keppel, Morrison, Meyer, & Boehmer, 2014; Lee & Jetz, 2008), but the extent to which they hinder progress and the specific type of capacity lacking has been unclear. In our survey, low staff capacity was the most frequently experienced barrier (85%) of those listed (except sections specific to barriers to 'collaboration' and 'turning data into useful information'). Specifically, capacity limitations in data analysis were considered a major barrier to turning data into useful information for management. As such, when practitioners were asked to choose the skills missing from their organisation that would greatly enhance their management effectiveness, the most commonly listed were data analysis, data management and leadership skills. The former two skills are clearly vital for successful evidenced-based conservation management, while the latter is essential for much of the coordination and communication needed to improve management, as this

quote from one respondent makes clear: “The main factor constraining effective management in organisations in ca. 15 countries / OTs I have worked with is leadership capacity (effectiveness of boards, quality of leadership, suitability of directors). Everything else is influenced by this and intervention, to be effective, must be at the organisational / constitutional management level to facilitate change.”

The proposed solutions listed in the survey were based upon suggestions by practitioners in the scoping interviews (Burt et al., 2021) and it is not surprising that the solutions with the most support from practitioners were those aimed at enhancing human capacity. These findings underline the need to invest in developing the skills that will most enhance management effectiveness. Such skills may not necessarily be gained through current academic training options, even within comparatively well-resourced nations, but even less so in SIDS (132 of our respondents were based in SIDS). According to this SIDS practitioner: “What would most benefit our work and goals is a higher level of education and training of local staff. The available in-country training is not sufficient for the level required for effective and independent conservation work on data collection, analysis and reporting. Organisations depend on foreign nationals to do this type of work and it is very difficult to train local staff without this basic level of education and understanding”.

Clearly building the right type of capacity for improving effective management of island ecosystems is complex and requires a combination of technical and soft skills, delivered in a way that ensures uptake, and is available to all in perpetuity. The mismatch between the skills that are taught

to students and the skills required in biodiversity conservation and management positions (Blickley et al., 2013; Bonine, Reid, & Dalzen, 2003; Lucas, Gora, & Alonso, 2017; Muir & Schwartz, 2009) has led to the development of a handful of conservation leadership courses that aim to cover both technical and soft-skills (e.g. Sandbrook, Nelson, Bolderson, & Leader-Williams, 2021). While these courses have a very positive impact, their overall effect is confined due to their operational scale or attendance costs (in addition to their location in only a few countries). Our survey clearly shows a consensus among island ecosystem management practitioners as to which skills would most enhance their efforts. Investment into developing specific modules which incorporate such skills into tertiary education – or as stand-alone courses (online or in-person) – could greatly enhance biodiversity management effectiveness, especially on islands where staff struggle to afford and access specific courses. Implementing this 'solution' admittedly requires funds to be made available. However, our aim is to bring attention to these issues by quantifying them and using these results to demonstrate that meeting objectives at local and ultimately national scales will require more equitable funding to those places at the frontline of biodiversity loss. To enable more transformative change will require long-term financial support to strengthen national capacity, both human and institutional, not simply through funding more projects for conservation actions or research. This inherent inequity is summarised in this comment from a SIDS practitioner: "We do not have any universities and so all tertiary and higher-level education must be carried out overseas…this often results in brain-drain as employment opportunities are better, and better-compensated, in this field elsewhere".

The requirement to ‘build capacity’ is now common in project funding calls, but the resulting efforts may not be greatly effective in developing the capacity that is required, as one respondent explained: “Skill transfer between academic researchers and staff is commonly requested but is not effective in the long-term as it provides only very specific training, often only an hour or two, or a single workshop, and while it can be a useful skill, it doesn't address the major capacity gaps”. To ensure that capacity building efforts are meaningful and not just a box-ticking exercise (Harden-Davies et al., 2022), we suggest that, from the outset, projects funders or institutions that collaborate with local organisations ask practitioners how they can best support the bridging of capacity gaps, for example by budgeting for local masters/PhD students within the project.

Turning data into useful information for management

Alongside capacity issues, the barriers to turning data into useful information for management were highly prevalent; for example, 61% of practitioners were unclear about why they were collecting certain data (always or sometimes), with 67% reporting either unclear monitoring aims or that monitoring programmes do not link clearly with management objectives, something that was probably exacerbated by a lack of standardised protocols (77% always or sometimes). These components are fundamental to successful monitoring programmes, yet our results show that these basic building blocks are too often not in place, or are poorly understood by staff. These issues undermine monitoring efforts and outcomes, making it difficult to gain meaningful insights from the data collected and wasting already limited resources (McCarthy et al., 2012). If our results are a benchmark for monitoring standards worldwide, it is perhaps easy to explain the seemingly

paradoxical result that recovery plans for threatened species with higher budgets allocated for research and monitoring have relatively poor recovery outcomes (Buxton et al., 2020). The investments made in data collection need to be considered wisely and ensure there are returns, to avoid wasting resources.

Despite these issues, effective monitoring programmes are vital components of biodiversity conservation and there is now a wealth of literature providing guidance on how to improve them, from conceptual design (Field, O'Connor, Tyre, & Possingham, 2007; Lindenmayer & Likens, 2010; Lindenmayer et al., 2012; Reynolds, Knutson, Newman, Silverman, & Thompson, 2016; Salafsky, Margoluis, Redford, & Robinson, 2002), to deciding what to monitor (Regan et al., 2008; Szabo, Butchart, Possingham, & Garnett, 2012), and how to implement adaptive monitoring (Lindenmayer & Likens, 2009). While useful, however, these guidelines are not necessarily specific or accessible enough for conservation practitioners, especially considering that many practitioners do not have access to literature (45% of practitioners in our survey) or struggle to find time to search and read literature (62%), let alone understand and apply it (36%; similar to Pullin & Knight 2005). Bridging these issues will therefore require actions outside site/project and organisation level. Training on the design of monitoring programmes and how they can be linked to and inform management objectives and actions should be a standard module of conservation courses and yet monitoring design is conspicuous by its absence from these (e.g. Gardner, 2021; Sandbrook, Nelson, Bolderson, & Leader-Williams, 2021; Van Heezik & Seddon, 2005). Such courses, which are mostly designed by academics, could benefit from co-development with practitioners or draw from research

such as ours to ensure that they more closely align with on the ground capacity needs outside the academic setting.

One of the most concerning results from the online survey was that nearly one-quarter (23%) of practitioners had experienced staff falsifying data. This result is not new (Fanelli, 2009). In one example given in the original scoping phase interviews, a practitioner described how: “staff fabricated the sightings of individuals belonging to [an endangered bird population], when these individuals were already known to be deceased, consequently this data was used to down-list the species from ‘endangered’ to ‘vulnerable’ on the IUCN Red List”. Given the extent of this problem, this needs to be considered and addressed and this can only really be done at site or project level. For example, by developing specific strategies to identify and prevent this malpractice such as double or triple data checking, additional training, close supervision of monitoring staff and regular review of data. Ultimately, the responsibility for data quality lies with the management or leadership of the project or organisation to ensure staff understand why data is collected, the implications of data falsification and are sufficiently motivated in their roles to avoid it. Staff morale is also tied to this type of issue: “Most field staff in my organisation do this work because they are passionate about it, but this passion quickly turns to cynicism and jadedness if they feel that the actual on-the-ground work isn't prioritised as it should be and senior leadership make decisions that are not in the best interests of conservation”.

3.5 Conclusion

The practitioners who manage island ecosystems may not necessarily be thinking beyond their site or species level objectives, but collectively their work can have profoundly positive impacts on species, sites and conservation progress worldwide and contribute to meeting national biodiversity targets. By undertaking an international study that directly engages with practitioners working at the frontline of island ecosystem management, we have categorically shown that most practitioners, regardless of the country they are working in, encounter multiple barriers that impact their ability to achieve effective management of island ecosystems worldwide. The practitioners in this study have shown us in no uncertain terms what it is they need to enhance this effectiveness.

Despite the undisputed need for truly transformative change (Chan et al., 2020) to address the underlying causes of many of these barriers, more immediate and direct investment in strengthening the people and systems that are at the frontline of preventing biodiversity loss on islands is needed. Specifically, funding should be prioritised towards SIDS, to mobilise SIDS-developed training initiatives that build human and institutional capacity and to promote initiatives that drive more strategic and collaborative efforts to meet objectives. Information generated from this and other studies that directly voices practitioner needs could be used to leverage funding towards targeted actions to bridge these barriers, enhancing the effectiveness of island ecosystem management and increasing our chance of meeting biodiversity targets, whether local, national or global.

3.6 Chapter Acknowledgements

We wish to thank all the respondents who took time to complete this survey, and everyone who helped share the survey through their networks. Thanks also to all the original interviewees that took part in our barrier scoping survey, which formed the base for this survey. Also, thanks to Inma Bullen and Annette Fayet for help translating the survey into French and Spanish.

Author Contributions

April J. Burt and Nancy Bunbury: Conceived the study. April J. Burt and Nancy Bunbury: Developed the methodology. April J. Burt: Conducted the interviews, analyzed the data under guidance of Ana Nuno, prepared the figures and tables and wrote the first draft of the manuscript. April J. Burt, Lindsay Turnbull, Frauke Fleischer-Dogley, Nancy Bunbury, and Ana Nuno: Contributed substantially to refining further drafts of the manuscript.

CHAPTER 4:

The Costs of Removing the Unsanctioned Import of Marine Plastic Litter to Small Island States



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"Always the edge of the sea remains an elusive and indefinable boundary. The shore has a dual nature, changing with the swing of the tides, belonging now to the land, now to the sea."

~Rachel Carson

4.1 Introduction

In the last decade the world has woken up to the extent and impact of plastic pollution in the oceans[167]. Approximately 6300 million metric tonnes of plastic waste has now been generated worldwide, and because collection and recycling facilities are unavailable or inadequate in most countries, up to 12.7 million tonnes is estimated to enter the oceans annually[64]. This figure is likely to remain high for the foreseeable future, despite global efforts to reduce single-use plastics[168–172] and the recent resolution to forge an international legally binding agreement to end plastic pollution[173]. Although these numbers provide an overview of the global problem, they do not reveal the full environmental and financial impact on countries that unwillingly import this waste, which arrives on their shores every day. While source interventions are being discussed and slowly implemented[174], the down-stream accumulation is taking its toll at both local and national level and cannot be ignored, especially in light of the accumulating evidence of the detrimental effects of plastic, microplastics and plastic leachate on species and ecosystems[68,175–180].

The Republic of Seychelles is one such nation: a small island state, with 155 islands stretching over 1.4 million km^2 of the Southwest Indian Ocean and

home to only 98,000 people[133]. One of the largest and most remote marine protected areas within Seychelles is Aldabra Atoll, among the largest raised coral atolls in the world and a UNESCO World Heritage Site. Aldabra is an iconic site, both within Seychelles and globally; heavily protected, it acts as an important benchmark for the impacts of global environmental change in protected areas. It is home to the last remaining population of Indian Ocean giant tortoises[59] (the Aldabra giant tortoise: *Aldabrachelys gigantea*) and provides one of the largest nesting sites for endangered green turtles (*Chelonia mydas*)[24] in the western Indian Ocean. The atoll supports large colonies of seabirds[181], 11 endemic land-bird species/sub-species[182] and the biomass of fish and sharks in its extensive coral reef and mangrove ecosystems is among the highest in the Indian Ocean[183]. The ecosystem services that Aldabra and other Seychelles island ecosystems provide are vital to human health and prosperity in the Seychelles and across the wider region but have already been subject to intense pressure from invasive alien species[122,123], habitat loss[121] and climate change[124]. To maximise the resilience of these ecosystems to climate change, especially in the marine ecosystems adjacent to islands, governments and managers must ensure the ecosystems are as healthy as possible. The arrival and accumulation of marine plastic litter is both an un-quantified threat to these ecosystems and yet another burden to the organisations and government departments tasked with managing and conserving sites and species[16].

The increasing accumulations of marine plastic litter along Aldabra's coastlines together with direct entanglement, ingestion and injuries to a wide range of species in discarded fishing gear (Figure 4.1) is unacceptable at this iconic site, as it would be if the same amount of plastic rubbish had been

allowed to accumulate in one of the world's great museums or art galleries. We (The Seychelles Islands Foundation (SIF) who manage the site) initiated a clean-up project in 2019 with the twin aims of: (1) documenting the extent and nature of the plastic problem and, critically; (2) attempting to remove as much accumulated plastic litter as possible from the south coast of Grande Terre Island (Figure 4.2), the largest of four islands that comprise the atoll. While previous studies have catalogued the extent of marine plastic pollution on remote islands around the world[74,184,185], these expeditions have never made a serious attempt to remove it, nor have they documented the associated costs. Quantifying the resources needed for removal efforts is critical to estimate the financial burden on small island states like Seychelles to manage marine plastic litter, and to allow such nations to adapt and plan accordingly.

With long-term management in mind, we estimated the total amounts and types of marine plastic litter found on Aldabra to quantify the source of the problem and to estimate the cost of a clean-up effort for the entire atoll. To do this we recorded all costs associated with the clean-up, and the effort required to do so, by timing clean-up sessions and estimating the amount of litter collected per person per unit time. The waste collected was weighed and categorised and additional surveys were conducted in each coastal habitat type to estimate the total remaining marine plastic litter on Aldabra and its composition. The composition data was used to determine the main sources of litter arriving on Aldabra.

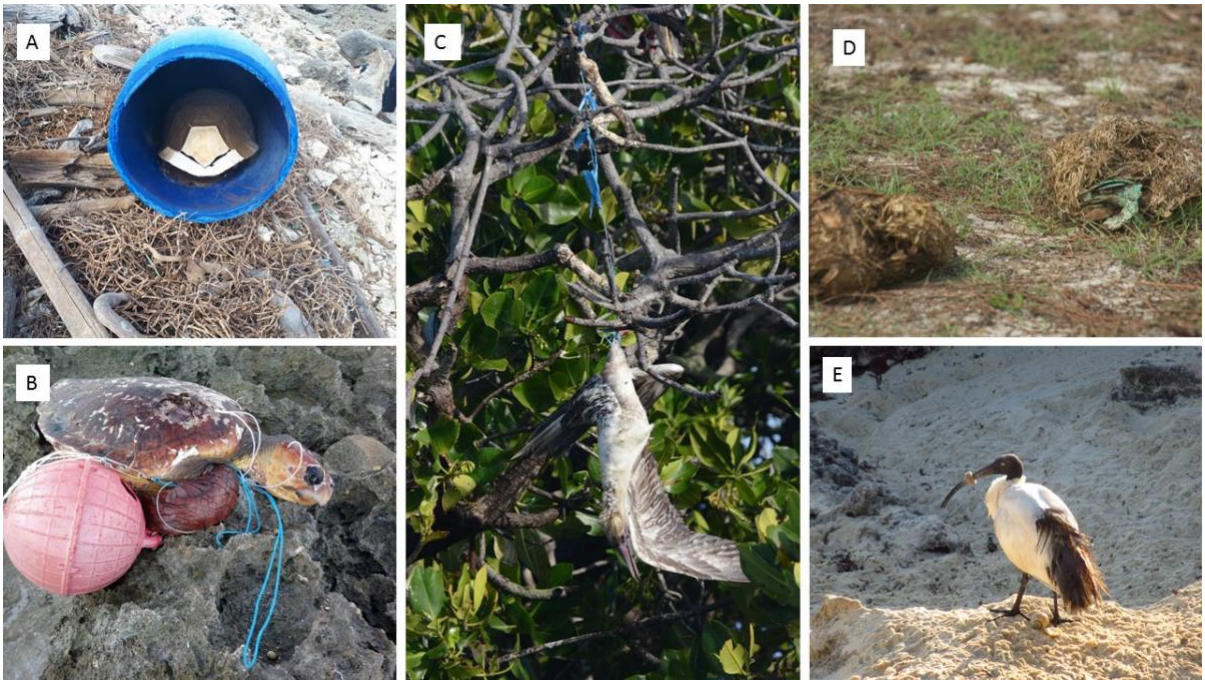


Figure 4.1: Impacts and threats from marine plastic litter to Aldabra's ecosystem: (A) dead giant tortoise (Aldabrachelys gigantea) inside plastic barrel; (B) dead loggerhead turtle (Caretta caretta)—one of many species to migrate past the atoll—entangled in fishing gear and washed up on the coast; (C) dead red-footed booby (Sula sula) entangled in plastic fishing-line; (D) giant tortoise faeces with partial flip-flop—evidence that tortoises are ingesting plastic; (E) sacred ibis (Threskiornis bernieri)—one of two individuals observed by the team with its beak trapped shut by a ring of plastic, possibly an eroded cap from a PET bottle.

4.2 Methods

Aldabra Atoll

Aldabra Atoll is one of the outer islands of the Seychelles archipelago and lies 1120 km southwest of Mahé Island (Figure 4.2). The closest inhabited land is the northern tip of Madagascar, 407 km to the south, while Tanzania lies 700 km due west. The atoll is 34 km long and 14 km wide and is comprised of four large coral islands (Picard, Polymnie, Malabar, Grande Terre) separated by narrow channels that enclose a shallow tidal lagoon. A fringing coral reef surrounds the atoll and provides partial protection to ocean-facing beaches, on which large numbers of green turtles nest. The atoll experiences two distinct seasons: the northwest monsoon from November to April which brings calmer seas and monsoon rains; and the strong southeast trade-winds from May to October, which are generally dry[186]. Of all the islands, Grande Terre is the most heavily impacted by marine plastic litter, especially during the southeast season, when the trade-winds blow directly onshore. It is also the most difficult part of the atoll to access; hence while clean-ups are regularly conducted by SIF staff on the island of Picard, the south coast has been accumulating litter since it began to arrive – probably in the 1980s. Fifteen turtle-nesting beaches and areas of tortoise-grazing habitat on the Grande Terre coast were deemed the most critical to clean up, as over many years the litter had accumulated into large piles of compacted trash, which inhibits adult turtles from laying eggs and hinders hatchlings from reaching the sea safely.

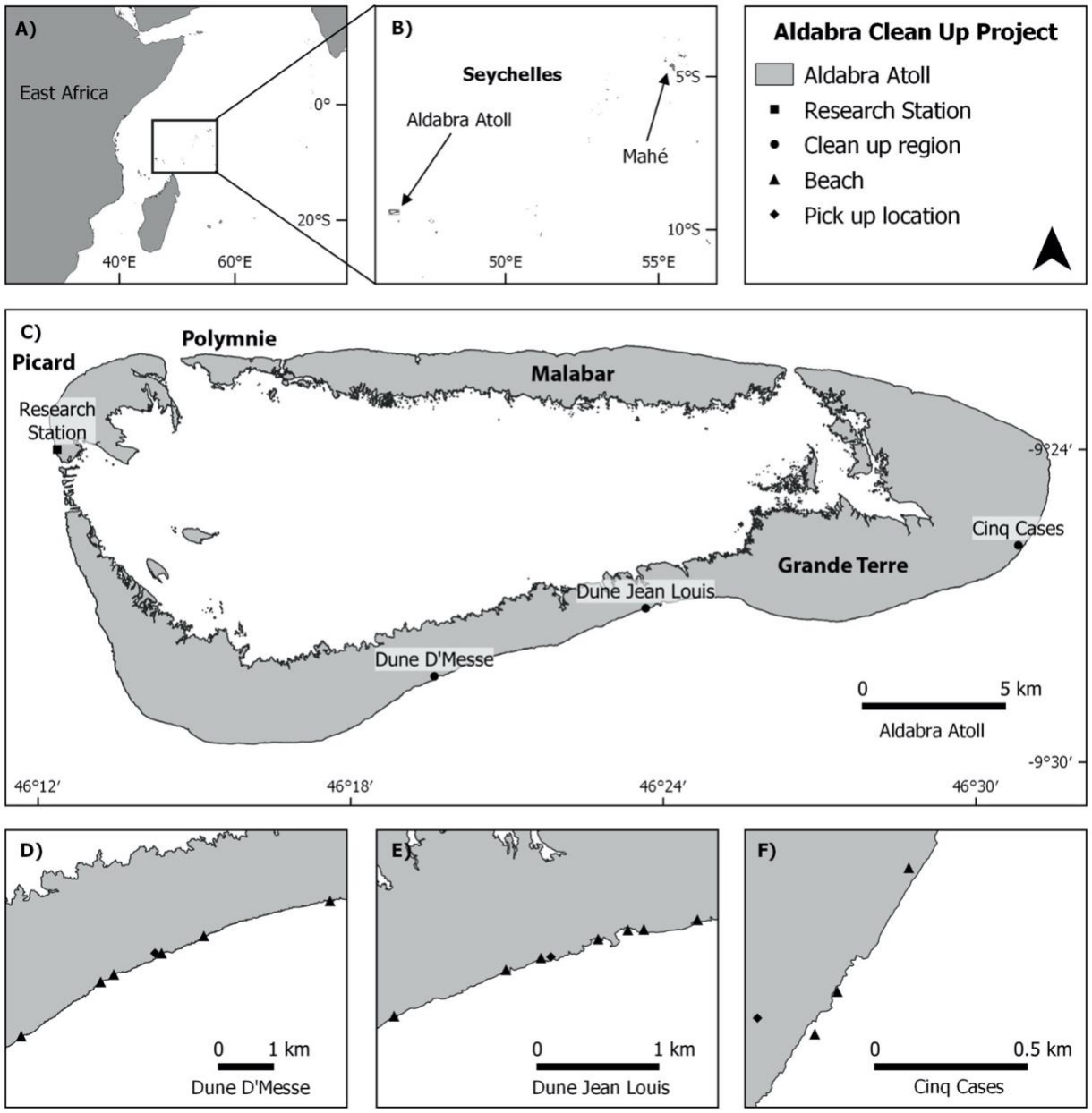


Figure 4.2: The location of Aldabra Atoll and the clean-up operations: (A) Aldabra in the Indian Ocean; (B) Aldabra's proximity to the main Seychelles Islands; (C) Aldabra atoll and the clean-up regions in relation to the research settlement; (D) Dune D'Messe camp and beach locations; (E) Dune Jean Louis camp and beach locations and (F) Cinq Cases camp and beach locations. QGIS Development Team V3.14, 2020. https://qgis.osgeo.org.

Clean-up details

A team of 12 volunteers comprised the clean-up work-force. The team spent three weeks stationed at three field camps. The camps are situated at the only locations along the coast where a boat can land safely from the ocean side: Dune d'Messe (DdM), Dune Jean-Louis (DJL) and Cinq Cases (CC) (Figure 4.2). These provided bases from which two teams could usually complete two four-hour cleaning sessions per day. All litter was placed into sacks or slings (with efforts to remove sand and other water) separated into six categories and weighed at the end of each session to get category totals. The six categories were: (1) *consumer plastic items* (e.g. toothbrushes, cigarette lighters); (2) *plastic packaging material* (e.g. PET bottles, cosmetic bottles); (3) *fishing-related items* (e.g. buoys, nets, fish-aggregating devices (FADS) and ropes); (4) *plastic footwear* (mostly flip-flops); (5) *unidentified plastic fragments* > 1 cm in diameter; (6) *other materials* (e.g. glass). These categories were defined based upon those outlined in the Tangaroa Blue Foundation Marine Debris Identification Manual, although we grouped all non-plastic items into the 'Other' category and segregated footwear into its own category due to the visible dominance of this type of debris. The full sacks and slings were left above the high-tide line at designated collection points.

The most difficult and potentially dangerous phase of the operation was the transfer of the collected litter from shore to ship and this is only possible on the south-coast of Aldabra in either late November/early December or in March, when the sea is calmest due to the shift in seasons. Small boats ferried sacks of litter from the beaches to a waiting supply ship that was anchored beyond the fringing reef and equipped with a crane to lift slings

from the small boats onto its deck. For this phase the volunteer teams were assisted by an experienced staff team from the Aldabra research station and a team from the Seychelles Peoples Defence Forces via the coastguard vessel.

Estimating amounts of plastic debris and costs of removal

The more frequent clean-ups on Picard Island, coupled with the small number of beaches and the higher elevation of the karst on Malabar means that there is substantially less accumulated waste on the northern islands of the atoll. We therefore focus on Grande Terre and consider that cleaning up Grande Terre would be synonymous with cleaning up the whole atoll. To estimate the total amounts and types of marine plastic litter found in different coastal habitats on Aldabra, we chose twenty locations along the south coast of Grande Terre. At each location, three coastal habitat types were identified: (1) sandy beach above the high-tide line (where green turtles nest); (2) coastal limestone karst; and (3) coastal vegetation, within 5 m of the beach or karst, as the amount of marine plastic litter declines with distance away from the coast. There were a small number of places with extreme accumulations, like blowholes (Figure S4.3), that were not surveyed. A single 20 m × 2 m transect was laid out at each location in each habitat type, parallel to the water's edge. In each transect, we picked up all surface-lying items of rubbish > 1 cm in diameter, including partially buried items. Items < 1 cm in diameter were not collected, as the effort involved in their removal during any large-scale clean-up operation would be prohibitive. All items were sorted into the six categories mentioned above and placed directly into separate collecting bags and weighed using a spring balance at the end of the session. This data were used to estimate how much litter in each category was

present in the different habitat types per square metre (Figure 4.3). To test whether the amounts of litter in each category varied among habitat types, we fitted a linear mixed effects model (details in supplementary material), where the response variable was the amount of litter removed, and the explanatory variables were litter type and habitat type. Location and transect identity was fitted as nested random effects. The model was fitted using the package *lmer* and *lmerTest* to provide approximate p-values using Satterthwaite's method in R Studio (version 1.3.959). The data were highly over-dispersed, so we modelled Log(litter mass + 1) which corrected the problem. To scale up from transects to the total litter on Grande Terre island we used the raw data, rather than estimates from the model, which we considered to be a conservative approach (variation associated with location and transect variability is then included in the standard errors of the estimates). The estimate for each litter category in each habitat type was then combined with estimates of the total area of each habitat on Grande Terre (Table S1), taken from Google Earth Pro (details in Supplementary material).

In addition to the transects, we recorded the total amount of litter collected in each of the 40 clean-up sessions, together with the length of the session and the number of people working in it. These numbers were used to estimate the amount of litter collected per person per hour. Once we had estimated the total amount of litter present on Grande Terre, we then estimated the total effort needed to remove all the accumulated litter from Grande Terre, assuming that future teams could work at a similar rate.

We provide a breakdown of costs for the clean-up operation and use these to estimate the costs per day of clean-up (our costs divided by the number of clean-up days) and costs per tonne (our costs divided by the number of tonnes) and the projected costs of a full-island clean-up (costs per tonne multiplied by estimated total island tonnage) , (Table 4.1). The main costs were: transport from Mahé to Aldabra in both directions for a team of 12 people; hiring a cargo vessel for 18 days (four days travel in each direction, plus one week of loading at Aldabra and three days unloading on Mahé) and the sacks and slings used. The staffing costs were based on an average daily-salary rate for the SIF team based on Aldabra. We have assumed that similar methodologies to those described here would be employed in any future clean-up effort of Aldabra or other Seychelles outer island: for example, the cargo vessel was the third largest in Seychelles and it was filled during this expedition, so to remove a larger volume at a single event would require either multiple vessels or multiple trips. The Seychelles Peoples Defence Force team were provided without charge by the Government of Seychelles, but there is no guarantee that they could assist with future expeditions and so this was not included in cost projections, making our estimates of cost conservative. Due to their being no cost data available from other island clean-ups, it is not possible to do more than present our own experience and this may help other managers planning clean-ups within and outside of Seychelles.

Origin of marine plastic litter

All the plastic litter was moved from Aldabra to a storage facility in Mahé. Once there, we estimated the total volume of plastic and sampled six haphazardly-selected sacks of PET bottles (a total of 470 bottles,

approximately 1.2% of total collected) to record the type and origin of all the bottles on which labels remained. For the fishing buoys we recorded the brand and/or origin of 50 buoys, also selected haphazardly. We also recorded the identification codes on each fish aggregation device (FAD); a free-floating human-made raft equipped with floats to ensure buoyancy and a sea anchor mostly built from old fishing net that are deployed to attract schools of fish in purse-seine fisheries, they are remotely monitored with a GPS-tracked buoy that includes an echo sounder unit[187,188]. Using the identification codes we could attempt to track their origins (FADs are usually labelled with the ship code they came from, and we checked this against the list of fishing vessels operating within the region).

4.3 Results

Collected waste

During the expedition a total of 26.4 tonnes of marine plastic litter was collected from the coastal areas of Grande Terre, but only 25.7 tonnes (approximately 250 m^3) could be removed from the shore to the cargo vessel and transported back to Mahé. The remaining 0.7 tonnes had to be left on Aldabra due to unsafe sea conditions that made removal from one of the smaller collection points (Cinq Cases) impossible.

Of the litter collected and removed from Aldabra, the largest component by weight of was fishing-related items (buoys, nets, FADS and ropes) which collectively made up 60% (15.8 tonnes) of the total, followed by plastic shoes (mostly flip-flops), which made up 24% (6 tonnes) of the total (Figure S4.1). During the entire five-week clean-up we estimate that 60,000 individual flip-flops were collected.

Estimations of remaining litter

The transects revealed that different habitat types accumulate different relative amounts of each type of plastic litter (Figure 4.3; Table S4.1; $F_{10,285} = 15.71$; $P < 0.001$): the proportion of heavy fishing ropes was highest on the limestone karst, while PET bottles and other light consumer items were collected in greater quantities on the beach and vegetation terrain. Based on the raw data, we estimate the total amount of accumulated litter on Grande Terre to be 513.4 (95% CI: 212 – 814) tonnes. The estimated composition of this litter by weight is 83% (426 tonnes) fishing related, 7% (36 tonnes) footwear, 4% (20.5 tonnes) fragments, 3% (15.4 tonnes) packaging, 2% (10 tonnes) other types of litter and 1% (5 tonnes) consumer items (Figure S4.1). Note, that the estimated composition of the litter remaining on Aldabra is different to the composition of the litter collected and removed during the expedition. This is because the expedition preferentially targeted beaches, rather than karst, where the proportion of fishing gear is lower.

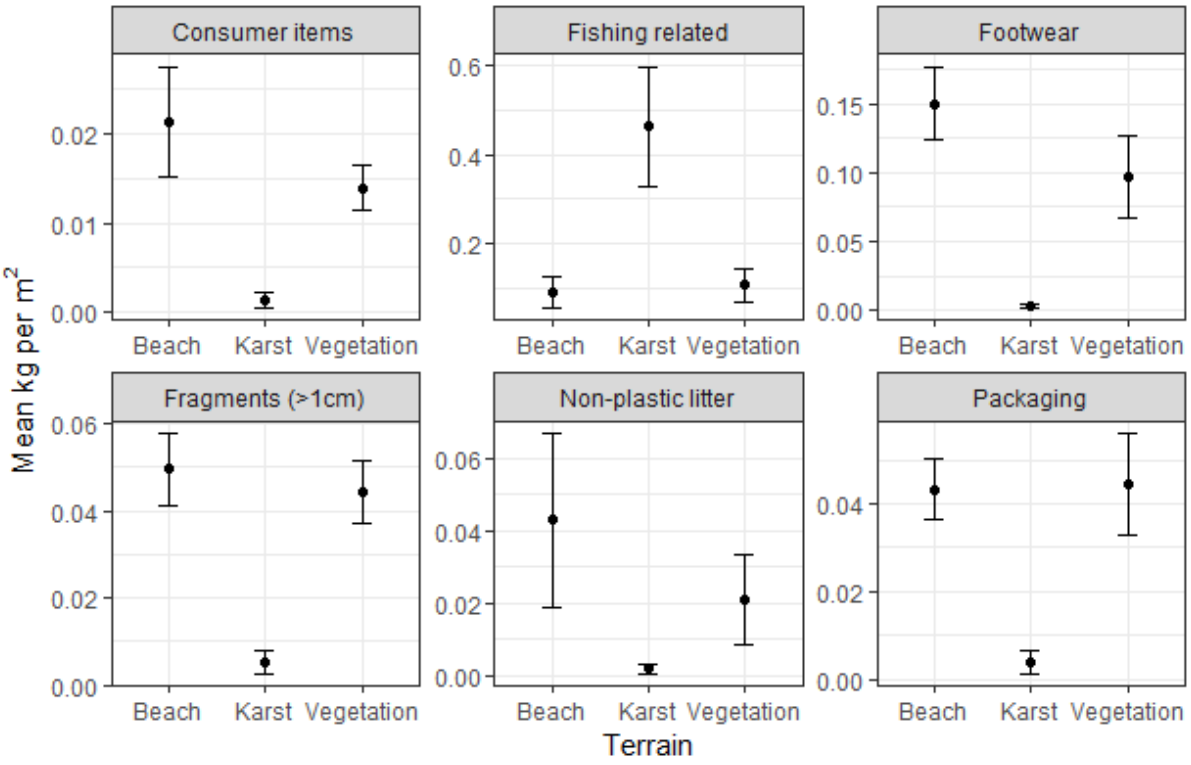


Figure 4.3: The amounts of plastic waste in each of six categories recorded in twenty transects in each of the three main terrain types (60 transects in total). Error bars show one standard error. The scale on the y-axis varies among plots.

Effort & Future Clean-Up

The mean collection rate calculated from 40 clean-up sessions totaling 980 collection hours was 28 kg (SE = 1.84) per hour per person, meaning that it requires 35.7 hours person-hours to remove 1 tonne of litter. We therefore estimate that it would take a team of 12 people approximately 191 (73 to 303) days (assuming two four-hour sessions per day) to collect the remaining 513 tonnes of marine plastic litter from the largest island of Grande Terre. It took four days to move 26 tonnes of waste from shore to ship, so we estimate that 82 days would be necessary to move all the remaining waste from shore

to ship. As the total cost of the five-week expedition was $224, 537, we estimate that a full clean-up would cost approximately $4.68 million (95% CI: $1.95 million – $7.28 million) (Table 4.1). This is around $10,000 per day of clean-up operations or $8,900 per tonne.

Table 4.1: Summary of the costs involved in the 34-day clean-up

Action	Cost in Seychelles Rupee	Cost in GB Pound	Cost in US Dollar	Average daily cost in US Dollar
Equipment (3000 sacks and 825 slings)	SCR 184,350	£ 10,323	$ 13,457	$ 395
Team Food (12 people)	SCR 64,438.9	£ 3,678.83	$ 4,703	$ 138
Team Transport	SCR 669,313	£ 38,211	$ 49,504	Not included
Cargo vessel (18 days in total)	SCR 2,057,318	£ 117,482	$ 152,163	$ 8,454
Small boats fuel (4 days of pick-up shuttles)	SCR 30,000	£ 1,694	$ 2,191	$ 547
SIF staff (based on average staff salary, daily rate for ten staff over 4 days for pick-up)	SCR 20,000	£ 1,129	$ 1,461	$ 365
Cost of coastguard deployment*	SCR 1,100,000	£ 62,111	$ 80,372	Not included
Total	SCR 3,025,420	£ 172,722	$232,588	$ 9,899

*This was not covered by project costs but by the Seychelles Government. The coastguard deployment would not necessarily be essential in future operations, if sufficient additional staff were present, therefore the cost has not been included here.

Origin & Type of Litter

Of the 470 PET bottles sampled, 40% were originally used for water, 8% for soft drinks (of which 62.5% carried labels from the Coca-Cola Company) and 52% were unidentifiable. Of the 470 sampled bottles, 45 had intact labels where the manufacturing country was identified (Figure S4.2). Of these, the majority were from China (21), with others coming from Indonesia (6), Thailand (4), Malaysia (3), India (3), Singapore (2) and South Africa (1).

Of the fishing floats sampled, 28% (*n* = 46) had 'Made in Taiwan' inscribed on them. The remaining floats were branded (e.g. 11 were Blue Dolphin, four were Blue Fin) but had no clear origin. Of the fish-aggregation devices or FADs (*n* = 13), seven had clearly decipherable identification codes and all came from purse-seine vessels registered to fish in the Seychelles EEZ; five were from Seychellois vessels; one was Spanish and one French.

4.4 Discussion

The expedition removed around 25 tonnes of marine plastic litter from Aldabra – around 5% of the estimated total – at a cost of $224,538 and 980 person-hours of effort. By combining information on amounts and types of litter with the effort required to remove it, we estimate a total projected cost of around $1.95– $7.28 million to clean up the entire south-island, where the vast majority of the litter lies. This eyewatering price-tag makes the economic burden of the unsanctioned import of plastic litter on small island states abundantly clear.

Our estimate of ~500 tonnes (within a total area of 1,166,508 m^2; Table S1) of marine plastic litter on Aldabra is probably conservative for a number of reasons: (1) it only includes the litter on Grande Terre, the largest island of Aldabra; (2) it does not include buried beach debris, which is substantial on some beaches, due to wind action and digging by nesting turtles. Nevertheless, our estimate is the highest recorded for any one island worldwide (0.44 kg per m^2). In comparison, the estimate for Henderson Island, another World Heritage Site, is 18 tonnes (ca. 0.18 kg per m^2)[184], and 238 tonnes on the Cocos Island group (ca. 0.41 kg per m^2)[185] using a similar methodology, although these studies also include micro-debris (2–5 mm) and buried debris (to 10cm depth). The amount of plastic litter accumulating on Aldabra seems to be typical of the situation on a number of other Seychelles islands[74,189], although no estimates of total waste accumulation have been made. All such islands have high conservation value due to the marine ecosystems they support[183].

The challenges and subsequent costs of removing 25 tonnes of litter from Aldabra are likewise representative of the likely costs involved in a significant clean-up of a remote tropical island anywhere in the world. The challenges include the distance from the mainland and the lack of facilities to support large-scale clean-up operations such as team accommodation, transport, food and water; not to mention the inherent danger in manually moving large fishing nets into small boats in considerable swell (Figure S4.3). The challenges at Aldabra may be more extreme than at other islands due to the remote location, although some other islands, e.g. Henderson Island, are equally remote, but have no resident team, and hence detailed knowledge of currents and landing sights is limited, making clean-ups potentially harder.

The estimated total project cost is conservative because this figure does not include in-kind contributions from SIF staff, who managed the planning and logistics for the clean-up, or the cost of the Seychelles coastguard vessel. A recent study estimated that the annual cost of marine plastic litter in terms of reduced natural capital of the affected ecosystems lies somewhere between $3300 and $33,000per tonne[190]; but this is only the cost of inaction, while the cost of active clean-up operations is rarely reported. In our case, the clean-up cost per tonne is around $8,900 and so, removing most or all of the accumulated litter from the largest island will likely cost around $1.95 million – $7.28 million – well beyond the capacity of non-profit organisations like SIF.

Understanding where this waste originated is a vital step in allocating accountability, to galvanise reduction at the source and potentially pinpoint where clean-up costs could be generated. It has been widely reported that approximately 80% of marine plastic litter originates on land, while the remaining 20% derives from marine sources[177,191], half of this being directly related to the fishing industry. Our results, however, suggest the opposite: 60% of the litter that we collected during the expedition – and 83% of the estimated total remaining on Aldabra – was fishing-related. This high proportion of fishing-industry waste is comparable to that found in the Great Pacific Garbage Patch (52%)[192], on islands in the Atlantic Ocean (> 40%)[73], on Australia's northern shores (63%)[193] and across the five sub-tropical gyres (58.3%)[70]. Elsewhere in the Indian Ocean, the proportion of litter from the fishing industry is much lower; for example, it constitutes 7.7% of the litter on Henderson Island, 1.5% of the litter on Cocos Keeling islands[184,185] and just 2% of that on nearby Alphonse island[74]. These large differences in the

proportion of fishing gear at sites within the region and the high proportion of fishing gear retrieved during this expedition suggest that Aldabra is a hotspot for accumulation. The arrival of particular types of waste may be heavily influenced by proximity to sources of litter, and/or by the location of islands in particular ocean currents, so will inevitably differ from place to place.

The economy of Seychelles is highly dependent on fishing, which directly and indirectly employs around 10% of the population. Industrial tuna fishing – mostly based on yellowfin (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*) and bigeye tuna (*Thunnus obesus*) – is one of the most important sources of foreign currency earnings and 326,461 tonnes of tuna was landed or transhipped in Victoria, the capital of Seychelles, in 2016[194]. The industrial fishery that operates within the Seychelles Exclusive Economic Zone (EEZ) is composed of licensed vessels, both Seychelles and foreign registered, that fall under two main categories: purse-seiners (mainly EU owned vessels) and longliners (mainly Taiwanese and Chinese vessels). Since the early 1990's, purse-seiners have been mainly operating using fish aggregative devices (FADs). The number of FADs that each ship can maintain is restricted, but because they float freely, they can enter marine protected areas, where the boats are not permitted to follow them. In an assessment of drifting FADs within the Indian Ocean, 9.9% of deployments by purse-seine fisheries were estimated to end with a beaching event, suggesting that 1500–2000 may be lost onshore each year in places like Maldives, the Chagos Archipelago, and Seychelles[195].

Of the 13 FADs collected during the clean-up expedition, we were able to trace the origin of seven, all to purse-seiners that are authorised to fish in the

Seychelles EEZ. A recent report for the Indian Ocean Tuna Commission investigated 214 individual FADs that had arrived on or entered into near-shore waters of a number of islands in Seychelles: 76% of the FADs were from Spanish owned or flagged vessels, licensed to fish in Seychelles[196]. These results are alarming: first because it shows that waste generated by the fishing industry within Seychelles is polluting island ecosystems within the same nation state; second, if the fishing industry is the major contributor to marine plastic litter in the region, then it is almost certainly having indirect negative impacts on the fish communities it needs to sustain[175]. Our results also indicate that the amount of litter estimated to be circulating in the region is greatly underestimated and highlights the flaws of using sweeping global estimates within a local context. In 1990 the Seychelles acceded to the MARPOL convention and its mandatory Annexes I (Prevention of Pollution by Oil) and II (Control of Pollution by Noxious Liquid Substances in Bulk). Largely in response to this clean-up and other similar efforts by local conservation organisations, which have already received widespread local publicity, the Seychelles Government decided to accede to the remaining MARPOL annexes in 2019; most importantly it acceded to Annex V- *Prevention of Pollution by Garbage from Ships*, demonstrating that highlighting the problem can lead to political action by concerned governments.

Previous studies of island litter accumulation have focused on quantifying the number of individual items found: 414 million on Cocos Island Group[185] and 37.7 million on Henderson Island[184]; however, we chose not to do this, focusing instead on the total weight and time required to collect and remove it, as these are likely to be more important for managers planning clean-ups.

We deliberately excluded fragments below 1 cm diameter and wish to highlight the impossibility of removing such small fragments as part of clean-up efforts in such remote locations unless new technology become available. Although small items generate microplastics, we suggest that removing larger items before they degrade into tiny particles is the best way to reduce the amount of microplastics entering the local ecosystem.

The six tonnes of flip-flops collected during the expedition equates to approximately 60,000 individual flip-flops, and the estimated 37.2 tonnes of footwear remaining on Aldabra approximates to 370,200 individual flip-flops. Unlike the litter from the fishing industry, it is less likely that the main source of these is Seychelles: there are simply too many to imagine that they originate from a population of 98,000 people. The flip-flop phenomenon is not unique to Aldabra, and other studies throughout the region have reported large numbers and speculated about their origins[72,74,189]. Duhec *et al*.[74] mention that flip-flops are the world's simplest, cheapest and most popular shoe[197], especially in countries that fringe the Indian Ocean, where waste management is extremely poor.

While we were unable to determine the source of individual flip-flops, as most were either too degraded or non-branded, we recorded the country of origin of a sample of PET drink bottles. Perhaps unsurprisingly, given its size and population density, 47% of plastic bottles found on Aldabra with intact labels were from China. This is similar to findings from islands in the Southern Atlantic Ocean[198], and on Alphonse Island in Seychelles, where more than 75% of labelled items originated in Southeast Asia (mainly Indonesia and Thailand) and 13% originated in East Asia (mainly China)[74]. In both cases,

the original studies suggested that the intact labels might indicate the source of the bottles was dumping from ships. Only a small proportion of bottles found on Aldabra had intact labels, so we suggest that this hypothesis does not hold for Aldabra. Those found with labels clearly indicate their origin and these data corroborate findings from previous studies showing that globally, the largest input of land-based marine plastic pollution is countries in Asia[65,199].

Regardless of where the waste originated, the people and government of Seychelles are left to manage and dispose of it. The current waste management system in Seychelles is restricted to landfills and several small-scale initiatives, such as collections of aluminium cans and PET bottles[200], which are then exported for recycling. At present, there are no in-country recycling options for any plastics[201] and marine-degraded plastic requires specialist recycling. The relatively small amount of waste we returned to Mahé spent six months in a holding site while we attempted to find local re-use and re-purposing solutions. In total, 9.2% of the litter was re-used by conservation organisations, local schools and artists, but these are not long-term pipelines for waste. A report by PEW Charitable Trusts outlines the need to establish recycling infrastructure in developing nations and the potential for unlocking value from waste via a circular economy that derives revenue from the circulation of materials rather than the extraction and conversion of fossil fuels[202]. Recycling solutions exist elsewhere in the world to enable a circular economy for the majority of plastic types (Table S4.2), although solutions may not exist at appropriate scales. One difficulty is that the costs of collecting and moving waste from remote sites are likely to make any solutions economically unviable, but this requires further analysis. For

example, if the resulting products can be branded as originating in a UNESCO World Heritage Site, it's possible that some value might be added; prior to the COVID-19 epidemic, Seychelles had a thriving high-end tourist industry[203] and there may be a market for high-quality goods made from recycled materials to sell to tourists locally.

It is reasonable to ask whether, given their extremely high cost, clean-up efforts should take place at all. However, we are not predicted to reach global "peak waste" before 2100[204] and it's simply unimaginable that plastic litter be allowed to accumulate on Aldabra at current rates for another 80 years. The arrival of tonnes of plastic litter compromises the integrity of this near-pristine system and potentially increases its vulnerability to climate change; for example, the likelihood of coral disease increases from 4% to 89% when they are in contact with plastic[205]. The impacts of large-scale plastic accumulation to both the marine and terrestrial ecosystems on Aldabra are yet to be quantified, for example, how the accumulated waste along the coastline which undergoes extreme degradation by ultraviolet photo-oxidation may interact with run-off and wave action to filter back onto the surrounding coral reefs. The value of clean-up efforts is therefore potentially under-played: they are a vital, if costly, management action, essential for small island nations with coral reef ecosystems, hoping to withstand a suite of impending threats. As such, we believe that in addition to improving waste management, more international funding should be directed towards clean-ups, considering the transboundary nature of the marine plastic litter problem *and* the transboundary nature of the ecosystem services provided by coral reefs.

4.5 Chapter Acknowledgements

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Author contributions

AJB & LAT designed the study; AJB, JR, CS, JB, FFD, RG, ST, MS, JM, JL, CQ, SR, CF, IC, AA, KB, TZ, JM, MR, JBO, RM, EC, JS were involved in data collection or directly facilitated the expedition; AJB carried out data processing and analysis and prepared the figures and tables, JL created the map; AJB & LAT wrote the first draft of the manuscript, and all authors provided input and comments.

CHAPTER 5

Genome-wide SNP genotyping of coral Porites sp. identifies key source and sink reefs in the Seychelles Archipelago

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COVID-19: Sampling was also impacted by the Covid-19 pandemic and a planned final field season in March 2020 was cancelled. Additionally, lab work was postponed and delayed due to the pandemic reducing the analysis time available,

"We are like islands in the sea, separate on the surface but connected in the deep"

William James



5.1 Introduction

Coral bleaching is the greatest threat to the persistence of tropical reef ecosystems[206] and bleaching events are increasing in both frequency and severity[207]. At a global scale, reducing greenhouse gas emissions is the only meaningful way to assure the future of reefs[208]; however, global coral cover has declined by half since the 1950s[209], transforming the functionality of reefs[210], so countries at the frontline of climate change must act now to reduce further impacts. Conservation actions at local scales aim to improve reef health and resilience[103,211–213], but effective action requires better knowledge of the regional reef system in which individual reefs are embedded and many countries are racing against time to map reefs and quantify their health and susceptibility.

The Seychelles archipelago hosts a regional reef system already impacted by bleaching[214,215]. Future projections of its long-term survival are bleak: bleaching is predicted to become an annual event in the next 15 to 40 years[216], making mitigation efforts and marine spatial planning essential. This includes identifying which reefs are most resilient to bleaching and mapping connectivity to determine whether or not resilient reefs are well connected to others. High connectivity should enhance resilience of the

regional system because larvae can be supplied from resilient reefs to those more badly affected.

Seychelles is a small island developing state that hosts 13% of the region's coral reefs[215] scattered across 1.4 million km^2 of ocean. The main inhabited or 'inner' islands in the north are granitic while the 'outer' islands in the south are coralline in origin and include several atolls, the largest being Aldabra, a UNESCO World Heritage Site. The outer coralline islands seem to be more resilient to bleaching than the inner granitic islands[84] and reefs within the Aldabra lagoon suffer less bleaching[217,218] and recover more rapidly[218] than seaward reefs. The enhanced resilience within the Aldabra lagoon might occur because the lagoon experiences three-fold higher fluctuations in mean daily sea surface temperature than the seaward reefs[218], which in turn might have selected for greater thermal tolerance[96]. Thermal tolerance in corals is generally thought to be a consequence of physiological acclimation, but a shift in thermal tolerance can occur through natural selection of heat-tolerant lineages of either the coral animal or algal symbionts[219–221].

If the outer islands are well connected to the inner islands, then they could play a crucial role in regional coral persistence, especially if they are supplying resilient coral genotypes to other reefs. However, a recent exercise using an ocean current model has predicted that no larvae from Aldabra would reach the inner islands, assuming a pelagic larval duration up to 60 days[101]. But there is a plausible route by which coral larvae from Aldabra or the other outer islands could reach the inner Seychelles; from the outer islands the North East Madagascar Current meets the East Africa Coastal Current (EACC) where it turns North and from November meets the

South Equatorial Counter Current (SECC; see Fig S1)[222] which travels eastward towards the Seychelles Plateau and hence the inner islands. This timing coincides with peak broadcast spawning at Aldabra, which is during October–December[223].

If viable larvae are able to travel from the outer to the inner islands, then a population genetic study should reveal that coral populations on the outer and inner islands show reasonably high levels of genetic connectivity. To investigate this, we sampled a bouldering *Porites sp*. from across Seychelles, including both inner and outer islands, with intensive sampling both inside and outside the lagoon at Aldabra Atoll. This is one of the most resilient species to bleaching stress[224,225] and one that has become dominant on many reefs since widespread bleaching began in 2016. We use genome-wide single nucleotide polymorphisms (SNPs) to estimate gene flow among reef sites and identify: (1) the degree of genetic admixture between the inner and outer islands; (2) and the direction of larval flow. By doing so, we hope to generate local-level information that is useful for management; in particular, whether the outer islands should have stronger protection and additional management resources, if they are indeed crucial to the persistence of the entire reef system of Seychelles.

5.2 Methods

Overview

We sampled individuals from a single putative species across Seychelles. DNA was extracted, sequenced, and mapped against a reference genome. Single nucleotide polymorphisms (SNPs) were called and these were filtered for use in different population genetics analyses to generate measures of population structure based on genetic similarity. One of these, ADMIXTURE, determines the most likely number of populations within the samples set (i.e. the K-value) and the proportion of mixed ancestry (i.e. admixture) for each sample. This was coupled with a Principle Component Analysis (PCA) to likewise assign samples to one population or another. Following this, BAYEASS was used to calculate estimates of geneflow between reef sites and used to identify patterns of connectivity within the Seychelles reef system.

Species choice

Porites lutea was chosen as the focal species for this study for logistical and biological reasons: 1) it is present and common across WIO reefs; 2) it has a broadcast spawning strategy which is the most common strategy and therefore representative of the broader coral community; 3) the genome for *P. lutea* has already been sequenced[226,227], allowing us to obtain greater depth of information from samples at the sequencing stage. Two additional species (*Acropora tenuis* and *Acropora cytherea*) were also included in initial sample collection but were not found in large enough numbers to address the aims of this study. These samples will instead be used in a wider regional

study including samples from Chagos, the East African coast and other WIO islands.

Sample collection

We collected coral fragments from 241 colonies across 19 reef sites (12 different islands; Table 5.1) in the Seychelles Archipelago from October 2018 to December 2019 (Figure 5.1). To reduce the chances of sampling clones, colonies were samples with a distance of at least 5 m between consecutive collections. The samples were transferred into individual ziplock bags and a photograph was taken of the colony with the labelled bag. After the dive each coral fragment was transferred into an individual tube with 99%+ ethanol and labelled with date, sampling location, presumed species and a unique identifier code. Due to the logistics of sampling multiple remote sites, the samples were stored at 4°C until return to the main island of Mahé where they were transferred to a -18°C freezer. Once the appropriate export permits were obtained, the samples were transported with cold packs back to the Oxford Laboratory for DNA extraction.

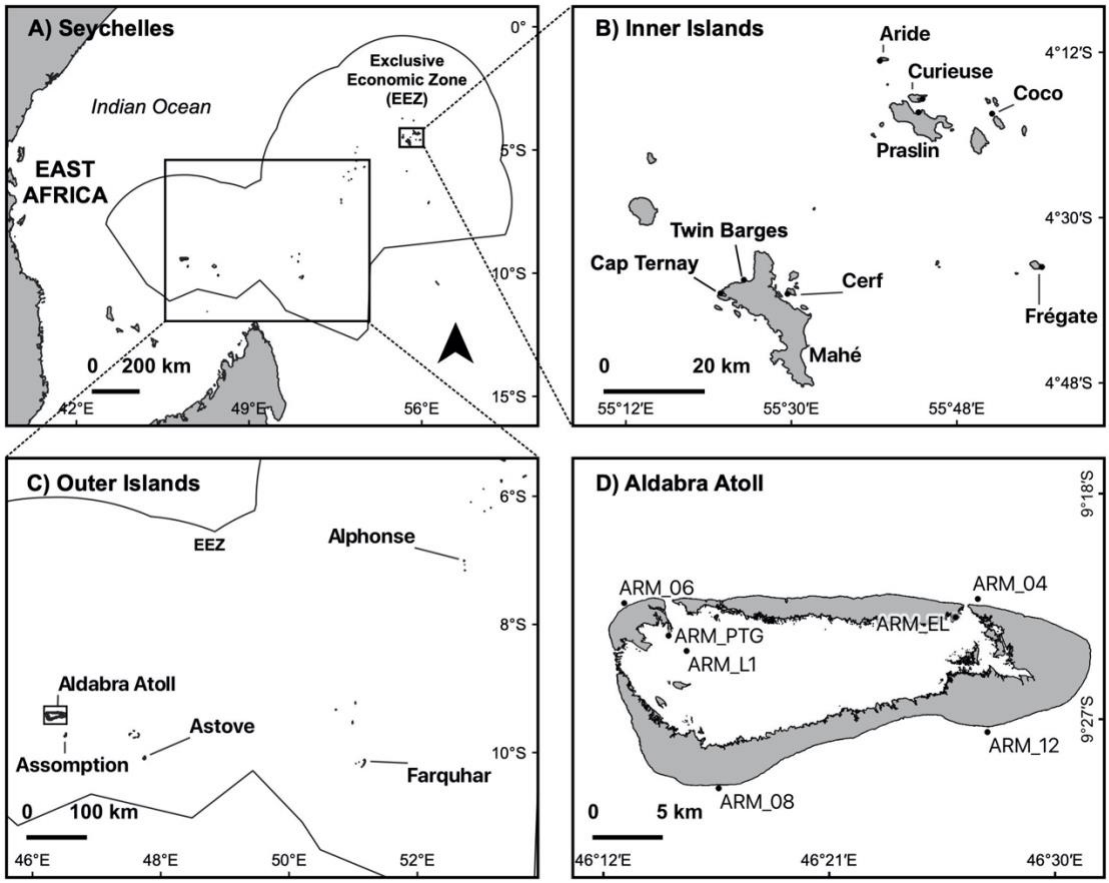


Figure 5.1: Map of the Seychelles Archipelago (a) showing sampling sites in the inner islands (b), the outer islands (c) and at Aldabra Atoll (d). Site name codes for Aldabra refer to specific Aldabra Reef Monitoring (ARM) locations that were used to collect samples from. Inside the lagoon sites include Point Tanguin (ARM_PTG), Lagoon site 1 (ARM_L1) and East lagoon (ARM_EL).

Table 5.1: Sample sites and quantities. 241 samples were sequenced, 21 of these were not included in analysis because they had significant divergence from the reference genome.

Site	Island group/location (& gene flow analysis grouping)	# 220 Samples included in analysis
Aldabra Reef Monitoring Site 6 (ARM06)	Aldabra North Coast	14
Aldabra Reef Monitoring Site 4 (ARM04)		14
Aldabra Reef Monitoring Site 8 (ARM08)	Aldabra South Coast	11
Aldabra Reef Monitoring Site 12 (ARM12)		14
Aldabra West Lagoon Site 1 (ARM_L1)	Aldabra West Lagoon	4
Aldabra Point Tanguin West Lagoon (ARM_PTQ)		16
Aldabra East Lagoon (ARM_EL)	Aldabra East Lagoon	15
Assomption (ASSU)	Assomption	15
Astove (AST)	Astove	9
Farquhar (FARQ)	Farquhar	14
Alphonse (ALP)	Amirantes	6
Cap Ternay (CAPT)	Mahé Area	6
Twin barges (TWB)		14
Cerf Is (CERF)		16
Fregate (FRG)	Fregate	10
Praslin APC (PRAS)	Praslin Area	7
Curieuse (CUR)		13
Ile Coco (COCO)		8
Aride (ARI)	Aride Island	14

DNA Extraction and quality control

Genomic DNA was extracted using Qiagen DNeasy PowerSoil Pro Kits (Qiagen, Hilden, Germany) with minor tweaks to the manufacturer's protocol (see Supplementary Material 1) and initial quality was assessed using a Nanodrop[228]. All samples were then sent to Novogene UK for further QC testing before sequencing; DNA degradation and contamination were assessed using agarose gel electrophoresis and DNA concentration was measured using Qubit DNA Assay Kit in Qubit 2.0 Flurometer (Life technologies, CA, USA).

Library preparation and sequencing

The library preparation was carried out by Novogene. Genomic DNA was randomly fragmented by sonication to size of ~350bp, and then DNA fragments were end polished, A-tailed, and ligated with the full-length adapters of Illumina sequencing, followed by further PCR amplification with P5 and indexed P7 oligos. The PCR products were purified with AMPure XP system, checked for size distribution by Agilent 2100 Bioanalyzer (Agilent Technologies, CA, USA), and quantified by real-time PCR. The resulting libraries were sequenced on a single Illumina HiSeq4000 lane (Illumina, San Diego, CA, USA) by Novogene UK, using paired-end 150-bp sequencing reads.

Read Quality Control

FASTQ[229] was used to assess read quality. For each sample Phred score averaged 30-40. The mean error rate for reads was <0.03% in all samples and therefore very few reads needed removal. Reads containing uncalled bases and/or bases of low quality were discarded using default quality

thresholds: (1) adapter-containing reads; (2) paired reads where uncertain nucleotides (Ns) constituted more than 10 percent of either read; (3) the paired reads when low quality nucleotides (base quality less than 5, Q ≤ 5) constituted more than 50% of either read.

Mapping to genome

Burrows-Wheeler Aligner[230] was utilized to map filtered paired-end reads to the *Porites lutea* genome[231]. The Reference genome was downloaded from: http://plut.reefgenomics.org/download/plut_final_2.1.fasta.gz. Resulting bam files were then sorted and indexed, with duplicated reads removed using SAMtools[232] Version 1.

Removing symbiont/holobiont DNA

It is likely that coral dna samples also contained dna from the symbiotic algae and microbiome that live within coral tissue. Due to the difficulties in separating these non-target species during the extraction process, we relied on post-sequencing processes to remove these. Mapping reads to the coral genome and calling SNPs (Single Nucleotide Polymorphisms) from the mapped reads eliminated any sequences of dna that were not from the coral genome. Furthermore we also mapped reads to both the symbiont genome and the holobiont genomes[231] to see what the mapping rate for these were and whether there is potential for additional analysis specific to symbiont diversity. As expected, mapping rate to the *P.lutea* genome was highest, mapping rate to the symbiont genome was lower 9–10% and even lower mapping rate to the holobiont genomes 1–2%.

SNP calling and filtering

GATK[233] was used to call SNPs from BAM files and ANNOVAR to annotate variants. The package VCFtools[234] was used to filter SNPs (Figure 5.2).

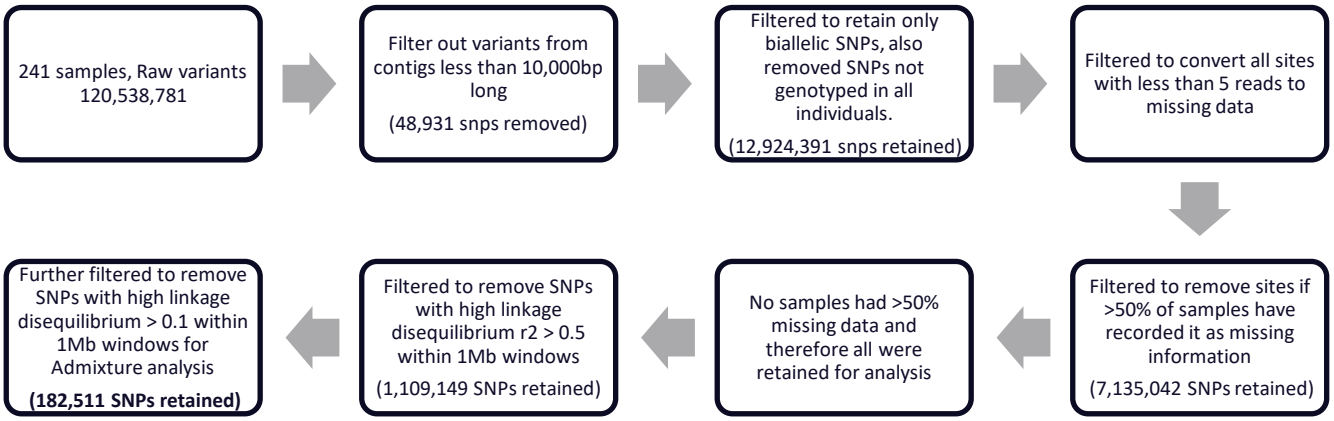


Figure 5.2: SNP filtering process (using VCFtools) from original raw variants to final SNPs retained for analysis

Species verification

We used IQTREE[235] (version 1.6.12) to produce a phylogenetic tree from the snp data of the 241 samples (Figure 5.4a). The tree was rooted using a subset of 21 samples that had >=5% sequence divergence from the reference genome because we did not have sequence data from a known outgroup. These divergent samples were removed from further analysis (See Cluster three in Figure 5.3 & far left of Figure 5.4a).

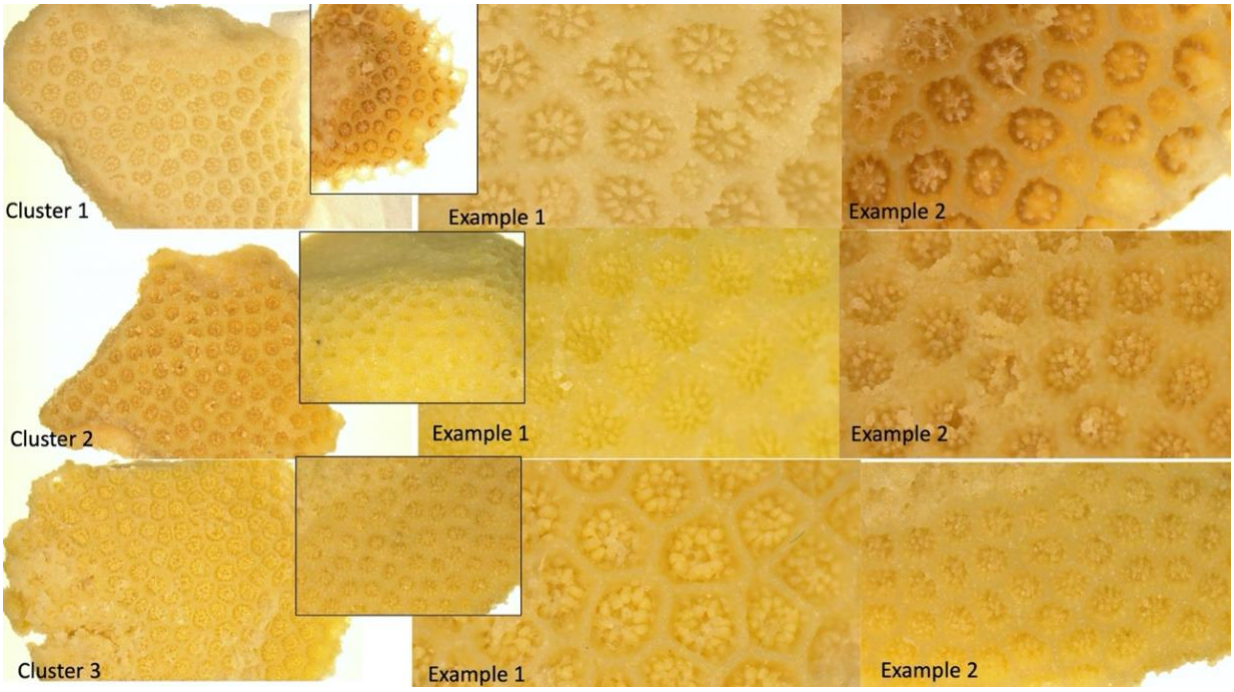


Figure 5.3: Dissecting microscope images (x9/x30) of coral samples from each of the three main clusters identified in analysis.

Population structure analysis

To investigate genetic structure among samples we conducted a Principle Component Analysis (PCA) using the filtered SNP dataset (182,511 SNPs) in the R package SNPRelate[236]. We also examined patterns of population structure by performing maximum likelihood estimation of individual admixture proportions using the program ADMIXTURE[237], testing K values 1–6. For each value of K, we conducted 100 independent runs and summarised runs using CLUMPP v.1.1.2[238]. As the ADMIXTURE manual recommends avoiding SNPs with high linkage disequilibrium, we used the '–indep-pairwise 100 kb 1 0' command in PLINK[239] to remove one of every pair of SNPs with r2 > 0.1 within 100 kb sliding windows (182,511 SNPs).

Gene flow analysis

We evaluated rates and directionality of recent migration using the software BA3-SNPs v1.1.0[240], a modification of BayesAss[241] that allows handling of large SNP datasets. We first assessed the optimal mixing parameters for migration rates (for each sample set), allele frequencies, and inbreeding coefficients by running ten repetitions in BA3-SNP-autotune V 3.0.4 as recommended by Mussmann et al. (2019). Subsequently, 10 runs of BA3-SNPs were performed using with the optimised parameters, 10^7 iterations, a burn-in of 10^6 and a sampling interval of 100. Convergence of the chains was then validated using Tracer v1.6[242], and an average of the gene flow estimates across runs was then calculated. For this analysis, samples were grouped not by specific sampling site but by the broader area, to ensure high samples sizes as suggested Meirmans[243]. Specifically, the samples were grouped by island/area except for the Aldabra reefs where samples were grouped based on which coast they were on or which side of the lagoon due to greater distance between sites and the different oceanographic conditions operating at these sites e.g. lagoon vs outer reef.

5.3 Results

Sequencing and bioinformatics

The mapping rate of samples to the 552,020,673 bp *P. lutea* reference genome ranged from 55% to 92% (mean 87%), mean sequencing error rate was 0.02% and read quality was high (Phred ≥30). The average read depth obtained was 10X. Of the 241 samples collected in Seychelles, 220 were retained for analysis based on their phylogenetic distribution (Figure 4a). The remaining 21 samples had >=5% sequence divergence from the reference genome and were therefore potentially another species of *Porites*.

Inbreeding coefficients

To avoid collecting samples that were potentially clones we sampled colonies that were over 5m apart, however there is still a risk that we collected potential clones. To check this, we have calculated the inbreeding coefficient for each sample site/group. A low inbreeding coefficient means a low level of inbreeding. As shown in Table 5.2, all sites have very low inbreeding coefficients and as such the absence of clones is verified.

Table 5.2: Inbreeding coefficients for samples within each cluster (identified in Fig. 5.4a) at each sampling location, calculated using BA3-SNPs v1.1.0[240] software.

Site/Group	Fstat Blue Cluster	Fstat Green Cluster
Alphonse Fstat	0.0014(0.0016)	0.0200(0.0157)
Farquhar Fstat	0.0009(0.0019)	0.0083(0.0080)
Astove Fstat	0.0000(0.0000)	0.0167(0.0112)

Cerf Fstat		0.0023(0.0065)
MaheArea Fstat	0.0000(0.0000)	
TwinBarges Fstat		0.0069(0.0055)
PraslinArea Fstat	0.0010(0.0019)	0.0000(0.0000)
Assomption Fstat	0.0004(0.0008)	0.0065(0.0077)
Aldabra Outer Reef Fstat	0.0000(0.0000)	0.0000(0.0000)
AldabraLagoon Fstat	0.0000(0.0000)	0.0067(0.0076)
Fregate Fstat	0.0004(0.0010)	
Aride Fstat	0.0005(0.0008)	0.0042(0.0039)

Population structure

Maximum likelihood estimation of individual ancestries calculated with ADMIXTURE (Alexander et al. 2009), consistently provided the lowest cross-validation error for K = 2 (mean cross-validation error across runs = 0.237), i.e the most likely number of genetic clusters was two. Based on the 220-sample set, both the PCA (Fig 5.4b) and the maximum likelihood estimation of individual ancestries (Fig 5.4c) grouped samples into two distinct clusters. The samples in each cluster identified by ADMIXTURE and the PCA correspond to two clades in the phylogeny (the blue and green clades in Figure 5.4a). The two clusters were not composed of samples with any clear geographical structure; with a mixture of samples from the inner and outer islands in each (although some samples collected inside the Aldabra lagoon formed clear outliers within cluster 1; Fig 5.4b). At a finer spatial scale, some samples from a given site were entirely assigned to one cluster, while others were entirely assigned to the other, with just 30% of samples having mixed ancestry (see Figure 5.4c). This suggest that, rather than being two separate

populations of one species of *P.lutea*, the samples within each cluster may belong to two separate species of *Porites*. However, a lack of comparative data on genetic distances estimated for corals or other invertebrates in relation to taxonomic separation hinders our ability to conclusively interpret these data as two species and therefore all possible options are explored.

Consequently, the sample set within the two clusters were re-analysed in case the two clusters identified in Figure 4a-c are different species, to see whether this resulted in clearer geographical clustering. Hereafter they are referred to as ‘blue cluster’ and ‘green cluster’ (as per Figure 5.4a). For both these clusters the maximum likelihood estimation of individual ancestries calculated with ADMIXTURE, consistently provided the lowest cross-validation error for K = 2 (blue cluster = 0.200; green cluster = 0.347). The Admixture plots for both the blue cluster (130 samples; Figure 5.5a–b) and the green cluster (78 samples; Figure 5.5c–d) show much clearer geographical patterns, mostly separating the inner and outer islands of Seychelles into two more distinct populations. There are also differences in population structure: 74% of samples in the blue cluster have mixed ancestry while in the green cluster this value is only 21% (Figure 5.5). Within the blue cluster, Astove appears to be more closely connected to the inner islands, despite being the most southerly site and over 1000 km away. In addition, the samples from the west lagoon on Aldabra are more closely related to other samples from Aldabra, while samples from the east lagoon have a higher proportion of admixture and shared ancestry with samples from the inner islands. The PCA produces a similar result, with samples from the east lagoon and a few from the west lagoon forming an outgroup (Figure 5.5b). In contrast, none of these patterns are observed in the green cluster, which

shows minimal admixture between populations, except at Cerf island off the coast of Mahé.

Gene flow

To estimate gene flow, we initially used the full sample set of 220 samples, but by lumping individuals of potentially different species together (i.e blue and green clusters), we may have over- or underestimated gene flow and therefore have re-run this analysis for the blue and green clusters separately (Figure 5.6). As such the groupings were slightly different, maximising spatial resolution where sufficient sample size allowed. For example, the Aldabra outer reef sites were not grouped into north or south coast for the blue cluster whereas the fewer samples in the green cluster meant the sites needed to be grouped to ensure the analysis was robust.

BayesAss analyses showed that self-recruitment was high at all sites for both the blue and green clusters (70%–86% of nonmigrants; Table S5.1). For the pooled sample analysis (Figures 5.6A & D) the two main larval sinks apparent are Mahé area and the north coast of Aldabra but all islands/sites receive some larvae from external sources. There is significant migrant exchange from Aldabra north coast, Aldabra south coast and Aldabra east lagoon to the Mahé area, likewise from Astove, supporting the idea that ocean currents can move larvae from the outer to the inner islands.

Analysis of the blue cluster shows fairly low but uniform migrant exchange between all sites (1.2<3%; Figure 5.6B & E) with the lowest migrant exchange (<1.2%) from the Mahé area, Aldabra West Lagoon and ARM06

(Aldabra North-West coast). However, when looking at the total gene flow from Aldabra to the inner islands, it clearly dominates other sources (Figure 5.6B & E, lime green arrows). Within-site gene flow was 72–84%.

In contrast, the green cluster has greater migrant exchange from the outer islands to Cerf Island (<8%; Figure 5.6C & F), particularly from Assomption, Astove, Aldabra north coast, Aldabra south coast, and Aldabra east Lagoon. The lowest levels of migrant exchange were from Cerf Island and Curieuse Island.

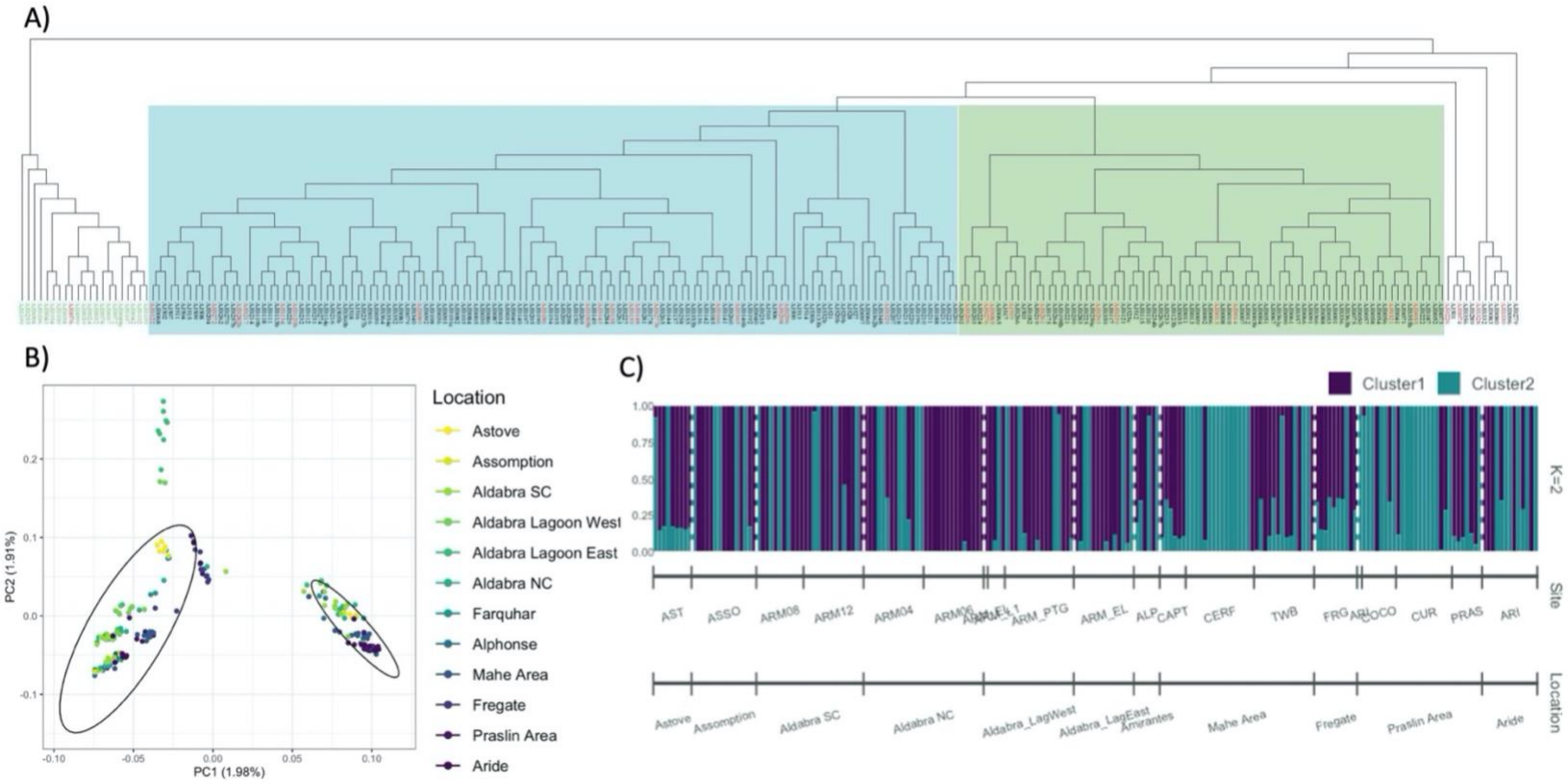


Figure 5.4: Population structure of 220 samples of Porites cf. lutea in the Seychelles archipelago: (A) phylogenetic tree based on SNPs of all 241 samples collected; (B) principal component analysis of genetic variation in P. lutea based on 182,511 LD-filtered SNPs, the variance explained by PC1 and PC2 is 1.98% and 1.91% respectively. Ellipses plotted based on population assignment from admixture for K=2. Sites are coloured lightest in the southern Seychelles, darkest in the northern Seychelles and; (C) Maximum likelihood estimation of individual ancestries calculated with ADMIXTURE (Alexander et al. 2009) testing K values 2 based on 182,511 LD-filtered SNPs (Mean cross-validation error for 100 runs of ADMIXTURE: K2= 0.237).

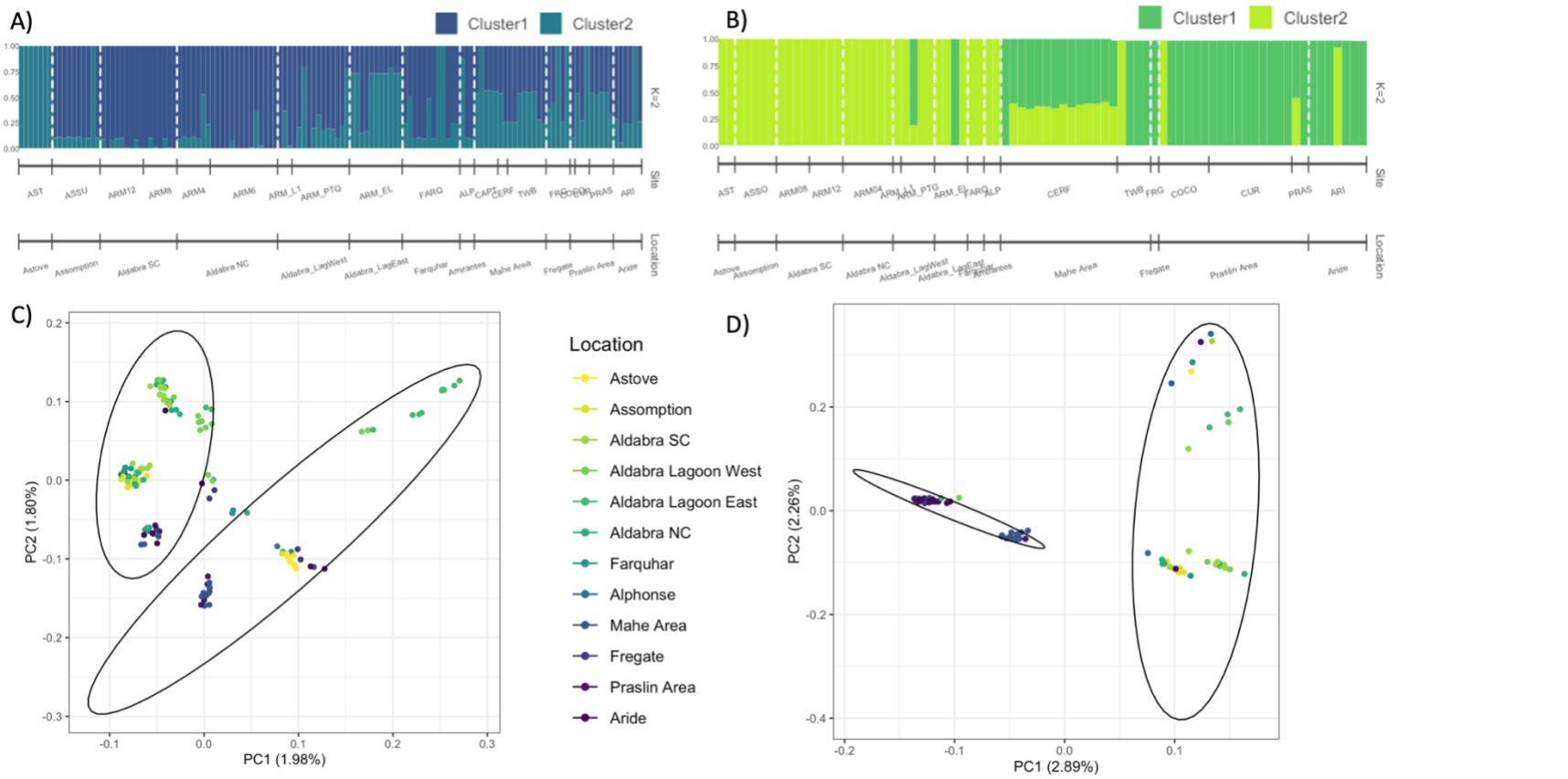


Figure 5.5: Population structure re-analyzed splitting Porites cf. lutea into two clusters (blue cluster and green cluster) identified in Figure 5.3a: Maximum likelihood estimation of individual ancestries calculated with ADMIXTURE testing K = 2 based on 182,511 LD-filtered SNPs for (A) Blue cluster (130 samples; mean cross-validation error for 100 runs of ADMIXTURE: K2= 0.200) and: (B) Green cluster (78 samples; mean cross-validation error for 100 runs of ADMIXTURE: K2= 0.347); and principal component analysis of genetic variation based on 182,511 LD-filtered SNPs in (C) Blue cluster (the variance explained by PC1 and PC2 is 1.98% and 1.80% respectively) and: (D) Green cluster (the variance explained by PC1 and PC2 is 2.89% and 2.26% respectively). Sites are coloured lightest in the southern Seychelles, darkest in the northern Seychelles.

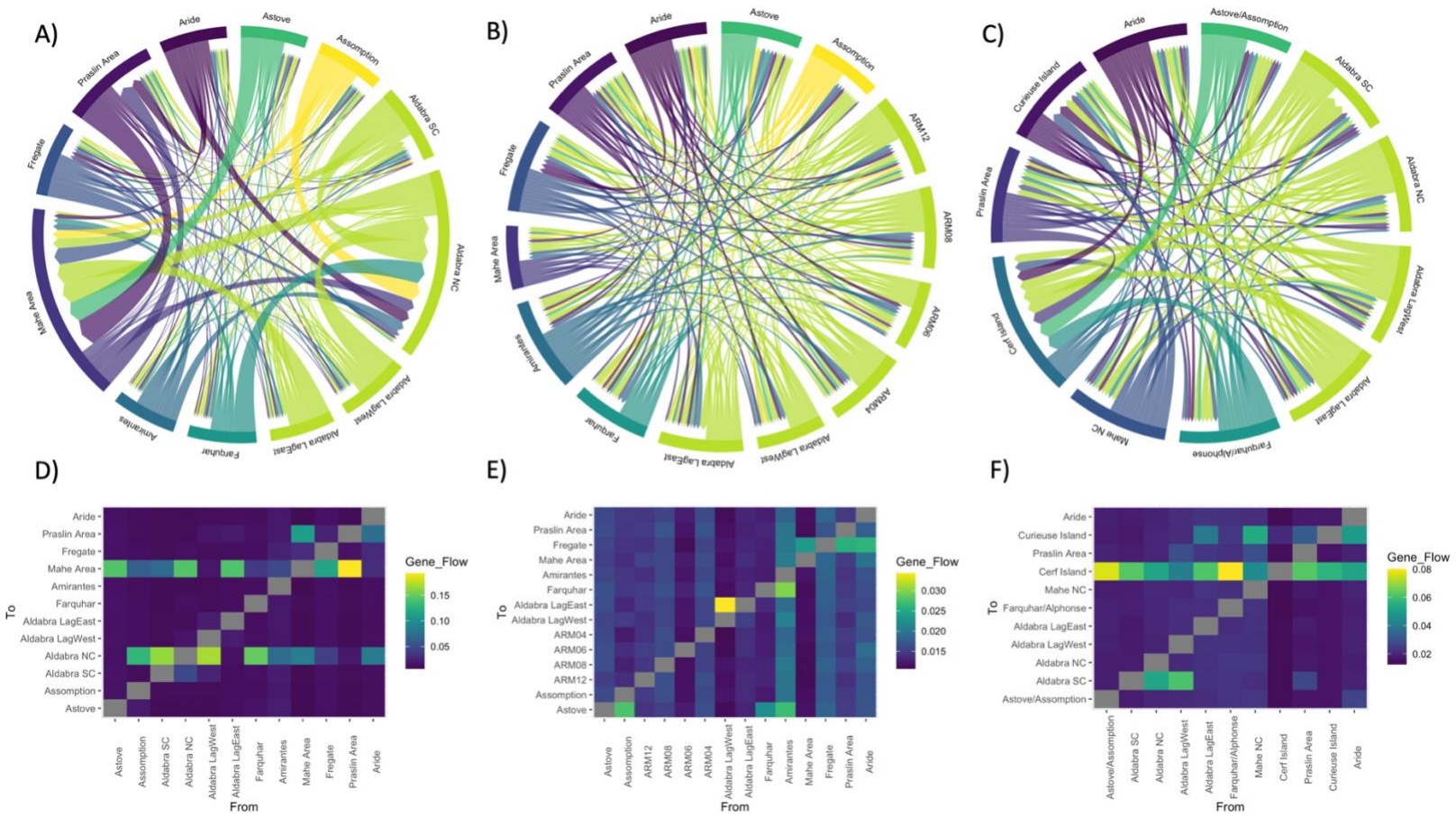


Figure 5.6: Contemporary gene flow estimates (m) were derived from BayesAss: chord diagram showing significant gene flow between island groups/sites for (A) Full 220 sample set, (B) Blue Cluster, (C) Green Cluster (arrow direction represents the direction of gene flow from one region to another. Arrow width denotes the relative amount of gene flow; i.e., the wider the arrow, the more gene flow) and heat diagram showing all between site pairwise gene flow estimates for (D) Full 220 sample set, (E) Blue Cluster, (F) Green Cluster (Note: Different scale on heat diagrams and different site groupings used in green and blue clusters in order to maximise sample numbers per grouping while retaining as low a geographical resolution as possible).

5.4 Discussion

This research marks the first coral reef connectivity study for the Seychelles archipelago using a genomics approach to inform local management. We found genetic connectivity between the inner and outer island groups, indicating that long-distance migrant exchange and dispersal occurs across the Seychelles. Important source reefs from the outer islands include those at Aldabra, Assomption, Astove and Farquhar, and these reefs potentially play an important role in the persistence of coral in the Mahé area. Furthermore, our analysis broadened our knowledge of the species delimitation of *Porites* cf. *lutea*, indicating that there are possibly three *Porites* species in the original dataset. Two of which we included in analysis and treated separately and these showed different population structure and levels of gene flow.

Connectivity between inner and outer islands

Despite a previous modelling study predicting that no coral larvae released from Aldabra would reach the inner granitic Seychelles[101], or *vice versa*, our analysis shows substantial admixture between the inner and outer island reefs in Seychelles for both putative species (blue and green clusters). The majority of migrant exchange was from the outer islands to the inner Seychelles, especially from Aldabra, likely as a result of dispersal via the East African Coastal Current and the South Equatorial Counter Current[222] and occurring from November when spawning peaks at Aldabra[223] (see figure S5.1). We also found, to a lesser extent, migrant exchange from the

inner islands to Aldabra, which is most likely to occur during the South-East monsoon season (May – October) via the southwards Ekman transports (the motion of surface water away from the equator as the result of a balance between Coriolis and prevailing winds) operating at that time (see figure S5.2). This may also coincide with peak spawning events in the inner islands which are thought to occur between Feb to May[244], however further research on peak spawning times in the inner Seychelles would help to clarify this.

While our gene flow clearly showed important larval sources it is also prudent to look at the reefs acting as larval sinks. Sink reefs may not be as crucial for coral regeneration, but they can be important repositories of genetic diversity, especially where they receive inputs from multiple sources[245] as is the case for Cerf Island in the Green cluster. As such, sink reefs may also act as important stepping-stones of genetic diversity; for example, Aldabra receives a high level of gene flow from all the outer island reefs, but Aldabra is also an important source reef for the inner islands and therefore a portion of the genetic diversity it receives is then spring-boarded to other reefs. Aldabra appears to be operating much like a hub airport, with larvae arriving from all over and dispersing larvae far and wide. This is supported by previous modelling research showing that Aldabra disperses larvae toward the Comoros Basin and East African coast[101]. In particular Aldabra had one of the highest 'betweenness centrality' scores in the region[101] (the number of times a site acts as a stepping-stone along the shortest path between two other sites), indicating its importance as a coral larval source site beyond the

Seychelles. The level of connectivity observed in this research is comparable with studies of *Porites. spp* over a greater geographical range in the South China Sea[246], and a much smaller geographical area in the Singapore Straights[247].

Population Structure and Reproductive Strategy

There are clear differences in the level of admixture between the blue and green clusters and yet it's difficult to assign a reason for these differences. The greater admixture seen in the blue cluster suggests this 'species' may have greater dispersal potential than the green cluster. While little is known about the pelagic larval duration in *Porites*, broadcast spawning species like *P. lutea*[248] generally have longer pelagic larval duration than those of brooding corals and these differences in levels of admixture could mean differences in spawning strategies. However, as both 'species' have some amount of gene flow to the inner islands it is likely they both have relatively long pelagic larval durations and are therefore more likely to have a broadcast spawning reproductive strategy.

It is important to note that due to their shorter pelagic larval duration, brooding corals are more reliant upon self-seeding for their long-term persistence, i.e. a reef is unlikely to receive larvae of brooding corals from distant reefs. For example, in modelling studies using shorter pelagic larval durations as would be expected in brooding species (5 days), reefs at Aldabra were completely disconnected from the wider region[101]. It is

therefore likely that under current pressures and future predictions, brooding corals may not benefit from management actions that aim to conserve 'source reefs', unless those reefs are relatively close. This is an important consideration when using connectivity research for marine spatial planning designation. For example, as a result of previous bleaching events, the inner Seychelles has reduced richness and diversity of coral and there are fewer bleaching-tolerant taxa[249]. Therefore, while the inner islands may receive larvae of broadcast spawners from the outer islands, they are unlikely to receive much incoming larvae from brooding species and so determining the most highly connected and healthy source reef within the inner islands would be important to promote greater brooding species recolonization of the inner islands.

The role of Aldabra Atoll in coral connectivity

One interesting finding was the relatively large spatial variability in connectivity found within Aldabra's reef sites, predominantly apparent in the blue cluster. For example, the east lagoon site has is a greater larval source than the west lagoon and some of the seaward reefs. This could be a consequence of the highly dynamic tidal system which shows substantial spatial variation throughout the lagoon[250]. The atoll's main islands are split by four narrow channel systems which, together with the large tidal range (sometimes exceeding 3 m), create some of the fastest currents in the world (>7 knots)[250]. The tidal dynamics vary considerably between neap and spring tides and even spatially, with amplitudes reducing into the lagoon with

increasing distance from channel mouths. This difference in connectivity between the east and west lagoon sampling sites could be explained by the west lagoon site being >1 km further from a channel mouth then the east sampling site, although this site is situated near the main channel, where the most tidal flushing occurs.

Recent research on coral recruitment from a site close to our west lagoon sampling site recorded recruit abundance to be seven- to 47-fold higher than at a seaward site and was substantially higher than those reported at other lagoonal reefs[223], suggesting that the west lagoon site could have higher self-recruitment than other areas. Sites that have high self-recruitment are considered to have high conservation value[245] because they are more genetically distinct. The fate of larvae released in the lagoon is dependent on the timing of the tidal and lunar cycles. As corals are known to spawn with the full moon phase[251,252] it is probable that the Aldabra lagoon corals spawning coincides with the strongest tides, maximizing their chances of escaping the lagoon (during neap tides the lagoon is virtually tideless[250]). However, there is evidence that spring tides within enclosed lagoons like Aldabra are subject to local variations and ponding effects, which may lead to areas of isolation[253]. Such ponding effects *could* increase local retention of larvae. However, since we do not have such fine-scale information available for Aldabra lagoon, and as our results show similar levels of within-site gene flow (67 – 70% across all sites; Table S1), we cannot make further conclusions about the differences in connectivity between the east and west

lagoon sites, especially as these differences are not apparent in the green cluster.

One other point worth discussion was the small outgroup of samples from the Aldabra lagoon apparent in the blue cluster. This outgroup mostly consisted of samples from the east lagoon but two also from the west lagoon. One of the reasons we sampled so extensively at sites inside and outside the lagoon was because recent evidence suggested that the Aldabra lagoon reefs are less susceptible to coral bleaching[217,218] and recover more rapidly[218] than seaward reefs due to the high temperature variability they are subjected to. While our research does not explore this, the outgroup we have identified does support the idea that there are genetic differences within lagoon colonies and further investigation of these data could enhance our understanding of the unique and potentially vital properties of the lagoon corals. Additionally, it is not only high frequency temperature variability that the Aldabra lagoon corals are uniquely exposed to; depending on the colony depth, corals are exposed to high levels of solar radiation, some being entirely exposed at extreme low water (A.J. Burt. pers. comm.). Early research on tidal regimes at Aldabra showed that extreme low water levels occur around 13.00 and 01.00, the former time being when solar radiation is most intense, and this is unique to Aldabra when comparing timing of extreme low water at other atolls in the region[253].

Considerations for Management and Future Research

When selecting our study species, we used the web resource ‘Corals of the world’ to identify to what extent *P. lutea could* be confidently identified *in-situ*. Of the three species identified on the web resource as morphologically similar, all except *P. lobata* were deemed sufficiently morphologically distinct not to be confused. Our phylogenetic tree clearly shows three clusters, one of which was genetically distinct enough to be removed from analysis, but all were morphologically similar enough to be identified as one species when conducting in-situ collections. Even with microscope work it was not possible to tell the samples from these three clusters apart (Figure 3). It is therefore possible that of the samples we collected we have a cryptic species complex. Accurate population genetic measurements, especially the assessment of gene flow, require cryptic species identification in corals [254], an important consideration for such studies and why we decided to analyse the blue cluster and green cluster separately.

The discrepancy between previous coral connectivity modelling research and our empirical results could be due to a number of things. Firstly, because we haven’t included the full regional reef system there is a possibility that the observed gene flow between the outer islands and the inner islands is not direct, it may be secondarily received from another site that is receiving high levels of larvae from the outer islands, for example sites on the east Africa coast. Alternatively, the model used isn't accurately reproducing the physics – or the biology – required to explain the transport of coral larvae, and this

could be attributed to a whole raft of factors, including insufficient spatial resolution or insufficient virtual larvae to capture low-probability long-distance dispersal events. Our results suggest that, to date, oceanographic modelling research to predict connectivity in the region has not been capable of predicting the evident connectivity between the inner and outer Seychelles. We therefore suggest that future modelling is done at higher resolution, using multi-decade and seasonal tracking to detect and capture these locally and regionally relevant corridors of connectivity. Once genetic results and modelling results more clearly align, modelling approaches will provide more relevant national and regional management information.

5.5 Conclusion

We have identified the general pattern of coral connectivity across Seychelles, information which could be used to strengthen or expand protection, or to select sites where active management would have the greatest impact towards promoting reef persistence. Additionally, while our research used coral as the focal species, the results are relevant to a wide range of commercially and ecologically valuable marine species with a pelagic larval stage, including reef fish, sea cucumbers, crabs and lobsters. Our results show that obtaining local-level information on coral reef connectivity that is highly relevant to management is possible even at a within-island scale. With greater resources and access to collect data from all the main islands in Seychelles (e.g. Cousin, Cousine, North, Silhoutte, Cosmoledo, Bird etc) a greater level of detail could be obtained that would

be highly relevant even to site-level management in order to make conservation actions more effective. Coupling these data with existing information on reef-scale projections of future coral bleaching conditions[216] and reef resilience assessments – of which few exist – could be used to adaptively manage the Seychelles Marine Spatial Planning zones, strengthening the management of the Seychelles coral reef system against the oncoming impacts of climate change.

5.6 Chapter Acknowledgements

We wish to thank the many people who assisted in big ways and small to getting fieldwork underway in Seychelles, especially to the free rides and dives onboard boats/ships provided by Le Ponant, the Seychelles Islands Foundation and the Seychelles National Parks Authority and the Marine Conservation Society Seychelles. We would also like to thank Luigi Colin at the Zoological Society of London for providing training in coral DNA extraction, plus Jude Brice, Cheryl Sanchez, Joel Bonne, Remie Asman, Anto Suzette, Cliff Emile, Bernard Bijoux, Nathalie Bodin, Gilberte Gendron, Victoria Beasley, Nasreen Khan and all the staff at SIF Seychelles for their assistance in sample collection. Finally, we wish to thank Liang Xu for programming assistance during data cleaning. A huge thanks to Jake Letori for producing the map for this chapter. The research was supported by the NERC environmental research doctoral training programme at the University of Oxford (Grant NE/L002612/1) with additional funding for the genetic sequencing by the Seychelles Climate Change Adaptation Trust (SeyCCAT).

Author contributions

AJB & LAT designed the study; AJB collected the samples, conducted the lab work under the guidance of CH, and analysed the data under the guidance of ASP, SC, SK. AJB prepared the figures and wrote the first draft of the manuscript, and all authors provided input and comments to later drafts.

CHAPTER 6

"The fact is that no species has ever had such wholesale control over everything on earth, living or dead, as we now have. That lays upon us, whether we like it or not, an awesome responsibility. In our hands now lies not only our own future, but that of all other living creatures with whom we share the earth."

— David Attenborough, Life on Earth



6.0 General Discussion

At first look, this thesis may appear to be a random suite of studies that have been loosely tied together under the umbrella of improving the management of island ecosystems. However, as a former employee of Seychelles' public trust, the Seychelles Islands Foundation and as a CASE partner with them throughout my Ph.D., these chapters all stem from and address specific needs identified and communicated directly from these frontline conservation practitioners and together we co-developed the research questions that culminate in this work. Broadly speaking this thesis has enhanced our understanding of the main barriers and solutions to more effective island ecosystem management as well as filling key information gaps that are

necessary to better inform local and national management (and potentially also national policy) of two threats to island ecosystems in the Seychelles: plastic pollution and climate induced coral mortality events.

6.1 Main Findings

Specifically, in chapters two and three of this thesis I generated a comprehensive list of barriers to island ecosystem management, which if bridged could make a huge impact towards achieving more effective management of island ecosystems at a range of scales. By defining them as collective issues, identifying which are most prevalent, and which have the most impact on management effectiveness and outlining solutions, we now have a greater baseline of evidence to provide incentive for action, especially as a guide for where funding and investment of resources could have the greatest impact.

In chapter four I provide the first quantification of the resources– both human and financial– that are required in SIDS plastic pollution clean-up, as well as furthering our understanding of the role that industrial fisheries play in plastic pollution impacting island ecosystems in the Western Indian Ocean (WIO).

Finally, in chapter five, by conducting the first genetic coral connectivity mapping research within the Seychelles and identifying important source reef sites, our understanding of regional connectivity has been enhanced, showing the first evidence of coral connectivity between the outer and inner

islands despite their geographic distance. This further supports the extension of MPA coverage now afforded to the Aldabra Group and lends support to potential further commitments of sites currently not included in the MPA/MSP framework.

6.2 Dissemination of Results

As one of the main aims of this thesis was to overcome barriers to information being used for management and policy, I spent time ensuring the information generated thus far (from published chapters) is disseminated in informative and understandable formats. For example, for both the interviews (chapter 2) and plastics (chapter 4) publications I sent a short and simple summary of results to relevant practitioners and government officials within the WIO region. I have also spent time generating visual abstracts (Figure 6.1) and blogs and shared these widely on social media. In conjunction with these efforts I also contributed to a blog describing '5 ways to get your conservation message to where it's needed (and avoid colonial science)'.

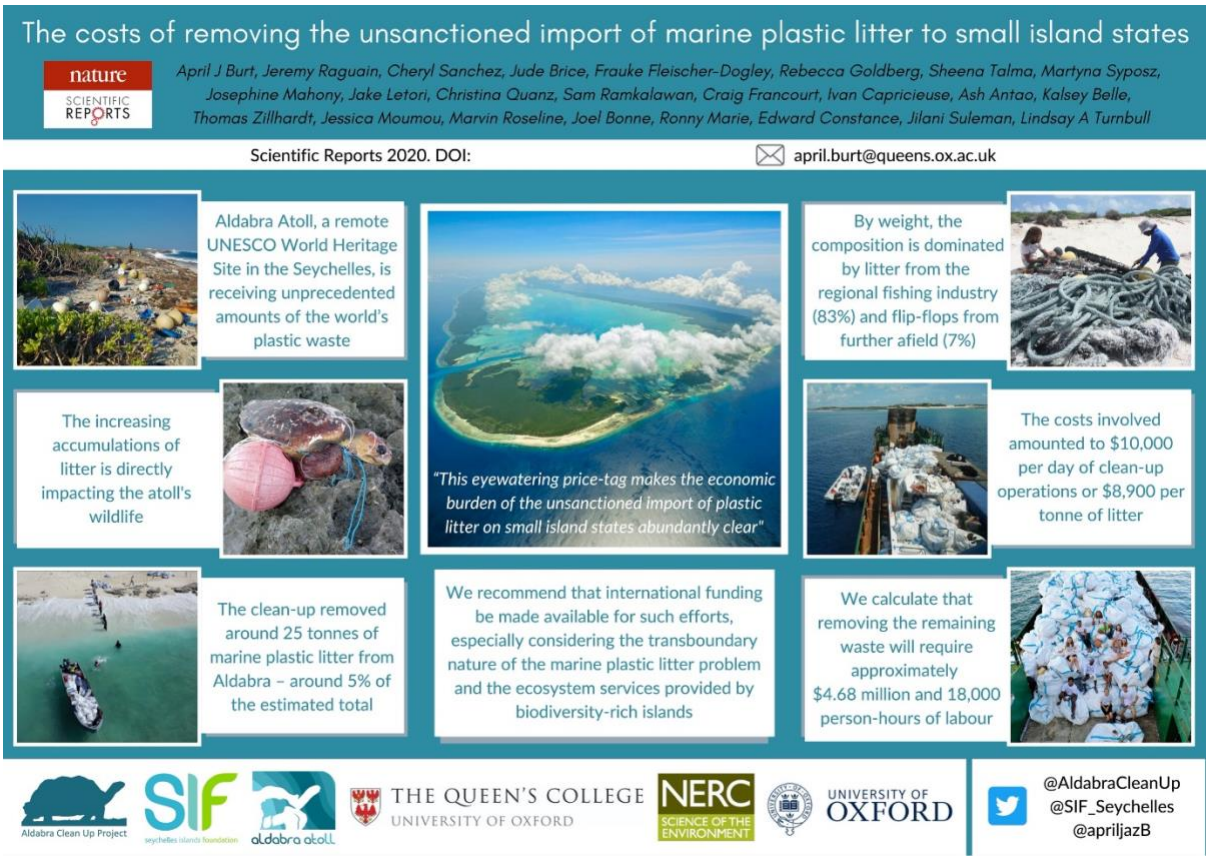


Figure 6.1: Visual abstract used to disseminate information from chapter four

6.3 Research Impact So Far

The first chapter to be published was chapter four on the costs of plastic pollution clean-up at Aldabra (published September 2020). This research was part of a broader project called the Aldabra Clean-Up Project (ACUP), a collaboration between the Seychelles Islands Foundation and The Queen's College at Oxford. The project was launched in mid-2018 and, aside from the research, involved fundraising, education and awareness, social media

campaigns and eventually a large-scale clean-up expedition in Feb/March 2019. The project was the highest profile plastic pollution campaign in the Seychelles, supported by the Seychelles government and championed by then President Danny Faure. Impact from this project included:

- The President of Seychelles highlighted the issue to other world leaders at the G7 summit in 2018 using images from the Aldabra Clean-Up Project media campaign. This led to pledged financial support to island nations such as Seychelles to tackle the issue of plastic pollution.
- 25 tonnes of plastic pollution was removed by the team from key turtles nesting beaches on the south coast of Aldabra during the expedition, which was covered live by Sky News and broadcast to millions of viewers worldwide, followed by a Sky News documentary about Aldabra and the plastic problem also broadcast globally.
- The research was published in the journal Nature Scientific Reports ("*The costs of removing the unsanctioned import of marine plastic litter to small island states*") and received further news coverage worldwide (altmetric 282) including coverage on Sky News and other mainstream media outlets such as The Times, Mongabay, Unilad, Mail Online and The Metro amongst others. The paper was also in the top 100 most downloaded from that journal for 2020, despite only being published in September.
- The research findings showing the huge proportion of waste coming from the industrial fishing industry contributed to the Seychelles

acceding to the additional annexes of the MARPOL convention and so has directly influenced policy (Mr. Alan Renaud, Principal Secretary for Civil Aviation, Ports and Marine).

- The research article triggered discussions within the Seychelles Climate Adaption Trust (who partially funded the project) who have, as a result, revised their funding priorities, to invest more into projects involving waste management, recycling, and efforts to implement a circular economy for plastics (pers. comm., former SeyCCAT CEO, Angelique Pouponeau).
- In addition to the Sky News Coverage the team also put together a documentary that was broadcast on national television in Seychelles and played in schools in Seychelles, Germany, USA and UK.
- As a direct result of the high coverage of our results, including through the UNESCO World Heritage media channels, SIF has been approached by major funders who are interested in investing in a full-scale clean-up of Aldabra.
- As a result of recommendations made, the SIF has adopted monitoring of plastic pollution accumulation rates and built plastic holding stations to enable small clean-ups to be made along the south coast and trash to be housed until a pick-up of trash is possible.
- By highlighting the huge contribution of industrial fishing to marine plastic pollution, specifically Fish Aggregating Devices (FADS), this research was used in a call to the Indian Ocean Tuna Commission to

curb the use of destructing drifting FADs and negotiations are ongoing.

Chapter two (Defining and bridging the barriers to more effective conservation of island ecosystems: A practitioner's perspective) was published in November 2021 and was featured in media articles for the University of Oxford, Seychelles Nation and wider afield. The article has so far achieved an Altmetric score of 37 and was added to the Convention on Biological Diversity Knowledge Base site. It was also featured in the Global Conservation News summary on the World Commission on Protected Area site and on the Environmental News Network. The study was also presented at the Seychelles Ocean Science Symposium in November 2020. As a result of the dissemination of this study and the discussions it generated, several organisations have started addressing specific barriers. For example, by developing and implementing research strategies and investing in improving data management. Another possible impact link was a round-table discussion about how to bridge the science to policy interface, hosted by the Seychelles Climate Adaptation Trust, where I was able to share the main results of the study, namely the lack of government coordination. This resulted in the proposal to establish an annual science-policy symposium/meeting in Seychelles. Additionally, a local Seychelles NGO celebrated the work in a newspaper article, highlighting the positives described in the paper. Further impact is planned through promoting and implementing the recommendations outlined in the next section.

6.4 Management Recommendations

The following recommendations are made with Seychelles in-mind but the majority can be applied to many island nations or biodiversity conservation sites.

Table 6.1: Management recommendations based on the findings of this thesis

Chapter	Aim	Recommendation/s
2	To promote great value and effectiveness in funder-driven capacity building requirements and ensure local needs are met	Funders and research permit providers should apply greater scrutiny when reviewing project proposals, specifically on the intrinsic value/quality of capacity building components to projects. This could be achieved by implementing a standardized assessment document co-designed by practitioners across levels of management.
2	To remediate poor data management	• Invest in creating specific roles for database management. • Ensure data share agreements are in place for all collaborations • Design databases to facilitate analysis • Develop data management protocols to ensure knowledge transfer when staff change

2	To ensure research/monitoring inform management and management needs drive research and monitoring	Invest in creating 'bridging positions' for high-capacity post-graduates who are able to critically review and implement science/research strategy etc.
2&3	To increase the capacity of graduates to work in the environmental/conservation sector and institutional capacity to enhance management effectiveness.	• Develop key modules for inclusion in existing undergraduate and post-graduate courses that tackle the current capacity gaps identified by practitioners. • Develop an MSc in island ecosystem management that specifically addresses the current gaps in capacity. • Focus funding on designing targeted capacity building training courses in the skills most commonly lacking according to practitioners; data analysis, data management and leadership skills. • Conduct organisation/department level capacity gap analysis to obtain fine-scale information that can be used to target training resources.
2	To promote a greater culture of science-based management	• Invest in national level research via a research institute that solely facilitates and coordinates national level research strategy. • Implement a science and policy annual symposium to bring together practitioners and policy makers.

2 & 3	To promote greater alignment of local and national research and management efforts, create greater transparency and enhance collaboration and management connectivity across sites/organisations	• Mandate regular reporting and facilitate regular knowledge/information sharing platform via a government-led annual research symposium. • Government should invest time and resources in creating and implementing communication forums for each target sector (e.g. fisheries, coral reefs, native forests etc) bringing all relevant practitioners together, to ensure individual management objectives link to national objectives.
2	To promote greater staff welfare and satisfaction and retain key staff	• Invest in incentive schemes for staff • Allow greater flexibility e.g. through flexible work hours/locations • Actively facilitate and staff training and career development opportunities.
2	To achieve greater leadership and therefore more effective management:	Invest in specific, targeted, and accessible environmental leadership courses for practitioners.
3	To alleviate issues with operationalizing national target commitments as seen with the Aichi targets	The new Global Biodiversity Framework (GBF) must include a roadmap that guides those implementing the NBSAPs all the way down to project/site level collaboration and communication, with clear, tangible guidance on how to coordinate, monitor and report efforts and avoid the barriers we have described.

3	To reduce the prevalence of ineffective/poorly designed monitoring programmes:	Develop a training course on the design of monitoring programmes and how they can be linked to and inform management objectives and actions. Incorporate this into undergraduate and post-graduate environmental education courses or stand-alone targeted training of staff within organisations/departments.
3	To reduce unhealthy behaviours interfering with management effectiveness	• Develop specific codes of conduct and integrate procedures for dealing with behavioural issues • Promote conversations about staff behaviour, targeting those behaviours that are most prevalent/detrimental. • Promote the ethos of inclusion and equality across staff levels. • Develop strategies for dealing with the barriers created by interpersonal relationships.
2&3	To enhance effective management of biodiversity	• Diversify funding calls to beyond simply funding active conservation/management actions, focussing instead on strengthening the people and systems on which management effectiveness relies. • Greater bottom up led funding decisions • Longer term projects and funding cycles

4	To increase awareness of and investment in plastic recycling and circular economy options	• Commission a scoping and feasibility study to investigate the options/solutions implemented elsewhere and how these could be replicated/used in Seychelles (other SIDS). • Create a priority list of which of these options could be implemented and promote these ideas to local investors.
4	To enable large-scale clean-up of Aldabra	• Invest in improving the on-site infrastructure such as water-catchment systems and field camp capacity to enable teams to be stationed for longer periods in the field.
4	To facilitate the implementation and enforcement of the MARPOL convention	• Greater scrutiny and transparency of the industrial tuna fleets use of FADs (e.g. via access to FAD location data). • Implement standard penalties for FAD loss in MPAs that are equivalent to environmental damage and provide enough of an incentive for the industry to make greater effort towards reducing FAD loss and impact. Such compensation schemes exist and there are precedents for implementation for damage and loss associated with coral reef ecosystems[255].
4	To increase funds available for clean-up and environmental restoration	Enact the 'polluter pays' principle whereby funds are leveraged from countries/companies that are evidenced to be the greatest polluters.

4	To ensure clean-up efforts are not simply moving the problem from one island to another	Ensure viable waste management pipelines are in-place before large scale clean-up.
5	To improve the value of oceanographic current modelling studies	Invest in research using high-resolution models, using multi-year and seasonal tracking to detect locally relevant levels of connectivity. Once genetic results and modelling results more clearly align, we can put greater trust in modelling approaches to provide relevant local scale management information.
5	To improve the effectiveness of management of Seychelles marine ecosystems	Incorporate connectivity into the MSP and if necessary, review and revise the current MPA coverage based on these finding.
5	To improve the effectiveness of coral reef restoration efforts	Use connectivity information to choose restoration sites where efforts could have the greatest impact.

6.5 Future Research Recommendations Generated from this Thesis

1. Generate location specific information on capacity limitations to enable more targeted capacity building and fund allocation.
2. Monitor and analyse the effectiveness of targeted capacity building exercises to determine what meaningful ‘capacity building’ really entails.
3. Implement a nationwide study of accumulation rate of plastic pollution into coastal ecosystems in order to better understand the quantity/scale of the effort required to maintain plastic free island ecosystems.
4. Generate information on the true environmental costs of plastic pollution in marine and terrestrial island ecosystems and how this translates to financial costs in relation to loss of ecosystem services. This research could be used to facilitate the polluter pays principal.
5. Investigate plastic pollution accumulation hotspots in the WIO using an oceanographic modelling approach. This research could channel funds for clean-up more appropriately.
6. Use fine-scale connectivity data to investigate the specific conditions in which coral larvae are able to ‘move away from home’, by better understanding the exchanges which enable/facilitate coral larvae leaving coastal near-shore sites and entering offshore currents will enable more accurate oceanographic modelling parameters to be set. Aldabra is an ideal site for this, based on the fine-scale sampling data we have and the variety of oceanographic conditions at play in this atoll system.

7. Establish coral reef monitoring at Astove reef and develop a greater understanding of this site in terms of its potential resilience.
8. A more in-depth coral connectivity genetics study, with greater coverage and higher sample sizes would be beneficial to conduct both within Seychelles, and regionally to extend our understanding of connectivity and the importance of certain sites, at both national and regional levels.
9. Use the genetic data obtained for this thesis, coupled with physiological studies, to further study the specific genetic-level differences between the inner and outer lagoon corals at Aldabra, for example whether lagoon corals greater thermal tolerance is being 'selected' for as well as adapted to.

6.6 Challenges

Numerous challenges arose throughout the process of generating and analysing the data for this thesis. Personal challenges include the steep learning curves involved in pursuing the scientific disciplines of social science and genomics. Another personal challenge/achievement was co-leading a large project alongside my PhD throughout the first 1.5 years and numerous other side projects along the way.

Specific research challenges included obtaining enough respondents for the online survey (chapter 3); while there was no specific target number it was not as easy as expected to get people to fill out the survey, and obtain global coverage, despite making the survey available in multiple languages. It was

also difficult to know when was the most time was to launch the survey considering the pandemic was underway.

The pandemic also created a set of challenges, of which the most disruptive were the lab closures and long delays in generating the genetic data to begin analysis. There were also IT related challenges that came with working from home and learning how to work solely in the command line to analyse large data sets remotely on the university server. Additionally, the costs involved in the genetics project (sequencing and sampling) were high and limited the number of samples we could collect and analyse and therefore the data coverage and scale. This was exacerbated when at the time of paying for the genetics, the value of the Seychelles Rupee has decreased substantially as a result of Covid and this meant the funds we had to analysis were impacted because we were paying a UK invoice from a Seychelles bank account.

6.7 Management Effectiveness and Connectivity

It has long been surmised that coordinated efforts between sites (i.e. management connectivity) can potentially reduce costs of protecting biodiversity and improve the efficient allocation of limited conservation resources[3–7]. This is especially true in the case of SIDS such as Seychelles, where there are multiple managing bodies (NGOs, government, private islands) managing species/sites/islands with evidently many of the same

challenges and barriers to success. I have found that management connectivity is lacking as a result of inadequate coordination of efforts and undefined research strategy at national level (i.e. by government), despite clear ecological connectivity between sites (Figure 6.2).

Increasing this management connectivity has the potential to greatly enhance overall management effectiveness at local and national levels, whether by understanding the impacts and costs involved in marine plastic pollution to generate funding and guide actions, or identifying important larval source reefs to better manage coral reefs for regional resilience to the impacts of climate change. But to achieve sustained management connectivity requires greater local collaboration, greater transparency in success/failure, higher levels of data pooling, stronger alignment of local-level efforts with national targets and overall greater sharing of knowledge and information between practitioners, government, and scientists.

All those involved in island ecosystem management should take responsibility for enhancing connectivity; scientists who collaborate with practitioners should ensure that research is co-developed with local partners on the ground and the information being generated is robust, relevant, disseminated widely, and delivered in an understandable format[256]. Practitioners within NGOs should ensure the work being carried out clearly links to research and management objectives and identify and implement solutions to the barriers that exist, they should also be open to building

collaboration and participating in national knowledge share forums– ensuring information is shared in an understandable format – and actively look for ways to enhance the value of outputs through collaboration. Government should actively be promoting collaboration and allocate resources to providing an overarching framework and forum to facilitate management connectivity across sectors, ensuring there are clear, inclusive ways for participation.

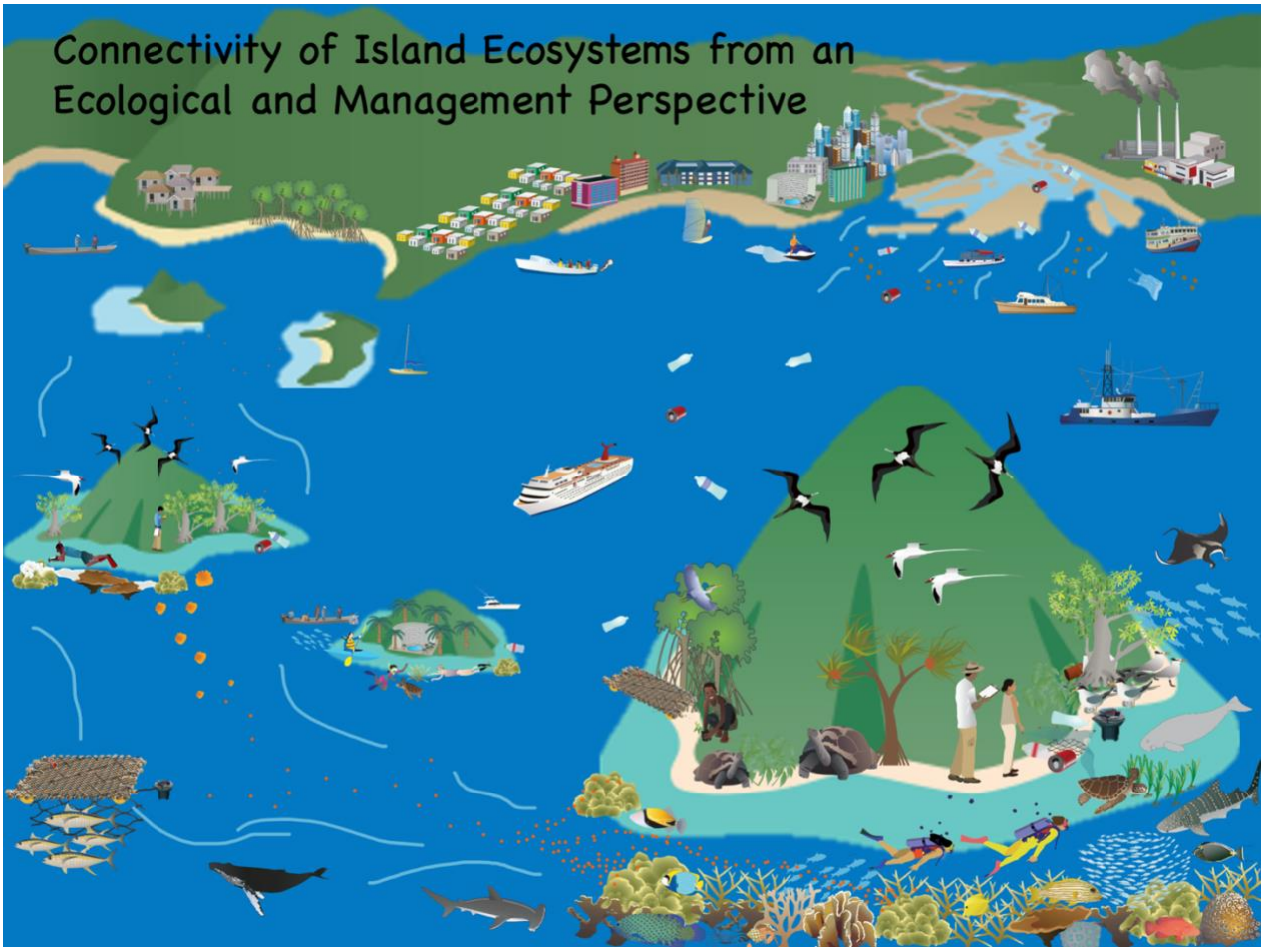


Figure 6.2: Visual representation of the connectivity of island ecosystems

6.8 Conclusion

Achieving effective management is not easy, and as this thesis has shown, there are myriad considerations and complexities that make it a challenging endeavour. However, there are relatively straight-forward paths to achieving greater effectiveness across levels of management. The challenge now is to turn the information relevant to improving management generated in this thesis into action and this is where the greater challenge lies. As scientists, we expect to simply 'pass the baton' in the form of a neat report or scientific publication, but without aligning our work with local organisations, local conservation goals, or actively pushing the evidence into the paths of those who can most utilize it, these messages often miss the target and end up in the literature soup, rarely seen by practitioners. While many academics may deem it unfeasible to spend time/resources beyond publication, there is simply no other way to ensure our work achieves practical impact. In fact, it is far more of a waste of resources to neglect this step, considering the huge resources that go into research and publication worldwide. So, to conclude this thesis I will end by saying that this work is a starting point for a great number of future actions/endeavours on my part, to ensure these findings are used. Even if this 'use' is within a local context, it will have had a positive impact towards achieving more effective management of island ecosystems and hopefully to the conservation of our precious biodiversity.

Appendix A: Supplementary Material for Chapter 2

Defining and bridging the barriers to more effective conservation of island ecosystems: A practitioner's perspective

Table S2.1: A summary of barriers raised by the 32 interviewees with examples of quotes to validate each barrier. The barrier list is organised firstly by provenance level (national/organisation/site and project) and also by discussion topic. NB: Names of organisations, countries or other identifying sections of quotes have been replaces with XXX.

Discussion Topic	Barrier	Example quotes
National level		
Education	Low quality in-country tertiary education	*"Most students are not getting the core skills needed or to a standard that's required to progress in any conservation research or management role"* *"Lack of in-country capacity, though this is changing…there are only a few graduates - many go overseas."*

		"Youth engagement needs improving. [There are] not a lot of mentors to look up to… No research culture…. Students cannot visualise their future." *"We still lack capacity in XXX, and in most organisations we still have foreigners; not because XXX is not interested, it's because they don't have the capacity."*
Government capacity and coordination	Government capacity issues	*"[The government departments] do not have the capacity for visualising research strategy…it's the blind leading the blind"* *"Problem is [that] most capacity is outside government, so more senior people are outside government saying they don't agree, so government needs to keep a few of these people."*
	Conflicting priorities hinder progress	*"Our mandate is to sustainably develop the fisheries sector and conserve our marine ecosystems, which are conflicting – the blue economy is to find new unexploited fisheries. It is difficult to balance that out."* *"…if you dig deep then nothing happening, government choose low hanging fruit, for example by banning plastic straws rather than banning non-recyclable plastics and sorting waste management."*

Policy and legislation	Lack of science-led policy	*"[There is] no general policy for reef conservation – e.g. no law for dropping anchor."* *"[Legislation] bills remain as bills for 4-5 years."* *"Lack of legislation - actual laws governing & guidance for practitioners/owners/stakeholders. An element of green-washing - say they want to protect turtles yet poaching continues. Sharks on the IUCN list are always on market - no enforcement & prosecution."* *"[There is a] big gap between result/work we do and how it is translated into law & policy"* "*The department is heavily reliant on NGOs/external-bodies/consultants to conduct research that informs policy… [the government] don't drive the research"* *"Hard to see where your work fits in and don't see it influencing strategy & policy"*
	Lack of public compliance to legislation	*"[We] are constantly under attack from poachers on land and sea. [The site] has been threatened with rat [introduction], from the poachers, thus making the personnel afraid of policing the waters."*
	Lack of enforcement of policy	*"Some of the major difficulties are implementation and monitoring of environmental laws and policies…"*

		"Currently, no law exists to protect the reef fish spawning aggregation sites. Only an agreement between XXX and XXX. Fishermen are not aware of this agreement making it difficult [for us] to enforce."
National research strategy	Lack of national research strategy	*"At the national level there is no mandate or outline for research. XXX has no national strategy. 0.003% of GDP goes towards research"* *"[There is a need for] consistent coordinated research - so many organisations [use] different methods to monitor the same thing… it's not easy to get an overall picture."*
	Lack of quality control in research/projects	*"[There is] very ad-hoc research, no quality control mechanism. [International]research proposals are reviewed and approved by committee but there are no follow-up reports asked for to check value and outcomes"*
Organisation/Department level		
Collaboration & Communication	International collaboration issues/failures	*"Some organisations do not have a research plan and so tend to just go along with whatever research students or supervisors from overseas suggest, which sometimes stands to benefit their*

		organisation little, but certainly takes up their staff time and resources…" *"There can also be a view of not using 'outsiders', generally expatriates from outside [the country], for conservation projects. I think that this view is decreasing but it is still held by many of the older generation and can mean gaining support for projects and research within an organisation or nationally is difficult."* *"some [international] research institutes want to impose - should be a win-win relationship"* *"Researchers come & leave rather than permanent. For example, PhD students come and collect data then often we don't hear what the outcome was"*
	Lack of local collaboration	*"I think that there are organizations very open to the collaborations but there are also many others that aren't at all."* *"There is a lack of data and knowledge sharing and a lack of collaboration between certain NGOs and individuals."* *"Many organisations work in isolation. Coral restoration is a good example of that. There are several NGOs and government agencies*

		conducting coral restoration, however, they are all using different methodologies/protocols."
	Fragmentation of research, efforts and methods due to site & staff isolation	*"[There is] more inter-island collaboration needed"* *"Too often we are all doing the same thing, in a slightly different way but are not sharing our lessons learned. This leads us [different organisations] to go through the same processes, wasting both time and money."* *"[We have] no idea what goes on on the other islands…would be good to learn and share methods for example, if we start a new monitoring programme, we should know what is done elsewhere"*
	Limited opportunity for Social/personal relationships to develop between organisation/site staff to promote collaboration	*"A lot of time collaboration starts at social level - this really helps - providing a platform, but there are few opportunities to mingle"*
	No incentive for collaboration	*"Funding mechanism needs to be structured so it enforces collaboration and higher-level data share."*

		"Collaboration needs supervision, and that means time." *"Most people are flat-out, especially on site and do not have the luxury of time, too busy with their own work. Sometimes we forget or don't realise the time we invest in something we feel we have to do could be better invested within a collaboration."*
	Staff turnover hinders collaborations	*"People [in positions] change and sometimes collaborations exist because of personal connections."*
	Interpersonal relationships interfere with conservation decisions and knowledge/data share	*"No one can contest the need [for collaborations], but dealing with different actors can be difficult, people are different…Conservation is not about managing species, but about managing people'… numerous relationships are an issue"* *"Often 'People Politics' comes before conservation."* *"[There are] lots of big egos - people put their own interests before national interest."* *"Some people don't want to collaborate. [There are] personal grudges… stepping on toes… competition"* *"Historic 'egos' govern organisations from a top-down approach. However, practitioners on the ground are ever willing to work with each other."*

	Personal gains driving conservation efforts	*"This isn't about one organization being better than another and holding data in order to just represent that organization; this should be about having the most and best information possible about species and ecosystems, about their health and their trends, and being able to make management decisions based on that."* *"Some organisations are only willing to get involved if there is significant benefit to them but are less concerned about the wider benefit to XXX or research."*
	Lack of trust prevents collaborations	*"[There is a] lack of trust; there have been loads of projects to set up national databases, but nothing has worked."* *"Most organisations are happy to collaborate but one or two less so. Some organisations are very protective of data, and don't feel the need or see the advantage to them [of sharing]."* *"Some organisations and practitioners often do not want to share their data"* *"The biggest obstacle is data ownership as many institutions do not want to assist as they worry that their data will be stolen or used without their consent."*

Knowledge exchange & communication forums	Communication platforms vary by subject/species and driven by individuals not gov	*"The level of available communication platforms depends on the field, for example for marine work there is a regional platform for data share but not national, for turtles there is a group although not any specific meetings, then for seabirds and [an endemic landbird] there are annual meetings"* *"…we still do not have a coral/coral reef network despite many organisations conducting valuable research and conservation management in this area."*
	Too few/ lack of communication platforms to facilitate knowledge and data share and collaborative reporting at national level	*"[There is a] lack of platforms to share this knowledge beyond [publication]"* *"Within XXX there is a lack of opportunity to share successes."* *"We host a symposium every 3–4 years to showcase the work and research we have completed, other opportunities are rare, although there is now more sharing via social media"* *"Project reports/documents are not easily or widely shared nationally"* *"[Under the previous minister] a Natural Environment Advisory Council was formed- it felt like good and proactive work- very good*

		people on board, but when the minister was changed, the board ceased. We need these forums to help government to structure policy and for us to prioritise research and projects." *"[There is a] lack of platforms for cross-pollination [between practitioners and organisations] …Stronger leadership needed. What data do we need? Are there funds going to waste? […There is a] lack of resources to bring people together."* *"Fragmentation of research effort is a big concern."* *"The Ministry of Environment should be the overarching frame for all island ecosystems in [the country] but because the MOE is relatively young and other organisations around longer so tend to go it alone… to have more organized collaborations can therefore be difficult."*
Resources	Resource constraints: Money & time	*"[There is little] capacity and not enough time…new positions are needed – but more money is needed to do this."* *"Many organisations are collecting large amounts of data and struggle with finding time to analyse the data, let alone lead more targeted projects."*

		"…insufficient resources mean things fall through the cracks, for example, having time to sit down and have proper consultation with staff, talking to staff, getting staff feedback etc." *"We depend on a lot of project funding to complete active conservation"*
	Lack of long-term funding	*"[Funding opportunities are] very competitive and the limited resources restricts [our work]"* *"After the lifespan of project there is no continuation of funding, no monitoring or support to ensure success and long-term validity"*
Staffing	Over-reliance on expats and volunteers to fill skill gaps	*"Pay so low, rely on expat volunteers because they are cheap/free."* *"[We have a] high level available with several staff qualified with PhDs and excellent research and publication experience in the team. Only issue is that these personnel are all expatriate. Only a few [local] members of staff and their capacity level remains low."* *"For a higher level of analysis, skilled volunteers are generally needed, not only because of their skill level, but also because dedicated time is needed towards the analyses for which most staff don't have the time for."*

	Low staff capacity	*"[There are] not many graduates or high-level [educated] people in XXX"* *"[We] lack experienced XXX, not enough capacity to conduct research"*
	Difficulty recruiting & retaining staff	*"Attracting staff to work on a remote island is difficult"* *"No one wants to work for weeks/months away from home for low pay"*
	Low staff motivation	*"[We have] difficulty in motivating staff"*
Leadership	Inconsistent leadership	*"[The organisation] suffers from a lot of change in management, which has had a lot of impact on activities."*
Project/Site level		
Data management & analysis	Lack of data management capacity including poor spreadsheet design, data loss due to technical failures, data entry errors, inconsistent methods,	*"[There is] very little data analysis done, very few organisations with capacity and time. If done, it's usually very basic & incomplete. The people with the skills are moved away from research into management."* *"There are not enough specialists to check, clean and analyse long-term data trends."* *"Limited capacity for data analysis, [it is done] just by chance depending on [staff]who comes in."*

	lack of protocols, low data analysis capacity, data fabrication	*"The analysis is basic; lack of time and skills means we only do it season by season and summarise."* *"None of us are trained in data analysis"* *"Microsoft Access was used but there were many issues with this. The main setback was that staff were not trained in using Access so didn't know how to maintain the database or how to use it to analyse data"* *"Very little understanding of what data is, the different types, cleaning data, data quality."* *"[We] don't have a database manager… most staff are university level, with little experience in data management."* *"Huge efforts have gone into data management, but we are not satisfied, we need professional service now, it is not possible in-house. Attempts by people lacking skills can be detrimental to the data integrity."* *"[We have had] issues ensuring data is comparable e.g., separate spreadsheets used annually so not easy to compare"* *"…each new warden starts new databases"*

		"Everyone works on their own laptops so hard drives get passed from laptop to laptop, increasing risks of human error or saving, then transferring if hard drive breaks down." *"Rusted electronics are continuous problems on conservation islands."* *"Data has been lost, accidently via deleted files or broken hard-drives/laptops. Also, everyone at each site has separate versions of excel and labelling versions has caused issues."* *"Human error in data entry and consistency is the big issue."* *"…data needs so much cleaning!"* *"[When preparing data to try to publish there have been issues with data quality or inconsistency due to method changes"* *"Over the years lots of data is collected but nothing happens to it which leads to lack of understanding, accuracy and team motivation. Teams on ground must see the value of it"* *"Data is inconsistent, sometimes missing and is not continuous. It is difficult to find/access and not of high quality"* *"Lousy data entering with too many errors"*

		"… as most conservation managers only stay a few years at most, there is the risk of changing methods with everyone who newly comes in (despite the handbook). Also, not everyone records what changes they have implemented" *"A tendency for when change happens; get the broom out and re-invent the wheel. For example [we have] experience of one person destroying a 20-year programme; this has happened multiple times."* *"Main problem is that methods and data collection hasn't been consistent in the past, so it is difficult to compare old data with the new."* *"Inconsistency between the conservation managers - some not stuck to methods which has had long-term ramifications."* *"…there is a problem where some staff make up the data, just hide in the forest and then make stuff up."*
	Data set gaps and separations/ staff turnover causes data	*"Lots of people come & go, this has led to missing data. If I wasn't here [for the past 10 years] then the data would have been lost."* *"High turnover of staff not helpful for data management consistency"*

	disappearance or data storage changes	*"Sometimes data has only been kept as processed data not raw data so impossible to analyse properly as a time-series. A lot of the data is accessible but means chasing old staff."* *"Each conservation officer had different organization methods. The data backups were not organised, and all being carried out by individual users"* *"If I hadn't transcribed data from notebooks then no historical data would exist."* *"[staff] need to enter the data on an external hard-disk and give it to me to copy on to the server. Because of this there are multiple versions of the data files, which sometimes goes wrong and data is lost"* *"The data set went to [the ministry] on CD – this got corrupted – the consultant still has the data set but refuses to re-share. This happens a lot. The XXX [research institute] withheld data they collected here. Likewise, some PhD students promise data share but did not produce any data or publications. Some people keep data to the grave."*

		"High staff turnover, no overlap, sometimes just one person. So there are big gaps." *"There are gaps in the data collection."*
	No time for analysis	*"Historically one of the issues was not having time. No one would fund you to write up"* *"So many data sets… e.g., 20 per island, which we cannot afford to analyse every year for each data set."* *"[It is difficult] finding time to work or research papers. Staff don't have time during working day so research papers are written on a voluntary basis"* *"[there are]no obstacles except time; if the 'A' team is in place then a lot can get achieved."* *"As a conservation officer, I am managing the conservation rather than having the time to do scientific analysis. I unfortunately do not have the time to analyse the island large data sets."* *"The major bottleneck is one of time"*
	No dedicated data analysis position	*"Having a resident researcher at each site would be hugely beneficial to constantly be moving forward. To do this we would*

		have to pay - probably international at this point…the research teams are focused on data collection not data analysis."
Leadership/management	Poor communication between seniority levels	*"blood samples are sent to the UK but we never get any information on the results of those back from the management team."* *"Change in management effects ability… Stable management leads to stable outputs & better vision."* *"A lot of senior management don't help to develop skills in their staff"*
	Poor staff welfare & development	*"I have lots of responsibilities as project leader but no contract"* *"…we struggle, we work overtime, we skip holidays."* *"… there is no encouragement to do a Masters degree and management are against it"* *"[I was the] assistant coordinator (really doing coordinator job) for 2.5 years but was volunteering for 1.5 years prior to that"* *"… Staff are overworked, salaries are low"* *"I think they block official job ascension because they don't want to pay more, they try and get so much from us but give us so little. If things go right then they take all the credit, if things go wrong then you get the blame."*

		"… lack of local staff because [the organisation], don't invest in staff, there is no reward for loyalty, no incentive to stay." *"Basic HR/Admin/Staff welfare/Staff retainment/ Staff seen as replaceable. No incentive, or staff development - no desire to empower staff - Very few good XXX staff - that stay within the organisation."*
Management objectives	Poorly defined objectives/ research strategy	*"A primary [difficulty] was defining the objectives/targets beyond a high-level: conserve the reefs"* *"[It is] difficult to determine measurable objectives"* *"I wouldn't call what we do research. We're just monkeys feeding birds."* *"[It feels like we are] collecting data forever without a reason why or any end goal"* *"The management shifts focus depending on who's in charge."*

Table S2.2: List of barriers and their probable causes. Major causal links highlighted in bold text.

Barrier #	Barrier (Effect)	Level	Causes
1	Low quality education	National	Poor in-country education management/leadership **capacity**. Not enough teaching **resources**, insufficient funds allocated to education
2	Low government capacity	National	In-country **capacity** issues
3	Conflicting priorities	National	Lack of management strategy to balance needs as a result of **poor government coordination** and **low capacity** (both management and scientific)
4	Lack of science-led policy	National	Low scientific **capacity** in government. Lack of science relevant to policy, lack of access to science, no national research strategy, no overview of regional/international science relevant at national level as a result of poor **gov coordination**
5	Lack of public compliance to legislation	National	Lack of public awareness and education in communities and lack of enforcement as a result of **resource** allocation and **poor government oversight**.
6	Lack of enforcement of policy	National	**Resource** limitations/allocations (enforcement officers etc.)

7	Lack of national research strategy	National	Low **scientific capacity** in gov/ research is a low priority for gov so an overall **lack of coordination** to implement a strategy.
8	Lack of quality control in research/projects	National	Low **scientific capacity** in government to critically review projects and outputs and generally gov don't review research except for international scientist wanting research permits.
9	International collaboration issues/failures	Organisation	Low scientific **capacity** in government to critically review projects so **lack stringent review** by gov for proposed projects. Self-serving collaborators (colonial attitude); short-term projects don't benefit local orgs; lack of local **leadership**/skill transfer; research frequently not aligned with national research or management needs
10	Lack of local collaboration	Organisation	Few opportunities to develop collaborations as there are few forums/groups to do so, the ones that exists are NGO led as there is a **lack of government coordination**. No funding/ **resources** for coordination of similar projects/shared goals by NGOs, low incentive but more effort required, competition for funding, limited time and personnel. **Personal issues** between practitioners/organisations/ interferes with collaboration, there is a lack of trust.

11	Fragmentation of efforts	Organisation	A lack of overall **government coordination** results in a lack of data/knowledge share opportunities/forums and lack of coordinated efforts to work towards a clear national research strategy.
12	Limited opportunity to develop collaboration	Organisation	Few occasions to bring practitioners together such as symposium, especially staff on further islands, **lack of government-led** meetings/forums.
13	No incentive for collaboration	Organisation	Collaboration locally requires coordination and time and there are few **incentives** for organisations to lead collaborative efforts; poor funding structure.
14	Staff turnover hinders collaborations	Organisation	Staff turnover breaks existing collabs/relationships; staff turnover is high as a result of low **incentive** (financial, training, promotion), poor contracts, low job satisfaction.
15	Interpersonal relationships interfere with conservation relationships	Organisation	Sense of ownership over species or sites/ **personal grudges**; previous experiences; egos
16	Personal gains driving conservation efforts	Organisation	Lack of accountability and transparency for actions, decisions, successes/failures. Often senior practitioners outside gov have big egos and answer to no-one. **Personalities** therefore drive this type

			of barrier. More stringent monitoring and **coordination by gov** could alleviate this issue.
17	Lack of trust prevents collaborations	Organisation	Mistrust in other organisations/individuals as a result of previous bad experiences or **personal issues** with practitioners.
18	Too few/ lack of communication platforms	Organisation	Lack of **gov coordination** as a result of low management **capacity** and lack of **resources** (time, money, personnel)
19	Communication platforms vary by subject/species	Organisation	Platforms rely on individual organisations organising and coordinating, so **lack of gov coordination**, **resource** restrictions
20	Resource constraints: Money & time	Organisation	Limited funding options/opportunities **Resources**
21	Lack of long-term funding	Organisation	Limited funding options/opportunities **Resources**
22	Over-reliance on non-native staff and volunteers to fill skill gaps	Organisation	Cheap/free labour but higher **capacity** than local candidate pool
23	Low staff capacity	Organisation	Poor tertiary onwards education, key skill sets not taught. **Capacity**

24	Difficulty recruiting & retaining staff	Organisation	Low **incentive** for local staff due to low wages (**resources**) comparative to other jobs + high personal sacrifice in living away from family and friends (anti-social contracts)/lack of skilled candidates, lack of in-country **capacity**.
25	Low staff motivation	Organisation	Few/low **incentives** to progress, low pay, few training opportunities, no options for career progression, lack of mentorship
26	Inconsistent leadership	Organisation	High staff turnover, **low incentive** to stay in position/ low job satisfaction. Poor leadership **capacity**
27	Lack of data management and analysis capacity	Project	Lack of data management **capacity**, poor data management, poor scientific **leadership**, low staff motivation, lack of supervision.
28	Data set gaps & separations	Project	**Poor leadership** results in ineffectual data management or staff leaving with data, plus **personal issues** mean data set separations
29	No time for analysis	Project	**Resource** limitations (time and personnel), not integral part of job descriptions so not prioritised
30	No dedicated data analysis position	Project	**Resource** limitations (personnel)
31	Poor communication between seniority levels	Project	Poor **leadership**/low leadership capacity

32	Poor staff welfare & development	Project	Lack of recognition/staff rewards/**incentives** or contract bonuses/ training opportunities or career development; poor management/HR/**leadership**
33	Poorly defined objectives/ research strategy	Project	Poor **leadership** and overall **scientific oversight capacity**

Table S3: Suggestions from practitioners for improving the effective management of island ecosystems in response to question: 'What would most enhance your ability to more effectively manage the site/s you or your organisation or department are responsible for?'

Suggestions for improving management effectiveness	**Example Quotes**
Staff retention inducements, e.g. pay increase with time, promotion opportunities etc.	*"[Organisations need to] pay staff more to keep staff longer and get better staff"* *"Permanent paid staff - full time [would improve our capabilities]"* *"[We need to] get more staff and pay for expertise needed."* *"Ensuring you have everything in place: The A team…getting the best, staff [would improve our capabilities]"* *"We [would] need the right people in the right jobs, appropriate pay and inducement [to improve our capabilities]"*
Higher in-country capacity through increased training opportunities and specific	*"[We would need to] train more people - like to build in-country capacity"* *"Increasing staff capacity [would improve our capabilities]"*

modules added to tertiary education syllabus	*"Investing in schemes to develop next generation conservation scientist in their country [would improve our capabilities]""*
Creation of additional roles	*"[We need] more staff, to allow more work to be done."* *"[We need] more human resources, to get correct expertise to push forward the objectives of the management plans"*
Improved equipment and infrastructure	*"More equipment, more infrastructure for accommodation [would improve our capabilities]"* *"Equipment and infrastructure are needed [would improve our capabilities]"*
Accountability and responsibility to communicate conservation success and failures.	*"There should be some accountability towards the data [organisations] are collecting, which is what should be guiding [organisations] in their management decisions."* *"Regular self-reporting should be mandatory for all to report on management plans - how is management being conducted and is it successful? We should be held to account and prove ourselves to cabinet once a year, for both government and the public"*

All organisations should have a management plan that links to a national research strategy.	*"All organizations should have a management plan that is clear and accessible to anyone."*
Transparency for actions, e.g. where project funds were spent and what was achieved with them.	*"…there should be transparency as to how those claims [of actions and funding] are actually being met."*
Greater information sharing and increased public education	*"Greater dissemination of information to people living in the rural communities… as well as advancement of public education [would improve our capabilities]"."*
Project funding that goes beyond the 2-3 years.	*"Conservation of threatened species and the associated habitat rehabilitation etc is not a sprint; it is a marathon that requires years of work, not 2-3 years which is the general length of project funding."*
Build a research institute to coordinate national research strategy and develop next generation scientists.	*"Build a research institute; An environment for idea sharing. Having an institute whose mandate is just to do research to inform management."*
Create a national research strategy	*"If there was a national research strategy then all organisations would have to show how they are working towards and alongside that"*

Improve mentorship to bridge gap between science and practitioners.	*"[More] Peer learning/mentorship [would improve our capabilities]"* *"Pair up conservation minded post-docs with a national proxy/partner/counterpart and make sure our knowledge is officially communicated. There is a lot of knowledge out there but doesn't filter down to management."*
More emphasis and acknowledgement on bridging positions	*"[regarding the gap between research and implementation] day-to-day [managers] are dealing with anything from staff sickness/HR issues to planning and science, these people need to be great drivers, diplomatic, and have strong communication and management skills and so we need something in between practitioners and academics and these 'linking' people are desperately overlooked….but we need to pay these people properly."*
A government-led annual research symposium	*"I would like to see a proper symposium every year, which is compulsory, a showcase, to ensure you get your research license, and every practitioner presents."*

Appendix B: Supplementary Material for Chapter 3

A Global Assessment of the Barriers Influencing the Effectiveness of Island Ecosystem Management

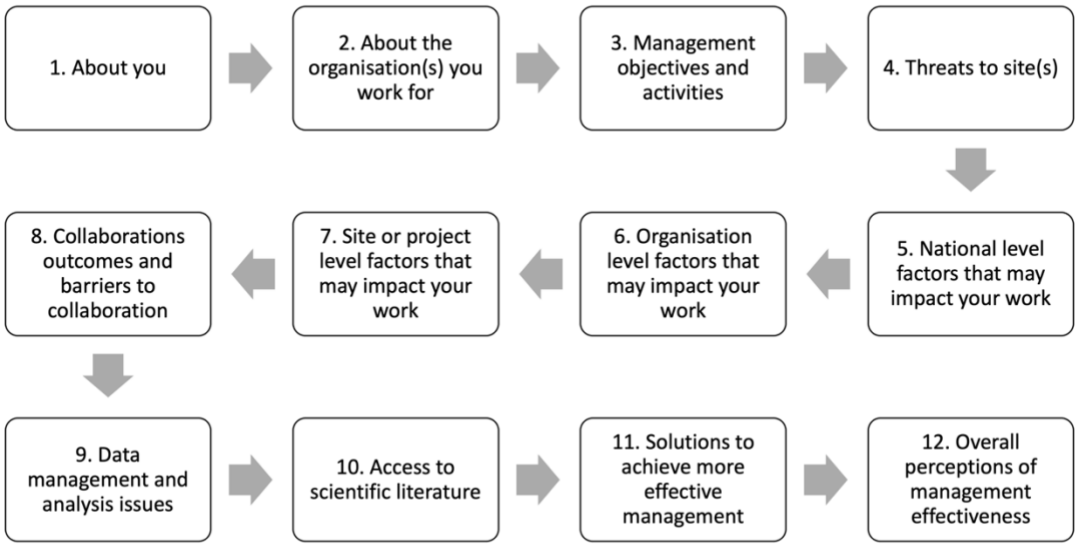


Figure S3.1: Outline of online questionnaire survey section design

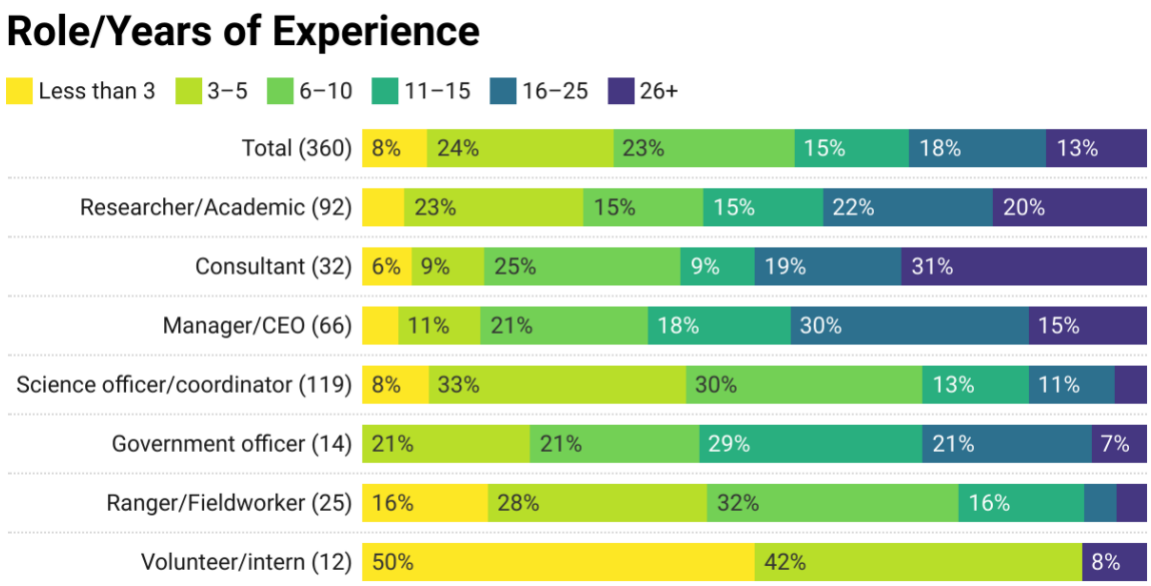


Figure S3.2: Respondent experience in island ecosystem management *(binned in years) composition for each role type, based on 360 practitioners.*

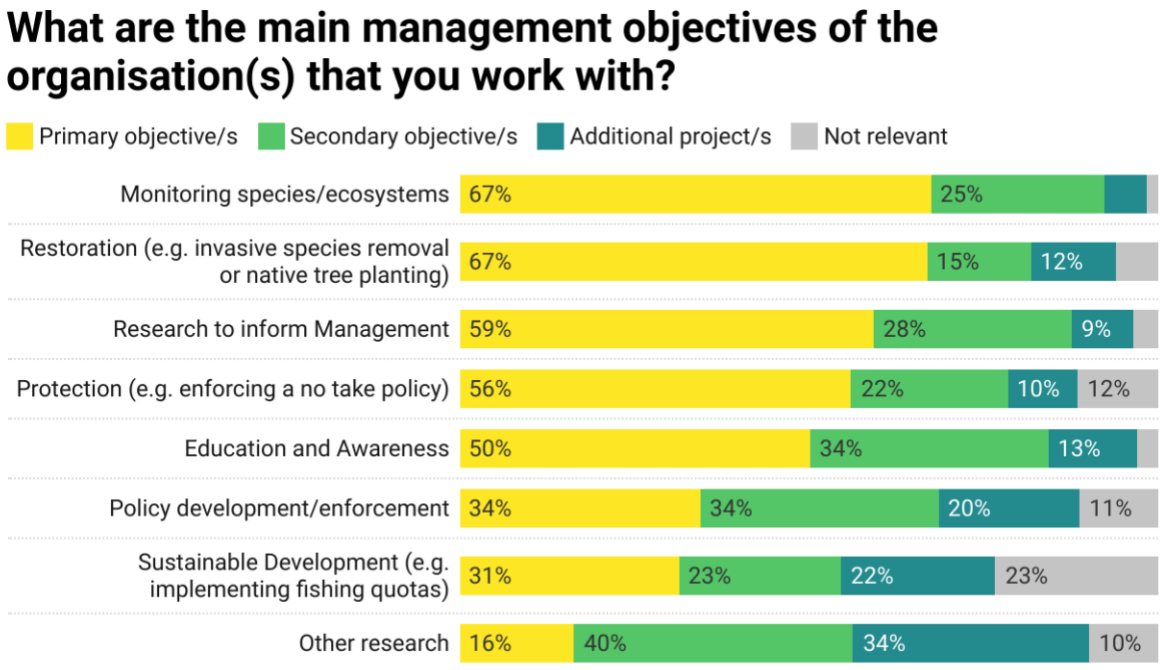


Figure S3.3: The main management objectives for the organisation/s the respondents work with in island ecosystem management, based on 330 respondents.

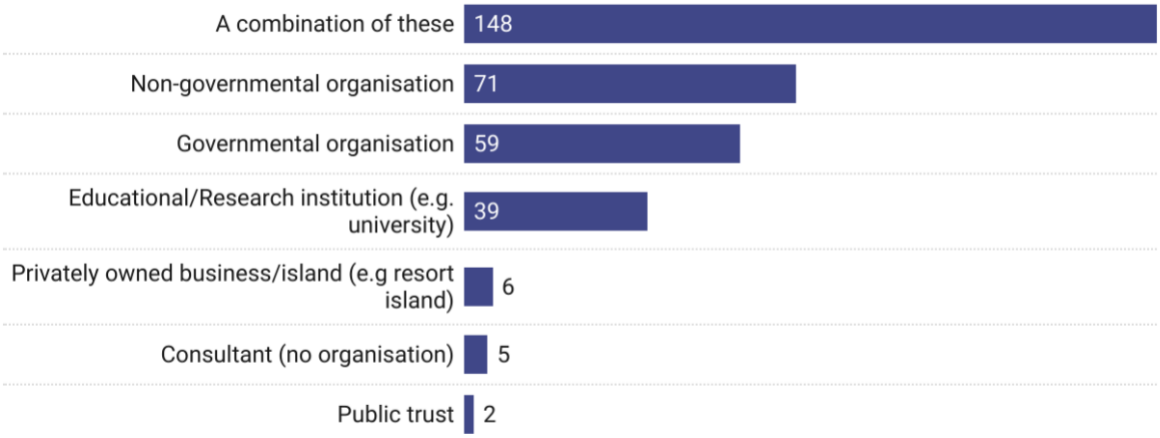


Figure S3.4: The type of organisation/s that respondents work with in island ecosystem management, based on 330 respondents.

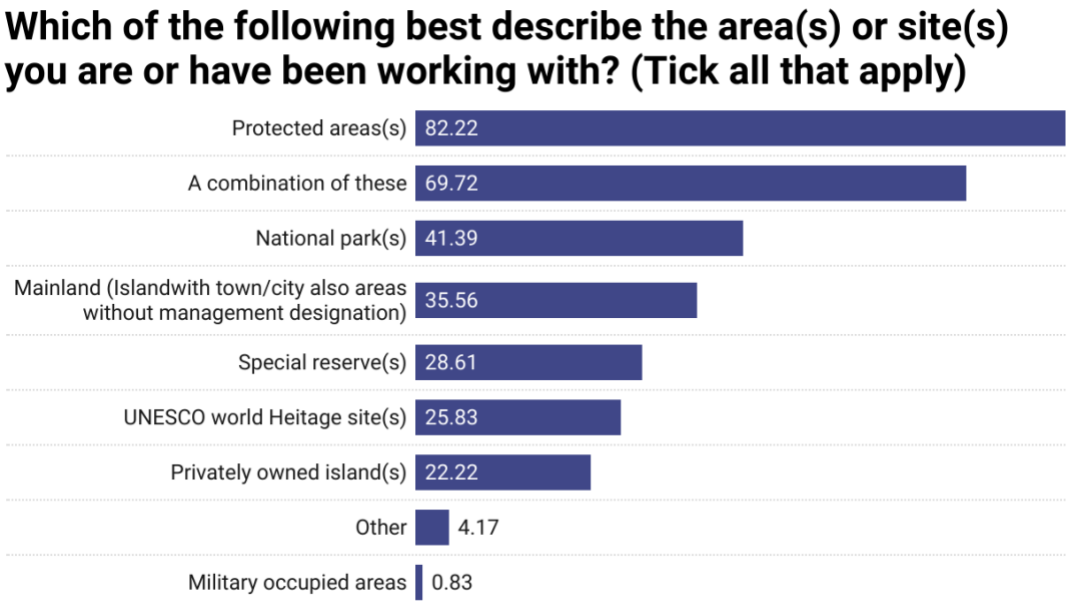
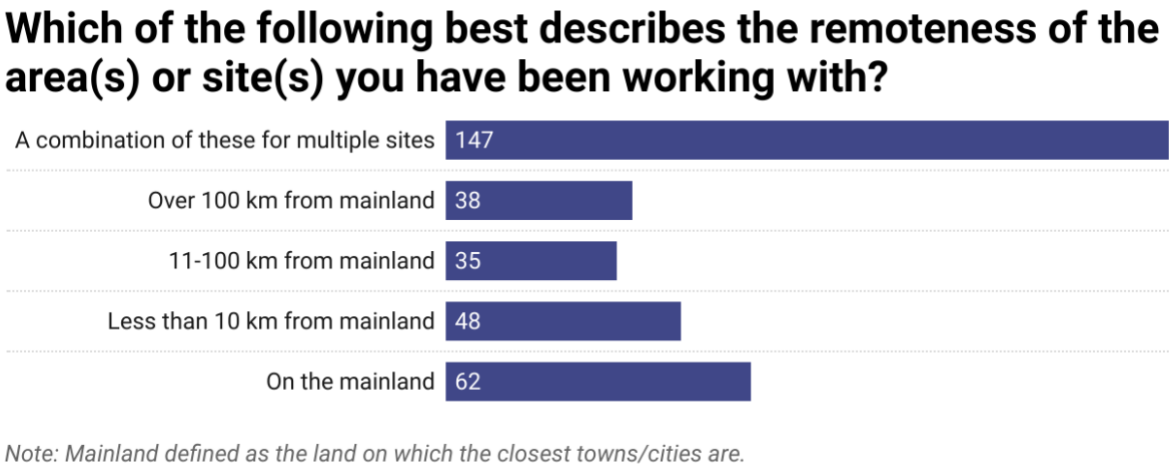


Figure S3.5: The type of area(s)/site(s) that respondents have been involved in island ecosystem management, based on all 360 respondents. NB: An extra category (a combination of these) has been added to show when a respondent ticked more than one type of area/site.



Note: Mainland defined as the land on which the closest towns/cities are.

Figure S3.6: The remoteness of site(s)/area(s) that respondents have been involved in island ecosystem management, based on 330 respondents.

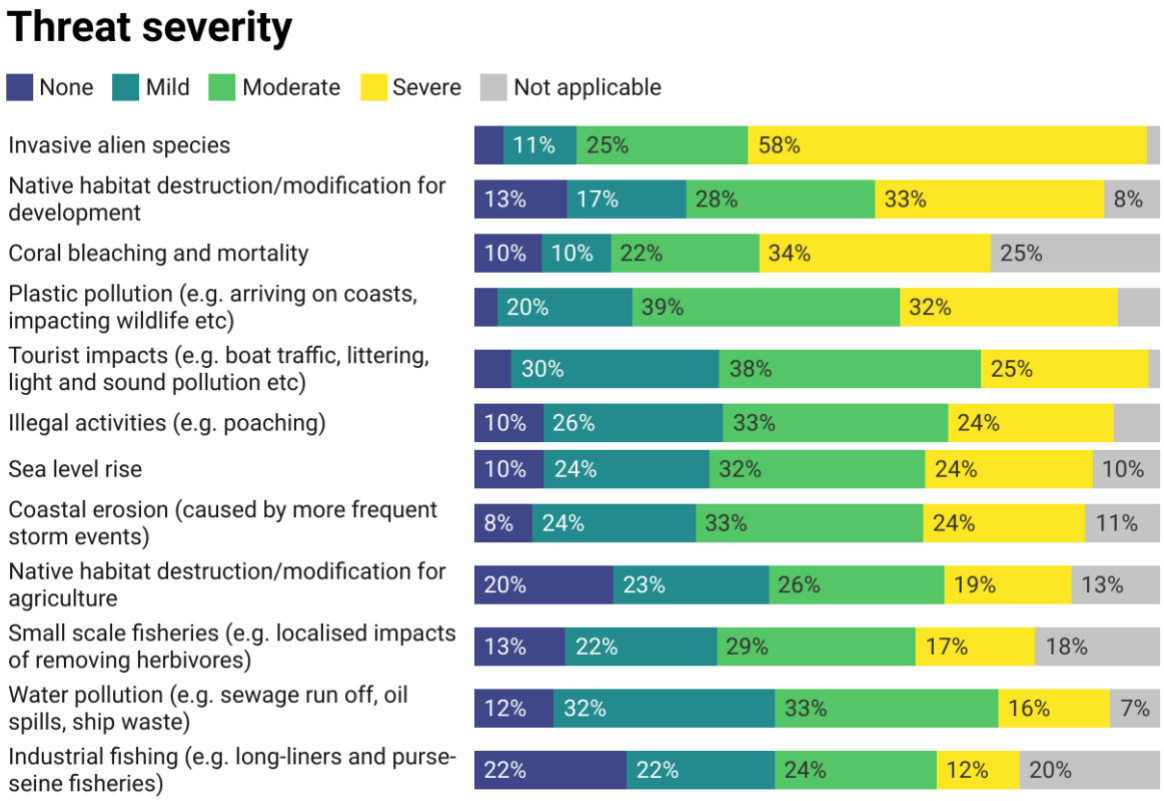


Figure S3.7: Respondent's perception of threat severity at the site/s they are most involved with island ecosystem management. Based on 330 respondents.

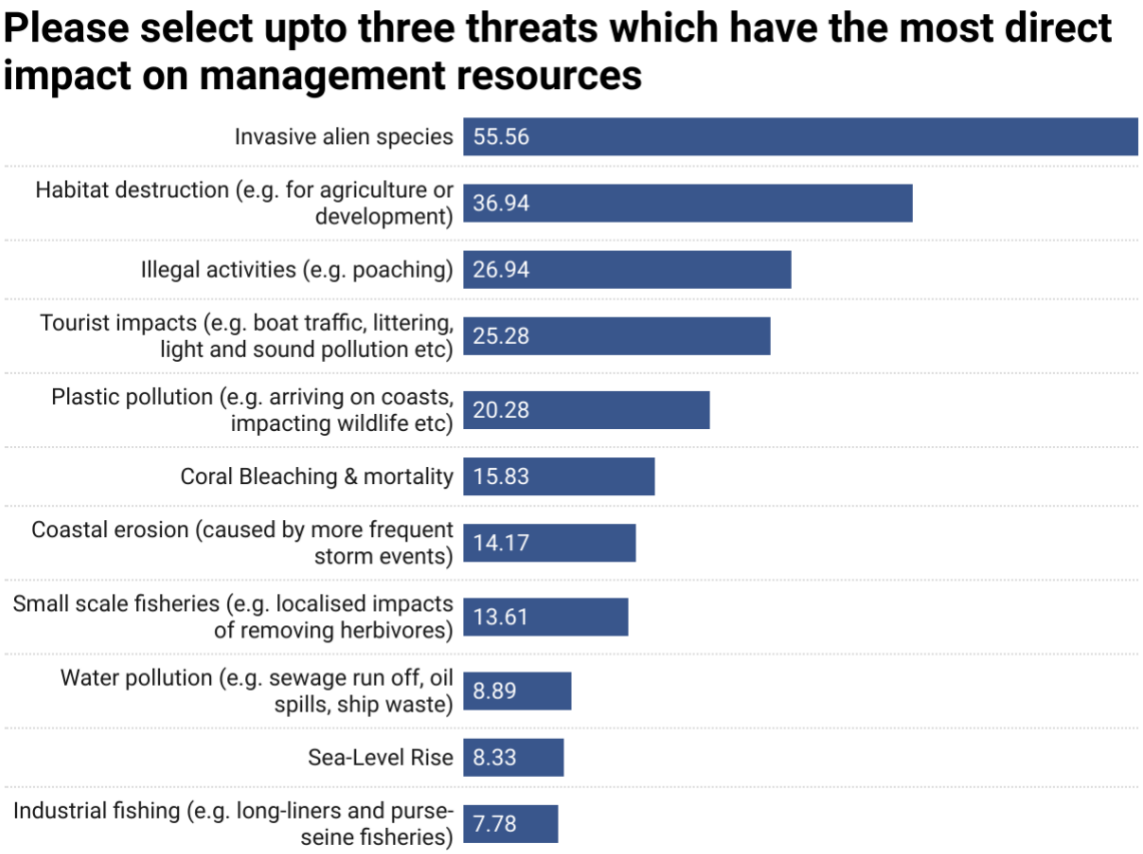


Figure S3.8: The proportion (%) of respondent's that perceived each threat to have the most impact on management resources, when asked to list the three threats which use most management resources. Based on 330 respondents.

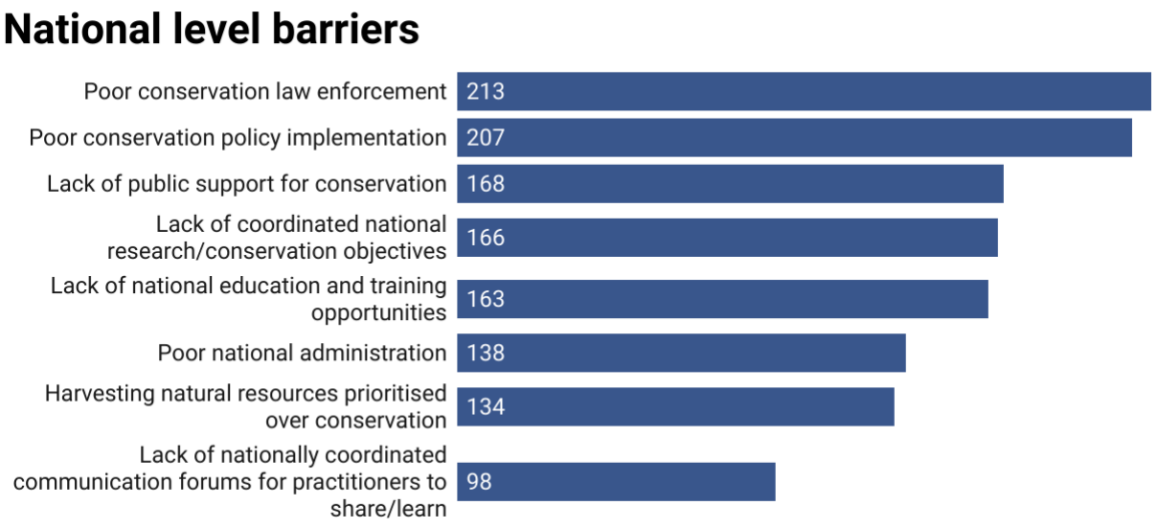


Figure S3.9: The number of respondents who have experienced national level barriers to the fulfilment of management, conservation or research objectives. Based on 330 respondents.

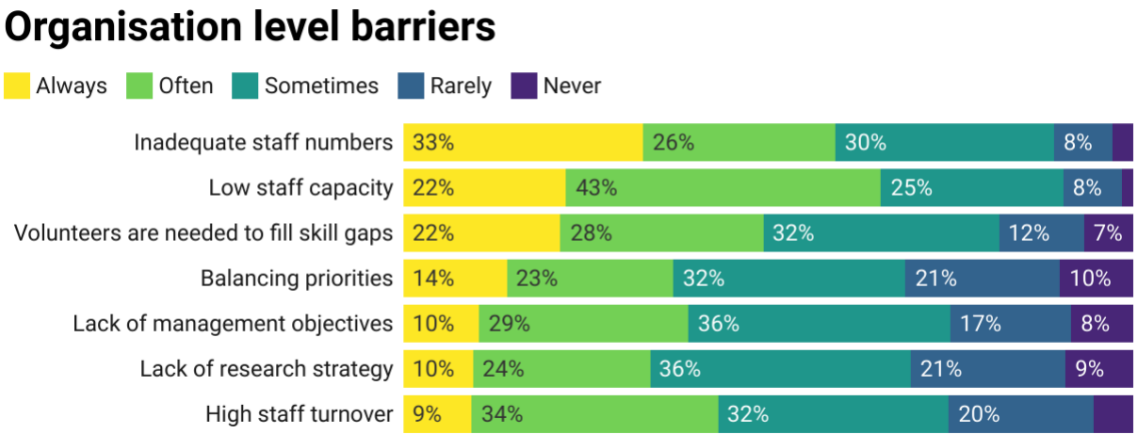


Figure S3.10: The frequency in which practitioners have experienced the seven organisation level barriers to effective management of island ecosystems listed in the survey. Based on 330 respondents.

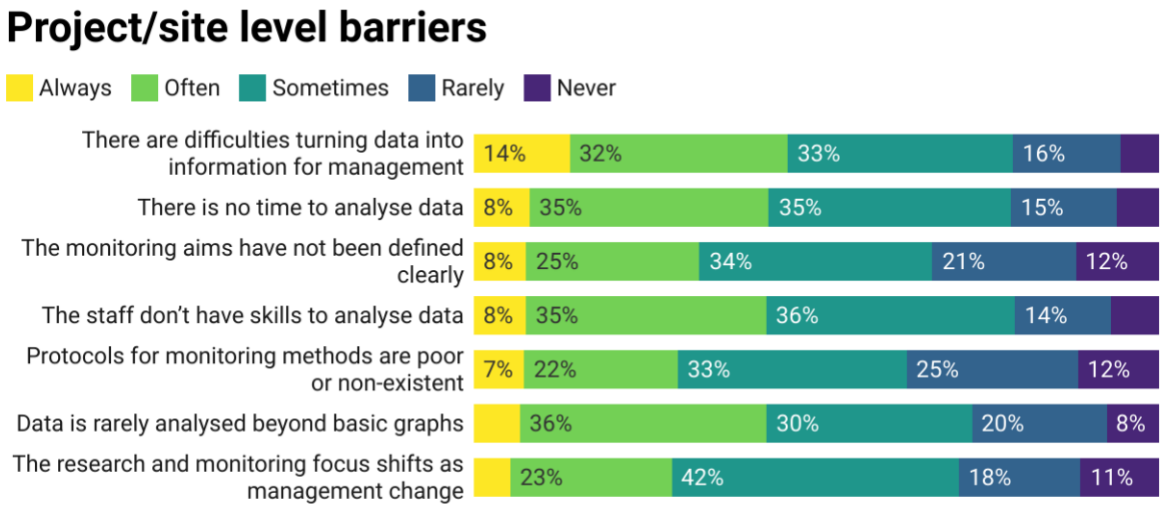


Figure S3.11: The frequency in which practitioners have experienced the seven project and site level barriers to effective management of island ecosystems. Based on 330 respondents.

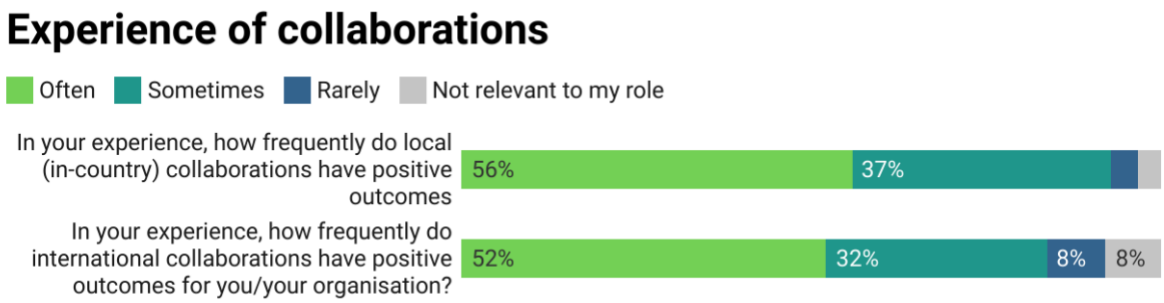


Figure S3.12: The frequency in which practitioners have experienced positive outcomes with local and international collaborations. Based on 330 respondents.

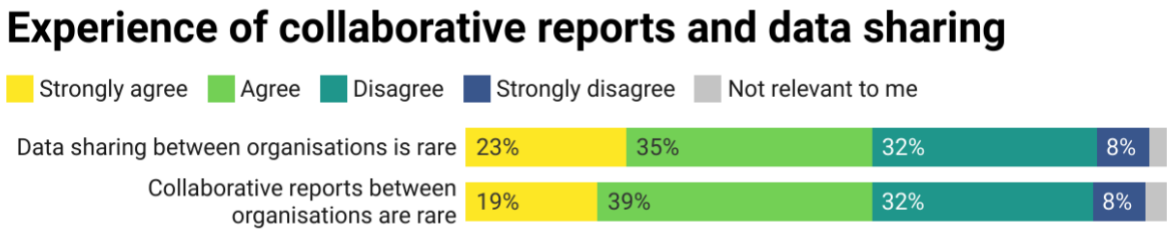


Figure S3.13: The extent to which practitioners agree to the rarity of data sharing and collaborative reporting between organisations. *Based on 330 respondents*

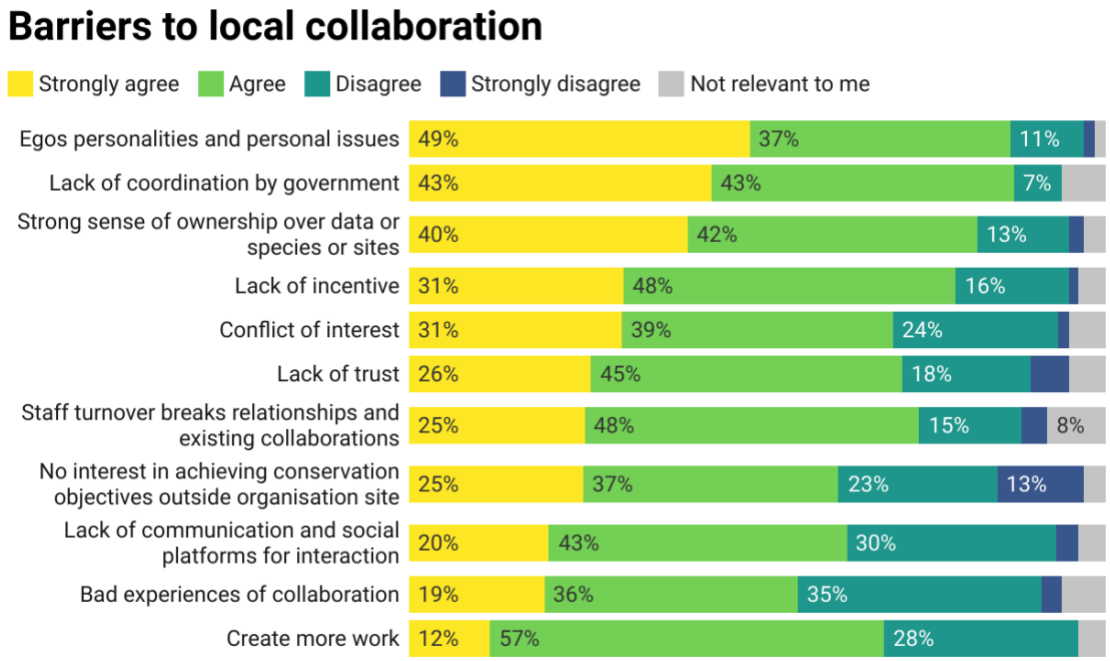


Figure S3.14: The extent to which practitioners agree with the eleven barriers listed in the survey being barriers to local collaboration. Based on the 134 practitioners who felt that local collaborations only sometimes or rarely had positive outcomes.

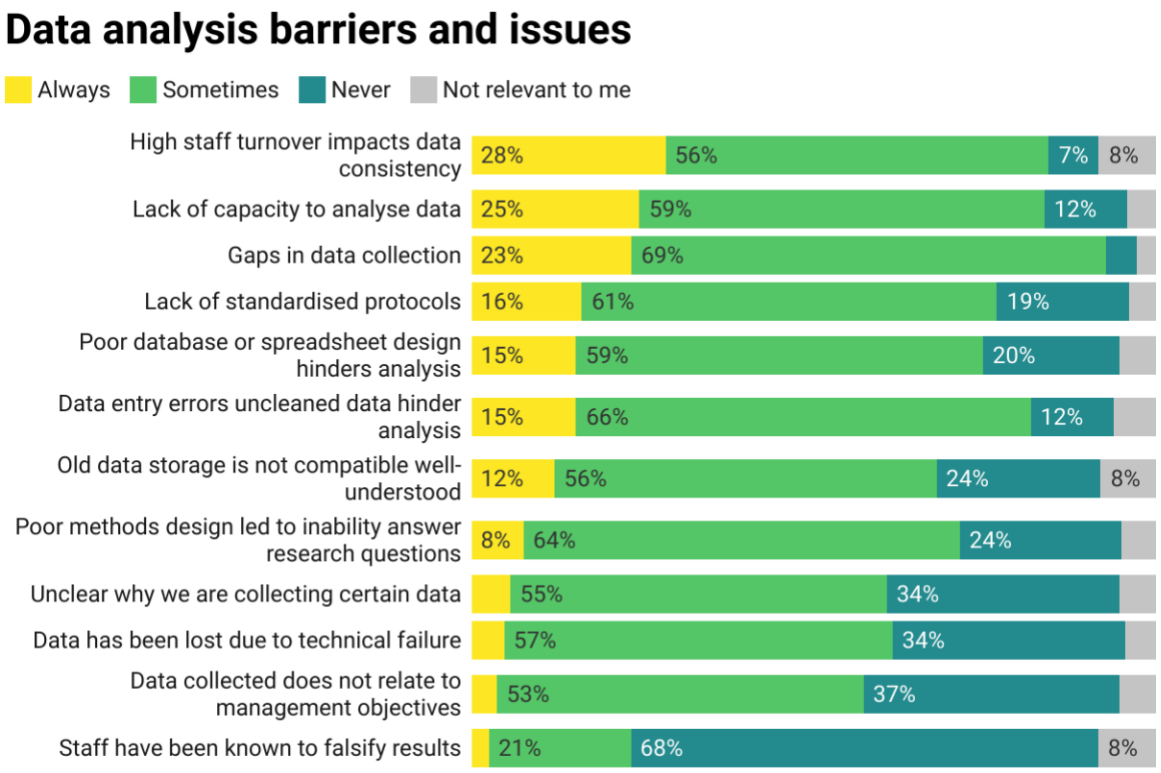


Figure S3.15: The frequency in which practitioners have experienced the twelve barriers to data analysis listed in the survey. Based on 320 respondents who were directly involved in data management or analysis.

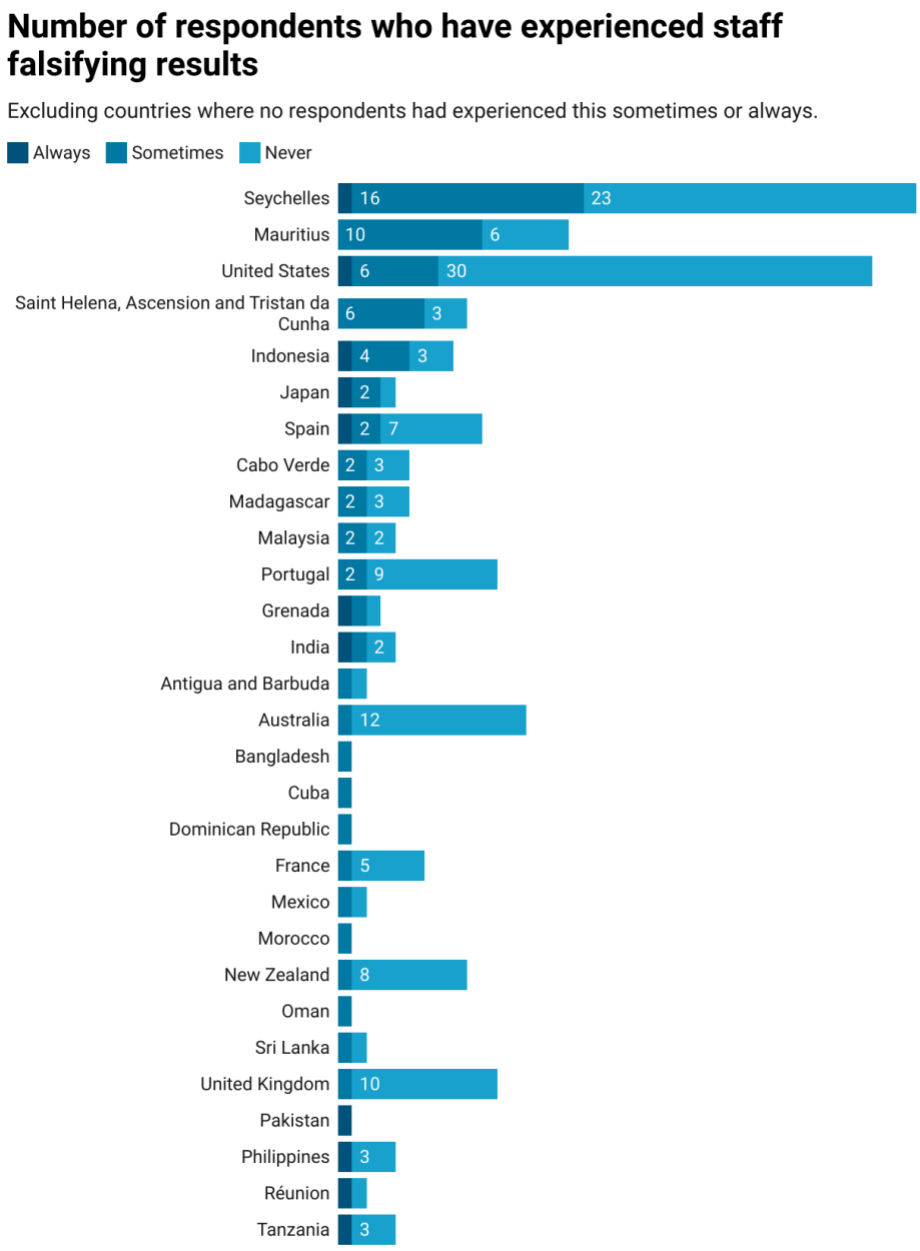


Figure S3.15b: A breakdown of where the highest number of respondents have experienced staff falsifying results.

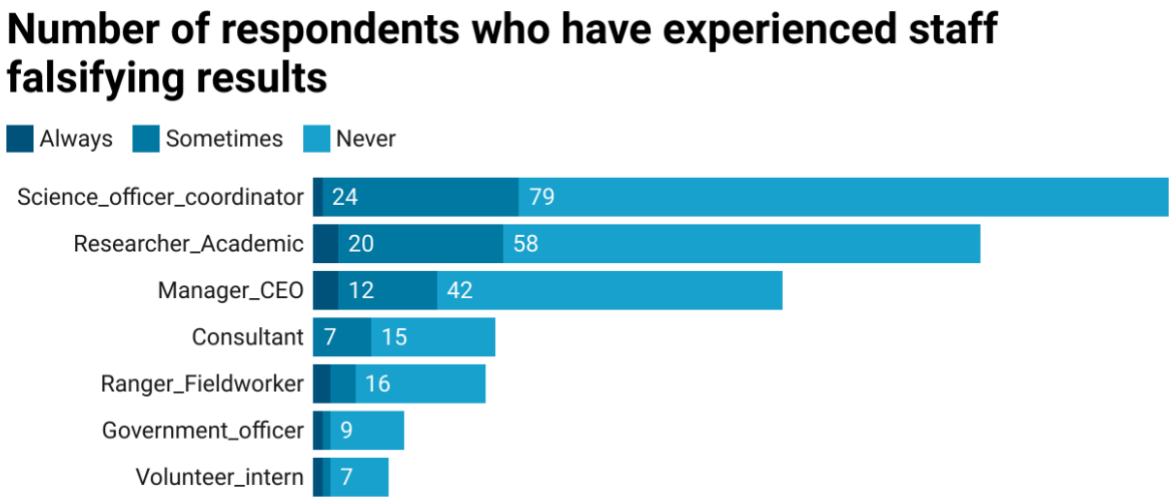


Figure S3.15c: A breakdown of which roles have most experienced staff falsifying results.

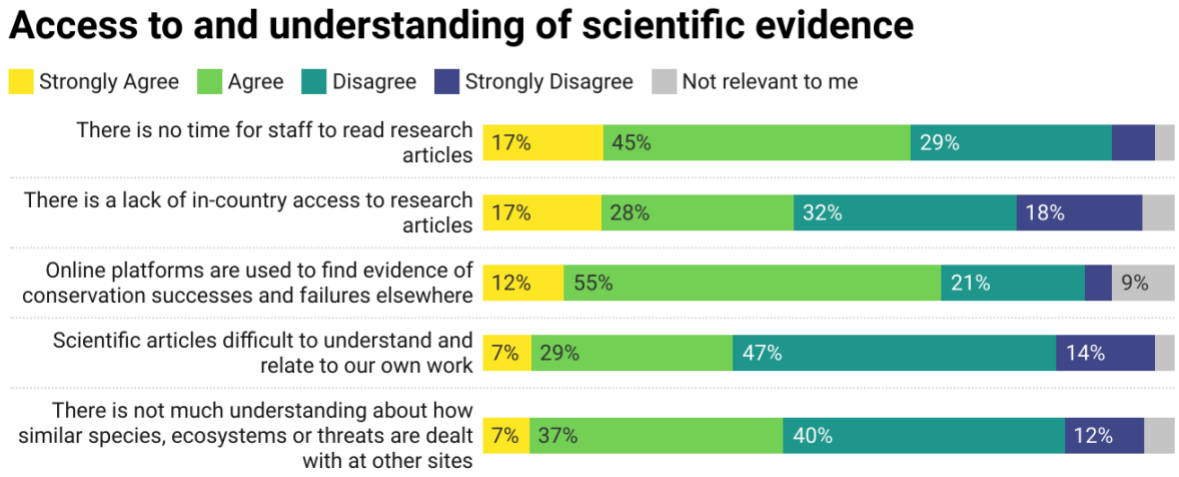


Figure S3.16: The extent to which practitioners agree with these five statements regarding access to and understanding of scientific literature. Based on 330 respondents.

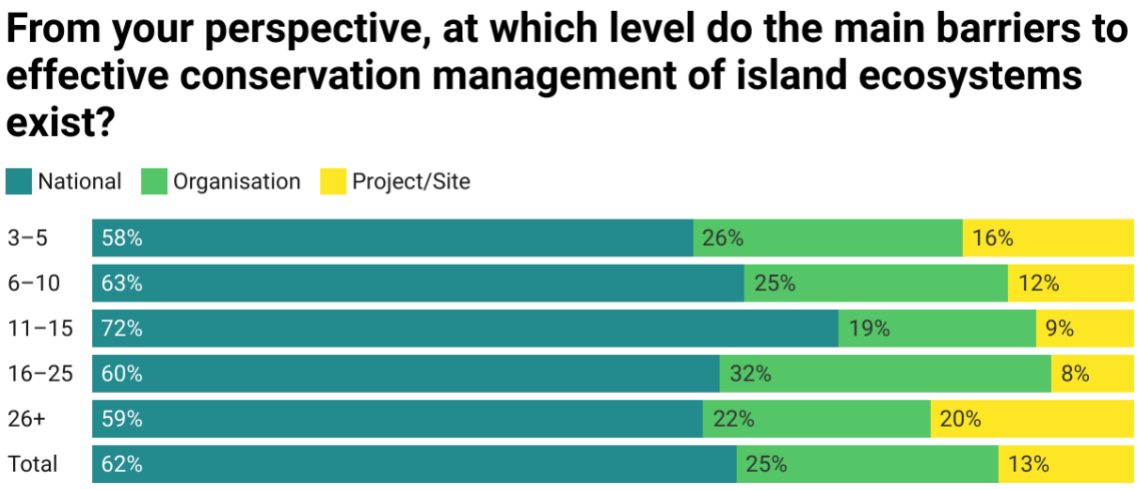


Figure S3.17: The level at which respondents perceived there to be the main barriers to effective conservation management of island ecosystems for each level of experience in years (binned). Based on 330 respondents.

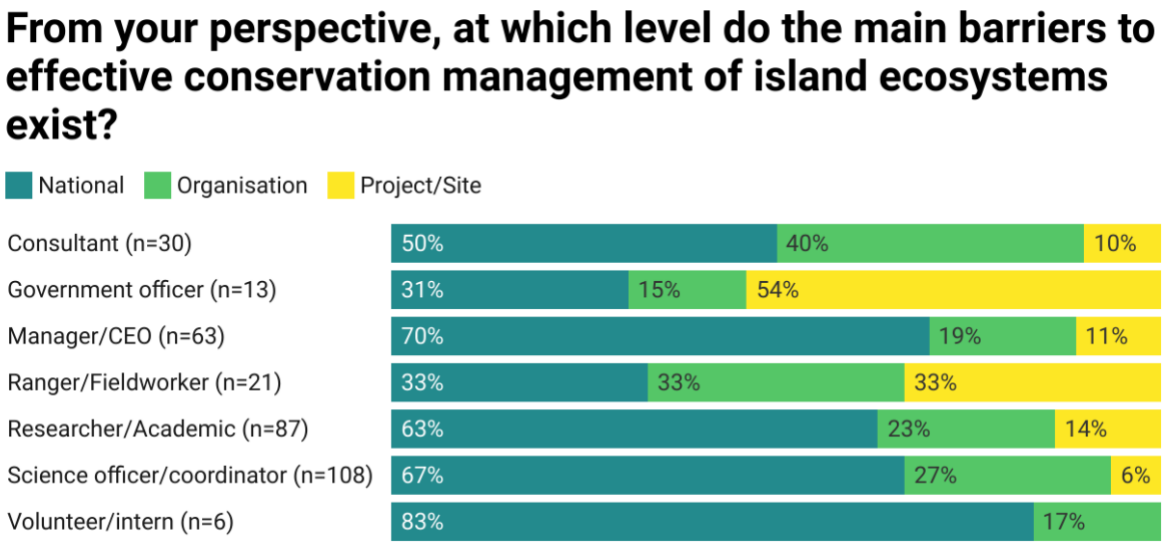


Figure S3.18: The level at which respondents perceived there to be the main barriers to effective conservation management of island ecosystems for each respondent role type. Based on 330 respondents.

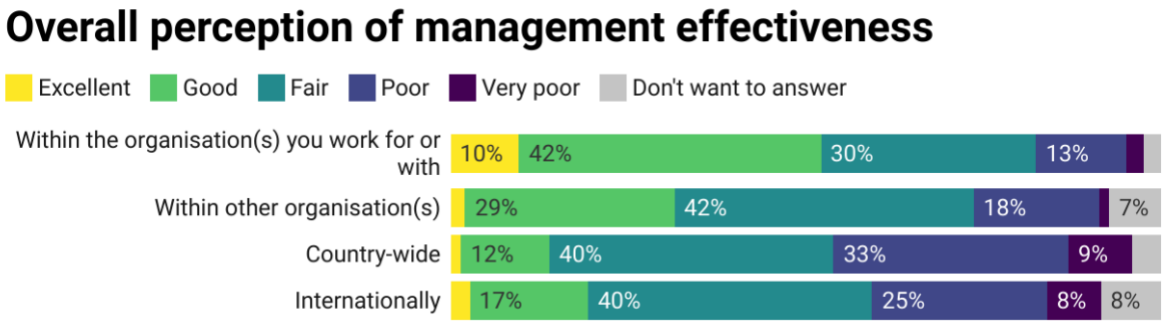


Figure S3.19a: The respondents rating of the current level of effectiveness of management and conservation of island ecosystems across these four scales. Based on 330 respondents.



Figure S3.19b: Respondent's perception of management effectiveness within organisation across the different role type.

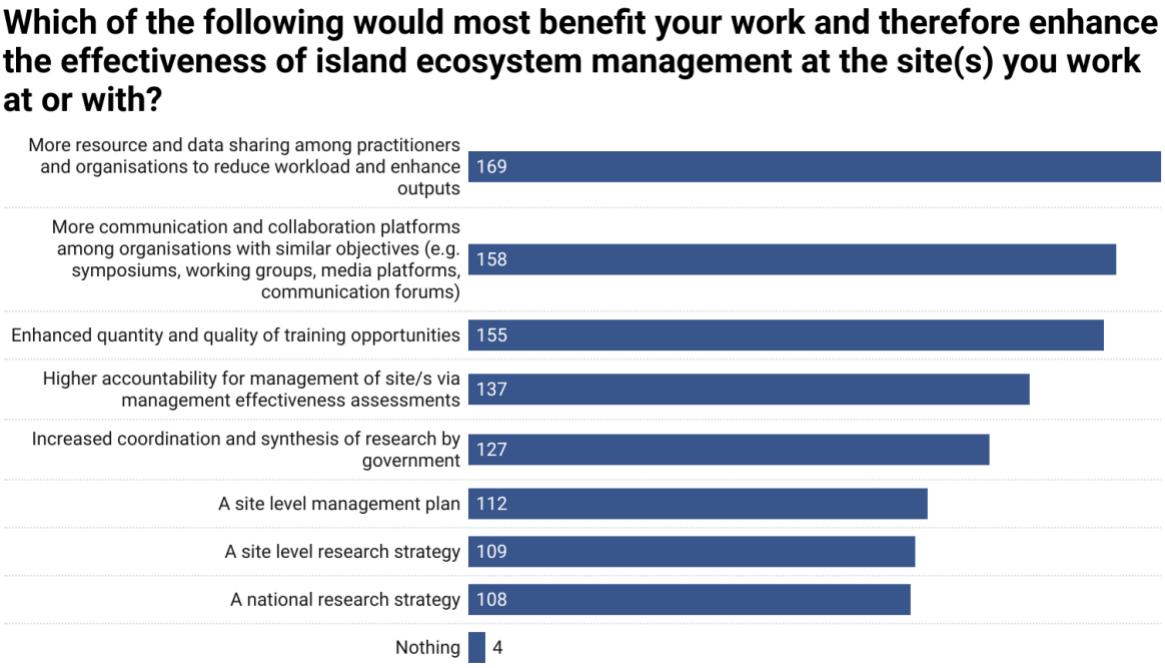


Figure S3.20: The number of respondents who believed the implementation/introduction of the points listed would enhance the effectiveness of island ecosystem management at the site/s they work with. Based on the 262 respondents who were happy to complete the solutions section of the survey.

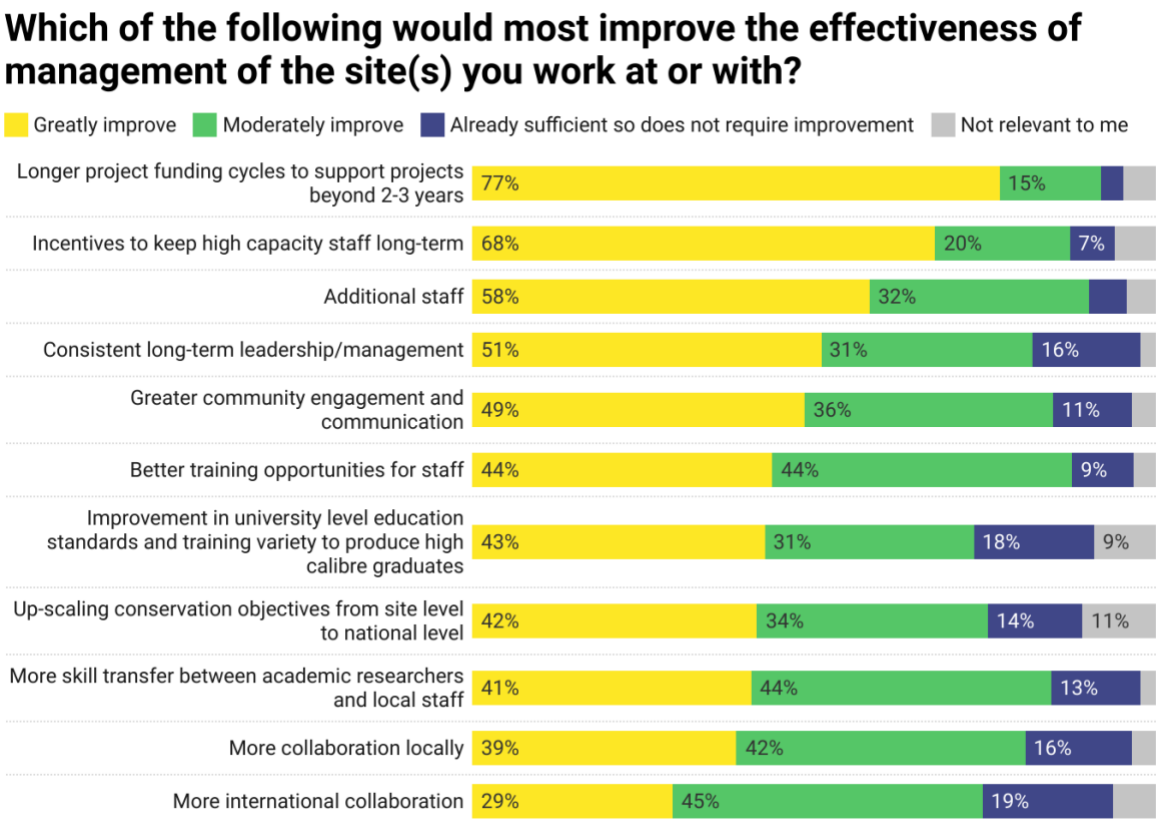


Figure S3.21: The level to which respondents believed each of the eleven actions/ statements would improve management effectiveness of the site/s they work with. Based on the 262 respondents who were happy to complete the solutions section of the survey.

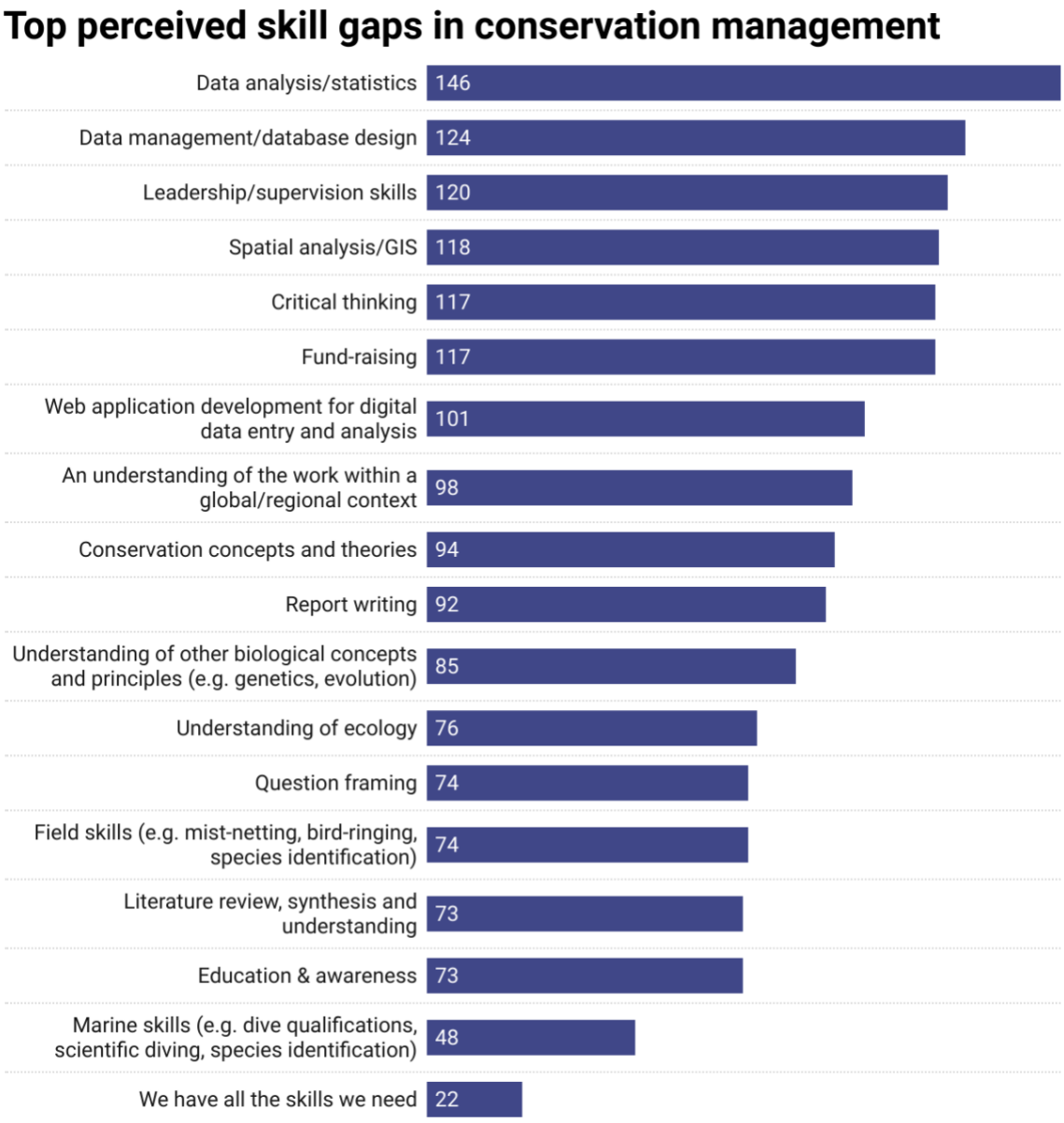


Figure S3.22: The number of respondents that feel each of the 18 skills listed are currently lacking within your organisation/team/collaborators and that would assist in achieving management objectives. Based on the 262 respondents who were happy to complete the solutions section of the survey.

Table S3.1: List of variables used in the main ordinal regression analysis

Variable Name (type)	Data type	Description	Cronbach's Alpha	Justification	Hypothesis
Overall perception of management effectiveness within your organisation/or Countrywide (Dependent/Ordinal)	Ordinal	Practitioners rated the current level of effectiveness of management and conservation across four levels. The ones to fit to the model will be (a) Within your organisation and (b) Nationally. I'll run the model for both these Dependent variables and then decide which one to include in main results section.	NA	The practitioners were asked to rate current level of management effectiveness, they are most likely to have an informed understanding of this for their own organisation and nationally, hence why we are focusing on these two. By fitting a model to investigate which variables had the most association/impact of practitioner's perspective of IE management we can identify which are the most important areas in which to focus improvement efforts on.	NA

Perception of threats (Independent)	Continuous	Index created from level of threat for each threat type, e.g 5 points for severe etc then added across all threats	NA	Threat types and severity vary from site to site and country to country, it will therefore be useful to include threat perception into the model to see whether those who experience a greater number of threats have a different perception of management effectiveness.	Practitioners who work on sites with more severe threats may be less likely to find management effective
Number of threats (Independent)	Continuous	Index created by adding the number of threats in which a practitioner perceived to be severe, moderate or mild (so not including the responses 'none' or ''not relevant'	NA	This variable provides a level of insight into the challenges that practitioners are facing.	Practitioners who work on sites with more threats may be less likely to find management effective
Experience of practitioner in years (Independent)	Continuous	Practitioners listed the number of years they had been working in island ecosystem management/conservation	NA	Practitioner perception of effectiveness may vary depending on how much experience they have	Practitioners with many years' experience are likely to be in more

					senior roles and may see less issues with their own management and more with national level.
Practitioner provenance (Independent)	Binary	Practitioners listed the country they are native to and the country they work mostly in island ecosystem management. We created a new variable based on whether these two countries matched (i.e practitioner was a national to the country they worked in island ecosystem management) or unmatched (non-national)	NA	We wanted to explore this variable to see if there was any differences in perception of management effectiveness based on whether you are native to the country you work with.	One might expect non-native practitioners to be more critical of management effectiveness.
Main management focus (Independent)	Categorical	Practitioners listed the management activities the organisation/site they work with carries out (question 12 of online survey), based on	NA	The threats facing marine vs terrestrial systems are very different and managing these threats is challenging. The amount of resources	No clear hypothesis although perhaps practitioners

		these responses we created a new variable with three levels based on their main management focus; if they listed all marine related actions, we listed their main focus as 'marine', if they listed all terrestrial based actions, we listed their main focus as 'terrestrial' and if a mixture of both then we listed 'marine and terrestrial'.		required to manage threats also varies with marine work generally being more costly and resource dependent. Therefore, there may well be differences in perception of management effectiveness between practitioners who work predominantly on terrestrial or marine sites.	focusing on both marine and terrestrial ecosystems will have more barriers to achieve objectives and therefore perceive management to be less effective.
Role in IE management (Independent)	Categorical	As per the survey groupings (e.g. ranger/CEO etc)	NA	Perhaps not the most important variable to include though would be interesting if large differences in outlook occur between role types.	Suspect there are differences in outlook depending on what level you are working at, for example CEO's are more likely to feel the

					management within their organisation is effective compared to say fieldworkers, or academics.
Region (Independent)	Categorical	Participants grouped by region as per the survey design (minus the Arab states and middle east who have too few)	NA	In the interviews we established a set of barriers that occurred to practitioners in the WIO, we wanted to investigate if these barriers were ubiquitous	Suspect barriers are experienced globally with no major differences detected regionally, except perhaps between the wealthier (Global North) where one would expect better

					management due to more resources etc.
Socio-economic and political characteristics (Independent)	Binary	Based on the countries the practitioners listed as their country of work, we assigned as a new variable the global economic demographic or either 'global south' or 'global north'	NA	Countries of the Global South have been described as newly industrialized or in the process of industrializing and frequently have a history of colonialism by Northern, often European states. Global South countries are also lower-income countries and therefore there are likely to be differences in resource levels, governance and education systems that may impact overall perception of management effectiveness.	Practitioners who work in the global south countries may encounter more issues and threats and therefore find management less effective.
Education standards (Independent)	Binary	Binary response whether the respondent had experienced 'Lack of national education and training opportunities'	NA	One of themes from original interviews was poor tertiary level education standards and low training	Perception of education standards likely to have some effect

				opportunities leading to poor capacity.	on practitioners' perceptions of management effectiveness.
Governance issues (Independent)	Binary	Binary response whether the respondent had experienced 'Poor conservation policy implementation' and 'Poor conservation law enforcement', these scores then summed to produce a three levels index (0= not experienced, 1=experienced one, 2= experienced both)	NA	One of themes from original interviews was policy & legislation issues	Level of governance issues likely to have some effect on practitioners' perceptions of management effectiveness.
Perception of limited government coordination (Independent)	Binary	Binary response whether the respondent had experienced 'Lack of nationally coordinated communication forums for practitioners to share/learn' and 'Lack of coordinated national research/conservation objectives', these scores then	NA	One of themes from original interviews was lack of government coordination	Level of government coordination of research and management objectives likely to have some effect

		summed to produce a three levels index (0= not experienced, 1=experienced one, 2= experienced both)			on practitioners' perceptions of management effectiveness.
Perception of staffing capacity issues (Independent)	Continuous	Single statement as per survey: 'Staffing capacity (e.g. data analysis/report writing/ leadership etc)' Responses scaled on 5-point Likert (Always=5, Never=1)	NA	Major issue from original interviews	Staffing capacity level likely to have some effect on practitioners' perceptions of management effectiveness.
Research/management strategy lack (Independent)	Continuous	Combined two 5-point Likert statements: 'Lack of focused management objectives' and 'Lack of research strategy' to combine one new variable.	0.85	At organisation level a lack of focused management and reser4ach objectives and strategy were key barrier themes	Lack of research or management strategy within organisations likely to have some effect on

					practitioners' perceptions of management effectiveness (at their own organisation level)
Perception of staffing issues (Independent)	Continuous	Low internal consistency so scale results added not averaged for following 5-point Likert statements: 'Inadequate staff numbers' and 'High staff turnover' to combine one new variable.	0.45	Staffing issues was identified as a key theme in interviews	Staffing issues likely to have some effect on practitioners perceptions of management effectiveness (at their own organisation level)

Perception of monitoring programme issues (Independent)	Continuous	Combined eight Likert statements (two originally 5-point, reduced to 3-point) into 3-point Likert scale by averaging score across statements to combine into one new variable. Statements were: 'Protocols for monitoring methods are poor or non-existent', 'Monitoring aims have not been defined clearly', 'It is not always clear why we are collecting certain data', 'The data collected does not relate to management objectives for the area(s) managed', 'Lack of standardised protocols and method drift impacts integrity of data', 'There are gaps in data collection', 'Poor methods design has led to inability to answer the research question/s' and	0.82	These issues have been a central theme at project level in relation to the many barriers that prevent monitoring data being used to inform management but are distinctly different from the data management and analysis also covered.	As monitoring is so central to conservation it is likely these issues will have some effect on practitioners' perceptions of management effectiveness.

		'High staff turnover impacts data consistency'			
Perception of data management issues (Independent)	Continuous	Combined four 3-point Likert statements by averaging score across statements to combine into one new variable. Statements were: 'Data entry errors/uncleaned data sets hinder analysis', 'Old data storage is not compatible or well-understood', 'Data has been lost due to technical failure (hard drive or computer malfunction)' and 'Poor database or spreadsheet design hinders analysis'	0.75	data management issues were identified as a key theme in interviews	Perhaps would only effect perception of management within the organisation they work for

Perception of data analysis issues (Independent)	Continuous	Combined five 3-point Likert statements by averaging score across statements to combine into one new variable. Statements were: 'There are difficulties with turning data into information for management', 'Data is rarely analysed beyond basic graphs', 'There has not been time to analyse the data', 'Staff do not have the skills to analyse the data' and 'There is a lack of capacity to analyse data'.	0.8	data analysis issues were identified as a key theme in interviews	Perhaps would only effect perception of management within the organisation they work for
Level of collaboration (Independent)	Continuous	Combined two 5-point Likert statements: 'Collaborative reports between organisations are rare' and 'Data sharing between organisations is rare'	0.83	Collaboration barriers were the most numerous raised by practitioners in interviews	Level of collaboration likely to have some effect on practitioners' perceptions of management effectiveness

Figure S3.23: English version of online survey

UNIVERSITY OF OXFORD

Barriers To Effective Island Ecosystem Management

About the survey

- En français
- En español
- Português
- عربی
- bahasa Indonesia
- 日本語
- Orang Malaysia

Are you working, or have you worked in conservation and management of island ecosystems in the past three years?

If so, we need your help to better understand the day-to-day challenges you are facing in your goal to meet management objectives and achieve effective conservation of island ecosystems.

By work we mean any role either directly working for an organisation (e.g. ranger, warden, fieldstaff, manager, CEO) or with them collaboratively (e.g. consultant, academic, researcher, governmental officer). This includes voluntary roles whereby the volunteer is part of the organisation team (i.e. not paying volunteer schemes).

By island we are specifically referring to those listed on the UNEP list, so ranging from small tropical islands to large oceanic islands like New Zealand. If you are unsure whether your location counts as an island you can check

About you

3. What country are you a national of? Overseas territories are also listed after countries. ('I would rather not say' is an option in this list) ✱ *Required*

4. Which of the following best describes the level at which you are involved in Island Ecosystem Management? ✱ *Required*

- Mainly International
- Regionally
- Nationally
- Local

5. Which is the country/territory you have **most experience** with working in island ecosystem management/conservation in the last three years? **If you are familiar with multiple countries, please select one representative country.** Overseas territories are also listed after countries. ✱ *Required*

6. Which of the following job titles **best describes your main role** in island ecosystem management/conservation over the past three years? ✱ *Required*

- Ranger/Warden/Fieldworker
- Science officer/Research assistant/Conservation officer/Science coordinator
- Manager/CEO/Director

- Government Minister/ Officer
- Researcher/Academic
- Consultant
- Volunteer/Intern
- I'd rather not say
- Other

6.a. If you selected Other, please specify:

7. How many years have you been working in island ecosystem management/conservation? (record to the closest number of years) * *Required*

Please enter a whole number (integer).

About the organisation(s) you work with

Please answer these questions based on the country and role you listed as having most of your island ecosystems management and conservation experience in the previous three years.

8. Which of the following best describe the organisation(s) you have worked for or with in your role regarding island conservation and management? (Tick all that apply) * *Required*

Please select between 1 and 7 answers.

- Privately owned business/island (e.g resort island)
- Non-governmental organisation
- Governmental organisation
- Public trust
- Educational/Research institution (e.g. university)
- Consultant (no organisation)
- Other
- I'd rather not say
- A combination of these

8.a. If you selected Other, please specify:

9. Which of the following best describes the area(s) or site(s) you are/have been working with? (Tick all that apply) * *Required*

Please select between 1 and 7 answers.

- Protected area(s)

- [ ] National park(s)
- [ ] UNESCO world heritage site(s)
- [ ] Special reserve(s)
- [ ] Privately owned island(s)
- [ ] Mainland (Island with town/city)
- [ ] Other
- [ ] I'd rather not say

9.a. If you selected Other, please specify:

10. Which of the following best describes the remoteness of the area(s) or site(s) you have been working with? **Note: Mainland defined as the land on which the closest human towns/citys are. If you work on an island with a town or city please select 'On the mainland'** ✱ *Required*

- [ ] Less than 2 km from mainland
- [ ] 3 to 10 km from mainland
- [ ] 11 to 30 km from mainland
- [ ] 31 to 100 km from mainland
- [ ] 101 to 500 km from mainland
- [ ] Over 500 km from mainland
- [ ] On the mainland
- [ ] A combination of these for multiple sites
- [ ] I'd rather not say

Management objectives and activities

11. What are the main management objectives of the organisation(s) that you work with? (or the project you work with within an organisation)

	Primary objective/s	Secondary objective/s	Additional project/s	Not relevant
Protection (e.g. enforcing a no take policy)	○	○	○	○
Restoration (e.g. invasive species removal or native tree planting)	○	○	○	○
Sustainable Development (e.g. implementing fishing quotas)	○	○	○	○
Research to inform Management	○	○	○	○
Other research	○	○	○	○
Monitoring species/ecosystems	○	○	○	○
Policy development/enforcement	○	○	○	○
Education and Awareness	○	○	○	○
Other	○	○	○	○

12. What site management and monitoring activities is the organisation(s) engaged in? (Tick all that apply) ✱ *Required*

Please select at least 1 answer(s).

- [ ] Marine ecosystem monitoring programmes (e.g. fish/benthic community)
- [ ] Marine species monitoring programmes (e.g. turtles, sharks, whales)
- [ ] Terrestrial ecosystem monitoring programmes (e.g. vegetation phenology, Climate)
- [ ] Terrestrial species monitoring programmes (e.g. land-birds, reptiles, insects, vegetation)
- [ ] Ecological process monitoring programmes (e.g. seed dispersal, coral recruit settlement, pollination)

- Active site management via invasive alien species management actions (e.g. invasive eradication or control)
- Active site management via restoration actions (e.g. native planting, translocations of native/endemic species)
- Active site management via protective actions (e.g. site regulations/zonation, legislation)
- Additional targeted scientific research (e.g. tracking species, genetic studies)
- Scientific advisory/supervisory role
- Not applicable to my role
- Other

12.a. If you selected Other, please specify:

Threats

13. What are the main threats to the site(s) that you are involved with? Rate their severity below or add additional threats to the comments section.

	None	Mild	Moderate	Severe	Not applicable
Sea level rise					
Coral bleaching and mortality					
Native habitat destruction/modification for agriculture					
Native habitat destruction/modification for development					
Invasive alien species					
Illegal activities (e.g. poaching)					
Tourist impacts (e.g. boat traffic, littering, light and sound pollution etc)					
Plastic pollution (e.g. arriving on coasts, impacting wildlife etc)					
Water pollution (e.g. sewage run off, oil spills, ship waste)					
Industrial fishing (e.g. long-liners and purse-seine fisheries)					
Small scale fisheries (e.g. localised impacts of removing herbivores)					
Coastal erosion (caused by more frequent storm events)					

14. Please select upto three threats which have the most direct impact on management resources, such as time and money for your orgainsation or the project you work with, within an organisation. * *Required*

Please select no more than 3 answer(s).

- [ ] Sea level rise
- [ ] Coral bleaching and mortality
- [ ] Habitat destruction (e.g. for agriculture or development)
- [ ] Invasive alien species
- [ ] Illegal activities (e.g. poaching)
- [ ] Tourist impacts (e.g. boat traffic, anchoring, light and sound pollution etc)
- [ ] Marine plastic pollution (e.g. arriving on coasts, impacting wildlife etc)
- [ ] Water pollution (e.g. sewage run off, oil spills, ship waste)
- [ ] Industrial fishing (e.g. long-liners and purse-seine fisheries)
- [ ] Small scale fisheries (e.g. localised impacts of removing herbivores)
- [ ] Coastal erosion (caused by more frequent storm events)
- [ ] Other

14.a. If you selected Other, please specify:

National level factors that may influence your work

15. Which of the following factors have impacted the fulfilment of management, conservation or research objectives? (Tick all that apply) ✱ *Required*

- [ ] Poor conservation policy implementation
- [ ] Poor conservation law enforcement
- [ ] Lack of national education and training opportunities
- [ ] Lack of public support for conservation
- [ ] Harvesting natural resources prioritised over conservation
- [ ] Lack of coordinated national research/conservation objectives
- [ ] Poor national administration
- [ ] Lack of nationally coordinated communication forums for practitioners to share/learn
- [ ] Other
- [ ] None

15.a. If you selected Other, please specify:

16. If you feel that there are national level initiatives that greatly enhance your work, please mention them here.

About organisation level factors that may impact your work

Please answer these questions based on the country and role you selected at the start of the survey

17. How often have the following factors been barriers to the fulfilment of management and research objectives?

	Never	Rarely	Sometimes	Often	Always	Not relevant to me
Staffing capacity (e.g. data analysis/report writing/ leadership etc)	○	○	○	○	○	○
High staff turnover	○	○	○	○	○	○
Balancing tourism with conservation priorities	○	○	○	○	○	○
Illegal harvesting	○	○	○	○	○	○
Lack of focused management objectives	○	○	○	○	○	○
Lack of research strategy	○	○	○	○	○	○
Inadequate staff numbers	○	○	○	○	○	○
Volunteers or interns are needed to fill skill gaps	○	○	○	○	○	○

17.a. Please add any additional factors you have encountered here

18. Please list any factors that in your experience have enhanced successful management at the organisation level.

About site or project level issues that might affect your work

Please answer these questions based on the country and role you selected at the start of the survey

19. Please read the statements below and indicate to what extent you have encountered the issue described. If you have an additional comment you can add this in the box at the bottom.

	Never	Rarely	Sometimes	Often	Always	Not relevant to me
The research/monitoring focus shifts as management staff change						
Protocols for monitoring methods are poor or non-existent						
Monitoring aims have not been defined clearly						
There are difficulties with turning data into information for management						
Data is analysed regularly to generate information used in management decisions						
Data is is rarely analysed beyond basic graphs						
There has not been time to analyse the data						

Staff do not have the skills to analyse the data						

20. If you can think of factors at site or project level that have greatly enhanced effectiveness then please write them here.

About work collaborations

Please answer these questions based on the country and role you selected at the start of the survey

21. Please read the following statements and decide to what extent you agree with each. If you have an additional comment you can add this in the box at the bottom.

	Strongly disagree	Disagree	Agree	Strongly agree	Not relevant to me
Collaborative reports between organisations are rare	○	○	○	○	○
Data sharing between organisations is rare	○	○	○	○	○

22. In your experience, how frequently do international collaborations have positive outcomes for you/your organisation? ✱ *Required*

- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ Not relevant to my role

23. In your experience, how frequently do local (in-country) collaborations have positive outcomes ✱ *Required*

- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ Not relevant to my role

24. Feel free to add any comments here

Obstacles to collaboration

25. Please read each statement and decide to what extent you agree with these obstacles to local (in-country) collaborations. If you have an additional comment you can add this in the box at the bottom.

	Strongly disagree	Disagree	Agree	Strongly agree	Not relevant to me
Lack of incentive (e.g. financial)					
They create more work and take up time					
Lack of communication and social platforms for interaction					
Lack of trust					
Bad experiences of collaboration					
Strong sense of ownership over data or species or sites					
Conflict of interest e.g. competition for funding					
Egos/personalities and personal issues					
No interest in achieving higher conservation objectives outside organisation /site.					
Lack of coordination by government					
Staff turnover breaks relationships that are building and existing collaborations					

25.a. Any additional obstacles to collaboration?

About data and analysis issues

26. Are you directly involved in data collection, management or analysis? * *Required*

- Never
- Sometimes
- Always

About data and analysis issues

Please answer these questions based on the country and role you selected at the start of the survey

27. Please read each statement and indicate how frequently you have personally encountered these issues with turning data collected into useful information for research and management

	Never	Sometimes	Always	Not relevant to me
High staff turnover impacts data consistency				
It is not always clear why we are collecting certain data				
The data collected does not relate to management objectives for the area(s) managed.				
Poor database or spreadsheet design hinders analysis				
Data has been lost due to technical failure (hard drive or computer malfunction)				
Old data storage is not compatible or well-understood				
Lack of standardised protocols and method drift impacts integrity of data				
There are gaps in data collection				
Data entry errors/uncleaned data sets hinder analysis				
Poor methods design has led to inability to answer the research question/s				
There is a lack of capacity to analyse data				
Staff have been known to falsify results				

Access to scientific literature

Please answer these questions based on the country and role you selected at the start of the survey

29. Please read each statement and indicate to what extent you agree. If you have an additional comment you can add this in the box at the bottom.

	Strongly Agree	Agree	Disagree	Strongly Disagree	Not relevant to me
There is a lack of in-country access to international research articles that would be useful					
There is generally no time for staff to read scientific research articles					
Scientific articles are difficult to understand and to relate to the research/monitoring or management of site(s)					
There is not much understanding about how similar species, ecosystems or threats are dealt with at other sites					
Online platforms are used to find evidence of conservation management successes and failures elsewhere					

29.a. Any additional comments here?

Additional solutions section

30. Are you happy to complete an additional section about solutions? (If not you can go straight to the final summary page) *Required

- Yes I'm happy to
- No thanks

About solutions to improve your work

Please answer these questions based on the country and role you selected at the start of the survey

31. Which of the following would most benefit your work and therefore enhance the effectiveness of island ecosystem management at the site(s) you work at or with? Click all that apply. *Required

Please select at least 1 answer(s).

- Nothing
- A site level management plan
- A site level research strategy
- A national research strategy
- Increased coordination and synthesis of research by government
- More resource and data sharing among practitioners and organisations to reduce workload and enhance outputs
- More communication and collaboration platforms among organisations with similar objectives (e.g. symposiums, working groups, media platforms, communication forums)
- Higher accountability for management of site/s via management effectiveness assessments
- Enhanced quantity and quality of training opportunities
- Other

31.a. If you selected Other, please specify: *Optional*

32. Which of the following would most improve the effectiveness of management of the site(s) you work at or with?

	Already sufficient so does not require improvement	Moderately improve	Greatly improve	Not relevant to me
Better training opportunities for staff				
Additional staff				
Incentives to keep high capacity staff long-term				
Consistent long-term leadership/management				
More collaboration locally				
More international collaboration				
More skill transfer between academic researchers and local staff				
Greater community engagement and communication				
Up-scaling conservation objectives from site level to national level				
Longer project funding cycles to support projects beyond 2-3 years				
Improvement in university level education standards and training variety to produce high calibre graduates				

32.a. Any additional comments here?

33. Please select the skill set(s) that you feel are currently lacking within your organisation/team/collaborators that would assist in achieving management objectives. Click all that apply. * *Required*

- [ ] We have all the skills we need
- [ ] Understanding of ecology
- [ ] Conservation concepts and theories
- [ ] Understanding of other biological concepts and principles (e.g. genetics, evolution)
- [ ] Critical thinking
- [ ] An understanding of the work within a global/regional context
- [ ] Leadership/supervision skills
- [ ] Literature review, synthesis and understanding
- [ ] Question framing
- [ ] Data management/database design
- [ ] Data analysis/statistics
- [ ] Report writing
- [ ] Spatial analysis/GIS
- [ ] Field skills (e.g. mist-netting, bird-ringing, species identification)
- [ ] Marine skills (e.g. dive qualifications, scientific diving, species identification)
- [ ] Fund-raising
- [ ] Education & awareness
- [ ] Web application development for digital data entry and analysis
- [ ] I do not wish to answer
- [ ] Not applicable
- [ ] Other

Overall perception

34. From your perspective, at which level do the main barriers to effective conservation management of island ecosystems exist? ✱ *Required*

Please select no more than 1 answer(s).

- ☐ National
- ☐ Organisation
- ☐ Project/Site

35. Overall, how do you rate the current level of effectiveness of management and conservation of island ecosystems

Please don't select more than 1 answer(s) per row.

Please select at least 4 answer(s).

	Very poor	Poor	Fair	Good	Excellent	Don't want to answer
Within the organisation(s) you work for or with	☐	☐	☐	☐	☐	☐
Within other organisation(s)	☐	☐	☐	☐	☐	☐
Country-wide	☐	☐	☐	☐	☐	☐
Internationally	☐	☐	☐	☐	☐	☐

36. If you would like us to send you a summary of our results, please leave your email address below

If you do include your email address:

Your data email address will only be used to send you an update of this study.

Data Protection

The University of Oxford is the data controller with respect to your personal data, and as such will determine how your personal data is used in the study. The University will process your personal data for the purpose of the research outlined above. Research is a task that we perform in the public interest.

Further information about your rights with respect to your personal data is available from http://www.admin.ox.ac.uk/councilsec/compliance/gdpr/individualrights/.

TABLE S3.2. Parameter unconditional estimates (i.e., obtained by averaging over all (306) models in the top model set) from the averaged ordered logistic regressions fitted to practitioners' perception of management effectiveness countrywide.

	Management effectiveness countrywide			
Parameter	Estimate (SE)	z-value	Relative variable importance	Main direction of parameter
Perception of governance issues	-0.48 (0.14)	3.37	1.00	Negative (i.e. if a practitioner experienced governance issues they were less likely to find national management of island ecosystems effective.
Perception of poor collaboration	-0.43 (0.14)	3.12	1.00	Negative
Perception of data management issues	-0.33 (0.27)	1.27	0.35	Negative
Practitioner provenance: Non-National	-0.01 (0.22)	0.027	0.08	Little effect
Lack of management and research strategy	-0.19 (0.11)	1.66	0.65	Little effect
Main management focus: Marine	-0.80 (0.39)	2.02	0.47	Negative (those practitioners working solely in marine systems were less likely to find national management effective).
Main management focus: Terrestrial	-0.04 (0.24)	0.18	0.47	Little effect
Perception of monitoring programme issues	0.09 (0.15)	0.442	0.14	Little effect

Lack of education and training opportunities	0.02 (0.19)	0.51	0.19	Little effect
Global categorisation: Global South	-1.17 (0.42)	2.72	0.99	Negative ((those practitioners working in the global south were less likely to find national management effective).
Threat severity index	0.17 (0.12)	1.36	0.38	Little effect
Lack of staff capacity	0.01 (0.11)	0.12	0.08	Little effect
Perception of staffing issues	0.01 (0.05)	0.265	0.09	Little effect
Perception of data analysis issues	-0.15 (0.15)	0.99	0.23	Little effect
Number of threats	0.07 (0.04)	1.57	0.61	Little effect
Perception of lack of government coordination	0.08 (0.14)	0.57	0.13	Little effect
Experience (years)	-0.01 (0.01)	0.61	0.13	Little effect
Region: Europe	-1.8 (0.53)	3.35	0.99	Negative
Region: North America	-1.35 (0.55)	2.42	0.99	Negative
Region: Asia & Pacific	-1.198 (0.33)	3.63	0.99	Negative
Region: South/Latin America	-0.721 (0.32)	2.25	0.99	Negative

TABLE S3.3. Parameter unconditional estimates (i.e., obtained by averaging over all (135) models in the top model set) from the averaged ordered logistic regressions fitted to practitioner's perception of management effectiveness within their organisation.

	Management effectiveness within organisation			
Parameter	Estimate (SE)	z-value	Relative variable importance	Main direction of parameter
Lack of education and training opportunities	0.06 (0.20)	0.31	0.08	Little effect
Number of threats	0.02 (0.03)	0.47	0.09	Little effect
Perception of poor collaboration	-0.22 (0.13)	1.65	0.69	Slightly negative effect
Lack of management and research strategy	-0.39 (0.12)	3.27	1.00	Slightly negative effect
Lack of staff capacity	-0.09 (0.13)	0.72	0.15	Little effect
Perception of monitoring programme issues	-0.47 (0.17)	2.71	1.00	Negative effect (those practitioners who experience more monitoring programme issues are less likely to perceive their organisation management to be effective)
Perception of data analysis issues	0.12 (0.16)	0.73	0.15	Little effect
Perception of staffing issues	-0.11 (0.05)	2.10	0.94	Little effect

Perception of governance issues	-0.09 (0.13)	0.70	0.15	Little effect
Global categorisation: Global South	0.08 (0.20)	0.37	0.09	Little effect
Experience (years)	0.01 (0.01)	1.08	0.26	Little effect
Threat severity index	0.04 (0.03)	0.08	0.09	Little effect
Practitioner provenance: Non-National	-0.02 (0.06)	0.03	0.07	Little effect
Perception of data management issues	-0.06 (0.30)	0.21	0.07	Little effect
Perception of lack of government coordination	0.02 (0.13)	0.13	0.07	Little effect
Main management focus: Marine	-0.36 (0.36)	1.00	0.10	Negative
Main management focus: Terrestrial	0.19 (0.21)	0.87	0.10	Little effect

Appendix C: Supplementary Material for Chapter 4

The costs of removing the unsanctioned import of marine plastic litter to small island states.

Habitat type area calculation methods

To estimate beach area: Area polygons were created in google earth pro for all south facing beaches on the south-coast of Grande Terre island (i.e. all the beaches targeted during the clean-up expedition). The west coast beaches of Grande Terre island were not included in this area total, neither were any beaches from Picard, Malabar or Polymnie islands. These beaches were not included in our overall total because they are under different wind and current conditions and without additional transects on these areas it is not representative to extrapolate to these. These other beaches may not accumulate plastic at the same rate and have been subject to periodic clean-ups by the Aldabra team.To estimate coastal karst area: At thirty haphazard

points along the seaward coastline, the width of the karst was measured using google earth pro, these were averaged to 16.05m (stDev: 4.5m). The total outer (seaward) rim length was calculated also in google earth pro. The total karst area was then calculated by multiplying estimated karst width by outer rim length (52.5 km).

To estimate coastal vegetation area: Although trash did spread further into the vegetation it was most highly concentrated in the first 5 m. We therefore confined our estimated to a width of 5m and multiplied this by the total outer (seaward) rim length to get an area we felt was most representative of the spread of trash into the vegetation.

Table S4.1: Estimated quantity and composition of accumulated marine plastic litter on the coast of Grande Terre based on surveys of the three dominant coastal habitats.

Terrain Type	Terrain Area m^2	Debris category	Mean kg per m^2	Standard Deviation	N	Standard Error	95% Confidence Interval	Total per category (tonnes)
Vegetation	262,300	Consumer	0.014	0.011	20	0.002	0.005	3.7
		Fishing related	0.107	0.161	20	0.036	0.07	28.1
		Plastic shoes	0.097	0.132	20	0.03	0.058	25.4
		Fragments	0.044	0.033	20	0.007	0.014	11.5
		Other Debris	0.021	0.055	20	0.012	0.024	5.5
		Packaging	0.045	0.053	20	0.012	0.023	11.8
Beach	62,225	Consumer	0.021	0.028	20	0.006	0.012	1.3
		Fishing related	0.093	0.159	20	0.036	0.07	5.8
		Plastic shoes	0.15	0.12	20	0.027	0.053	9.3
		Fragments	0.05	0.037	20	0.008	0.016	3.1
		Other Debris	0.043	0.107	20	0.024	0.047	2.7
		Packaging	0.043	0.031	20	0.007	0.014	2.7
Karst	841,983	Consumer	0.001	0.004	20	0.001	0.002	0.8
		Fishing related	0.463	0.604	20	0.135	0.265	389.8

		Plastic shoes	0.003	0.006	20	0.001	0.003	2.5
		Fragments	0.005	0.012	20	0.003	0.005	4.2
		Other Debris	0.002	0.006	20	0.001	0.002	1.7
		Packaging	0.004	0.011	20	0.003	0.005	3.4
Total tonnes for Island (95% CI)								513.4 (212–814)

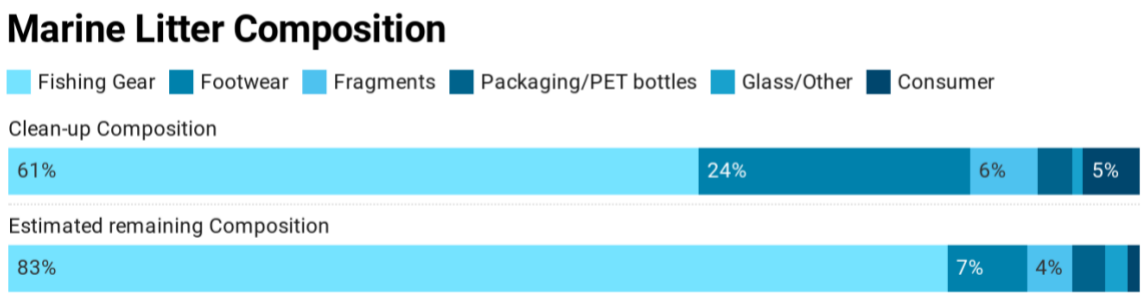


Figure S4.1: Percentage composition for all marine litter collected during the expedition and the estimated composition of the remaining litter on Aldabra. The difference is due to the expedition focussing on beaches rather than karst, which collects more fishing gear.

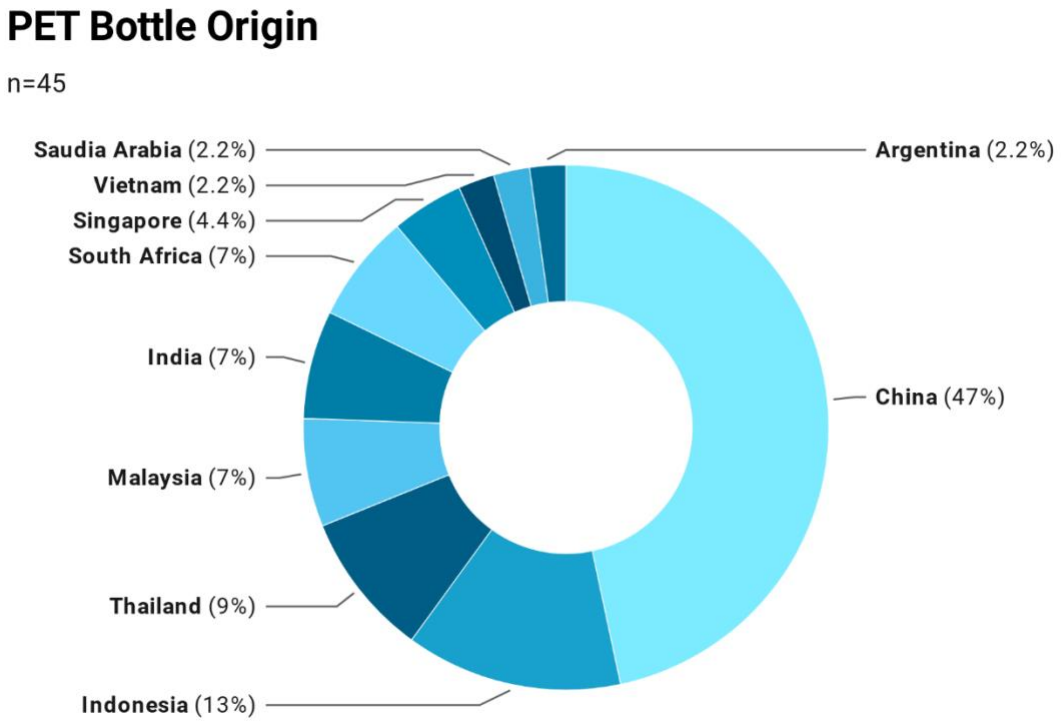


Figure S4.2: Country of origin for 45 bottles that had labels remaining.



Figure S4.3: Expedition: A) Loading slings onto small shuttle boat; B) Team loading sacks onto shuttle boat; C) Loading slings onto vessel; D) Karst inlet which trap trash brought by crashing waves.

Table S4.2: Potential solutions for long-term, circular plastics economy in Seychelles.

Material	Proposed solution	End Product
All Plastics -polyethylene terephthalate PET (common for beverage bottles and food packaging), polyethylene HDPE (used in detergents, bleach, and motor oil containers), poly- vinyl chloride PVC (toys, furnishing), polyurethane (beach sandals), and polystyrene PS.	Pyrolysis is the process of decomposing plastic at moderately high temperatures, in the absence of oxygen, to produce an oil-like substance. Significantly, the process is able to handle mixed plastics, negating the need for sorting and separation.	Oil/Fuel
Mostly fishing nets and gear e.g. polypropylene	Plastix Global in Denmark transform used, obsolete and abandoned fishing nets, ropes and post-use rigid plastic that would previously have ended up in the ocean or on landfill, by mechanically recycling them into high-quality raw plastic material: Green Plastic.	Kayaks, furniture, packaging, phone cases, community waste bins, etc.
Fishing gear	Aquafil are a company who turn nets into a material called ECONYL, which companies such as Fourth Element - a dive clothing brand - make swimwear and rash-guards.	Clothing
Flip-flops	TerraCycle is an innovative recycling company that has become a global leader in recycling typically hard-to-recycle waste.	None yet

Appendix D: Supplementary Material for Chapter 5

1. DNA extraction protocol

Manufacturer's protocol with amendments in red

- Spin the PowerBead Pro Tube briefly to ensure that the beads have settled at the bottom. Add up to 250 mg of soil and 800 µl of Solution CD1. Vortex briefly to mix.
- Secure the PowerBead Pro Tube horizontally on a Vortex Adapter for 1.5– 2 ml tubes (cat. no. 13000-V1-24). Vortex at maximum speed for 10 min. Note: If using the Vortex Adapter for more than 12 preps simultaneously, increase the vortexing time by 5–10 min.
- Centrifuge the PowerBead Pro Tube at 15,000 x g for 1 min. (3 minutes instead of 1m, with the same speed)
- Transfer the supernatant to a clean 2 ml Microcentrifuge Tube. Note: Expect 500–600 µl. The supernatant may still contain some soil particles.
- Add 200 µl of Solution CD2 and vortex for 5 s.
- Centrifuge at 15,000 x g for 1 min at room temperature. Avoiding the pellet, transfer up to 700 µl of supernatant to a clean 2 ml Microcentrifuge Tube. Note: Expect 500–600 µl.
- Add 600 µl of Solution CD3 and vortex for 5 s.
- Load 650 µl of the lysate onto an MB Spin Column and centrifuge at 15,000 x g for 1 min.
- Discard the flow-through and repeat step 8 to ensure that all of the lysate has passed through the MB Spin Column.
- Carefully place the MB Spin Column into a clean 2 ml Collection Tube. Avoid splashing any flow-through onto the MB Spin Column.
- Add 500 µl of Solution EA to the MB Spin Column. Centrifuge at 15,000 x g for 1 min.

- Discard the flow-through and place the MB Spin Column back into the same 2 ml Collection Tube.
- Add 500 µl of Solution C5 to the MB Spin Column. Centrifuge at 15,000 x g for 1 min.
- Discard the flow-through and place the MB Spin Column into a new 2 ml Collection
- Centrifuge at up to 16,000 x g for 2 min. Carefully place the MB Spin Column into a new 1.5 ml Elution Tube.
- Add 50–100 µl of Solution C6 to the center of the white filter membrane (50µl C6 and 10 minutes stop before the last centrifugation).
- Centrifuge at 15,000 x g for 1 min. Discard the MB Spin Column. The DNA is now ready for downstream applications.
- Additional Admixture Plots

Table S5.1 Within-site gene flow results from BayesASS

Cluster	From	To	M	Error
Blue	ARM06	ARM06	0.84	0.03
Blue	Mahé	Mahé	0.84	0.03
Blue	Aldabra_LagWest	Aldabra_LagWest	0.83	0.03
Blue	Aldabra_LagEast	Aldabra_LagEast	0.82	0.03
Blue	Farquhar	Farquhar	0.82	0.03
Blue	ARM12	ARM12	0.81	0.03
Blue	Assomption	Assomption	0.81	0.03
Blue	Praslin	Praslin	0.80	0.03
Blue	Astove	Astove	0.79	0.03
Blue	ARM04	ARM04	0.79	0.03
Blue	ARM08	ARM08	0.79	0.03
Blue	Fregate	Fregate	0.77	0.04
Blue	Aride	Aride	0.77	0.04
Blue	Amirantes	Amirantes	0.73	0.04
Green	Cerf Island	Cerf Island	0.86	0.03
Green	Curieuse Island	Curieuse Island	0.80	0.07
Green	Aldabra SC	Aldabra SC	0.78	0.06
Green	Praslin Area	Praslin Area	0.76	0.07
Green	Astove/Assomption	Astove/Assomption	0.76	0.07
Green	Aride	Aride	0.74	0.07
Green	Aldabra NC	Aldabra NC	0.74	0.07
Green	Aldabra LagWest	Aldabra LagWest	0.72	0.06
Green	Aldabra LagEast	Aldabra LagEast	0.72	0.05
Green	Farquhar/Alphonse	Farquhar/Alphonse	0.72	0.05
Green	Mahé NC	Mahé NC	0.72	0.05
Combined	Alphonse	Alphonse	0.69	0.02
Combined	Amirantes	Amirantes	0.69	0.02
Combined	Aride	Aride	0.68	0.01
Combined	Assomption	Assomption	0.68	0.02
Combined	Faruquar	Faruquar	0.68	0.02
Combined	Aldabra_LagWest	Aldabra_LagWest	0.68	0.02
Combined	Astove	Astove	0.69	0.03
Combined	Aldabra_LagEast	Aldabra_LagEast	0.71	0.05

Combined	Fregate	Fregate	0.69	0.03
Combined	Aldabra_SC	Aldabra_SC	0.68	0.03
Combined	Aldabra_NC	Aldabra_NC	0.70	0.05
Combined	Praslin_Area	Praslin_Area	0.70	0.05
Combined	Mahé_Area	Mahé_Area	0.71	0.06

2. WIO Ocean Currents

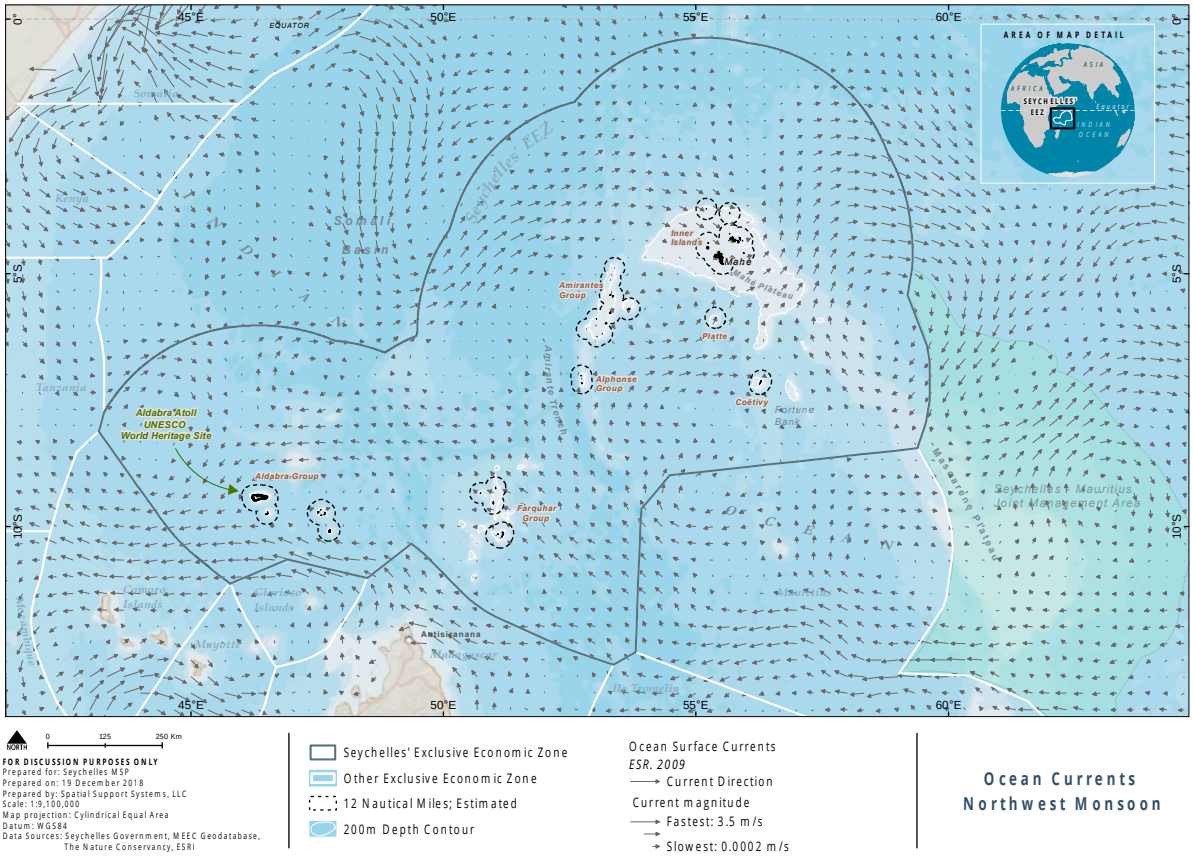


Figure S5.1: Western Indian Ocean prevailing currents in the North-West Monsoon Season.

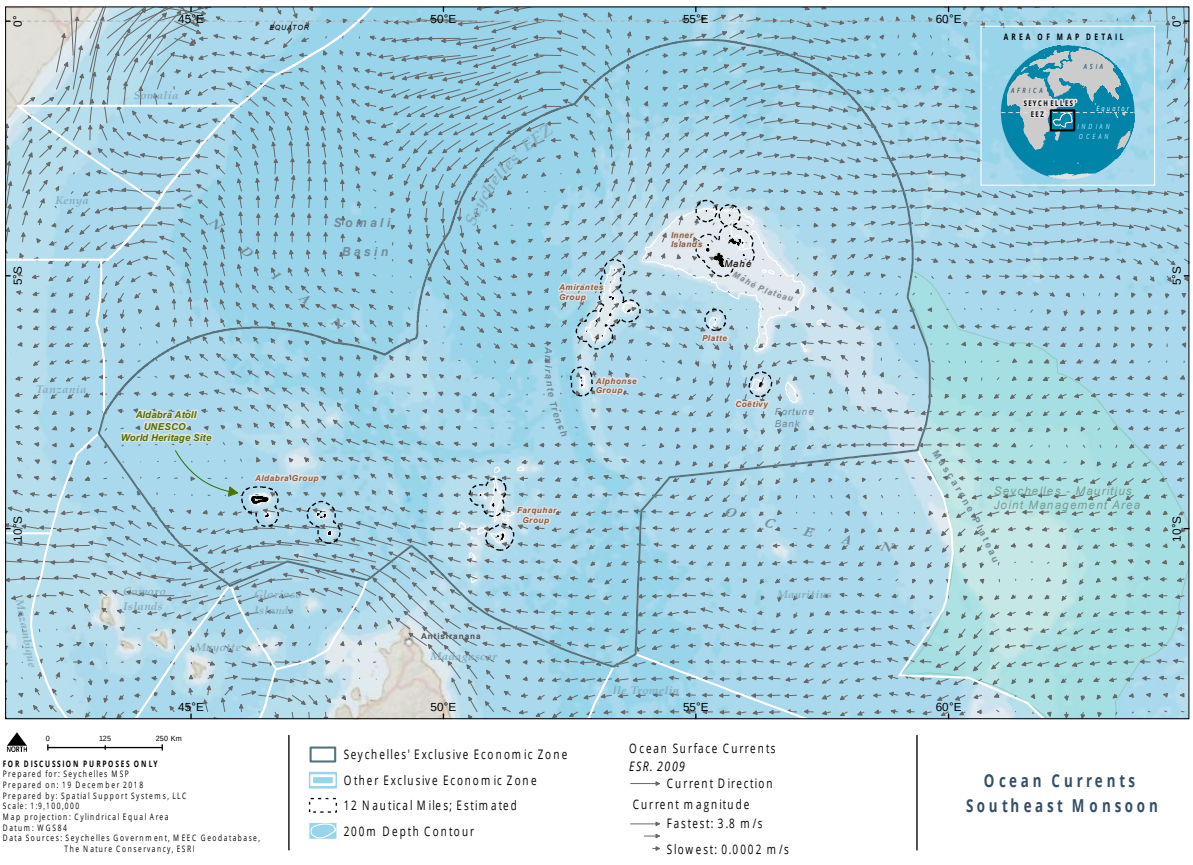


Figure S5.2: Western Indian Ocean prevailing currents in the South-East Monsoon Season.

Site Heterozygosity

Analysis of the heterozygosity of our sites shows that the sites have low levels of genetic variability (Figure 2) with slightly lower than expected diversity seen at Fregate. If the observed heterozygosity is lower than expected, we seek to attribute the discrepancy to forces such as inbreeding. If heterozygosity is higher than expected, we might suspect an isolate-breaking effect (the mixing of two previously isolated populations).

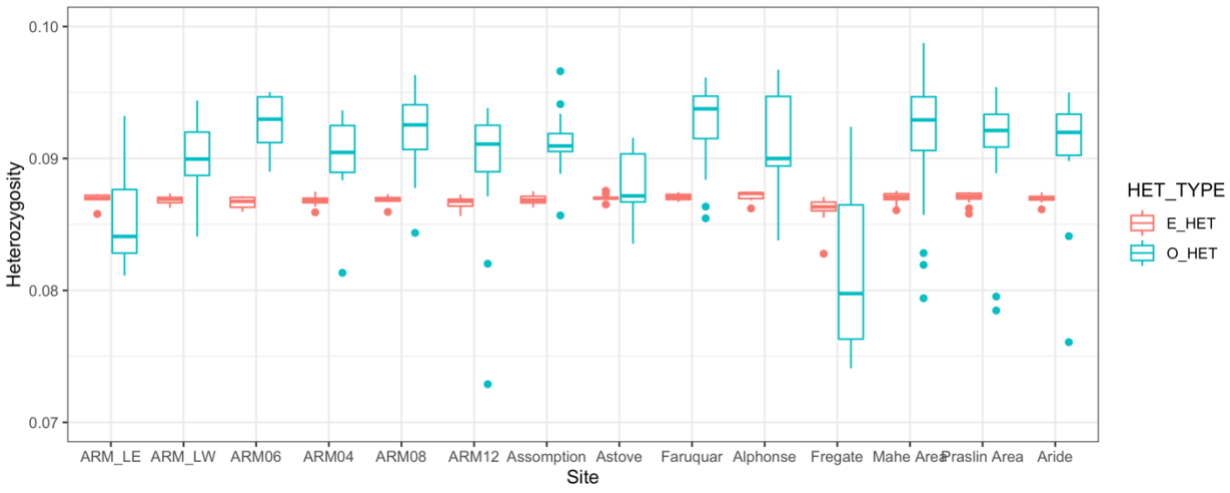


Figure S5.3: Expected (under the Hardy-Weinberg equilibrium) and Observed heterozygosity for samples at each site.

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