Evaluation of Ecosystem Goods and Services for Seychelles' Existing and Proposed Protected Area System

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About this project:

The purpose of this project was to assess of the extent to which the marine protected area system developed under the Seychelles' Marine Spatial Plan, in combination with pre-existing protected areas, can be expected to both preserve and enhance ecosystem services provided by the marine and coastal areas. The Nature Conservancy (TNC) worked in partnership with the Ministry of Agriculture, Climate Change and Environment (MACCE) and the Third South West Indian Ocean Fisheries Governance and Shared Growth Project (*SWIOFish3*) to complete this assessment and report.

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List of Abbreviations:

AONB	Area of Outstanding Natural Beauty
BODs	Birder Observer Days
CHI	Coastal Hazard Index
EEZ	Exclusive Economic Zone
IUCN	International Union for Conservation of Nature
MACCE	Ministry of Agriculture, Climate Change and Environment
MOW	Mapping Ocean Wealth
MSP	Marine Spatial Plan
NDB	Nature Dependent Beaches
NP	National Park
PAM	TripAdvisor Photos by Attraction by Member
PUD	Photo User Days
RSI	Relative Selectivity Index
SFA	Seychelles Fishery Authority
SWIOFish3	South West Indian Ocean
TNC	The Nature Conservancy
VMS	Vessel Management System

Executive Summary

The Republic of Seychelles spans a vast expanse of the western Indian Ocean, with over 100 islands, 1,200 km of shoreline, and a marine area of 1.35 million square kilometers. The Seychelles also ranks among the most ocean-dependent economies on earth, its population of under 100,000 people relying heavily on ocean and coastal ecosystems for income, employment, health, and well-being. Thus, maintaining healthy ocean ecosystems and sustainable use is a key principle of Seychelles' Blue Economy strategy, including appropriate valuation of ecosystem goods and services in planning and national accounting.

Over the past decade the Seychelles has been a world leader in developing a comprehensive system of marine protected areas in a highly inclusive and equitable process with key stakeholders. The current coverage of this network encompasses over 444,000 km^2 (33%) of the total maritime jurisdiction of the country. The purpose of this study was to quantify the ecosystem goods and services provided by Seychelles Protected Area System.

The process largely worked with existing data alongside local expert input to assess ecosystem services, or the benefits of nature to people. These included: artisanal fisheries, coastal protection, recreation and tourism, and carbon storage by mangroves and seagrasses (blue carbon). The process included collaboration with local stakeholders, notably during 3 workshops to: (1) review the methodology and identify available sources of data; (2) review preliminary models and results; and (3) review final models and the assessment of values among protected areas. This work was conducted between May 2020 and November 2021.

This work can support adaptive management of Seychelles' waters. The process of quantifying ecosystem services provides us with a reference base against which changes can be evaluated going forward, and management actions can be adapted as necessary. This project quantifies and *maps* natural capital across the entire country, before assessing their coverage by the current protected areas system. Such data can enable subsequent assessment of where that capital is likely being "spent down" the fastest, or where it is relatively safe from threats. Key findings from the modelling and stakeholder review are as follows:

<u>Ecosystems</u>: The Seychelles' Protected Area System includes a very large expanse of deep ocean space, with its rich pelagic ecosystems. In addition, it includes 89% of shelf waters (<200m depth), 80% of all beaches, 92% of mangroves, 90% of coral reefs, 78% of granitic reefs and 85% of seagrasses.

<u>Blue Carbon</u>: Every protected area in Seychelles contains blue carbon from either seagrass, mangroves, or both, with the total sum of blue carbon found in protected areas estimated to be 156.7 million metric tons (mt). The numbers are dominated by the contribution of seagrasses most notably from the Mahé Plateau.

<u>Coastal Protection</u>: In Seychelles, approximately 90% (1,149 km) of shorelines benefit from protection by fringing coral reefs, with 77% (889 km) of these shorelines located in or adjacent to protected areas. Most of the latter, however, are far from human habitation, and of the 44,280 people who live in low-lying (<30m) coastal areas, only about 18% receive risk reduction from reefs that fall within protected areas.

<u>Artisanal Fisheries</u>: Fishing effort and the selectivity with which people fished among seafloor habitat types were used to estimate of the value of those habitats to support small-scale fisheries. We analyzed data separately for whalers and schooners that are tracked using vessel management system (VMS) technology, and for smaller vessels powered by outboard engines.

We estimated a Relative Selectivity Index (RSI) for different habitat types based on observed fishing effort and used this as an index to the value of each habitat for fishing. In the VMS model, island groups, or sub-regions, provided a surrogate for distance to fish landing sites, which in the outboard fishery model we used a simple distance-based metric. We estimated relative value among protected areas as the sum of total area for each habitat type multiplied by its RSI. This provides a quantitative index to the overall value of each protected area (RSI-weighted fishing areas), as well as a percent of the cumulative total of all fishing activity (% of total RSI-weighted fishing areas).

Using this approach, Seychelles Protected Areas cover a total of 89% of RSI-weighted fishing areas for (VMS) vessels and 27% of RSI-weighted fishing areas for smaller outboard vessels. The Amirantes (Marine) to

Fortune Bank (Marine) Area of Outstanding Natural Beauty alone represents 83% of RSI-weighted fishing by the VMS fleet and 26% by the outboard fleet.

Recreation and Tourism: Within Seychelles, we estimate that coral reefs are generating US $51.5 million annually from on-reef activities such as snorkeling and diving and that these activities generate the equivalent of 30,156 visitors to the Seychelles. Natural values of the beaches in Seychelles are estimated to be generating a combined total of US $160 million of tourism expenditure annually with 94,000 visitors who are attracted specifically to the natural aspects of Seychelles' beaches. These represent spending and visits that would be at risk if the natural values of these beaches were to be degraded. Of these, we estimate that 34% of all on-reef tourism and 15% all tourism associated with nature-dependent beaches are supported specifically by Seychelles' Protected Areas. The poor representation of nature-dependent beaches within the Seychelles' Protected Area System partly reflects the focus of protected areas away from the granitic Seychelles, but also the fact that beaches may fall between terrestrial and marine spaces and not be effectively covered by either.

The coverage of ecosystem services by the Seychelles Protected Areas Network:

Taken together our maps cover some of the most important ecosystem services in the Seychelles, and they show a generally comprehensive coverage of these services by the new and extensive protected areas network. The network is particularly comprehensive over the atolls and shallow banks where most of all values are incorporated into MPAs. By contrast some of the highest individual values, notably for small-scale fishing, coastal protection, recreation, and tourism, have lower levels of protected areas coverage.

The role that protected areas play in strengthening and enhancing ecosystem services may vary considerably between services. For recreation and tourism, they can provide a framework for management and can help to enhance values by, for example, allowing the growth of fish-stocks enjoyed by divers, or of resilient healthy reefs, better able to reduce wave energy and to recover from damage. They can also prevent losses of such values by preventing development, such as the clearance of mangroves or dredging of seagrass systems. For fisheries the role that protected areas play depends on their management approach – some can help to ensure that fisheries are controlled and management for sustainability, others, which may be closed to fishing, can play a crucial role in enhancing fishery gains through larval and adult spillover in adjacent areas, while also providing resilient refugia which may be critical in times of reef stress.

It is important to note that our maps of ecosystem services may not indicate stability of provision, or the sustainability of nature-based activities. Sustainability, in terms of fisheries, or tourism use, can be extremely hard to determine – locations may already be degraded, but still providing benefits, or they may be utilised way below capacity and yet they could have equal values. This fact was raised during stakeholder review with respect to nature-dependent beaches, as some of the highest values are associated with beaches on the 3 main islands that are considered by some to be already degraded. Such beaches still hold natural values. Their value is a product of both natural value and visitor use and so heavy use raises apparent value, even when the relative natural value is lower than many other beaches. This highlights an important area for future research on the relationships among human activities, ecosystem health and the sustainability of benefits that people derive from ecosystem services. These important questions are relevant both within and outside of the PAs, but PAs can provide an important framework for managing activities in a manner to ensure sustainability.

The ecosystem service data generated through this project can strengthen existing knowledge, but can also create new understanding, filling knowledge and data gaps on human uses that had been less widely considered or mapped. The results of this analysis suggests that in general Seychelles' protected areas make a very strong contribution toward protecting the values that underpin the nation's Blue Economy. We highlight outstanding ecosystem service values within marine protected areas that can help guide development of future management plans, as well as potential gaps where important services may not be adequately represented within the PAS for the long-term sustainability of these values.

Acknowledgements

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All maps and data presented in this report are available from the Mapping Ocean Wealth in Seychelles Online Map Viewer and Data Catalog (https://oceanwealth.org/project-areas/seychelles/).

Overview of Ecosystem Services

Ecosystem services can be broadly defined as the suite of benefits that people derive from nature (Reid et al. 2005). Typically, three classes of such services are identified: regulating, provisioning, and cultural (Fig. 1). Provisioning services generate tangible physical products that are of value to people, for example through the harvest of fish. Regulating services provide indirect use values to people, through modifying the environment for the benefit of people. These include protection from storms and erosion provided by coral reefs and mangroves, which reduce wave energy, and the wider function of storing and sequestering carbon which helps to mitigate climate change. Cultural services include the non-material benefits that people derive from nature, for example through recreational activities, but also traditional, spiritual, or other cultural activities, including tourism.

Underpinning these three classes of value are a series of ecosystem characteristics and functions. These are sometimes terms supporting services – they are of critical importance for people, but they continue even regardless of people being present. They include the generation of sand by coral reefs, the processes of photosynthesis, and the biodiversity itself which underpins the very function of all ecosystems.

The importance of nature to people is gaining greater understanding (Reid et al. 2005), and individuals and nations are increasingly considering the protection of these benefits as a critical component of natural resource management (CBD 1992). At the same time, many of the functions of ecosystems have remained poorly understood, and many benefits have been overlooked and indeed impacted by a failure of management. While it has been easy to understand the importance of maintaining fish stocks for food and commodity, managing coral reefs to protect coasts from erosion, or maintaining clean coastal waters for the recreational benefits of local people or visiting tourists has often been ignored. In coastal and marine areas in particular, growing demands from different sectors have drawn attention to many ecosystem service values, and the need to better understand such values as a means to secure long-term sustainability.

In parallel, a rapidly growing body of science is enabling a variety of methods to quantify and map the varied values of nature more accurately. In many cases "value" is not expressed in monetary terms – while such approaches may be popular, they can also greatly misrepresent popular perceptions of value which may be felt in terms of culture, tradition, health, jobs, or metrics such as tonnes of carbon or kilograms of fish. There are ways to convert many of these into monetary units, but this brings in additional steps and assumptions and many not always stand through time.

By quantifying ecosystem service values, and particularly through mapping such values, we can start to place these values into the broader context of planning and ecosystem management. We can also help to inform society and key sectors, including governments, industry, and civil society, so that nature is no longer sidelined and so that benefits can be secured for the long term.

Seychelles is a country with rich natural resources and the economy and well-being of its people are very closely and directly linked to the natural environment, notably through its two major economic pillars of fisheries and tourism. The focus of this project is on coastal and marine ecosystem services, and in Table 1 we set out a framework for considering the roles of some of the key ecosystems in generating benefits for people. In this descriptive inventory we will seek to be as comprehensive as possible, whether or not the value of such services can be quantified, in order to lay a foundation within which the Mapping Ocean Wealth approach can be applied.

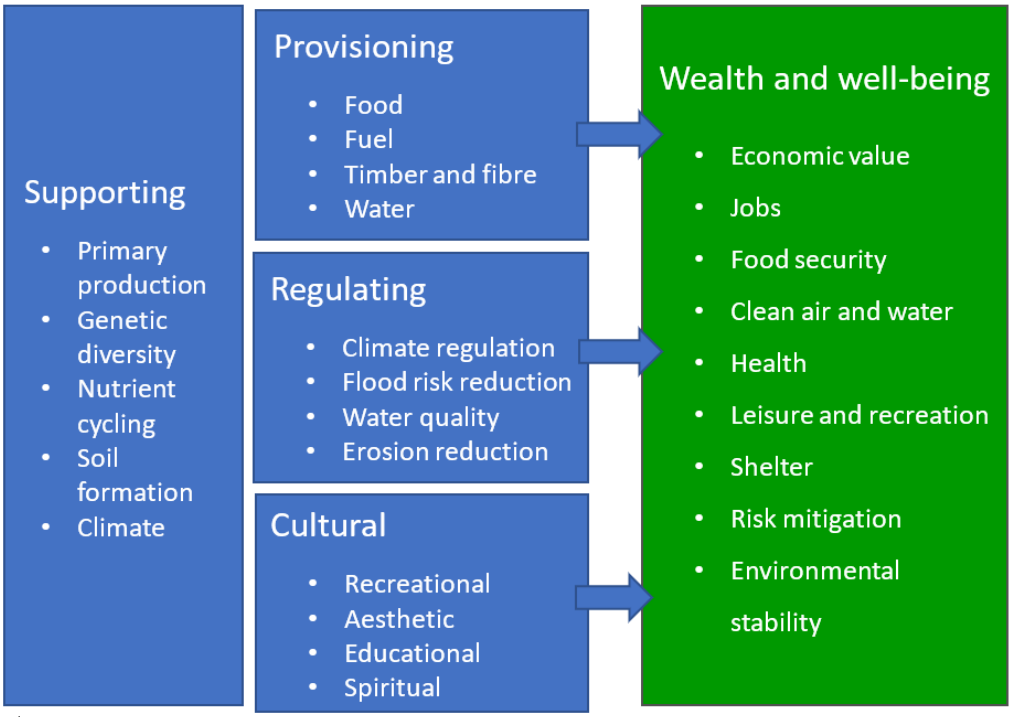


Figure 1. Supporting services provide the underpinning for the three broad classes of ecosystem services that provide a host of goods and benefits to people. While monetary value can provide one means to quantify the importance of these services, there are many other metrics as indicated on the right. (Reid et al. 2005)

Coastal and marine ecosystems of the Seychelles

Located over a very large expanse of the western Indian Ocean, the Seychelles is an archipelagic nation, and with over 100 islands, 1,200 km of shoreline and a marine area of over 1.35 million square kilometers, it is what many are now calling a “large ocean state” (Chan 2018). While much of this area is dominated by deep pelagic waters, it is an archipelagic state with several island groups that are dominated by coral banks and atolls, with generally small sand islands of coralline origin. The Mahé Plateau and associated granitic islands represent a micro-continent, and, associated with these higher elevation islands is a distinct and ancient biodiversity that has remained intact over past high sea levels giving them important biodiversity including many unique and endemic species.

The open pelagic waters support important highly mobile and migratory fish stocks, including multiple tuna (*Thunnus sp.*) and billfish *(Istiophoridae, Xiphiidae*) species which play an important part in both the commercial and sport fishing industries in the country. The deep benthic waters are less well studied but there are numerous seamounts which are known to represent steep biological gradients that support enhanced local biodiversity, while deep canyons and the deep Amirantes Trench are poorly documented and studied. Coral reefs predominate in shallow shelf areas and have built many of the islands and atolls. Indeed, Seychelles is an important coral reef nation, not only because it hosts almost 1% of all the world’s coral reefs (placing it about 20th globally by reef extent), but also because many of these reefs are relatively unimpacted by intense local human pressures and may be more resilient to global change (Obura and Gudka, 2017). As the reefs extend into deeper waters, they transition to mesophotic reefs which are only just beginning to be explored (Stefanoudis et al, 2020). Not all shallow areas are coral dominated, however and the shallow waters, particularly over the Mahé Plateau, are made up of a mix of soft sediments and rock, with varying conditions of depth, substrate, exposure, and structural complexity contributing to a variety of ecological features (Klaus 2015). Seagrass ecosystems are particularly widespread on the Mahé Plateau, but also common on some of the other shallow banks, such as Providence-Cerf area of the Farquhar archipelago.

Between the sea and the land are several important intertidal ecosystems. Mangroves are found adjacent to shores around the granitic islands and over large areas in the southern atoll group, notably the very large, raised atoll of Aldabra. Widespread everywhere are sandy beaches – typically these are dominated by fine white sands, formed from the natural breakdown and erosion of offshore corals and coralline algae. Between these are rocky shores which can host greater diversity than shifting sand, notably of benthic invertebrates which gain a foothold on the stable rock.

Table 1. A generalized framework for assessment of ecosystems and ecosystem services in Seychelles.

	Ecosystems							
Ecosystem Services	Coral Reefs	Granitic reefs	Shallow Shelf Areas	Mangrove	Seagrass	Beaches	Seamounts	Pelagic waters
Regulating				X	X			X
Carbon Sequestration*				X	X		X	X
Coastal Protection*	X	X		X	X	X		
Water Quality				X	X			
Provisioning								
Artisanal Fishing*								
Pelagic fish species	X	X	X				X	X
Demersal fish species	X	X	X	X				
Invertebrates	X	X	X	X	X			
Cultural								
Recreation & Tourism (all)								
On-Reef Tourism*	X	X						
Natural Beaches*	X	X	X			X		
Sport Fishing*	X	X	X	X	X	X	X	X
Wildlife Watching*	X			X	X	X		
Other nature-based activities *	X		X	X	X	X		
Aesthetic	X	X	X	X	X	X		
Spiritual	X		X	X	X	X		X
Research & Education	X	X	X	X	X	X	X	X
Supporting								
Photosynthesis			X	X	X		X	X
Soil formation				X	X			
Sand formation	X					X		
Nutrient cycling	X			X	X	X		

* Mappable Ecosystem Services

Ecosystems Within the Seychelles' Protected Areas System

To build a secure future for Seychelles' marine ecosystems, and the critical ecosystem services they support, the government of Seychelles has developed a Marine Protected Area System which covers a total area 444,300 km^2 or approximately 32.9% of Seychelles' Exclusive Economic Zone (EEZ). This system is divided into 26 marine protected areas that include marine waters and/or coastal fringe ecosystems (Fig. 3). Together, these areas contain approximately 23,937 ha of coral reefs (90% of all coral reefs in the country), 26,097 ha of granitic reefs (78%), 2,757 ha of mangroves (92%), 1.7 million ha of seagrasses (85%), 494 ha of beaches (80%) and 4.6 million ha of shelf waters (89%) (Table 2).

Protected Areas and Ecosystem Services

The internationally accepted definition of protected areas describes sites that are established to support the conservation of biodiversity and ecosystem services (Dudley 2008). The degree to which protected areas serve this role depends on the specifics of the site and its regulations. Protected areas are often used to prevent the direct destruction of habitats by preventing activities such as land reclamation, dredging, or destructive fishing practices. Some may also regulate against pollution, seabed mining, oil and gas extraction or the placement of new infrastructure such as renewable energy platforms.

A critical role of protected areas, but one that is both highly variable and, in some cases, challenging, concerns the management of extractive activities, notably fishing. No-take zones or strict nature reserves are protected areas where no fishing is permitted. Among the ecological effects of such closures are dramatic increase in abundance and productivity (Halpern 2003, PISCO 2007). At the same time, it is clear that by closing any area to fishing, the ecosystem service benefits from fishing are lost in that area. One effect of such closures is to enhance fishing effort in adjacent waters, and this "spillover effect" where both adult fish and juvenile recruitment is enhanced (Di Lorenzo et al. 2020). There is strong research evidence, especially around coral reefs, that marine reserve networks could be designed to increase net fisheries benefits, with many suggesting that net catches can be maximized when 30% of all marine areas are closed to all fishing (see, for example Green et al. 2014, Munguia-Vega et al. 2018). Beyond these no-take areas, most other marine protected areas nonetheless make some restrictions on fishing practises, often focusing on gear restrictions and, although not providing comprehensive protection, can still reduce pressure on some species and remove more damaging practises.

Not all ecosystem services are fully complementary, and in Seychelles the two major industries of tourism and commercial fishing may, in some cases require trade-offs for the benefits of one or the other. SCUBA-diving, for example, greatly benefits from the attraction of very healthy fish populations often found in no-take reserves (Lopes et al. 2015, Sala et al. 2013). Likewise recreational fishing is perhaps most valuable where commercial fishing pressure is lower and fish stocks are higher. Trade-offs are inevitable, but should help to build an understanding of the need for holistic and comprehensive assessments in the design of protected areas networks.

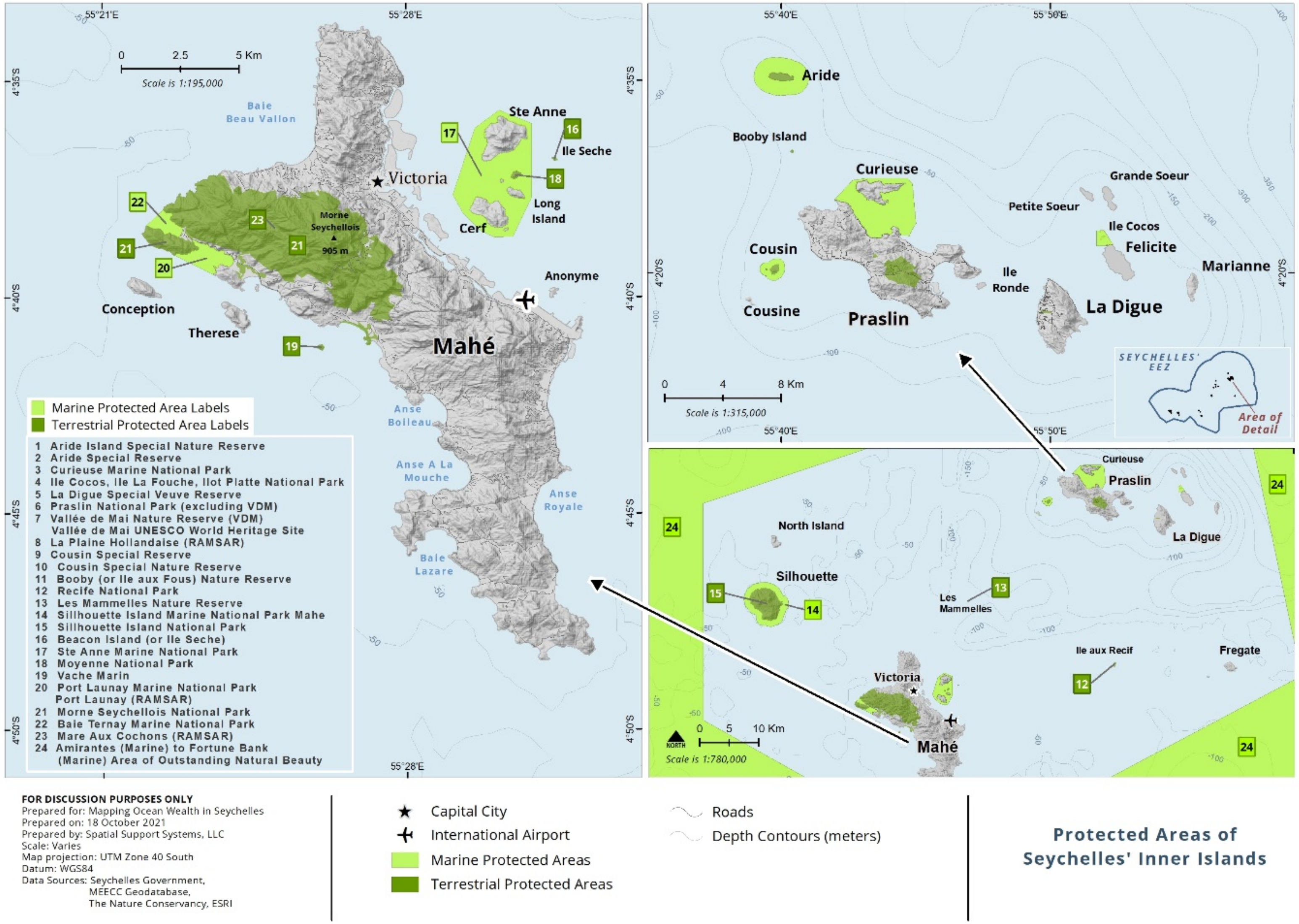


Figure 2. Seychelles' protected areas in the vicinity of Mahé, Praslin and Inner Islands (Data source: MACCE, map from Seychelles MSP Initiative).

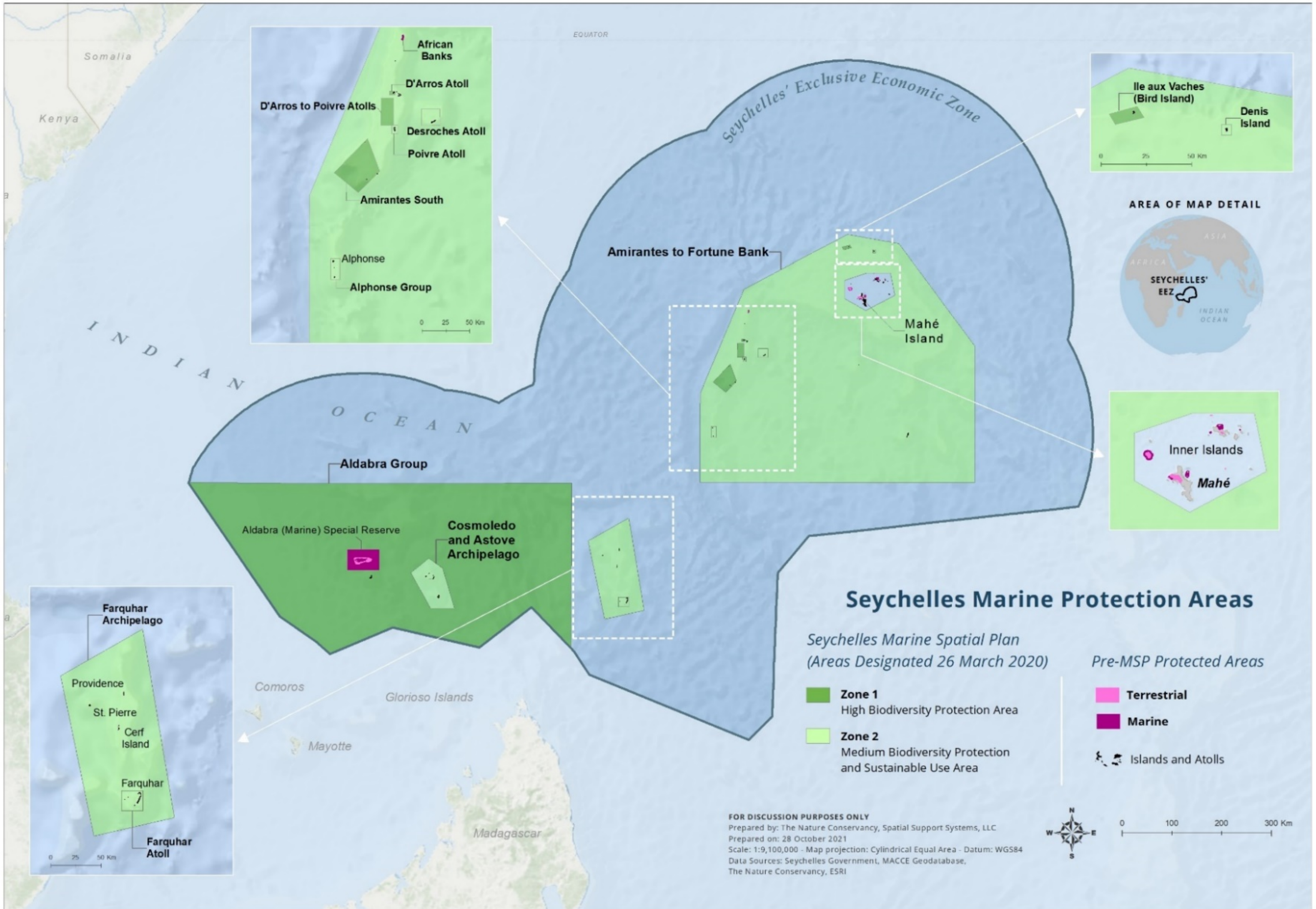


Figure 3. Protected areas designated by Seychelles Marine Spatial Plan and those that were designated prior to MSP (Data source: MACCE, map from Seychelles MSP Initiative).

Table 2. Composition of major ecosystem types within Seychelles' Marine Protected Areas

Protected Areas & Other	Total Area (sq. km)	Ecosystem Extent (hectares)					
		Beaches	Mangroves	Coral Reefs	Granitic Reefs	Seagrasses	Shelf Areas (<200m depth)
MSP Protected Areas (all)	**441,506**	**444**	**320**	**22,190**	**19,425**	**1,754,732**	**4,569,979**
Aldabra Group (Marine) NP	201,236	0	0	257	164	159	6,171
Alphonse Group (Marine) AONB	215	25	2	840	2,593	4,263	17,052
Amirantes (Marine) to Fortune Bank (Marine) AONB	217,580	76	17	3,562	2,396	1,611,057	4,162,562
Amirantes South (Marine) NP	1,335	22	0	234	68	46,643	90,661
Bird Island (Ile aux Vaches) (Marine) NP	106	35	0	84	70	2,608	10,508
Cosmoledo and Astove Archipelago (Marine) AONB	5,321	91	265	1,596	4,853	8,962	25,817
D'Arros Atoll (Marine) NP	25	35	0	65	148	1,319	2,361
D'Arros to Poivre Atolls (Marine) NP	370	0	0	87	32	16,746	36,957
Denis Island (Marine) AONB	31	10	0	170	66	1,275	2,964
Desroches Atoll (Marine) AONB	333	21	0	1,398	246	7,155	26,850
Farquhar Archipelago (Marine) AONB	14,482	0	0	10,527	5,268	40,443	154,029
Farquhar Atoll (Marine) AONB	415	113	30	3,154	2,964	10,688	29,213
Poivre Atoll (Marine) AONB	56	16	6	217	557	3,414	4,834
Pre-MSP Protected Areas	**2,738**	**50**	**2,437**	**1,747**	**6,672**	**17,080**	**59,726**
African Banks Protected Area	8	3	0	90	130	518	822
Aldabra (Marine) Special Reserve	2,669	0	2,437	1,147	5,055	13,145	52,917
Aride Special Reserve	7	0	0	7	120	619	718
Baie Ternay Marine NP	1	0	0	3	24	44	87
Cousin Special Reserve	2	5	0	20	79	62	158
Curieuse Marine NP	13	7	0	65	70	824	1,340
Ile Cocos Ile La Fouche Ilot Platte Protected Area	1	0	0	6	61	42	83
Mahé (Anse Faure-Fairy Land) Shell Reserve	3	1	0	93	154	96	334
Port Launay Marine NP	2	1	0	10	42	49	163
Silhouette Marine NP	21	14	0	81	776	1,233	2,132
Ste Anne Marine NP	10	18	0	224	160	448	972
All Marine Protected Areas	**444,244**	**494**	**2,757**	**23,937**	**26,097**	**1,771,812**	**4,629,705**
(% of Seychelles Total)	(33%)	(80%)	(92%)	(90%)	(78%)	(85%)	(89%)
Other (not in protected area)	**907,476**	**123**	**253**	**2,549**	**7,516**	**311,356**	**572,789**
Grand Total within Seychelles	**1,351,775**	**617**	**3,009**	**26,486**	**33,613**	**2,083,168**	**5,202,494**

Mapping Ecosystem Services in Seychelles Protected Areas

In this section, four ecosystem services will be described: two regulating, one provisioning and five cultural. For each service, the model will be described including assumptions, the data sources, the methods, and results including maps.

Artisanal Fisheries

Artisanal fisheries are a critically important value that people in Seychelles derive from coastal and marine ecosystems (SFA, 2018). Artisanal fisheries is a domestic fishery, restricted to Seychellois, and targets demersal and pelagic species on Mahé Plateau and to Amirantes Group (MFA 2019). These fisheries support food security and local economies, with total annual catch between 4,500 – 8,000 Mt between 1990 – 2019 (Robinson 2021),with an estimated value of SCR 169 million ($12.3 million USD)(SFA, 2016). Monetary values, although useful, underestimate the social value of such fisheries – artisanal fisheries are a key provider of employment and can provide a highly distributed benefit flow (Teh et al, 2013).

The purpose of this assessment was to evaluate the contribution of Seychelles' marine protected areas to support artisanal fisheries. To do this, we used data on fishing effort in relation to availability of seafloor habitat types (% use / % availability), to estimate a Relative Selectivity Index (RSI; Thomas & Taylor 1990) with which artisanal fishers targeted specific areas. The assumption is that the selectivity with which fishers targeted specific areas provides an index to the value of that area to support the overall fishery.

To estimated relative contribution of each protected area, we calculated the total area of each habitat multiplied by its RSI, summed across all habitats within the MPA. We used raster-based calculations in ArcGIS to calculate the average RSI of all areas within each protected area, the sum of all RSI values in each protected area, and the percent contribution of each protected area to the grand total of all shelf waters in Seychelles (Table 4). This percent contribution of each protected area to the total of all shelf waters in Seychelles represents the relative contribution of each area to the artisanal fishery, weighted by habitat-selectivity patterns of fishing. This provides a "selectivity-weighted index" of habitat areas within each MPA. This index also can be used to evaluate habitats within MPAs where fishing is prohibited, under the assumption that fish production will be enhanced in nearby areas where fishing is allowed (Di Lorenzo et al. 2020).

We evaluated patterns of selectivity in fishing effort separately for whalers and schooners equipped with VMS-tracking technology (Robinson et al., 2020) and smaller vessels with outboard engines that fish relatively near the Inner Islands of the Mahé Plateau (Daw et al., 2011). These two vessel types represent approximately 98% of the artisanal fishing catch (SFA, 2016).

Artisanal Fishing by VMS-equipped vessels

Within Seychelles' artisanal fisheries, the whalers and schooner vessels represent >60% of total catch from 2007 - 2016 (SFA, 2016). These vessels can make extended fishing trips on the Mahé Plateau and to the Outer Islands, and data on the distribution of these vessels is available from SFA Vessel Monitoring System (VMS; Fig. 4). The methodology used to analyse the VMS data followed Robinson et al. (2020), who used these data to estimate locations of fishing activity based on criteria of vessel speed and proximity to ports. VMS-based locations of fishing effort are currently our best estimate of the spatial distribution of this component of the Seychelles artisanal fishery. Note that data on sea cucumber fishery was not included in these analyses.

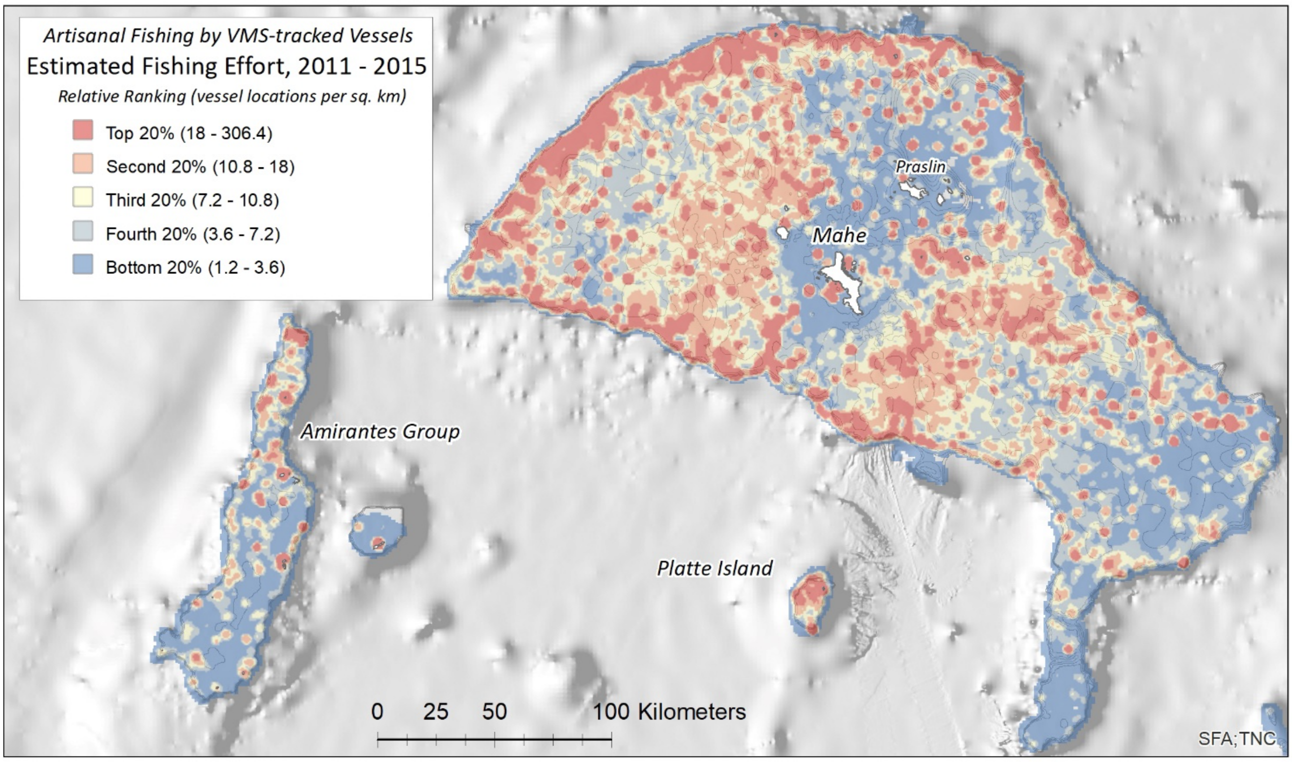


Figure 4. Estimated fishing effort from VMS vessel locations during 2011 – 2015. This time period was the most recent with relatively widespread use of VMS technology (Data source: SFA). Sea cucumber fishery was not included in this analysis.

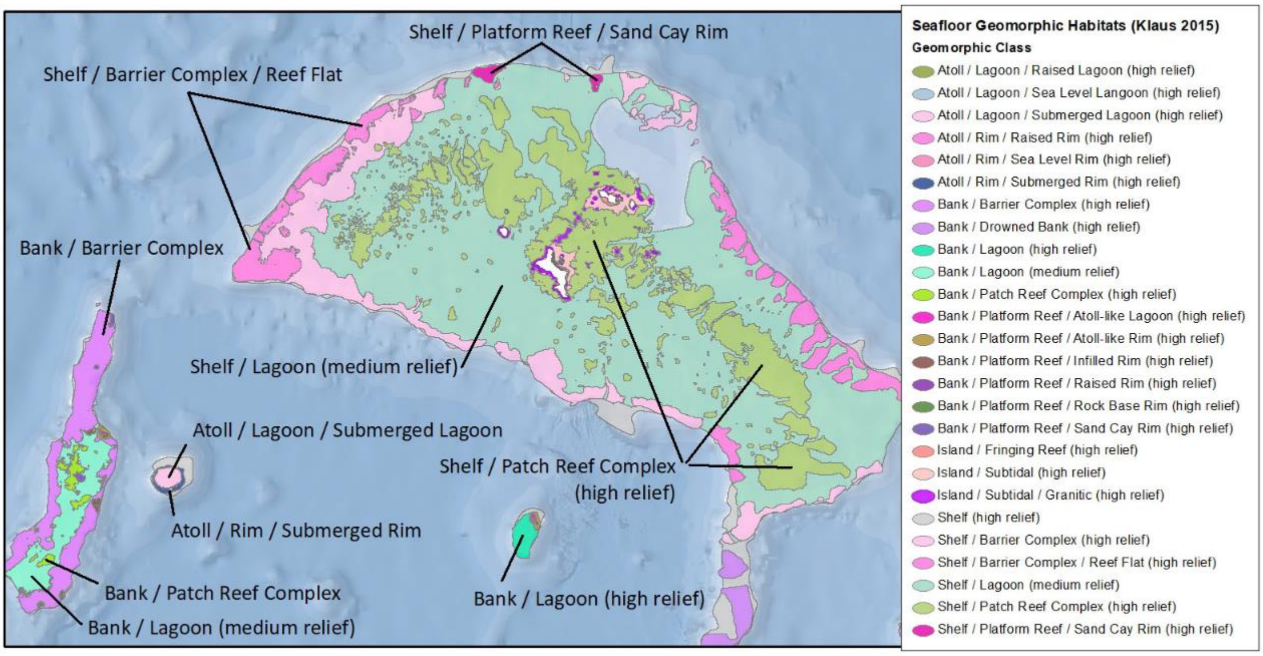


Figure 5. A hierarchical classification of seafloor geomorphic habitats, illustrated for the Mahé plateau to Amirantes Bank (source: Klaus 2015).

Selectivity of fishing activity was evaluated by comparing fishing effort (Fig. 4) to the proportional availability of seafloor geomorphic habitat using an unpublished shallow geomorphology developed by Klaus (2015) (Figure 5). We developed a Relative Selectivity Index (RSI) calculated using the percent of total fishing effort within a particular habitat type divided by the percent availability of that habitat type (Thomas & Taylor

1990). Our analysis was limited to shallow habitats with depth <200m. We stratified geomorphic types by sub-regions (or island groups) that represent similar characteristics of geography and distance to landing sites, as well as unique physical geomorphologies and associated habitat compositions. For each combination of sub-region and seafloor habitat, we calculated the % availability within shelf waters and the proportion of estimated fishing locations (% use) during the period 2011 - 2015. An RSI value of 1.0 indicates fishing effort is in proportion to habitat availability, while RSI values >1 mean higher than expected fishing intensity relative to habitat availability (i.e., preference) and values <1 show lower than expected fishing intensity based on habitat availability (i.e., avoidance).

The results of the RSI showed a wide range of values amongst geomorphology types in Seychelles (Table 3). The highest fishing effort by VMS-tracked vessels occurred on the Mahé Plateau (89.75%), including cays along the shelf edge and dropoff, followed by Amirantes (5.96%), Farquhar (2.48%) and Platte (1.25%) (Table 3). In terms of relative selectivity among sub-regions, the RSI value for Platte was the highest at 2.3 followed by Mahé Plateau at 1.08. All other sub-regions had RSI values less than 1, likely due to long travel distances from the Inner Islands. Geomorphic habitat types with highest RSI values were “Atoll-like Lagoon (high relief)” within the Platte sub-region at 13.5-times it’s availability, followed by Amirantes “Infilled Rim (high relief)” at 7.25-times availability and “Sand Cay Rim (high relief)” at 6.5-times availability. Within the Mahé Plateau, “Platform Reef / Sand Cay Rim (high relief)” was fished at 5.91-times availability and “Subtidal / Granitic (high relief)” was fished at 5.0-times availability (Fig. 6). Under the assumption that fishers choose locations to optimize their return within various constraints, the RSI represents a reasonable estimate of the relative value of each location and adjacent seafloor type for the Seychelles artisanal fishery.

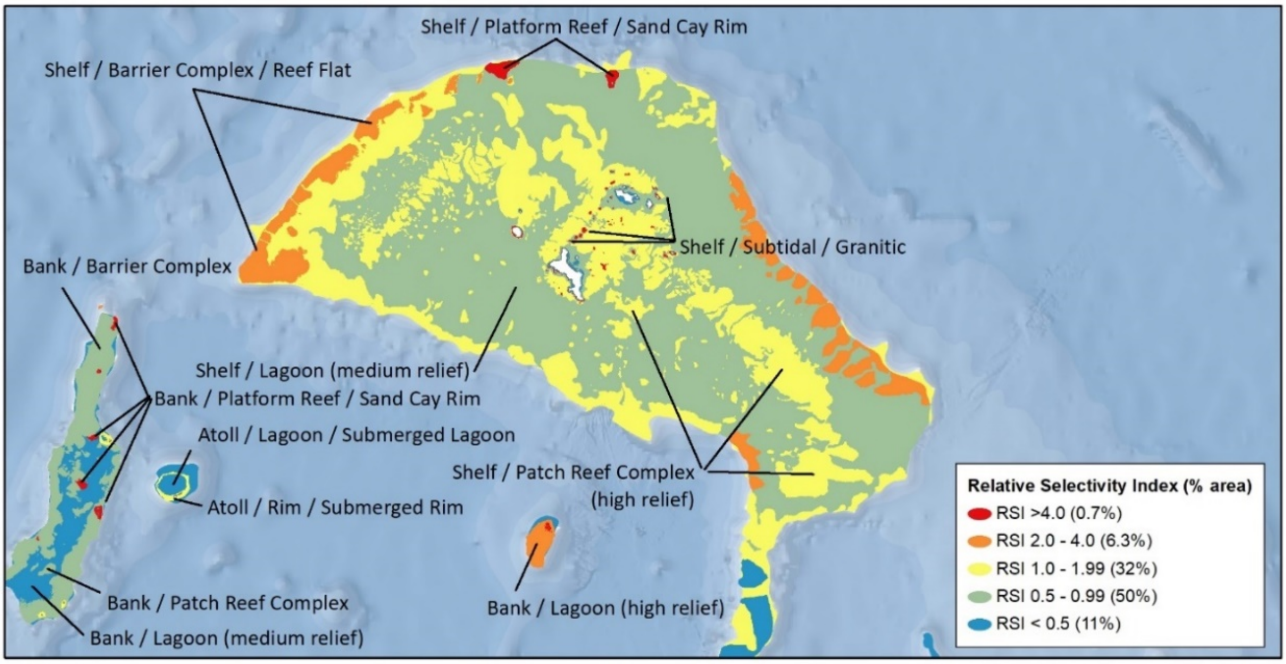


Figure 6. A spatial representation of the Relative Selectivity Index for VMS-equipped artisanal fishing vessels among island groups and seafloor geomorphic habitat classes of the Amirantes to Fortune Bank area of Seychelles (data: SFA 2011-2015).

Table 3. Relative Selectivity Index for artisanal fishing effort by VMS-equipped vessels during 2011 – 2015 by seafloor habitat and sub-region in the Seychelles.

	Shelf Area		Fishing Effort		Relative Selectivity Index
Sub-region / Seafloor geomorphology type	**(km²)**	**(%)**	**(locations)**	**(%)**	
Mahé Plateau (all)	**43,047**	**82.77%**	**518,070**	**89.75%**	**1.08**
Island / Fringing Reef (high relief)	72	0.14%	54	0.01%	0.07
Island / Subtidal (high relief)	478	0.92%	4,886	0.85%	0.92
Island / Subtidal / Granitic (high relief)	76	0.15%	4,213	0.73%	5.00
Bank / Drowned Bank (high relief)	535	1.03%	1,821	0.32%	0.31
Shelf (high relief)	1,504	2.89%	17,148	2.97%	1.03
Shelf / Barrier Complex (high relief)	4,218	8.11%	78,570	13.61%	1.68
Shelf / Barrier Complex / Reef Flat (high relief)	2,856	5.49%	65,513	11.35%	2.07
Shelf / Lagoon (medium relief)	24,856	47.80%	236,108	40.90%	0.86
Shelf / Patch Reef Complex (high relief)	8,317	15.99%	100,926	17.48%	1.09
Shelf / Platform Reef / Sand Cay Rim (high relief)	135	0.26%	8,831	1.53%	5.91
Platte (all)	**283**	**0.54%**	**7,241**	**1.25%**	**2.30**
Bank / Lagoon (high relief)	208	0.40%	4,619	0.80%	2.00
Bank / Platform Reef / Atoll-like Lagoon (high relief)	10	0.02%	1,432	0.25%	13.50
Bank / Platform Reef / Atoll-like Rim (high relief)	25	0.05%	886	0.15%	3.15
Shelf (high relief)	40	0.08%	304	0.05%	0.68
Amirantes (all)	**4,379**	**8.42%**	**34,403**	**5.96%**	**0.71**
Atoll / Lagoon / Sea Level Lagoon (high relief)	19	0.04%	230	0.04%	1.12
Atoll / Lagoon / Submerged Lagoon (high relief)	123	0.24%	706	0.12%	0.52
Atoll / Rim / Sea Level Rim (high relief)	76	0.15%	855	0.15%	1.01
Atoll / Rim / Submerged Rim (high relief)	68	0.13%	827	0.14%	1.10
Bank / Barrier Complex (high relief)	2,118	4.07%	18,904	3.27%	0.80
Bank / Lagoon (medium relief)	1,295	2.49%	3,826	0.66%	0.27
Bank / Patch Reef Complex (high relief)	213	0.41%	2,250	0.39%	0.95
Bank / Platform Reef / Atoll-like Lagoon (high relief)	5	0.01%	0	0.00%	0.00
Bank / Platform Reef / Atoll-like Rim (high relief)	28	0.05%	422	0.07%	1.37
Bank / Platform Reef / Infilled Rim (high relief)	30	0.06%	2,411	0.42%	7.25
Bank / Platform Reef / Rock Base Rim (high relief)	19	0.04%	260	0.05%	1.26
Bank / Platform Reef / Sand Cay Rim (high relief)	39	0.07%	2,789	0.48%	6.50
Bank / Drowned Bank (high relief)	3	0.01%	132	0.02%	3.81
Shelf (high relief)	345	0.66%	791	0.14%	0.21
Adelaide (all)	**148**	**0.29%**	**304**	**0.05%**	**0.18**
Bank / Drowned Bank (high relief)	69	0.13%	212	0.04%	0.28
Shelf (high relief)	80	0.15%	92	0.02%	0.10
Coetivy / Fortune Bank (all)	**1,178**	**2.26%**	**1,277**	**0.22%**	**0.10**
Bank / Lagoon (high relief)	233	0.45%	515	0.09%	0.20
Bank / Platform Reef / Infilled Rim (high relief)	61	0.12%	360	0.06%	0.53
Bank / Drowned Bank (high relief)	662	1.27%	327	0.06%	0.04
Shelf (high relief)	222	0.43%	75	0.01%	0.03

Table 3 (continued). Relative selectivity in artisanal fishing effort by VMS-equipped vessels during 2011 – 2015.

	Shelf Area		Fishing Effort		Relative Selectivity Index
Sub-region / Seafloor habitat	**(km²)**	**(%)**	**(locations)**	**(%)**	
Farquhar (all)	**2,128**	**4.09%**	**14,305**	**2.48%**	**0.61**
Atoll / Lagoon / Sea Level Lagoon (high relief)	208	0.40%	102	0.02%	0.04
Atoll / Rim / Sea Level Rim (high relief)	615	1.18%	10,010	1.73%	1.47
Bank / Platform Reef / Raised Rim (high relief)	3	0.00%	156	0.03%	5.58
Bank / Drowned Bank (high relief)	169	0.33%	2,572	0.45%	1.37
Shelf (high relief)	1,134	2.18%	1,465	0.25%	0.12
Aldabra (all)	**841**	**1.62%**	**1,642**	**0.28%**	**0.18**
Atoll / Lagoon / Raised Lagoon (high relief)	265	0.51%	52	0.01%	0.02
Atoll / Rim / Raised Rim (high relief)	232	0.45%	1,250	0.22%	0.48
Bank / Platform Reef / Raised Rim (high relief)	21	0.04%	24	0.00%	0.10
Shelf (high relief)	323	0.62%	316	0.05%	0.09
All Areas	**52,005**	**100%**	**577,242**	**100%**	**1.00**

Artisanal Fishing by Outboard Vessels

Another important component of the Seychelles' artisanal fishing fleet are comprised of smaller vessels powered by outboard engines (Payet, 1996). These vessels operate primarily from the islands of Mahé (80%) and Praslin (20%) and stay on the Mahé Plateau. The outboard vessels accounted for an average of 37% of the total catch during the period 2007 - 2016, with an increasing trend throughout this period (SFA, 2016). Given the importance of this segment of the fishery, as well as a distinct spatial extent of fishing effort, it was recommended during the stakeholder workshops that we should conduct a separate analysis to estimate the distribution of effort in this fishery and associated provisioning services within Seychelles PA system.

The best available data to describe the spatial extent of fishing effort by outboard vessels was developed by Daw et al (2011) during a participatory mapping study based on a survey of (n = 62) artisanal fishers. The reliability of these data to accurately represent the current distribution of fishing by outboard vessels is limited by two factors. First, in the decade since publication of this study outboard technology has advanced, and it is likely that modern outboard vessels can travel farther and faster than those surveyed in the 2011 study. Second, the study area boundary of the survey was limited to waters <50 km of the Inner Islands, and did not include areas at the shelf edge that have been shown to be important by the VMS-equipped vessels (Fig. 7A). Thus, the data were used to provide a coarse-scale assessment of habitats associated with artisanal fishing from outboard vessels.

Outboard Vessel Relative Selectivity by Distance and Seafloor Habitats

To model selectivity in fishing by outboard vessels, we first developed a quantitative model to estimate the spatial distribution of fishing effort using a combination of distance to the nearest landing site, and seafloor geomorphic habitat (Fig. 7). We overlaid the maps of fishing intensity by survey respondents from Daw et al. (2011) with shallow seafloor geomorphic habitats types in Klaus (2015) as a coarse estimate of the relative fishing intensity within each habitat type as represented in this survey. Our estimate of fishing effort was represented as the number of survey respondents that reported fishing in each area (Fig 7A). We then calculated a relative selectivity among seafloor habitat types as the percent of all reported fishing activity divided by the percent availability for each seafloor habitat within the study area boundary (Fig. 7.B.2).

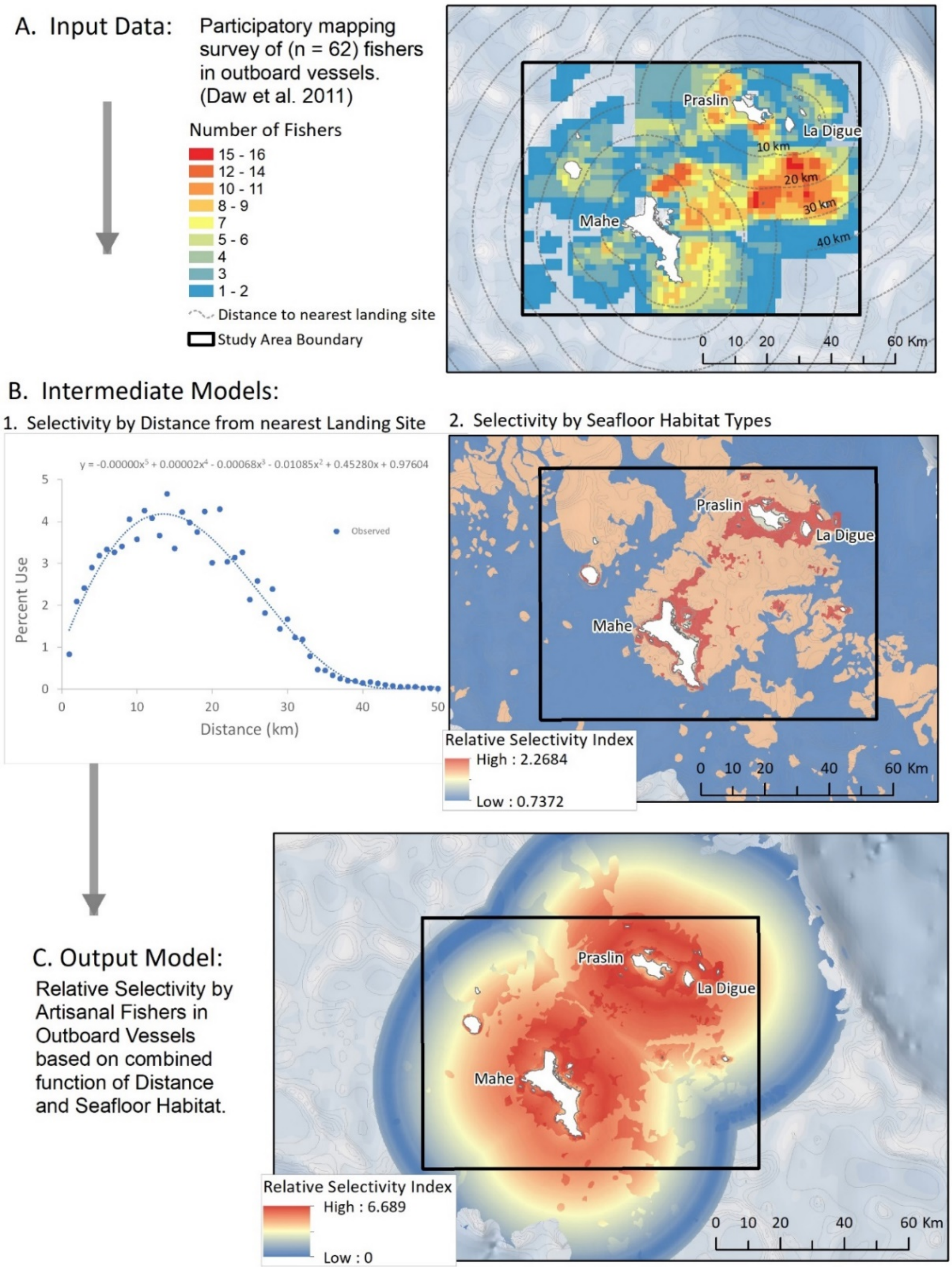


Figure 7. A modeling approach to estimate the spatial distribution of artisanal fishing in outboard vessels around the Inner Islands of Seychelles (source data: Daw et al., 2011).

We also calculated a Relative Selectivity Index as a function of distance to the nearest landing site. For small vessels, distance to potential fishing areas is an important factor in determining where people fish, both from the standpoint of time and fuel costs, but also for safety in travel across open water. To account for this, we calculated a separate RSI function based on the distance to the nearest landing sites as the percent of fishing effort divided by the percent availability of potential fishing areas areas at increasing distance intervals (Fig. 7.B.1). In the final model, we multiplied the distance-based and habitat-based relative selectivity indices for a combined RSI value that reflects the effects of both travel distance and seafloor habitat types on where people fished.

Relative Artisanal Fishery Values among Protected Areas

The value of marine protected areas to support the artisanal fishery can be characterized by the composition of seafloor habitats that they contain, weighted by the selectivity with which each type of habitat was targeted for fishing by artisanal vessels. We characterized the value of protected areas using 2 measures: (1) the average selectivity (RSI) for all areas within the MPA boundary; and (2) the % of the total RSI-weighted fishing areas that each MPA contains (Table 4). The former measure (average RSI) is useful to identify small MPAs that contain high proportions of preferred habitats, while the latter is an indication of the contribution (or importance) of each MPA to the overall fishery.

Among VMS-equipped vessels, the MSP Milestone 3 marine protection areas represent the largest portion of RSI-weighted fishing areas (88.95%), primarily due to the large contribution of the Amirantes (Marine) to Fortune Bank (Marine) Area of Outstanding Natural Beauty (82.77%). However, the average RSI values for this entire area was only 0.44, indicating that this large MPA contains a mix of habitats with highly variable selectivity in fishing effort (Table 4). Fishing will be conditional once the Zone 2 area is implemented including for example recommendations for bag and or size limits in the management plans to address sustainability. Highest average RSI values were observed on seafloor habitat types contained in Bird Island (Ile aux Vaches) (Marine) National Park (Mean RSI = 4.64), Denis Island (Marine) Area of Outstanding Natural Beauty (Mean RSI = 3.89), Ile Cocos, Ile La Fouche, Ilot Platte Protected Area (Mean RSI = 3.75) and D'Arros Atoll (Marine) National Park (Mean RSI = 3.6), indicating a high level of fishing effort on these relatively rare seafloor habitats. The Fisheries Comprehensive Plan (2019) notes that artisanal fishing operates within 112 nautical miles from Port of Victoria; D’Arros is beyond these limits. Bird and D’Arros are both designated as Zone 1 and when implemented, fishing will not be allowable. Based on other studies of fully protected marine areas, the Zone 1 areas would have provided benefits with potential fishing enhancement in adjacent areas linked to spillover (Di Lorenzo et al. 2020). Outside of Seychelles’ Protected Area System, the Port of Victoria Boundary in the Inner Islands represented 10.74% of the total RSI-weighted fishing by VMS-vessels (Table 4).

Among outboard vessel, the Amirantes (Marine) to Fortune Bank (Marine) Area of Outstanding Natural Beauty accounted for 25.72% of RSI-weighted fishing areas, with the other protected areas making up the remaining 1.14%. The Highest RSI values for outboard vessels among protected areas were found at Ile Cocos, Ile La Fouche, Ilot Platte National Park (RSI = 5.62), Aride Special Reserve (RSI = 4.81) and Cousin Special Reserve (RSI = 4.16) (Table 4). These areas are closed to fishing and thus the ecosystem composition indicates that they are of high value as a “provisioning” ecosystem service to adjacent areas where fishing is allowed. Outside of Seychelles’ Protected Area System, the Port of Victoria Boundary in the Inner Islands represented 73.14% of the total RSI-weighted fishing by outboard vessels (Table 4).

Table 4. Relative contribution of Seychelles protected areas to support artisanal fisheries based on patterns of fishing selectivity by VMS-equipped and outboard vessels.

	VMS Vessels			Outboard Vessels		
Protected Areas	Shelf Area (ha)	Mean RSI	% of Total	Shelf Area (ha)	Mean RSI	% of Total
MSP Protected Areas (all)	**4,574,680**	**1.49**	**88.85%**	**943,851**	**0.03**	**25.76%**
Aldabra Group (Marine) National Park	12,150	0.09	0.02%	0	0.00	0.00%
Alphonse Group (Marine) AONB	17,015	0.67	0.22%	0	0.00	0.00%
Amirantes (Marine) to Fortune Bank (Marine) AONB	4,162,500	1.03	82.66%	943,851	0.44	25.76%
Amirantes South (Marine) National Park	90,596	0.59	1.03%	0	0.00	0.00%
Bird Island (Ile aux Vaches) (Marine) National Park	10,474	4.64	0.93%	0	0.00	0.00%
Cosmoledo and Astove Archipelago (Marine) AONB	25,345	0.26	0.13%	0	0.00	0.00%
D'Arros Atoll (Marine) National Park	2,299	3.60	0.16%	0	0.00	0.00%
D'Arros to Poivre Atolls (Marine) National Park	36,790	0.78	0.55%	0	0.00	0.00%
Denis Island (Marine) AONB	2,991	3.89	0.22%	0	0.00	0.00%
Desroches Atoll (Marine) AONB	26,798	0.57	0.30%	0	0.00	0.00%
Farquhar Archipelago (Marine) AONB	153,806	0.67	1.97%	0	0.00	0.00%
Farquhar Atoll (Marine) AONB	29,093	0.63	0.35%	0	0.00	0.00%
Poivre Atoll (Marine) AONB	4,823	3.31	0.31%	0	0.00	0.00%
Pre-MSP Protected Areas (all)	**59,534**	**1.65**	**0.41%**	**6,061**	**2.59**	**1.01%**
African Banks Protected Area	820	6.08	0.10%	0	0.00	0.00%
Aldabra Special Reserve	52,653	0.14	0.14%	0	0.00	0.00%
Aride Special Reserve	718	1.64	0.02%	718	4.81	0.21%
Baie Ternay Marine NP	172	0.48	0.00%	172	2.82	0.03%
Cousin Special Reserve	151	2.53	0.01%	151	4.16	0.04%
Curieuse Marine NP	1,276	0.73	0.02%	1,276	2.67	0.21%
Ile Cocos Ile La Fouche Ilot Platte Marine NP	88	3.75	0.01%	88	5.62	0.03%
Mahé (Anse Faure-Fairy Land) Shell Reserve	318	0.10	0.00%	318	1.26	0.02%
Port Launay Marine NP	326	1.36	0.01%	326	2.33	0.05%
Silhouette Marine NP	2,074	2.31	0.09%	2,074	1.82	0.24%
Ste Anne Marine NP	938	0.44	0.01%	938	3.03	0.18%
Other (not in MPA)	**572,555**	**0.98**	**10.74%**	**541,214**	**2.18**	**73.23%**
All	**5,206,769**	**1.0**	**100%**	**1,491,126**	**1.0**	**100%**

In summary, the marine protected areas system in the Seychelles show a high degree of overlap with areas of fishing importance from the two types of vessels we have modelled. The whalers and schooners represented in the VMS model are predominantly fishing on the Mahé Plateau within a Zone 2 marine protection. The relatively low coverage by stricter forms of protection with tight restrictions on fishing are likely to have more significant impacts on the biomass of commercially valuable species, and potentially on the wider resilience of reefs and shallow water communities to other impacts (Russ & Alcala 2010, Mumby et al. 2014). It is likely that the benefits of fully protected areas will become increasingly noticeable in terms of enhanced fishing in adjacent areas, although this will depend on compliance. By contrast, the highest value outboard fisheries largely fall outside of the MPA network – with only 26% of the RSI-weighted fishing areas are covered by the Zone 2 Amirantes to Fortune Bank AONB.

Taken together, the extensive coverage of habitats important to the artisanal fishing by MPAs in the Seychelles is noteworthy. The MPA network may provide a valuable framework for ongoing and future management to secure long-term sustainability to these fisheries. The role of High Protection or fully protected areas as a management tool needs further investigation. Effective management in these Zone 2 (sustainable use) areas could likely enhance fisheries productivity and sustainability, but could also be used as a means to support other ecosystem services, notably around tourism.

As a caveat, we recognize that where people fish may be an imperfect indicator of where fish are caught, and even less of an index to the full suite of ecosystems that support fish populations and fisheries production. Because more comprehensive data on catch are not currently available, we rely on the assumption that where people fish reflects their best attempt to maximize success within the constraints of time, fuel costs and other factors. In this way, an accounting of selectivity in artisanal fishing effort among ecosystems provides a reasonable, although admittedly limited estimate of their value to provision these fisheries. Key gaps in available data that we encountered in this effort included the spatial distribution and status of fish populations, rates of catch per unit effort, and how habitat conditions may have changed as a result of past coral bleaching events (Robinson et al., 2019). Future analyses may incorporate updated datasets, such as those included in SWIOFISH-funded stock assessments and/or data from SFA statistical bulletins.

Coastal Protection

In this section we evaluate the regulating service of coastal protection by coral reef ecosystems. From a physical perspective, coral reefs adjacent to coastal areas can be viewed as powerful submerged breakwaters, with capacity to reduce the impacts of waves, including erosion and coastal flooding (Ferrario et al, 2014). This role is further enhanced by their ability for self-repair and to grow vertically in the face of rising seas, but it is also a role that can be diminished with the decline of reefs in the face of local or global threats (Sheppard et al 2005). In this section, we assess the protective function of coral reefs to reduce coastal hazards from storms, sea level rise and associated coastal flooding, and evaluate the contribution of Seychelles' protected areas to support these protective functions into the future. Storms and coastal flooding have long been recognized as an important source of risk for people in Seychelles (Seng & Guillande, 2008), and recent work evaluated risk to people and critical infrastructure on the island of Mahé (Rice et al., 2019).

InVEST Coastal Vulnerability Model

For this assessment, we adapted the Coastal Vulnerability model developed by the Natural Capital Project Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) toolbox (Arkema et al., 2013; *InVEST*, 2021) (Fig. 8). The model couples coarse-scale, global datasets on wind speed and direction, wave power, bathymetry, and elevation, with finer-scale data on shoreline erosion potential to derive a relative index of coastal hazards. We calculated the average width of reef crests and reef flats as a relative index to the protection provided to adjacent shorelines (Fig. 9). The inclusion of data on coastal population provides an assessment of where people are most exposed to these hazards during storm events.

We modified terminology in our application of the InVEST model. We used the term "hazard index" reflect the combined external forces that contribute to coastal risk, rather than the term "exposure index" as used in the InVEST model. We restrict use of the term "exposure" specifically to describe the relative number of people exposed to coastal hazards (Fig. 8).

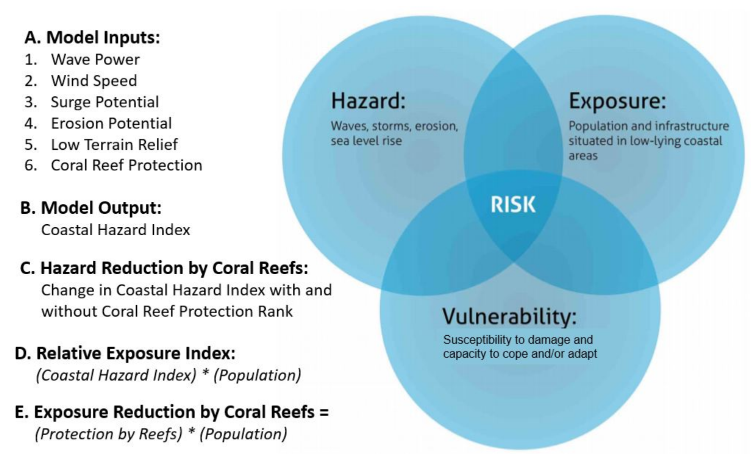


Figure 8. Conceptual framing of coral reef coastal protection using the InVEST Coastal Vulnerability Model.

Input data sources for the InVEST model included:

- Wind and Waves: Data on wave and wind characteristics were provided as part of the InVEST data package from 8 years of the WaveWatch III database (Tolman 2009) (Figure 10A & 10B). For each shore point, the model calculated the average of the top 10% of values for wind speed, wave height and wave power at 16 equiangular compass directions. The model also calculated average ocean depth along 'fetch rays' that measure the distance over open water from each shore point along 16 equiangular compass directions. In this way, the model accounts for seasonality of wind and waves in Seychelles, with prevailing winds from the northwest during December – March and winds from the southeast during May – October (Chang-Seng, 2007). For more detail on wind and wave calculations, see documentation of the InVEST Coastal Vulnerability Model (2021).
- Bathymetry: Data on bathymetry were obtained from the 2014 version of the General Bathymetric Chart of the Oceans (GEBCO) with a resolution of 500m (Weatherall et al. 2015). We used the 2014 version of that dataset in response to stakeholder feedback that the 2020 version (GEBCO 2020) contained a deep-water anomaly on the Mahe Plateau that is not consistent with local knowledge or navigational nautical charts of the area. In the InVEST model, bathymetry contributed to the calculation of wave height and storm surge potential (Fig. 10C).
- Shoreline Substrate: Shoreline erosion potential was derived from a geomorphologic classification developed by Klaus (2015) and categorized as low for granitic substrates, moderate for carbonate or fill substrates, and high for sand beaches (Fig. 10D).
- Elevation: Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM; Farr et al. 2007) with a resolution of 90m. These data were used to calculate the maximum elevation within 1km of each shore point for the Low Terrain Relief metric (Fig. 10E), as well as the number of people in coastal areas below 30m in elevation.
- Population: Data on human population was obtained from the WorldPop database (www.worldpop.org) with a resolution of 100m, constrained to match auxiliary data on the built

environment (Reed et al 2018) and adjusted to match United Nations national population estimates for the year 2020 (UNDESA 2019, Linard et al. 2012.

- Coral Reefs: We reviewed available datasets on coral reefs and determined that the Allen Coral Atlas (2020), with its classification of geomorphic attributes was best suited to characterize the relative coastal protection by coral reefs (Fig 9). We assigned ranks by the average width of reef crests and flats at each 500m sample point along the shoreline (Ferrario 2014; Fig. 10F).

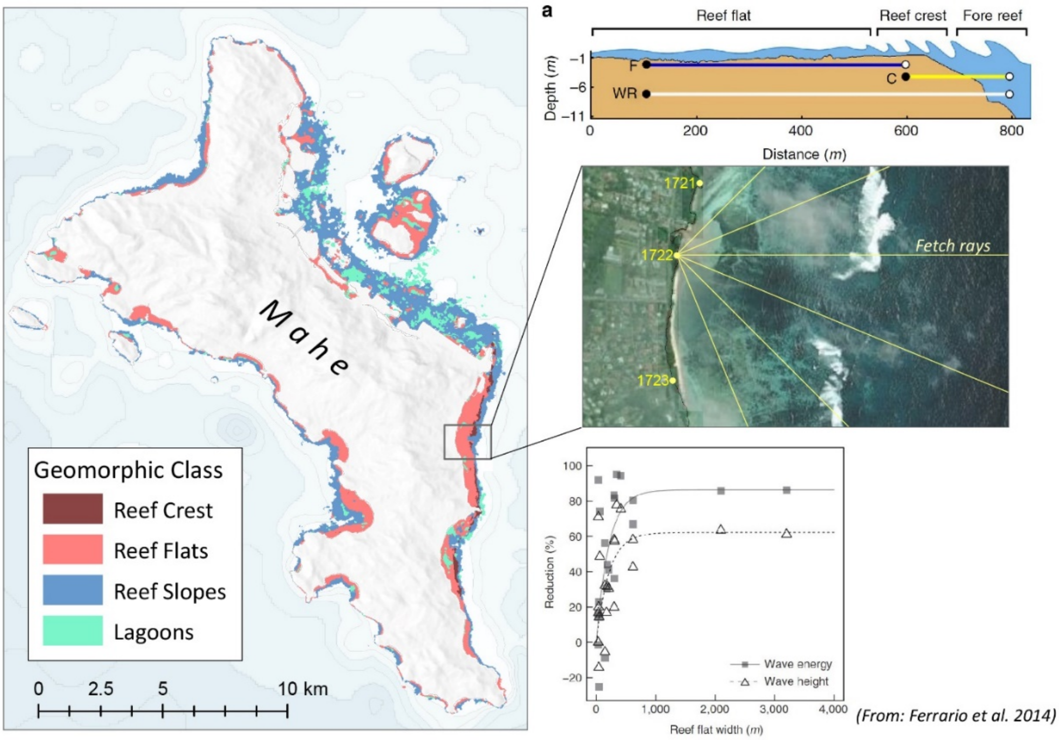


Figure 9. The relative value of coral reefs to attenuate wave energy was estimated based on the average width of reef crests and flats for each 500m shore point (Data source: Allen Coral Atlas 2020; Ferrario et al. 2014).

Table 5. Biological and physical variables for the InVEST Coastal Vulnerability model: index and hazard ranking system information (source: InVEST Coastal Vulnerability Model 2020).

		Hazard Ranking System				
Variable	**Index**	**1 (very low)**	**2 (low)**	**3 (moderate)**	**4 (high)**	**5 (very high)**
Wave Power	WaveWatch III	0 – 20 Percentile	20 – 40 Percentile	41 – 60 Percentile	61 – 80 Percentile	81 – 100 Percentile
Wind Speed	WaveWatch III	0 – 20 Percentile	20 – 40 Percentile	41 – 60 Percentile	61 – 80 Percentile	81 – 100 Percentile
Erosion Potential	Shoreline geomorphology	Rocky Shore		Carbonate or Fill		Sand Beach
Storm Surge Potential	Distance to shelf edge	<2.7 km	2.7 – 4 km	4.1 – 5.8 km	5.9 – 40 km	>40 km
Low Terrain	Max elevation within 1 km	>120 m	91 – 120 m	61 – 90m	30 – 60 m	<30 m
Coral Reef Protection	Width of reef crests + reef flats	>600m	150m – 600m	60m – 150m	1m - 50m	No Reef

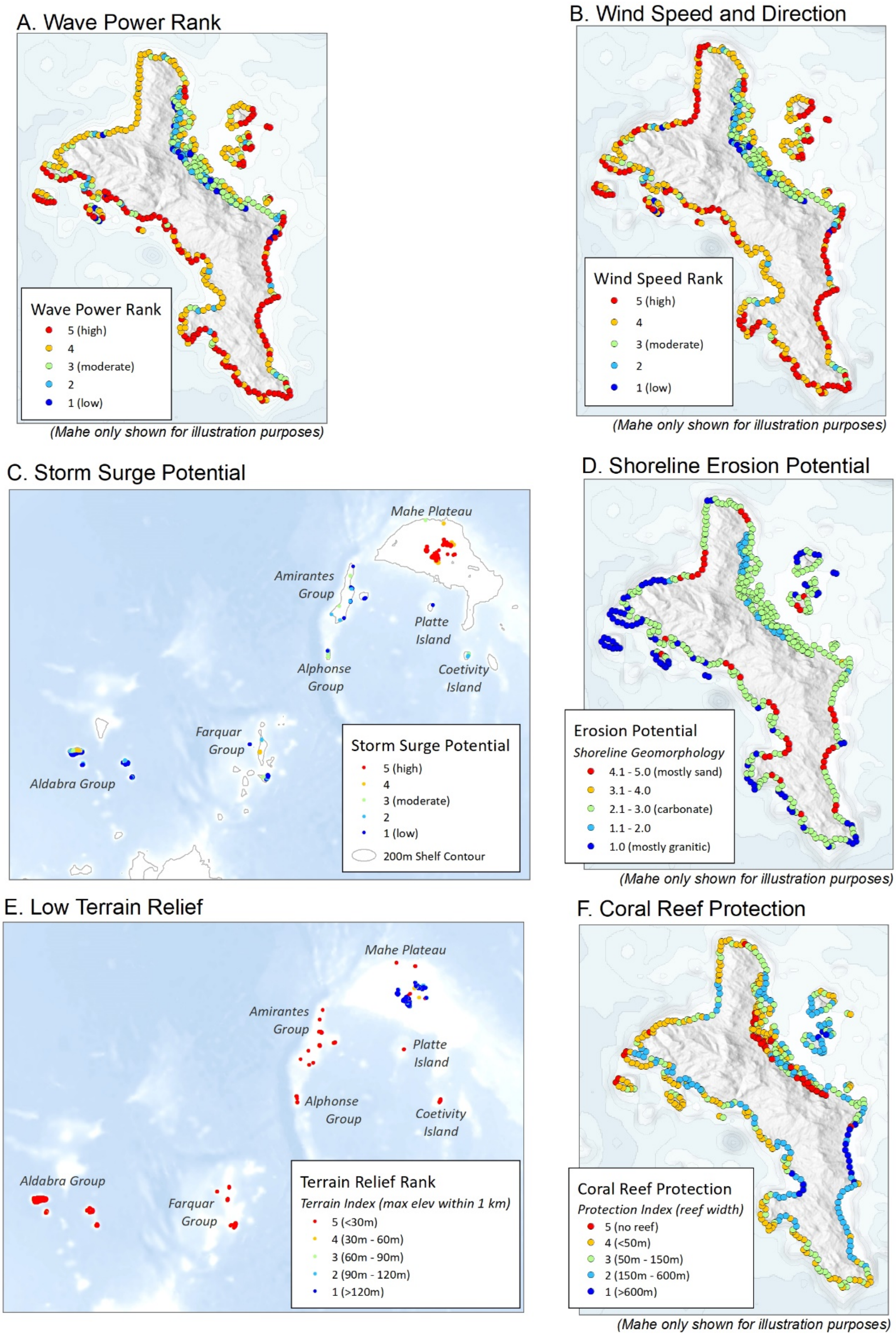


Figure 10. Inputs to the InVEST Coastal Vulnerability Model included wave power, wind speed, storm surge potential, shoreline erosion potential, terrain relief and habitat protection provided by coral reefs

The InVEST model estimated values for each of these factors for point locations at 500m intervals along all shorelines, and assigns a categorical rank based on the relative magnitude of each factor from 1 (low) to 5 (high) (Table 5). The combined Coastal Hazard Index is the geometric mean of ranked values from each of the input variables:

$$\text{Coastal Hazard Index} = (R_{wind} * R_{waves} * R_{erosion} * R_{surge} * R_{terrain} * R_{reef}s)^{1/6}$$

(Fig 11a)

The Coral Reef Protection Rank was assigned values from 1 (high protection) to 5 (low protection) based on the width of nearby reef crests and flats (Table 5). Hazard reduction by coral reefs was calculated for each shore point as the difference in this Coastal Hazard Index with and without inclusion of the Coral Reef Protection Rank.

$$\text{Hazard Reduction by Coral Reefs} = \text{Hazard Index}_{(\text{Without Reef Rank})} - \text{Hazard Index}_{(\text{With Reef Rank})}$$

(Fig. 11b)

The number of people living in coastal areas at elevations <30m was assigned to the nearest shoreline sample point, and the Coastal Exposure Index was calculated by multiplying the Hazard Index times the number of people:

$$\text{Exposure Index} = (\text{Hazard Index}) * (\text{\# of people})$$

(Fig. 11c)

Finally, the relative reduction in exposure because by adjacent coral reefs was calculated as

$$\text{Exposure Reduction by Coral Reefs} = (\text{Hazard Reduction by Coral Reefs}) * (\text{\# of People})$$

(Fig. 11d)

Coral reefs encircle most of the islands and atolls of the Seychelles (Fig. 9), and hence their role in “coastal protection” as a potential ES function is widespread (Fig. 11b), but ultimately the importance of reefs as a coastal protection ecosystem service relates to how many people are benefiting (Fig. 11c).

Coral Reef Protection among Protected Areas

The role that marine protected areas can provide in safeguarding the regulating ecosystem service function of coral reefs may be important: while it is the physical structure of the reefs that breaks waves and reduces the energy reaching the shore, this structure is greatly influenced by living coral cover. Protected areas can provide an important role in ensuring that reefs remain healthy and are resilient to both local and global impacts – they do this by reducing local threats, and by ensuring healthy and balanced populations of key species such as grazing fish, are present which in turn enable rapid recovery from perturbations.

Out of a maximum Coastal Hazard Index (CHI) ranking of 5.0, protected areas with the highest CHI values included Cousin Special Reserve (CHI = 4.29), Denis Island (Marine) AONB (CHI = 4.16), Bird Island (Ile aux Vaches) (Marine) NP (CHI = 4.01), Ile aux Recif Special Reserve (CHI = 4.05). Protected Areas with the highest Hazard Reduction by Coral Reefs included Alphonse Group (Marine) AONB (HR = 0.79), D'Arros Atoll (Marine) NP (HR = 0.73), Farquhar Atoll (Marine) AONB (HR = 0.705) and Farquhar Archipelago (Marine) AONB (HR = 0.703) (Table 6).

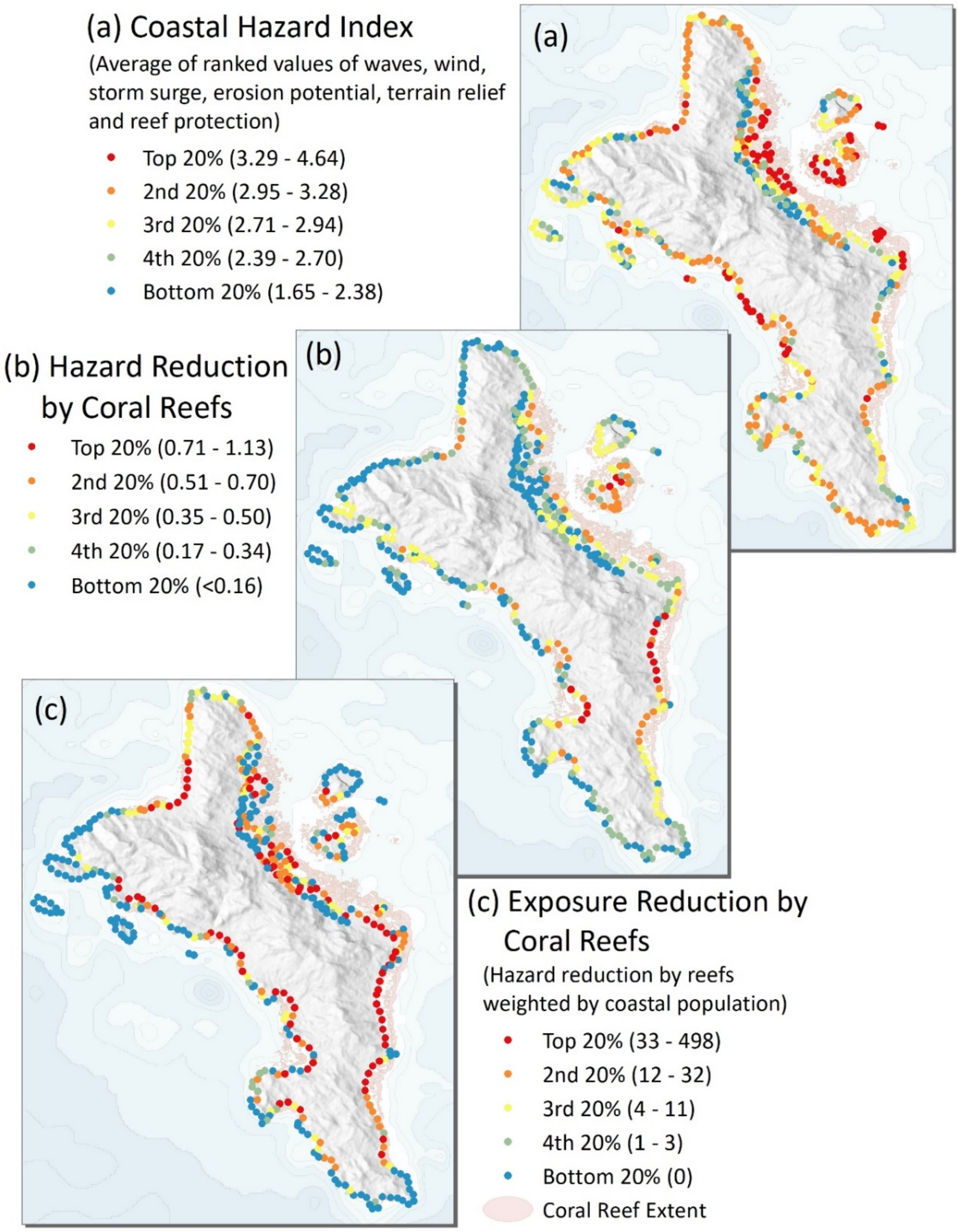


Figure 11. An illustration of the coastal defense by coral reefs model for Mahé, showing the results for 500m shoreline segments: (a) The Coastal Hazard Index developed as the geometric mean of the six input layers (Fig. 10); (b) Hazard Reduction by Coral Reefs was the difference in Hazard Index calculated with and without the Coral Reef Protection Rank; and (c) Exposure Reduction by Coral Reefs reflects hazard reduction weighted by coastal population below <30 m in elevation (Showing Mahé only for the purpose of illustration).

Overall, approximately 44,000 people live in coastal areas below ~30m in elevation, and approximately 18.5% (8,167 people) benefit from coastal protection by reefs within Seychelles Protected Areas. Of these, nearly half (~4,000 people) live on the southeastern shore of Mahe adjacent to the Mahé (Anse Faure-Fairy Land) Shell Reserve. Other top ranked Protected Areas providing coastal protection benefits include Curieuse Marine NP (963 people), St. Anne Marine NP (694 people) (Table 6). Several terrestrial protected areas are listed in Table 6 because they protect uplands to the shoreline and are presumed to have some benefit for subtidal reefs that provide coastal protection as well.

Table 6. A comparison of coastal population, coastal hazards, and exposure reduction by coral reefs among Seychelles' Protected Areas

	Coastal Population (elev. <30m)		Coastal Protection Indices			
Protected Areas	(P)	(%P)	Coastal Hazard Index (CHI)	Hazard Reduction by Reefs (HR)	Exposure Reduction (HRxP)	Exposure Reduction (% of total)
MSP Protected Areas (all)	**599**	**1.4%**	**3.43**	**0.583**	**356**	**2.4%**
Aldabra Group (Marine) NP	24	0.1%	3.41	0.386	11	0.1%
Alphonse Group (Marine) AONB	54	0.1%	3.22	0.791	46	0.3%
Amirantes (Marine) to Fortune Bank (Marine) AONB	154	0.3%	3.33	0.637	84	0.6%
Amirantes South (Marine) NP	7	0.0%	3.85	0.347	2	0.0%
Bird Island (Ile aux Vaches) (Marine) NP	45	0.1%	4.01	0.480	24	0.2%
Cosmoledo and Astove Archipelago (Marine) AONB	43	0.1%	2.86	0.538	23	0.2%
D'Arros Atoll (Marine) NP	38	0.1%	3.69	0.733	18	0.1%
Denis Island (Marine) AONB	36	0.1%	4.16	0.545	18	0.1%
Desroches Atoll (Marine) AONB	150	0.3%	3.21	0.599	90	0.6%
Farquhar Archipelago (Marine) AONB	7	0.0%	3.43	0.703	7	0.1%
Farquhar Atoll (Marine) AONB	26	0.1%	3.03	0.705	21	0.1%
Poivre Atoll (Marine) AONB	13	0.0%	2.99	0.527	12	0.1%
Pre-MSP Protected Areas (all)	**7,568**	**17.1%**	**3.11**	**0.281**	**3,778**	**25.9%**
Aldabra Special Reserve	66	0.1%	2.68	0.389	30	0.2%
Aride Special Reserve	7	0.0%	3.16	0.211	2	0.0%
Baie Ternay Marine NP	18	0.0%	2.62	0.279	9	0.1%
Cousin Special Reserve	32	0.1%	4.29	0.305	11	0.1%
Curieuse Marine NP	963	2.2%	3.05	0.236	289	2.0%
Grand Anse AONB	646	1.5%	3.21	0.286	265	1.8%
Ile aux Recif Special Reserve	0	0.0%	4.05	0.195	0	0.0%
Ile Cocos, Ile La Fouche, Ilot Platte Protected Area	25	0.1%	2.96	0.129	2	0.0%
Mahé (Anse Faure-Fairy Land) Shell Reserve	4,008	9.1%	2.76	0.532	2,294	15.7%
Morne Seychellois NP	636	1.4%	2.82	0.164	287	2.0%
Port Launay Marine NP	425	1.0%	2.74	0.276	177	1.2%
Silhouette Marine NP	47	0.1%	3.03	0.206	23	0.2%
Ste Anne Marine NP	694	1.6%	3.12	0.446	390	2.7%
Other (not in protected area)	**36,113**	**81.6%**	**3.02**	**0.251**	**10,470**	**71.7%**
Grand Total within Seychelles	**44,280**	**100%**	**3.26**	**0.419**	**14,605**	**100%**

Recreation and Tourism

In this section we provide an overview of five ecosystem service models describing nature-dependent recreation and tourism (cultural ecosystem services). These services are: on-reef tourism, nature-dependent beach tourism, charter sportfishing, mangrove tourism, and birdwatching.

On-Reef Recreation and Tourism

On-reef recreation and tourism is defined as activities undertaken by tourists taking place directly on a reef, such as SCUBA and snorkeling. Seychelles is considered a leading destination in the Indian Ocean for diving. Earlier global models estimate that the opportunity to dive and snorkel on Seychelles' coral reefs was generating > USD $34 million in tourist spending annually (Spalding et al. 2017). For this project, we have refined this estimate using updated tourism data, locally specific datasets and innovative artificial intelligence/machine learning (AI/ML) techniques. The outputs have been mapped to new, fine-scale, coral reef habitat maps.

Coral reef distribution

A new map of coral reef distribution became available during the course of this project: the Allen Coral Atlas' benthic habitat layer (Allen Coral Atlas 2020). A subset of the mapped data (Coral/Algae) provide the most up-to-date map of areas with active coral reef growth/slopes, with a good match to previously-generated maps of coral reefs. The Allen Coral Atlas was amended with two additions. First, the Atlas does not cover the granitic reefs, a regionally unique feature of the Mahé Plateau, being rocky structures, often with some coral growth, but not built by corals. Thus, the granitic reef layer from Klaus (2015) was added. Both input datasets were gridded to a 100m resolution and merged. Secondly, locations of reefs described in online diver logs (Table 7) were added if these locations were not present in either of the underlying habitat layers. The Allen Coral Atlas contains shallow reefs down to ~10m depth and while most dive-sites occur on reefs that extend into shallow water, some do not and so these deeper sites were added from the on-line diver logs.

Estimating on-reef tourism activities

Estimates of tourism activities on coral reefs were derived from locations of underwater photos and the location of dive sites. Microsoft Lobe, a free desktop AI/ML tool was used to classify photos from Flickr and return photos that depicted underwater scenes. Underwater photos were then standardized to Photo User Days ("PUDs") as an indication of the intensity of image-uploads from any location. The PUDs thus generate a score of the number of images, but with a filter to ensure that only one image per user per day can be counted across a 500m resolution grid spread across the region (see methods in Wood et al., 2013). The final PUD score is thus an unbiased score for independent photo density from each cell. For this project we combined a new review of imagery with the data previously derived from the global analysis (which used older images, identified with keywords).

Independently, a map of dive site locations was developed from the global source, DiveBoard, and a Seychelles-specific data layer provided by MEECC (now MACCE). The initial layer was further refined using online sources (including TrekDives, DiveAdvisor, Dive Seychelles, Big Blue Divers, Okeanos-Cruise and Dive.Site) and direct input from one tourism operator with data for the Outer Islands (Blue Safaris). For some dive sites, the number of dives logged at the site was available – while this clearly gives some indication of use intensity, where available, it was moderated to a simple score between 1 (low) and 3 (high), enabling the few sites with known high intensity diving to have some additional weighting without overly influencing the model.

Table 7. Data inputs used in on-reef recreationand tourism model

Data input	Source(s)	Model Treatment
PUDs (Underwater Photos)	Flickr; Spalding et al. 2017	Buffered by 1km
Reviews of attractions featuring on-reef activities	TripAdvisor	Used in calculation of proportion of tourists enjoying on-reef activities
Dive Sites	Diveboard, MACCE, TrekDives, DiveAdvisor, Dive Seychelles, Big Blue Divers, Okeanos-Cruise, Dive.Site, Blue Safaris	Weighted by popularity; Buffered by 1km
Dive Shops	Diveboard, TripAdvisor, Diveary	Used in calculation of proportion of tourists enjoying on-reef activities
Hotels	GARD, MHILT	Used in calculation of proportion of tourists enjoying on-reef activities
Coral Reef Habitat	Allen Coral Atlas, Klaus 2015	Coral/Algae class extracted, merged with areas of granitic reef and additional buffered dive sites; gridded to 100m raster
Tourism Arrivals & Expenditures	Government of Seychelles National Bureau of Statistics	% driven by on-reef tourism calculated via proxy indicators

Images and dive-sites were both used to generate a weighted map of the intensity of on-reef tourism activities to get a measure of a cultural ecosystem service. To create a use-intensity weighted map, each point location of PUD images or dive intensity was buffered by 1km, and the total reef area within that 1 km radius was calculated for each point. Each point's score (# of PUDs or dive intensity) was then divided by the total area of the reef within the buffered area to spread the intensity based on the total area of reef tract. The result of this was that larger reef areas had values spread across them more broadly. A point density analysis was then performed on each of these input layers (i.e. dive sites or PUDs) based on that value and these two layers were summed to provide an intensity score which incorporated overlapping scores where PUDs and/or dive sites were generating overlapping scores. This layer was then clipped to the map of coral reefs such that every 100m tract of reef had a unitless use-intensity score (Figure 14B).

Estimating overall importance of on-reef activities in the Seychelles

Following the approach taken by the global model of coral reef recreation and tourism (Spalding et al. 2017), and recently refined for the Caribbean (TNC 2020), a series of indicators were developed to give a clear indication of the proportion of persons enjoying on-reef activities or their equivalent spending. These indicators were drawn from visitor exit surveys (National Bureau of Statistics, 2017); the ratio of underwater PUDs to total Flickr photos; and the ratio of dive shops (derived from DiveBoard and supplemented with data from TripAdvisor and Diveary) to the number of hotel rooms (Global Accommodation Reference Database cross-referenced to data provided by Ministry for Habitat, Infrastructure and Land Transport (MHILT)). Using this approach, comparing these indicators to similar indicators from around the world (e.g, exit surveys and crowd-sourced data from small island states in the Caribbean), and informed by further academic studies on the relative importance of on-reef activities in certain countries (see Appendix A in Spalding et al. 2017), the team determined that the value of on-reef recreation and tourism activities on coral reefs, for overall tourism in the Seychelles, was 9% of the annual tourism expenditures and visitor arrivals (Table 8). The values for coral-reef associated arrivals and expenditures were distributed across the coral reefs weighted by the intensity maps to arrive at the final version of the maps, in which each 100m tract of coral reef has an associated tourism expenditure ($USD expenditure per hectare per year) and visitation value (# of visitors per hectare per year) (Figure 13 and 14C).

Table 8. Input metrics used to determine on-reef tourism expenditure and visitation values.

Input Data	Tourist Expenditures ($USD) Average 2015 - 2019	$572,559,683
	Tourist Arrivals (Average 2015 – 2019)	335,064
Dive shop to hotel room modifier	Number of hotel rooms	4816
	Number of dive shops	27
	Ratio of dive centers to 1000 hotel rooms	5.6
TripAdvisor review modifiers	Number of On-Reef TripAdvisor Reviews	7187
	Total TripAdvisor Reviews	65853
	TA Review Ratio	10.9%
Flickr Photo Modifier	Number underwater PUDs	20
	Total Flickr PUDs	829
	PUD ratio	2.4%
TripAdvisor attraction modifiers	TripAdvisor underwater review locations	467
	Total Review locations	1567
	TA Review location ratio	29.8%
Exit survey findings	% of tourists who report snorkeling	60%
	% of tourists who report diving	9%
Output Metrics	Total tourist expenditure attributed to on-reef recreation (9% of input)	$51,530,371
	Total tourist arrivals attributed to on-reef recreation (9% of input)	30,156

Nature-Dependent Beach Tourism

Seychelles is widely described as having some of the world's most beautiful beaches. Previous work has quantified and mapped the importance of coral reefs supporting these values – reefs generate white sand, clear, calm waters and many of the superlative views across the adjacent ocean. Such values have been termed "reef-adjacent" benefits (Spalding et al. 2017). In this study, we adjusted our approach, linking these values to the beaches themselves, rather than to nearby reefs, and including a slightly broader range of 'natural' factors that also contribute to the enjoyment and appreciation of beaches. This is an improvement over a strictly reef-centric approach as it is both challenging and to some degree misleading to focus attention solely on coral reefs benefits to beaches when natual values are much more broadly derived from an array of coastal and nearshore ecosystems, that are themselves tightly connected. Nature-dependency is a term used to describe, or assess, the level of dependence that any beach tourism may have on key natural values (independent variables) such as: white sand (coral-derived); natural vegetation adjacent to, or dominating views from the beach; turquoise; and/or dappled clear water. This model assumes that imagery and text from crowd-sourced data such as Flickr and TripAdvisor that capture these natural values can be used as a proxy to locate areas where these nature-dependent values influence the decision to visit a location and the level of enjoyment derived from nature at that location. The application of a value (both in expenditure and visitation) also suggests that the loss of natural values would imply a direct and immediate change in tourism arrivals and expenditure. In reality, this relationship would be difficult to prove; however, this premise is supported by analyzing survey data of other small island states with a high degree of dependence on beach tourism (Schuhmann, per comm).

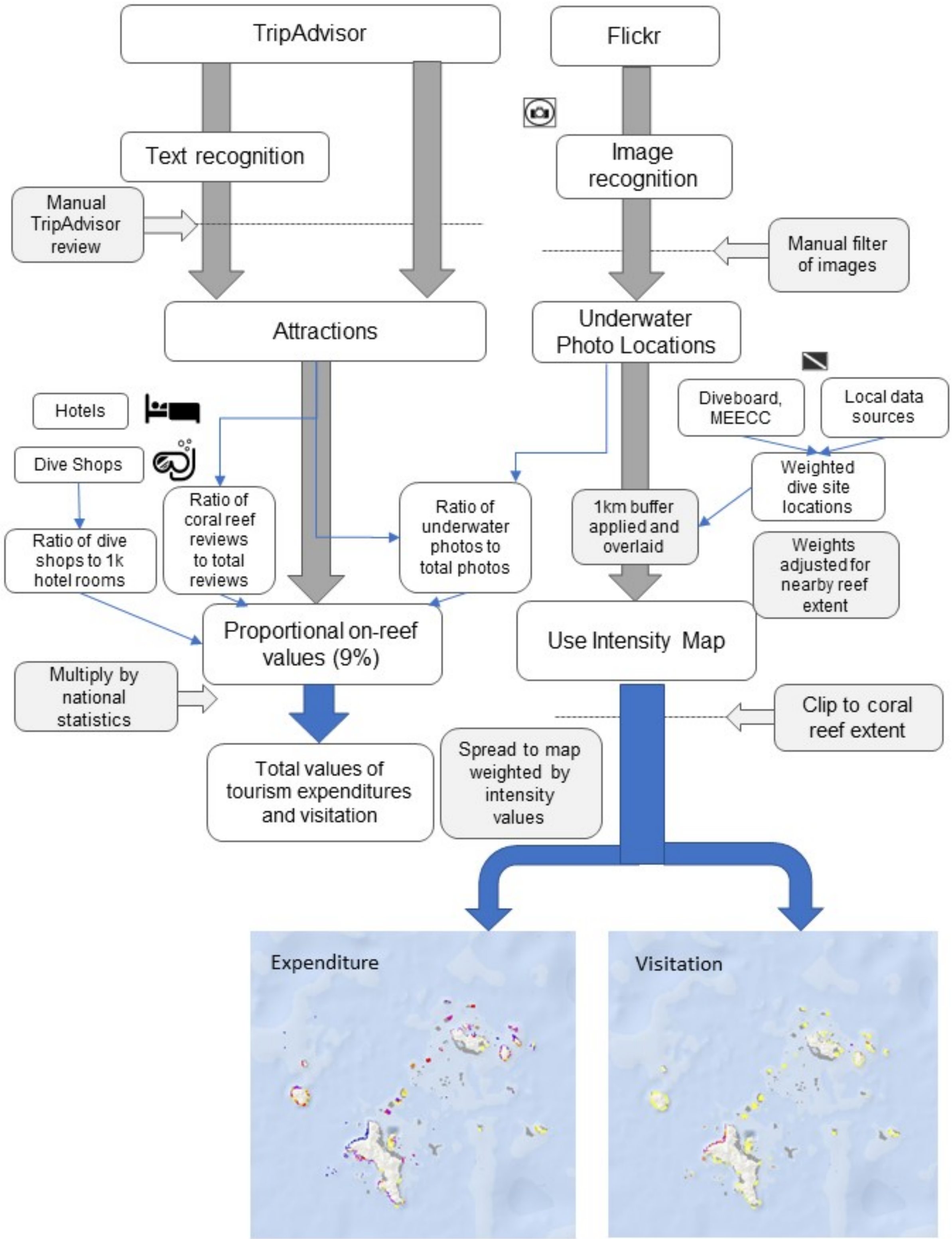
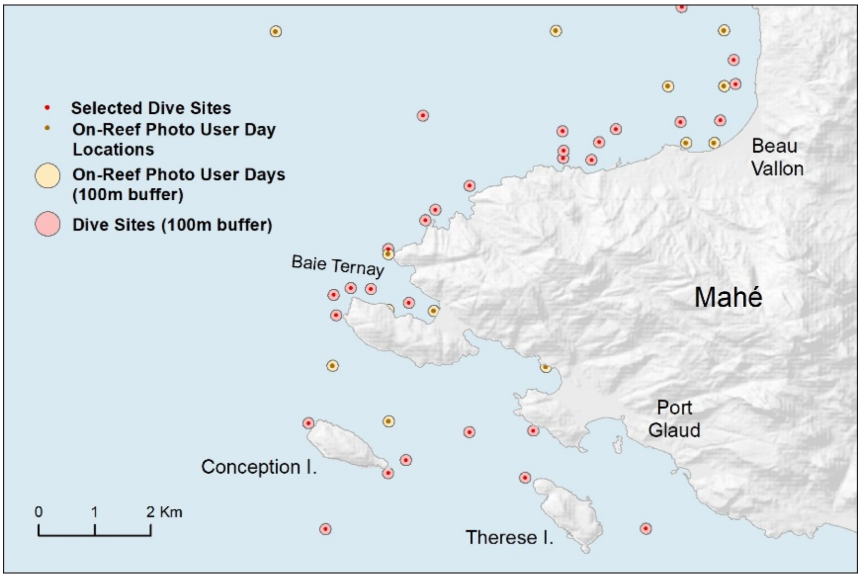
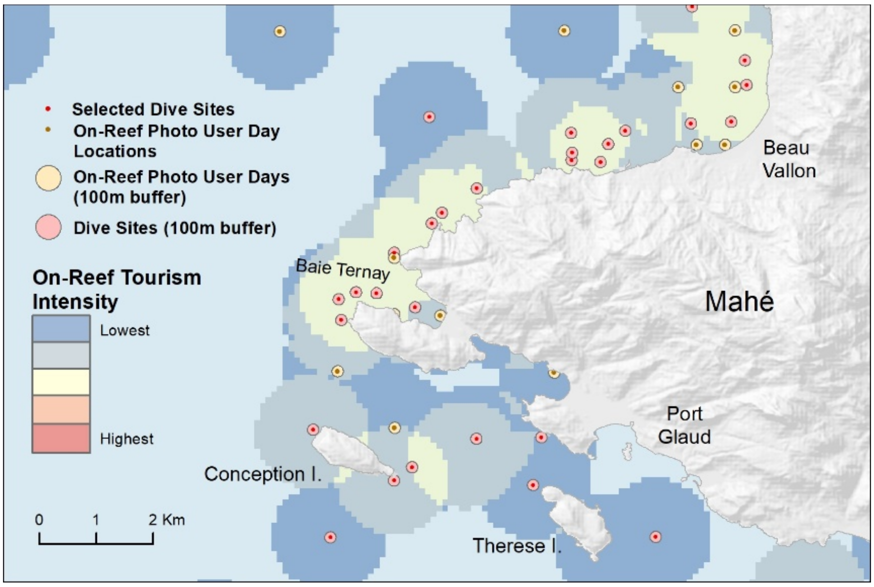


Figure 13. Data inputs and modelling process to estimate value of on-reef tourism in Seychelles' protected areas.

A. Input Data



B. Estimated intensity of use



C. Estimated on-reef tourist expenditures, illustrated for western Mahé island

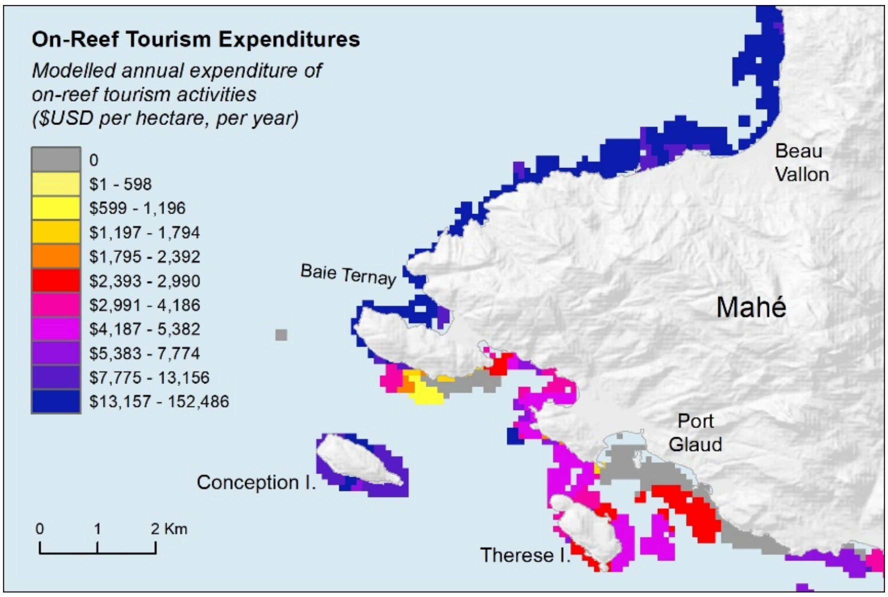


Figure 14. Data inputs and modeling process to estimate on-reef tourism visitation and expenditures (illustration for western Mahé Island only).

A spatial data layer depicting the locations of beaches was developed under MACCE (Klaus 2015) and provided the underlying habitat layer for this analysis. For the purpose of this analysis, this layer was gridded to a 100m raster resolution. The primary assessment of nature-dependent beach values was the identification of nature dependency in photos (from TripAdvisor and Flickr) and reviews (from TripAdvisor). Microsoft Lobe, a free desktop AI/ML tool was used to classify and return images of beaches where natural elements were dominant (e.g., white sands, turquoise waters, vegetation) and where buildings, beach furniture and debris, and beachside infrastructure were absent. These were then mapped as points based on the TripAdvisor attraction to which they were linked, or, in the case of Flickr photos, to the location at which the photo was taken. Flickr photos were then standardized to PUDs (see above) across a 500m grid. Similarly, TripAdvisor photos were standardized to photos by attraction by member ("PAMs") such that if a TripAdvisor user uploaded multiple photos for an attraction, only one would be counted. Both PUDs and PAMs thus provide a weighted score of value for each location, without any bias that might be introduced from multiple uploads from single users.

A text recognition model originally derived for the Eastern Caribbean was deployed on TripAdvisor reviews for Seychelles. This model was trained to return reviews that mentioned beaches as well as other natural elements (e.g., coral reef, turtles), beach features (white sand, clear water) or activities (snorkeling, kayaking) that indicated that the beach had a high natural value. An expert team from Microsoft then applied a random-forest regression model to automatically classify the remainder of the reviews and return a list of reviews that matched each set of criteria. These were then mapped as points based on the attraction to which they were linked. Each attraction was weighted by the number of PAMs, and again by the number of relevant reviews at that location.

Both Flickr points and attractions were buffered to a 1km radius and the total value of each buffer was spread evenly across all beach areas within that buffer. The larger area of beach within a buffer, the more broadly the value would be spread. Each of the values per beach were summed to give total values. Finally, this intensity layer was clipped to the beach extent, giving a map of the intensity of "nature dependency" for all beaches in the Seychelles.

Table 9. Input metrics used to determine expenditure and visitation values for nature-dependent beaches.

Data input	Source(s)	Model Treatment
PUDs (Nature-Dependent Beaches)	Flickr	Buffered by 1km
PAMs (Nature-Dependent Beaches	TripAdvisor	Buffered by 1km
Reviews of attractions featuring on-reef activities	TripAdvisor	Used in calculation of proportion of tourists enjoying on-reef activities
Beach habitats	Klaus 2015 (MEECC)	Gridded to 100m raster
Tourism Arrivals & Expenditures	Government of Seychelles National Bureau of Statistics	% driven by on-reef tourism calculated via proxy indicators

Estimating 'natural value' of beaches in the Seychelles

Proxy indicators and prior research were used to develop a metric characterizing the relative importance of nature, or natural values, to beach tourism at the national level. In order to understand the relative importance of nature to beach tourism at the national level we undertook a three-step process:

1. Beach importance to tourism: for the region. Unfortunately the exit surveys undertaken in the Seychelles do not assess any aspects of beach-going. Given the reference to beaches in user-generated content and the ubiquitous use of beaches in almost all marketing for the Seychelles it must be assumed that beach-going is a widespread or even near ubiquitous driver. Ongoing and earlier work for small island nations in the Caribbean, including a review of several exit polls led to a decision to use a figure averaged from several sources estimating that beach tourism generates 77%

of all tourism value. Using such a figure for the Seychelles is reasonable, or possibly conservative: the tourism model is very similar for these countries, although it is likely that the cultural drivers for tourism may if anything be lower for the Seychelles (the Caribbean islands have larger populations, and probably stronger family links to countries of tourism origin).

2. Natural values of beaches: The value of beaches is not entirely derived from their natural features, indeed for some beach users it may be proximity to infrastructure, the provision of beach furniture or other human elements that more strongly influence their enjoyment. For most it will be a combination. From an ecosystem service perspective, however, it is important to understand the contribution of nature and natural ecosystems to beach value. As above, we were unable to locate any local data to enable us to tease apart these values. Once again, however, there is highly relevant work from the Caribbean (Schuhmann et al. 2019 and unpublished). Through detailed visitor surveys this work projected declines in visitor returns based on environmental degradation. We therefore decided to use the same numbers to project likely losses from a 5% decline in environmental condition (a combination of water quality, marine life and other factors) as a metric for **current natural beach value.** Based on this, we projected a 31.2% loss of return in the face of relatively low environmental degradation (Schuhmann, per comm) and we used this number to calculate current natural values.

National modifiers

Based on our work in the Caribbean such national statistics beaches and the final stage of this work involved a national level assessment of the relative importance of nature between countries. This work utilised data from images and reviews to develop a national modifier for each country. The apparent importance of nature in both image and review data for Seychelles beaches is higher than any of our data from the Caribbean as shown in Table 10. Taken in combination, the data from reviews and from both Flickr and TripAdvisor images show that 3% of user generated data sources indicate places with natural beach values, which is double the same figure for the Eastern Caribbean states. For this reason, it was decided to add a 20% increase on likely nature dependency for Seychelles.

These three steps were thus combined. Beach tourism was assumed to be driving 77% of all arrivals and expenditure. A generic figure of 32% of that value was considered vulnerable in the face of minor environmental decline, and was thus considered a useful estimate of current natural contribution to overall beach value. Finally, in recognition of the particular importance of the natural component of beaches to the Seychelles a mark-up in value was applied of some 20%. This multiplier was then applied to average tourism arrival and expenditure values from the Department of Statistics (2015 –2019). These values for nature-dependent beach-associated arrivals and expenditures were then distributed across the beaches weighted by the intensity maps to arrive at the final version of the maps, in which each 100m tract of beach has an associated tourism expenditure and visitation value (Figures 15 & 16).

Table 10. Input metrics used to determine nature-dependent beach expenditure and visitation values.

Input Data	Tourist Expenditures ($USD) Average 2015 - 2019	$572,559,683
	Tourist Arrivals (Average 2015 – 2019)	335,064
TripAdvisor review modifiers	Number of NDB TripAdvisor Reviews	1,784
	Total TripAdvisor Reviews	65,853
	TA Review Ratio	2.7%
Flickr Photo Modifier	Number NDB PUDs	384
	Total Flickr PUDs	829
	PUD ratio	46.3%
TripAdvisor Photo Modifier	TripAdvisor NDB PAM	625

Table 10 (continued). Input metrics used to determine nature-dependent beach expenditure and visitation values.

	Total PAMs	31,223
	TA Review location ratio	2%
Exit surveys, comparison to Caribbean data, and Schumann et al. (2019)	Estimated beach use/dependency	77%
	Estimated loss of returns resulting from environmental decline	31.2%
	National modifier for particular beach dependency of Seychelles	20%
	Nature dependency of beaches as proportion of overall tourism value	(0.77 * 0.312 * 1.2) = 28%
Output Metrics	Total tourist expenditure attributed to natural values of beaches (28% of input)	$160,316,711
	Total tourist arrivals attributed to natural values of beaches (28%% of input)	93,818

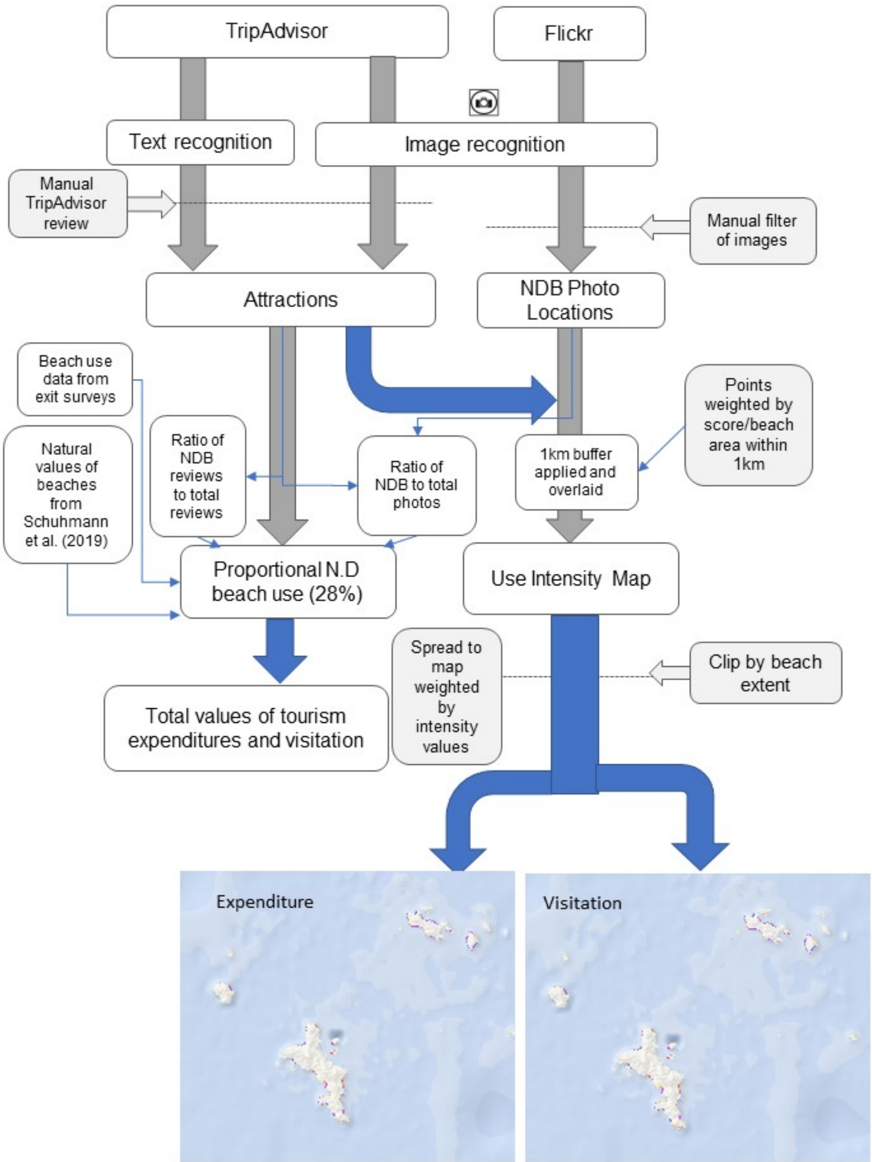
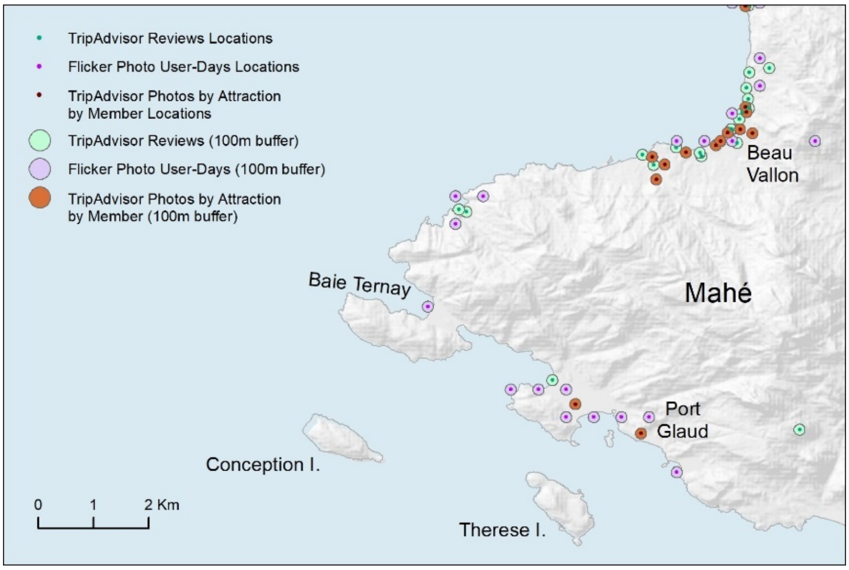
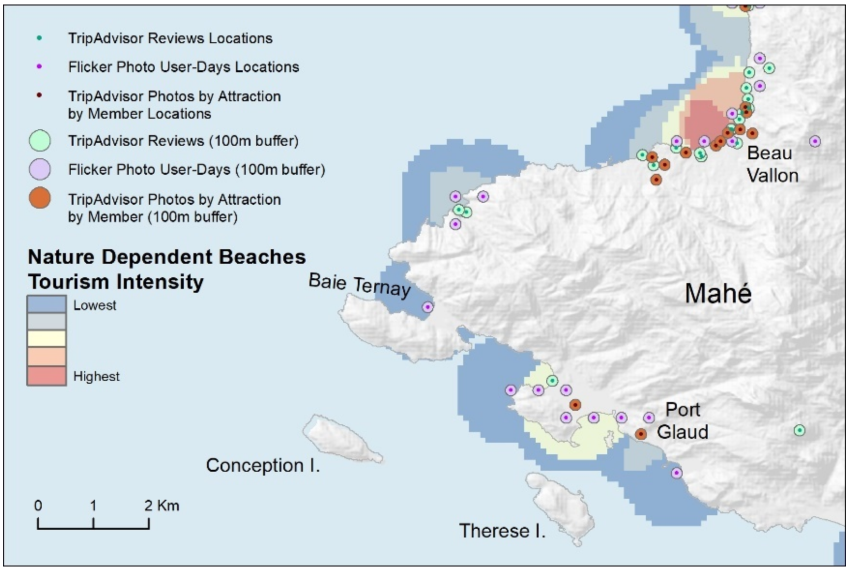


Figure 15. Data inputs and modelling process to estimate tourism values associated with nature-dependent beaches in Seychelles' protected areas.

A. Buffered locations of attractions, photo-user days and TripAdvisor reviews.



B. Modelled use intensity



C. Modelled annual expenditure of on-reef tourism activities ($USD)

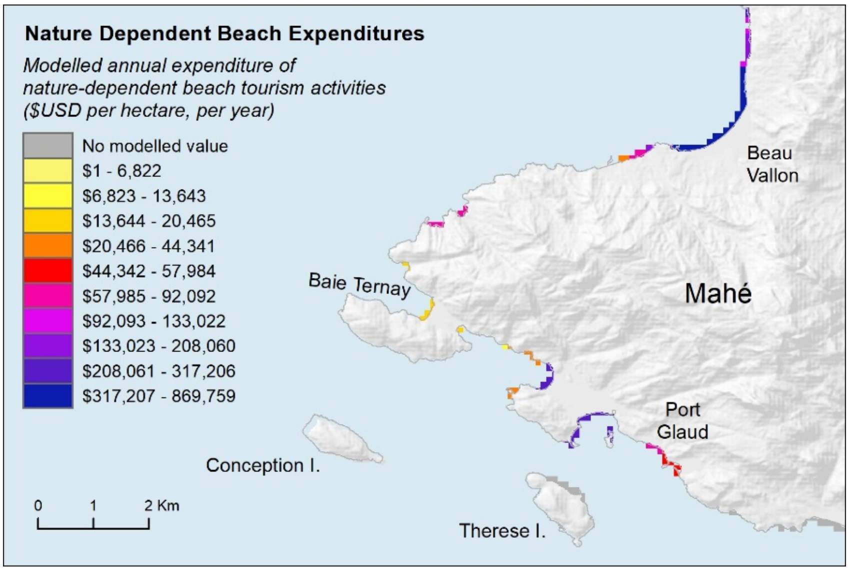


Figure 16. Data inputs and modeling process to estiamte on-reef tourist visitation and expenditures (illustration for western Mahé Island only).

Charter Sportfishing

Recreational sportfishing is an important component of the Seychelles' economy. The Seychelles is well known for its ample opportunities to fish for multiple species, using diverse methods, in relatively pristine settings. During the MSP process, stakeholders identified primary sportfishing areas as any shelf areas (i.e. <= 200m depth), plus a 16km buffer into deeper water (drop-off areas). Sport fishing occurs on or around the Mahé Plateau and in other outer islands locations, excluding Aldabra Atoll and surrounds. Sport fishing activity occurs in shallow and deep water alike, with fishers pursuing big-game species (e.g. tuna and billfish), demersal species (e.g. groupers and snappers), and reef-associated semi-pelagic species (e.g. bonefish and giant trevally). While a popular activity for many tourists, recreational fishing is also widely undertaken by local residents. Beyond that, little is documented about the spatial distribution of sport fishing activities across the EEZ, or the extent to which specific areas contribute to the revenue generated by this sector.

Initially, the team had planned to use a combination of crowd-sourced data, and the on-shore locations of charter to operators to spatially model the distribution of this activity in the EEZ. Some 80 operators were identified through a combination of TripAdvisor and various in-country advisors, however these data alone were insufficient to assess fishing effort and distribution. To address this gap, on August 24, 2021, we initiated a survey of 81 Seychelles' sport fishing charter operators, aimed toward increasing our understanding of spatial patterns of use by this sector of the recreation and tourism industry.

The purpose of the survey was to identify not only the areas that are most important for these businesses, but also to illustrate the extent to which Seychelles' marine protection areas might support these enterprises. The survey was designed using the ArcGIS Survey123 platform, which allows respondents to use a participatory mapping interface to identify areas of Seychelles' EEZ that are important for their charter businesses. The survey integrated a series of additional questions related to the specific areas mapped covering: points of departure, the number of trips made to each location; the number of clients; and the charges associated with visiting the areas. The survey was open between August 24 and September 7, 2021.

The project team received a limited set of responses, comprised of 6 charter operators (7% of the total invited to participate). Respondents mapped 14 discrete areas across the EEZ that are used in their sport fishing charter trips. Due to the small sample size, it is not possible to conduct meaningful analyses of effort distribution or revenue generated. Even so, this data enables us to highlight certain patterns in the data that validate our current understanding of sport fishing patterns in Seychelles (Fig. 17).

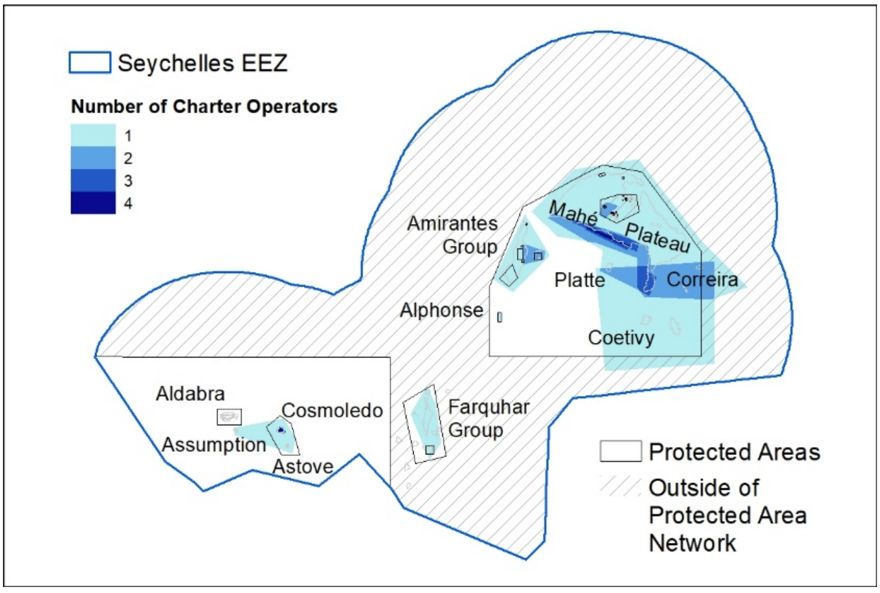


Figure 17. Spatial areas identified from an online sport fishing survey to identify important fishing areas used by charter operators in 2021.

Not surprisingly, the Mahé Plateau is of primary importance, frequently used by most operators. Across the Plateau there is likely to be considerable focus near the granitic islands where most operators are based, although was not captured in our survey. The southern margins and drop-off of the Plateau, as well as areas between Platte Island and Correira Bank were also identified in the survey, and represent important areas for game fishing on day-trips from the granitic islands.

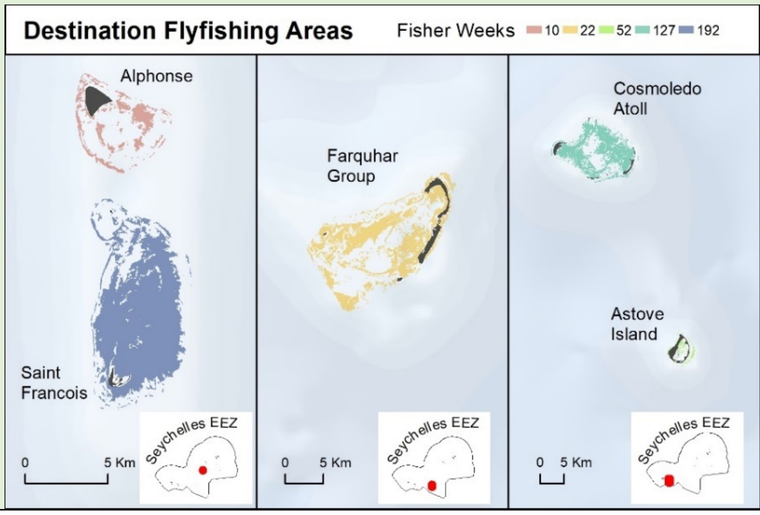
Beyond the Mahé Plateau there are fewer operators and much lower fishing intensity, although from our survey all those visiting these areas regard them as "Highly Important" *regardless of their frequency of use.* Most fishing in these areas is undertaken from specialist boat charters or from the few island based operators in these places, with land-based recreational fishing operations from Desroches and Alphonse in the Amirantes Group, and other bases in Farquhar, Cosmoledo and Astove.

One key fishery, particularly away from the Mahé Plateau, is catch-and-release fly fishing, a high value fishery which takes place in shallow water. This is particularly important in areas around Alphonse, Cosmoledo, Astove, and Farquar. Due to the different considerations around this type of fishing, we have considered it separately from the largely half or full-day sportfishing charters targeted by the survey, based on a dataset provided to us by one of the operators in the region (See Box 1).

Box 1. Highlight on destination flyfishing

Charter fishing in the outer islands is a very high value, low volume tourism activity run by a relatively small number of operators. Most fishing in these areas falls into either fly fishing or bluewater fishing (game fishing, deep sea fishing). Fishers access these islands either on liveaboard charter vessels or though the main land-based operators on these atolls which operate from Alphonse and Desroches atolls, with the former also operating smaller fishing activities on Farquhar, Astove and Cosmoledo Atolls.
A large proportion of both fishing types is catch-and-release, or with limited catch retention for immediate consumption, making these fisheries highly sustainable. It is also important to note that fishing in these atolls, particularly fly-fishing, is considered to be near the top of the range, even from a global perspective, and this is attracting very high-paying visitors such that, although total visitor numbers are relatively small, their economic importance may be considerable.

Data provided by Blue Safari enabled us to build a picture of their fisheries operations on the four atolls where they are based and these are plotted in the figure below. Clearly these do not represent a full spatial map of outer island charter fisheries, however they likely represent a significant proportion of the total fishing activity from these fisheries, as there are very few operators sending trips to these remote locations. Details from these fisheries describe the focus for the fly fishing as shallow lagoon and reef flat areas (defined using benthic habitat data downloaded from the Allen Coral Atlas) with target species including bonefish, milkfish, giant and bluefin trevally and permit. The units represent weeks, summed by the numbers of fishers each week. Typically the "season" for these activities lasts from 10 to 30 weeks a year. The Bluewater fishery targets pelagic species including tuna, wahoo and billfish – these are largely targeted in off-reef waters between the 70 and 200m contours, but occasionally going further offshore for marlin.



Mangrove Tourism

At the global scale, the TNC's Mapping Ocean Wealth team has developed a point-based map of mangrove tourism (Spalding and Parrett 2019). For the purpose of this assessment, the map was updated and improved with more recent and comprehensive TripAdvisor data and local-scale mangrove maps.

The primary source of data for this analysis was provided by TripAdvisor, and consisted of locations of attractions and their associated reviews. We conducted a keyword search of all reviews (~65,000), and identified any that included the word "mangrove". We then manually reviewed these reviews, removing any where the mangrove reference did not directly relate to the attraction location. Attractions that were directly associated with mangroves where then weighted by the number of reviews for that location as a proxy for their popularity. The map below and the associated table shows the results of this analysis (Figure 18). In Table 11, attractions are annotated with information about each location as it relates to mangroves. Constance Ephelia, which borders the Port Launay Marine National Park (a Ramsar site) had, by far, the highest number of reviews (Table 11).

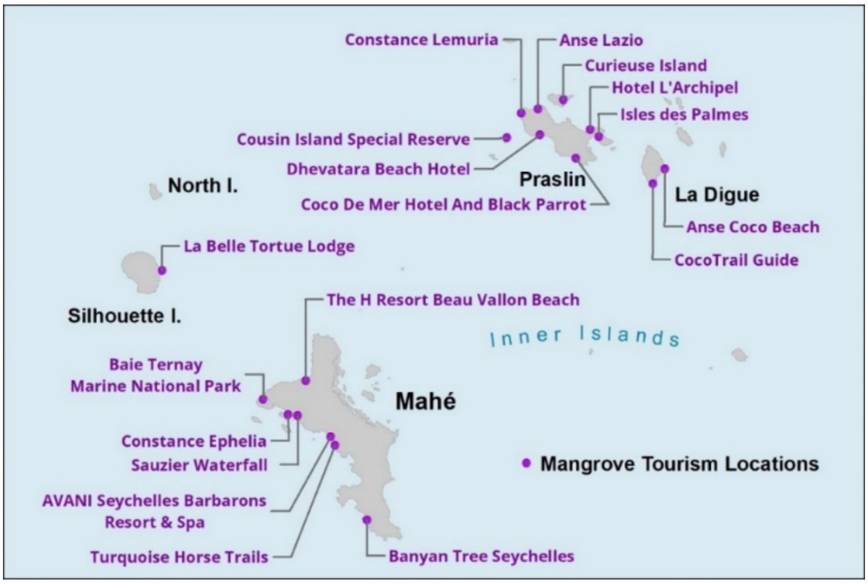


Figure 18. Locations of mangrove tourism sites in the Seychelles Inner Islands (TripAdvisor).

Birdwatching

The unique and diverse avifauna of the Seychelles provides a selling point for visitors interested in birdwatching that are choosing between various holiday or vacation destinations. Seabirds are an important part of birdwatching activities, especially the mass-nesting of certain species on offshore islands, and including terrestrial species that are endemic and add to the overall value of a holiday. Our study highlights an opportunity to tap into the growing interest in marine birdwatching.

Data was obtained from eBird, a popular online tool widely used by birdwatchers and citizen scientists worldwide to record and share their findings. It provides a rich source of data with relatively high spatial precision. In Seychelles, over 230 observers have contributed data to eBird , between them generating over 73,000 birdwatching observations for a total of 212 species. Recorded sightings go back as far as 1966 with the majority of sightings recorded between 2006 and 2019. eBird data has already been used in other academic studies (e.g., Johnston et al. 2020, Zhang 2020), and while there are some weaknesses in its use as a precision tool for mapping bird species and abundance, our intention was to use it to map where birdwatchers go. As the users of eBird are likely to be high level or experienced bird enthusiasts, it is important to note that the spatial patterns of these observations may not fully reflect the activities of other tourists who nonetheless enjoy seeing wild birds.

Table 11. Mangrove attractions and frequency of reviews on Trip Advisor

Attraction Name	Attraction Type	No. Reviews
Constance Ephelia	Accommodation	137
Isles des Palmes	Accommodation	2
Banyan Tree Seychelles (Now Closed)	Accommodation	2
Coco De Mer Hotel And Black Parrot	Accommodation	1
AVANI Seychelles Barbarons Resort & Spa	Accommodation	9
Anse Lazio	Attraction	1
Constance Lemuria	Accommodation	1
The H Resort Beau Vallon Beach	Accommodation	1
Curieuse Island	Attraction	104
Cousin Island Special Reserve	Attraction	1
Hotel L'Archipel	Accommodation	1
Dhevatara Beach Hotel	Accommodation	1
Anse Coco Beach	Attraction	1
La Belle Tortue Lodge	Accommodation	1
Turquoise Horse Trails	Attraction	3
Sauzier Waterfall	Attraction	1
Baie Ternay Marine National Park	Attraction	2
CocoTrail Guide	Activity	2

Two map layers were developed to understand intensity of birdwatching in Seychelles: (1) Birder footfall and (2) Species importance. Birder footfall is a measure to capture a person's birdwatching effort, standardized to one record per observer per day per 500 x 500m grid cell. Species importance is a method of weighting a birder's effort based on sightings that are of particular interest to birdwatchers, such as an endemic, breeding birds, or a migrant. Birds were assumed to be of charismatic interest if they were endemic, rare, seabirds, and/or had other notable or eye-catching features (e.g., large, or having bright plumage). While this designation is somewhat subjective it was informed by a similar approach in the Eastern Caribbean (TNC 2021). To capture species importance, we weighted each species by 3 factors: IUCN Status, Distribution, and Charisma as follows:

Table 12. Definitions and sources for scoring of species importance for bird watching in Seychelles

	Score of 1	Score of 0	Source
IUCN Status	Vulnerable, Endangered or Critically Endangered	Near Threatened or Least Concern	IUCN Red List of Threatened Species (www.iucnredlist.org)
Distribution	Endemic or Accidental/Rare	Introduced or No Category	AviBase (avibase.bsc-eoc.org)
Charisma	Identified as a species of charismatic interest	Not identified as such	Expert opinion

Scores for each bird were summed, and any species with a species importance score of at least one is considered a "key species". There was a total of 160 key species for the Seychelles. To develop the map layer of species importance, the species importance scores of all sightings within a 500 x 500m grid cell are summed. The effect of distinguishing between overall birdwatcher effort alone versus effort based on species importance is to highlight areas away from tourism centers (where effort is likely to be high) to focus on destinations to which birders are likely to make a dedicated trip to locate a bird of interest.

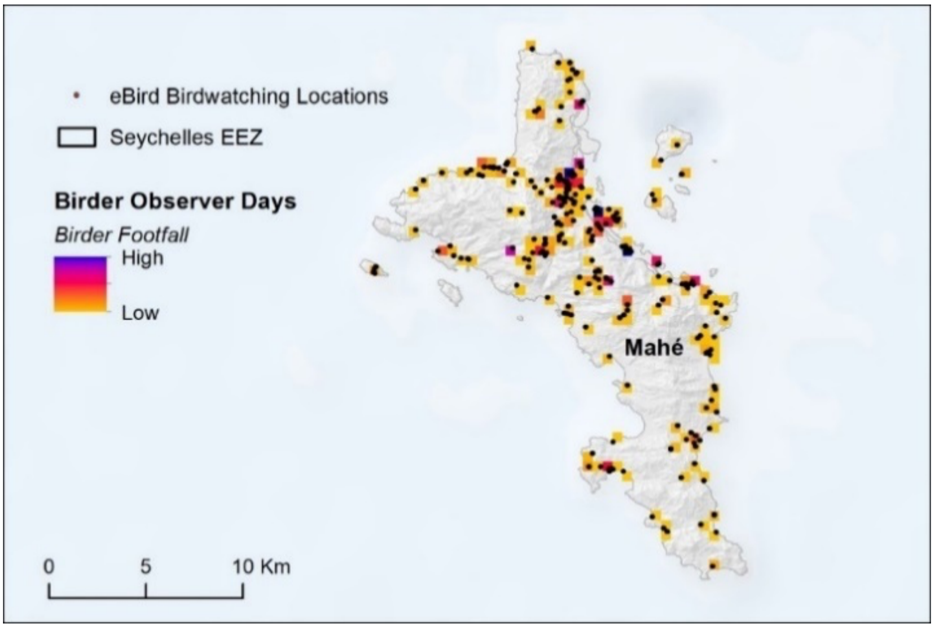


Figure 19. Maps of Birder Observer Days and Birder Intensity; eBird location, illustrated for the island of Mahé

Recreation and Tourism Values among Protected Areas

On-reef recreation and tourism: The final model results show that tourism activities on coral reefs are responsible for generating $51.5 million in tourism expenditure annually, drawing over 30,000 tourist arrivals. The model results can be interpreted to mean that these are the expenditure and visitation values that would estimated to be lost if were it not for the attraction of on-reef recreation and tourism activities. Of these values some 36% are derived from coral reefs within the Seychelles protected areas network.

As would be expected, many of the highest ecosystem service values were calculated for reefs near the areas generally known to have higher overall concentrations of tourist facilities: notably around the northwest coast of Mahé, the northern side of Praslin, and around La Digue. Lower concentrations of tourists can be found around Ile Cocos and Ile Seche. In these locations on the Mahé Plateau the protected areas network provides important coverage in the Baie Ternay Marine National Park, Curieuse Marine National Park, Ile Cocos, Ile La Fouche and Ilot Platte Protected Area and the Silhouette Marine National Park. Baie Ternay Marine National Park has the highest value on a per pixel (100m x 100m tract of reef) basis, with mean values of USD $28,250 per hectare of reef per year. At the same time it is noteworthy that the majority of coral reefs with high ecosystem service values on the Mahé Plateau fall outside of designated marine protected areas.

Away from the Mahé Plateau, the majority of reefs have no direct value for diving and snorkelling, but those that do all fall within protected areas[1]. The Alphonse Group (Marine) Area of Outstanding Natural Beauty has the highest total on-reef but values for Cosmoledo and Astove Archipelago Area of Outstanding Natural

[1] On-reef values are often lower in more remote locations. However these still represent key values, and may be generating some of the only available benefits from these. Additionally, it should be noted that the expenditures associated with traveling to and staying on these islands is high. Consultations with stakeholders suggested that while it would not be appropriate to weight these areas differently in the model methodology, caution should be used when interpreting the results for islands that have low visitation and high spending.

Beauty expenditures and Desroches are also of considerable importance. Of these reefs only a small extent (3% of total value) is protected in Zone 1 Marine National Parks.

Nature dependent beaches: Even larger figures are derived from the natural values of beaches which are generating over USD $161 million in tourism expenditure and drawing over 94,000 tourist arrivals. The model results can be interpreted to mean that these are the expenditure and visitation values that would estimated to be lost were it not for the natural value of its beaches. As with on-reef activities, the highest values are heavily centred around the granitic islands, where the international airport is located.

Alongside the highly popular Beau Vallon Bay on the north coast of Mahé, are many other smaller beaches with values of $300,000 or more per hectare. The weighting of all these value is driven by the predominance of natural elements in user-generated photos and reviews, which enables the model to pick out beaches which may have considerably lower overall visitation than Beau Vallon if the proportion of nature-dependent identifiers is high. For example, Anse Lazio on Praslin is a relatively small beach with high natural values, and indeed the beach's striking granite boulders and lush vegetation are common subjects of user photographs. Also on Praslin, Anse Volbert reflects high natural beach values, as does Anse la Reunion on La Digue which is popular for swimming and snorkelling.

While we accounted for the influence of nearby protected areas (marine or terrestrial within 100m) on beaches due to a scale mismatch between the beach data and the protected area boundaries used in the spatial analysis, very few of these highest value beaches fall within protected areas (either marine or terrestrial). Indeed only 20% of nature dependent beach values are driven by locations within the protected areas network (including both marine and terrestrial protected areas).

Beaches contain both marine and terrestrial habitats, with intertidal zones submerged and exposed throughout the day. Beaches may not always be a focus for the development of marine protected areas, or indeed of terrestrial protected areas, and the relatively low overall levels of protection may indicate a need for future conservation attention in Seychelles. In some cases, partial protection to natural beach values may be provided by adjacent protected areas which, while not extending over the full area of beach, may still provide protection, as is the case with some of the beach areas of northwest Mahé, where the Morne Seychellois National Park extends to the coast from far inland. Typically, however, the most significant protection will come where the protected area includes both land and sea on either side of any beach. Thus, in Mahé both Port Launay and Baie Ternay Marine National Parks are directly adjacent to part of the coast of the Morne Seychellois National Park, and beaches in both of these locations are among the highest value, with mean annual expenditure in the former averaging over $120,000 per hectare.

The highest total value for nature-dependent beach tourism within a marine protected area is Curieuse Marine National Park, which encompasses beaches both on Curieuse Island and part of northern Praslin, that, in total, are generating USD $9.5 million in annual spending. This destination is notable for beautiful, remote beaches so its high value is not surprising.

Away from the granitic islands only a few beaches have tourism and most have no registered values in our maps. Beaches on these islands likely have high intrinsic natural value, but their value from a current tourism perspective remains low[2]. What tourism there is, is entirely covered by protected areas, with well over $1 million of expenditure per year being driven by the natural beach values in both Bird and Denis Islands – two coralline islands on the northern edge of the Mahé Plateau, and in Desroches Atoll in the Amirantes.

[2] As with on-reef tourism, consultations with stakeholders suggested that while it would not be appropriate to weight these areas differently in the model methodology, caution should be used when interpreting the results for islands that have low visitation and high spending.

Sportfishing: While the results of the sportfishing charter survey were limited, they did validate and provide additional context to the data collected on this sector during the MSP process. In particular, data on passenger expenditures on the cost of the charters provide an improved picture of the magnitude of spending that can occur within this sector. In the coming months, the Seychelles Fishing Authority (SFA) will be buillding on this assessment to better understand the overall contribution and socioeconomic importance of this sector and to understand the implications of new policy measures in the country.

Mangrove tourism: Mangroves are not widespred in the Seychelles, and the most extensive areas are beyond the reach of most tourists, in Aldabra Atoll. Mangroves were once more widespread than they are now, especially on Mahé (Seychelles NBSAP). Even so, our records show that multiple visits to mangroves occur from tourists that use two hotels that include mangroves in or adjacent to their grounds. The utilisation of mangroves as a point of interest may be giving some added value to those locations. The other major mangrove site is Curieuse, where mangroves are incorporated into a popular day-trip circuit to a nature reserve.

Of these sites, the most widely cited by tourism are mangroves protected in the Morne Seychellois National Park. The second most important are the mangroves in Curieuse which, although not directly overlapping any protected areas are immediately adjacent to the Curieuse Marine National Park. The limited extent of mangroves in the Seychelles may preclude any widespread increase in its use, however the rarity and natural beauty of these habitats may give an added value, and it will be important to ensure that such values are not lost with future development. Studies of ecotourism in mangroves from other locations can point to the potential opportunity to further develop this sector both as a means for enhancing tourism revenue as well as an incentive for mangrove protection and restoration.

Birdwatching: Of the 1,949 independent observations (or use BODs based on a 500x500m grid cell) across the Seychelles, some 854 (43.8%) were in protected areas (marine or terrestrial). Among these, Praslin National Park, Alphonse Group Area of Outstanding National Beauty, Bird Island (Ile aux Vaches) (Marine) National Park, and Vallee de Mai Nature Reserve had the three highest numbers of Birder Observer Days 116, 106, 102, and 102, respectively. These areas also had relatively high numbers of key species (45, 82, 66, and 37, with 82 being the highest for any PA in the Seychelles). The possibility of seeing at least one of these key species was likely a driver of overall effort to these areas. Indeed, Praslin Island also boasts the second highest birding importance score (1015) with Vallee de Mai, home to the endemic Black Parrot, the third (896), but Cousin Island, with 31 key species and 99 Birder Observer Days has the highest birding importance score. Cousin Island was purchased in 1968 by what is now Birdlife International in order to protect the remaining population of the Seychelles warbler (*Acrocephalus sechellensis*). It is home to four other species of terrestrial endemic birds, and also provides important nesting habitat for seabirds which congregate in spectacular numbers.

Overall, birdwatching value is most strongly associated with terrestrial protected areas, most of which were established prior to the MSP process in the Seychelles. The key exceptions to this are Bird Island Marine National Park and the Alphonse Group already mentioned.

In general, birder observer days were correlated with birding importance scores; areas where birding importance scores are disproportionately lower compared to birder observer days are areas of high tourism intensity, such as around Eden Island, where birdwatchers may be logging many sightings, but not making dedicated trips for birds of interest.

While it was beyond the scope of this project to conduct detailed analysis of birdwatcher expenditures related to this activity in Seychelles, data from other studies illuminate the opportunity to further promote Seychelles as a unique birdwatching destination. In a survey by Mwebaze & MacLeod (2013), birdwatching was among the top ten reasons tourists provided that influenced their decision to visit Seychelles.

Other work points to the potential role of tourism revenue in protected areas as a means for promoting the conservation of endangered bird populations (Steven et al 2013). It was suggested during a stakeholder workshop in 2021 that the project team look for correlations between Seychelles national park entry fees and these birdwatching metrics. While none were found, this does point to an opportunity to investigate whether increasing visitor fees based on birdwatching opportunities may be a way to drive increasing management resources towards bird conservation. An assessment of tourists willingness-to-pay for access to several marine parks in the Seychelles suggests a justification for the Marine Parks Authority to raise entry fees commensurate with the demand for recreational experiences within marine parks (Mwebaze & MacLeod 2013).

This assessment provides a clear illustration of the high importance of nature to tourism to the Seychelles economy. This is in itself not a surprising finding – tourism is the most important economic contributor to Seychelles' economy (WTTC 2019) and the importance of nature, worldwide, has been understood for decades, and been the subject of regular government policies and actions (see for example Seetaram and Joubert, 2018; de-Miguel-Molina et al 2014). Importantly, by quantifying such values systematically, and by linking those values to maps of the ecosystems that are generating value we hope that our work can provide a critical help in natural resource management.

A key element in this assessment was to investigate the degree to which the growing network of marine protection are supporting tourism. Protected areas can play an important role in safeguarding the natural values which, in turn, are supporting the Seychelles economy. Depending on the regulatory regime they can constrain activities which may be damaging to these ecosystem values, activities such as unsustainable coastal developments, the clearing of mangroves, building on or destroying coral reefs, pollution and, of course, the impacts of overfishing and destructive fishing. Protected areas also send a positive message to tourists in terms of stewardship of natural resources, and there are many locations where proximity to a protected area, or activities, such as diving, within a protected area become sought after, and can even generate a price premium.

Our results show a somewhat variable story for nature-dependent recreation and tourism across the protected area network (Table 13). Beyond the Mahé Plateau the very large extent of protected areas (zone 1 and 2) effectively cover all tourism related activities. Whether the regulatory regimes associated with these different protected areas will be effective to support such management when the MSP areas are implemented is beyond the scope of this work, and merit further consideration during the future monitoring of the MSP.

Across the Mahé Plateau, where the great majority of tourism takes place, the extent of protected areas is far more limited and many areas of importance for nature dependency in tourism are not included in the current protected areas systems. This may be particularly true for beaches: some of these fall just outside, or on the margins of, terrestrial or marine protected areas, while others are far from any protection. Areas which are well protected including a number of sites of importance for bird-watching, notably in the inland protected areas, and around some of the very smallest islands, including Bird, Denis, Aride, Cocos, Curieuse, Cousin, St Anne and Silhoette. Among the granitic islands opportunities exist for enhancing sustainable tourism and potentially to increase both ecological and economic benefits.

Table 13. Summary of estimated visits and expenditures generated by on-reef and nature-dependent beaches, and bird watching activity among Seychelles' protected areas.

	On-Reef Tourism		Beaches		Bird Watching	
Protected Areas	Visits	Expenditure	Visits	Expenditure	Birder-days	Importance
MSP Protected Areas (all)*	**6,147**	**$10,508,064**	**2,381**	**$4,068,700**	**315**	**1,559**
Aldabra Group (Marine) NP	44	$75,069	0	$0	8	29
Alphonse Group (Marine) AONB	2,103	$3,593,699	219	$374,749	106	397
Amirantes (Marine) to Fortune Bank (Marine) AONB	338	$577,668	0	$0	12	60
Amirantes South (Marine) NP	0	$0	0	$0	3	7
Bird Is. (Ile aux Vaches) (Marine) NP	176	$301,788	721	$1,231,317	102	747
Cosmoledo and Astove Archipelago (Marine) AONB	1,538	$2,631,479	0	$0	12	53
D'Arros Atoll (Marine) National Park	113	$193,574	0	$0	19	73
D'Arros to Poivre Atolls (Marine) NP	0	$0	0	$0	0	0
Denis Island (Marine) AONB	163	$278,474	658	$1,124,246	9	13
Desroches Atoll (Marine) AONB	1,628	$2,783,122	783	$1,338,388	26	69
Farquhar Archipelago (Marine) AONB	0	$0	0	$0	6	36
Farquhar Atoll (Marine) AONB	43	$73,192	0	$0	7	24
Poivre Atoll (Marine) AONB	0	$0	0	$0	5	51
Pre-MSP Protected Areas (all)	**4,194**	**$7,168,875**	**11,849**	**$20,248,436**	**556**	**5,702**
Aldabra Special Reserve					24	278
Aride Island Special Nature Reserve					61	645
Aride Special Reserve			0	$0	46	62
Baie Ternay Marine NP	926	$1,582,035	94	$160,607	0	0
Cousin Island Special Reserve					99	1,110
Cousin Special Reserve				$214,142	3	41
Curieuse Marine NP	1,148	$1,962,658	5,583	$9,540,631	7	25
Grand Anse AONB			601	$1,027,798	2	5
Ile Cocos Ile La Fouche Ilot Platte Protected Area		$1,003,522		$42,828.42	2	3
La Digue Veuve Special Reserve					98	882
Mahé (Anse Faure-Fairy Land) Shell Reserve			1,653	$2,824,136	4	8
Morne Seychellois NP			1,073	$1,834,267	82	662
Port Launay Marine NP	215	$368,258	1,951	$3,333,149	1	3
Praslin NP					116	1015
Silhouette NP and Marine NP	1,377	$2,353,130	2,913	$4,978,804	7	41
Ste Anne Marine NP	528	$902,794	2,569	$4,389,914	4	2
All Protected Areas	**10,341**	**$17,676,940**	**14,230**	**$24,317,136**	**854**	**7,261**
Grand Total within Seychelles	**30,460**	**$52,062,971**	**96,619**	**$165,103,579**	**1,949**	**11,920**

**Values that fell within 100m of a protected area were counted as being part of that protected area; therefore certain areas may have been counted twice if they fell on the border of two protected areas.*

Every effort has been made to ensure the best possible models, but these remain models which are based on a series of assumptions, including the motivations and activity patterns of tourists. This work builds on a growing body of expertise and has been strengthened by experts and stakeholder review. Nonetheless, the interpretation of maps and statistics, especially for very small areas, should be treated with caution. Estimates will be more robust when based on larger areas. Not all values will be captured in this modelling approach and so some areas apparently showing zero values may still have importance, particularly places that are important for local residents who may be less likely to document activities in social media sources.

Future analysis can build on these findings by collecting additional data and applying additional economic analyses. Some of the models have resulted in basic expenditure estimates for various tourism activities; however, more in-depth economic analysis such as value chains, and downstream impacts of these services such as job creation would be a potential next step in enhancing these datasets. In other cases where it was not possible to estimate expenditures, collecting the necessary data to do so would be helpful in enhancing the models.

Blue Carbon

Mangroves and seagrasses represent rich sources of blue carbon, that is carbon stored and sequestered by coastal and marine ecosystems(Nellemann et al. 2009)). In mangroves, carbon is stored and sequestered in living aboveground biomass and in the soil.

Mangrove Carbon

Estimates of mangrove carbon have been calculated for Seychelles using the global mangrove map developed by Global Mangrove Watch (GMW) 2016. Unfortunately, the GMW misses several key mangrove areas in the Seychelles, most notably in the Aldabra group. While these errors are being amended in newer versions of the global mangrove map, the GMW base-map is relatively low resolution while the mangrove layer created for the MSP (Klaus 2015) provides higher resolution and an estimate of 30.7 km^2 of total mangroves. Existing estimates of mangrove carbon for the Seychelles from the global extents (~45,000 metric tons) are thus undestimates.

To improve estimates of carbon stored in Seychelles' mangroves, we used the Global Mangrove Watch models of aboveground biomass (AGB) (derived from Simard et al. 2019) and soil organic carbon (SOC) (derived from Sanderman et al. 2018) and applied them to the locally-derived mangrove map layer (Klaus 2015). For areas of the local-scale layer that overlapped with the global carbon estimates, we used zonal statistics to find the mean AGB and SOC values (expressed in MgC per ha) per mangrove polygon. We then multiplied this value by the area (in ha) for each polygon to get the total values AGB and SOC values per polygon.

For local-scale mangrove polygons that did not overlap with the global carbon estimates, we used a spatial join to assign the nearest aboveground biomass and soil organic carbon values to each polygon, and converted the values from MgC per ha by multiplying the value by the polygon area to obtain total aboveground biomass and soil organic carbon. To convert aboveground biomass to aboveground carbon , we used a conversion factor of 0.451 (Simard et al. 2019); aboveground carbon and soil organic carvon values were summed to get total carbon values (Figure 20 and Table 14).

Seagrass Carbon

As no known global or local-scale estimates of seagrass carbon exist for Seychelles, we provide an estimate based on maps of seagrass derived for the MSP (Klaus 2015). These maps assign a density class (high, medium, low) to each mangrove polygon. To estimate the above and belowground biomass for each seagrass polygon, we used aboveground and belowground dry weight biomass estimates per unit area (m^2) for low, medium, an high density seagrass from Mallombasi et al. (2020). These biomass values were then converted to carbon using a conversion factor of 0.35 (from Fourqueran et al. 2012) and then converted to total carbon by multiplying by the area of the seagrass polygon.

To obtain soil carbon estimates, we used estimates from Palacios et al. (2021) and Githaiga et al. (2016) to assign soil carbon estimates per unit area to each seagrass polygon. Totals per polygon were then obtained by multiplying by the area of each polygon. Aboveground, belowground, and soil carbon values were then summed to get total carbon values for each polygon.

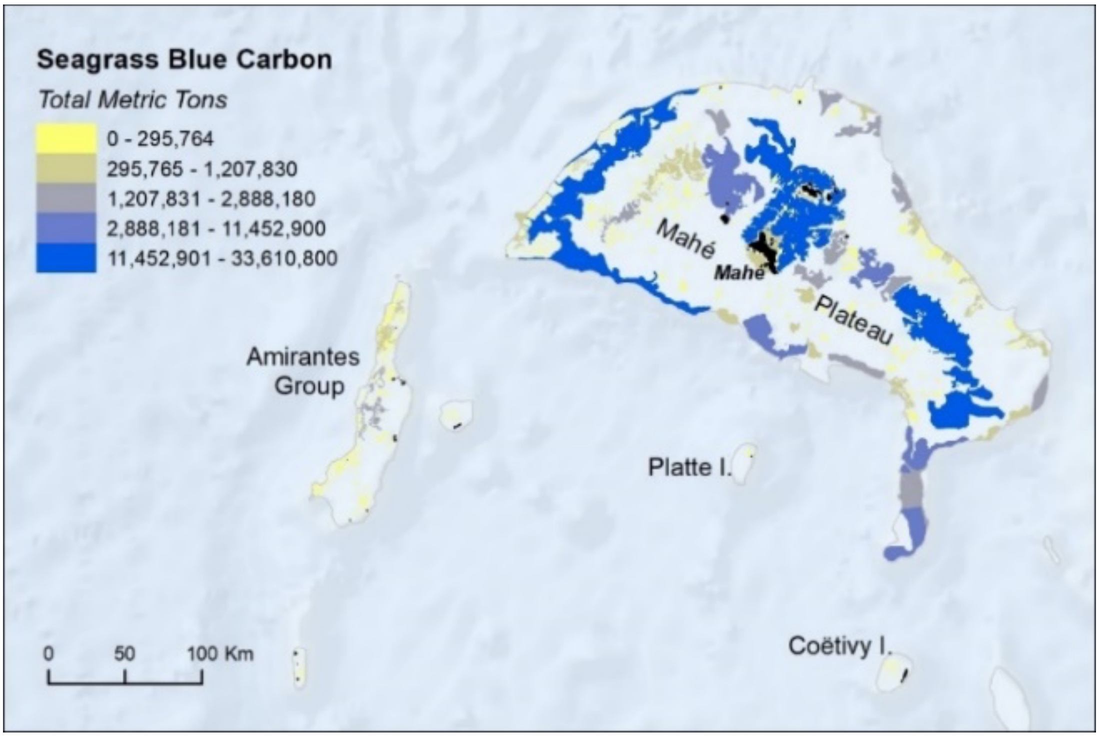


Figure 20. Estimated blue carbon in seagrass beds on Mahé Plateau and neighboring areas.

We report these values with the knowledge of two upcoming projects taking place in Seychelles that will likely result in more accurate estimates of both mangrove and seagrass blue carbon. The seagrass mapping and carbon assessment being led by the University of Oxford in partnership with the University of Seychelles, Island Conservation Society, the German Aerospace Agency, SeyCCAT, and Pew will provide a ground-truthed seagrass map and a first-time in-situ carbon stock assessment for seagrass. In a separate study. Deakin University conducted a literature review of studies assessing blue carbon values In the Western Indian Ocean (Palacios et al. 2021) and some of this information was used to inform our analysis of seagrass blue carbon. Under the Deakin project, there were also plans to develop training for collecting blue carbon data in the field, however, those plans were put on hold due to Covid-19. While upcoming projects will not provide data in enough time to inform our analysis before the project ends, it will be useful to compare the results from the rapid assessments conducted under this project to the work being conducted in the future.

Table 14. Estimated blue carbon contained in mangroves and seagrasses within Seychelles' Protected Area System.

	Mangroves (mt)			
Protected Areas	Soil Carbon	Above-ground biomass	Total	Seagrass (mt)
MSP Protected Areas (all)	**140,299**	**26,986**	**167,285**	**154,347,126**
Aldabra Group (Marine) National Park	NA	NA	NA	NA
Alphonse Group (Marine) AONB	713	92	806	230,606
Amirantes (Marine) to Fortune Bank (Marine) AONB	5,879	1,588	7,467	149,700,100
Amirantes South (Marine) National Park	0	0	0	1,302,482
Bird Island (Ile aux Vaches) (Marine) National Park	0	0	0	237,660
Cosmoledo and Astove Archipelago (Marine) AONB	121,343	22,932	144,275	428,901
D'Arros Atoll (Marine) National Park	0	0	0	84,190
D'Arros to Poivre Atolls (Marine) National Park	0	0	0	1,007,640
Denis Island (Marine) AONB	0	0	0	107,783
Desroches Atoll (Marine) AONB	0	0	0	205,462
Farquhar Archipelago (Marine) AONB	0	0	0	468,812
Farquhar Atoll (Marine) AONB	10,297	1,815	12,112	484,598
Poivre Atoll (Marine) AONB	2,067	558	2,625	88,894
Pre-MSP Protected Areas (all)	**936,469**	**107,297**	**1,043,766**	**1,179,572**
African Banks Protected Area	NA	NA	NA	1,893
Aldabra Special Reserve	936,445	107,295	1,043,740	918,406
Aride Special Reserve	0	0	0	35,043
Baie Ternay Marine National Park	0	0	0	1,951
Cousin Special Reserve	0	0	0	5,165
Curieuse Marine National Park	0	0	0	66,877
Ile Cocos Ile La Fouche Ilot Platte Protected Area	NA	NA	NA	NA
Mahé (Anse Faure-Fairy Land) Shell Reserve	0	0	0	1,632
Port Launay Marine National Park	24	2	26	2,440
Silhouette Marine National Park	0	0	0	113,789
Ste Anne Marine National Park	0	0	0	34,269
All Protected Areas	**1,076,768**	**134,283**	**1,211,051**	**155,526,698**
Grand Total within Seychelles	**1,183,185**	**137,442**	**1,320,627**	**189,816,394**

Ranking of Relative Ecosystem Service Values within MPAs

A central objective of this assessment has been to develop spatially explicit model outputs of ecosystem services that can be applied at a range of spatial scales within Seychelles' marine protected areas to inform marine protected area and implementation of the Seychelles Marine Spatial Plan. In this section we summarize the results of the models presented in Section 3 to draw broad conclusions about the relative contributions of each protected area toward the suite of recreation & tourism (cultural), fisheries (provisioning), coastal protection and blue carbon (regulating) services.

We categorized protected areas based on the relative contribution to each ecosystem service into 4 levels using Jenks Natural Breaks (Chen et al. 2013). "Jenks natural breaks" is a data classification method that determines the best assignment of values into different classes, by minimizing a given class's average variation from that class's mean, while maximizing each class's variation from the means of the other classes. This classification method seeks to reduce the variance within classes and maximize the variance between classes (Table 15).

<u>Artisanal Fisheries</u>

For characterization of the provisioning value of ecosystems for artisanal fisheries, we selected 2 metrics. The first represents the average (per hectare) value for artisanal fishing within each protected area and the second represents the total value that reflect the average value multiplied by the total area, represented as a percent of all fishing within the entire study area (Table 4). In this way, we describe both the total value of large marine protected areas as well as small areas with particularly high or disproportionate values for artisanal fishing. Further (as described in Section 3), we divided the artisanal fishery into 2 groups based on the types of vessels: whalers and schooners equipped with VMS tracking and smaller vessels powered with outboard engines. VMS-equipped vessels travelled much further distances and essentially fish throughout the Seychelles EEZ (Robinson et al. 2019) while our assessment of outboard vessels was limited to <50 miles of the main Inner Islands or Mahé and Praslin (Daw et al. 2011).

As described in Section 3, the average (per hectare) value was calculated as a Relative Selectivity Index (RSI) from the percent use of a particular seafloor habitat divided by the percent availability of that type in the study area. The average RSI value for VMS-equipped vessels was RSI = 1.68 (Range = 0.09 – 6.08), with highest values observed at African Banks Protected Area (RSI = 6.07), Bird Island (Ile aux Vaches) (Marine) National Park (RSI = 4.64), Denis Island (Marine) AONB (RSI = 3.88), Ile Cocos Ile La Fouche Ilot Platte Protected Area (RSI = 3.75), and D'Arros Atoll (Marine) National Park (RSI = 3.6). In terms of the cumulative percent contribution of protected areas for provisioning of VMS-equipped artisanal vessels, the average was 3.7% (Range = 0 – 82.7%), with by far the highest value provided by the Amirantes (Marine) to Fortune Bank (Marine) AONB at 82.7% of the provisioning value for these vessels throughout the entire Seychelles EEZ. For outboard-powered vessels, the average RSI was 1.21 (Range = 0 – 5.62), with highest provisioning value estimated from Ile Cocos Ile La Fouche Ilot Platte Protected Area (RSI = 5.62), Aride Special Reserve (RSI = 4.8) and Cousin Special Reserve (RSI = 4.16). Similar to the VMS-equipped vessels, the highest percent contribution to provisioning of outboard artisanal fishing was provided by Amirantes (Marine) to Fortune Bank (Marine) AONB (25.7%).

<u>Recreation & Tourism</u>

Some $17.7 million USD of expenditure of on-reef activities is spent within protected areas (some 34% of the total). Using our models, the highest visits and expenditures are from three of the Areas of Outstanding Natural Beauty (AONBs) in the southern Seychelles (Alphonse, Cosmoledo and Astove Archipelago and Desroches Atoll). This is partly influenced by the very extensive reef area in these MPAs. Across the Mahé Plateau, values of over $1.5 million per year are also being recorded from much smaller sites (Silhouette, Curieuse and Baie Ternay Marine National Parks). These sites include some particularly high value reefs, generating average expenditures for on-reef tourism of over $28,000 per hectare per year.

Table 15: Cut points used for a relative ranking of ecosystem services provided by Seychelles' protected areas using Jenks Natural Breaks categorization.

		Relative Ranking of Protected Areas			
Models	**Units**	**Low**	**Med**	**High**	**Very High**
Recreation & Tourism					
On-Reef Tourism	Est. Visits Est. Expenditures	<100 <$193K	101 – 338 $193K - $577K	529 – 1,377 $902K - $1.9M	1,378 – 2,103 $2.3M - $3.6M
Nature-dependent Beaches	Est. Visits Est. Expenditure	<25 <$40,000	25 – 251 $40K - $1.0M	252 – 1,073 $1.0M - $2.0M	1,652 – 5,583 $2.0 – $9.5M
Birding Importance Index	(Bird User-Days) x (Rel. Species Importance)	<25	26 - 73	74 - 397	398 - 747
Artisanal Fisheries					
VMS Vessel Value (per hectare)	Relative Selectivity Index	<026	0.27 – 1.03	1.04 – 2.53	>2.53
VMS Vessel RSI-weighted fishing areas (% of total)	(RSI$_i$ x Area$_i$)/∑(RSI x Area)	<0.16%	0.17% - 0.55%	0.56% - 1.97%	1.98% - 82.66%
Outboard Vessel Value (per hectare)	Relative Selectivity Index	<0.45	0.45 – 1.82	1.83 – 3.03	3.04 – 5.62
Outboard RSI-weighted fishing areas (% of total)	(RSI$_i$ x Area$_i$)/∑(RSI x Area)	0%	0.01% - 0.05%	0.06% - 0.24%	0.25% - 25%
Coastal Protection					
(Hazard Reduction) x (# of People)		<43	42.9 – 117.3	117.4 – 309.4	309.4 – 2,135
Blue Carbon					
Mangroves	Tons of CO2e	<4,713	4,714 – 13,676	13,677 – 144,275	144,276 – 1,043,740
Seagrass	Tons of CO2e	<113,789	113,790 – 484,598	484,600 – 1,302,482	1,302,482 – 149,700,100

Visitation associated with nature-dependent beaches generated an average 506 visits per year (Range = 0 - 5,583) and expenditures of $864,000 USD (Range = 0 - $9.5M) per year. Highest values associated with nature-dependent beaches were estimated to occur at Curieuse Marine National Park, Silhouette Marine National Park and Ste Anne Marine National Parks. Values for nature dependency reflect the proportion of the total value of any beach which we believe is linked to its natural values. They take into account the relative contribution of nature in different settings, but in order to provide an overall value metric, they also incorporate beach use. Thus, a natural, clean, scenically beautiful beach, whose core values are highly nature dependent, will only generate very low total value for nature dependency if it is rarely visited. By contrast, for somewhat degraded beaches, which usually still have some natural values, the proportional importance of nature may be small, but if those beaches are very popular the total natural values in monetary or visitation terms may still be high.

These issues are clearly illustrated in Seychelles. Beau Vallon Bay in Mahé, for example, is one of the most popular beaches in Seychelles but is considered by local stakeholders to be experiencing negative impacts from over-tourism. Our input data show that about 10% of all images uploaded for this beach illustrate natural values. By contrast this figure is over 70% for smaller, but well-known beaches such as Anse Source D'Argent, Anse Lazio and Anse Cocos, and this proportional difference is reflected in our values. While we show that Beau Vallon Bay still has high natural values (exceeding $300,000 per beach hectare), these are proportionally far lower than they could be, and make up a much lower proportion of total value than they do for other beaches. Importantly such values are also vulnerable and could be diminished further by additional development or loss of water quality. By contrast other small beaches across the Seychelles show similar values per hectare to Beau Vallon, despite far lower visitation levels. In a world (particularly post-Covid) where concerns of over-tourism and crowds are likely to increase, the maintenance of natural values may be particularly critical. A key challenge for the people of Seychelles, and protected area managers in particular, is to determine sustainable levels of use for various types of seascapes that do not degrade the natural values that draw visitors in the first place.

For birding, we calculated an "Importance Index" that combined the number of birder days (photo-user days) multiplied by the importance of each species based on global rarity. The average Birder Importance Index was 89.9 (range = 0 – 747), with highest values estimated at Bird Island (Ile aux Vaches) (Marine) National Park, Alphonse Group (Marine) AONB and Aldabra Special Reserve.

<u>Coastal Protection</u>

Approximately 44,280 people live in coastal areas below <30m elevation in Seychelles, and nearly all benefit to some extent from coastal protection functions afforded by coral reefs (Fig. 11). Approximately 8,000 of these people (~18%) benefit directly from coral reefs that are included in some form of Marine Protected Area (Table 5), with nearly ½ of these (~4,000) living just onshore of the Mahé (Anse Faure-Fairy Land) Shell Reserve. Other protected areas that rank relatively high in coastal protection include the Curieuse Marine National Park, Port Launay Marine National Park and Ste Anne Marine National Park (Table 16). Within the MSP Milestone 3 MPAs, the Alphonse Group (Marine) AONB, Desroches Atoll (Marine) AONB and Amirantes (Marine) to Fortune Bank (Marine) AONB ranks at medium levels of protection based on the degree of exposure reduction to coastal populations.

<u>Blue Carbon</u>

The Seychelles appears to have a significant mass of blue carbon, primarily due to extensive distribution of seagrass, and most notably from the Mahé Plateau. Every protected area in Seychelles contains blue carbon from either seagrass, mangroves, or both. By far, the largest quantity can be found in the Amirantes (Marine) to Fortune Bank (Marine) Area of Outstanding Natural Beauty (over 140,000,000 tonnes). Aldabra Special Reserve has the largest amount of mangrove carbon (over 1,000,000 tonnes), while Cosmoledo and Astove Archipelago (Marine) Area of Outstanding Natural Beauty have the highest density of carbon (545 tonnes/ha). Amirantes (Marine) to Fortune Bank (Marine) Area of Outstanding Natural Beauty has the largest quantify of blue carbon from seagrass (over 140,000,000 tonnes), while seagrass carbon density is relatively consistent across all protected areas containing seagrass (~117 tonnes/ha).

These numbers highlight the important role of protected areas in preserving carbon stores, and this information can be used towards climate and policy goals and commitments. Under the Paris Climate Agreement, countries define Nationally Determined Contributions (NDCs) which describe national climate goals and action plans. Data on blue carbon from wetlands can help to articulate how natural climate solutions are contributing towards these goals. Assuming that the mangroves and seagrasses falling withing the bounds of these protected areas are protected from loss and degradation under the areas' management plans, the blue carbon stores within these boundaries can define annual avoided loss of carbon towards greenhouse gas emissions.

As described above, the values were calculated based on global-scale carbon estimates (for mangroves) and literature-derived estimates (for seagrass). Spatial data on both ecosystems are somewhat outdated and may be incomplete. Likewise the maps themselves, particularly the seagrass maps, were developed without substantive ground-truthing and may contain considerable errors. These estimates will thus benefit greatly from current and forthcoming projects to better characterize these habitats at a local scale, especially when ground-truthed values are incorporated. The Oxford/ SeyCCAT/ Pew seagrass mapping and carbon assessment project described in previous sections will provide an updated field validated map and in-county carbon assessment for seagrass.

Ecosystem Services in the MPA Network of the Seychelles

The expansion of the MPA network of the Seychelles to cover over a third of the country's vast ocean expanse was a remarkable step, placing the Seychelles among the leading nations for marine conservation globally. Further enhancing this achievement, this network was developed through a highly collaborative and open process of marine spatial planning: it considered the views of numerous stakeholders from government, industry, and civil society.

In the current work we have developed, for the first time, a relatively detailed series of models that have mapped the value of key ecosystem services from coastal and marine ecosystems in the Seychelles. While these are not fully comprehensive, they cover a broad spectrum of values, including tourism and fisheries, the two most important industries in the country.

Marine protected areas are often seen as a critical means of protecting ecosystem services. For many such services this role is relatively simple – MPAs can simply prevent activities that would damage the service, preventing pollution or physical damage which might otherwise compromise their value. Limiting access or restricting certain activities can achieve the same result, but with some activities, it can also reduce the direct value to certain users. Typically, for example, the closure of fishing can halt any fishing benefits from within protected areas. At the same time the burgeoning fish stocks within the MPA can greatly enhance fisheries in adjacent waters and can also provide a resilient refuge which may be of considerable importance if reefs are impacted, for example, by climate change. Also, benefits are not equal across all services. Fisheries restrictions may greatly enhance values for scuba diving, as has been shown with many marine reserves around the world, attracting large volumes of divers and generating high expenditures.

Our findings deserve consideration in these contexts. For tourism in general, very high total ecosystem service values were calculated within some of the largest MPAs across the western and southern archipelagos, and indeed virtually all on-reef tourism in these areas is incorporated. By contrast the highest concentrations of values over small areas are concentrated on the Mahé Plateau, where a much lower proportion falls within protected areas.

For fisheries, it is notable, once again, that almost all the VMS fisheries are covered within the MPA network, including some of the very highest concentrations of fishing ecosystem service values (fishing effort relative to habitat type) around Bird and Denis Islands and D'Arros. By contrast, the outboard fishery, which is concentrated in the central Mahé Plateau has relatively lower representation within protected areas. From a fisheries perspective two broad classes of marine protection categories can be considered. Zone 2 Marine Protection Areas are for medium biodiversity protection and sustainable uses, aimed at improving fisheries sustainability. For Zone 1 Marine Protection Areas, studies for coral reefs have shown that full protection may increase fish biomass to adjacent areas, increase resilience to climate change and, and provide benefits to other users, which could include on-reef tourism activities.

Taken together it is notable that the MPA network of the Seychelles represents a truly remarkable advance. It is to be hoped that the existence of more detailed information about multiple ecosystem services in these islands also presents an opportunity to help in the development of management plans and approaches for these protected areas, and to inform future changes or extensions to fill any gaps in this protection.

Table 16. Relative ranking of ES values among Seychelles Marine Protected Areas for Recreation and Tourism, Artisanal Fisheries, Coastal Protection and Blue Carbon using Jenks Natural Breaks classification.

		Recreation and Tourism			Artisanal Fisheries				Coastal Protection	Blue Carbon	
	Protected Area	On Reef	Beaches	Bird Watching	VMS Fleet (% of total)	VMS Fleet (per hectare)	Outboard (% of total)	Outboard (per hectare)	Coastal Protection	Mangrove	Seagrass
MSP Marine Protection Areas	Aldabra Group (Marine) National Park	L	L	M	L	L	NA	NA	L	NA	L
	Alphonse Group (Marine) AONB	VH	M	H	M	M	NA	NA	M	L	M
	Amirantes (Marine) to Fortune Bank (Marine) AONB	M	L	M	VH	M	VH	L	M	M	VH
	Amirantes South (Marine) National Park	L	L	L	H	M	NA	NA	L	NA	VH
	Bird Island (Ile aux Vaches) (Marine) National Park	M	M	VH	H	VH	NA	NA	L	NA	M
	Cosmoledo and Astove Archipelago (Marine) AONB	VH	L	M	L	L	NA	NA	L	H	M
	D'Arros Atoll (Marine) National Park	M	L	M	L	VH	NA	NA	L	NA	L
	D'Arros to Poivre Atolls (Marine) National Park	L	NA	L	M	M	NA	NA	NA	NA	H
	Denis Island (Marine) AONB	M	H	L	M	VH	NA	NA	L	NA	L
	Desroches Atoll (Marine) AONB	VH	H	M	M	M	NA	NA	M	NA	M
	Farquhar Archipelago (Marine) AONB	L	NA	M	H	M	NA	NA	L	NA	M
	Farquhar Atoll (Marine) AONB	L	L	L	M	M	NA	NA	L	M	M
	Poivre Atoll (Marine) AONB	L	L	M	M	VH	NA	NA	L	L	L
Existing Marine Protection Areas	African Banks Protected Area	L	L	L	L	VH	NA	NA	L	NA	L
	Aldabra Special Reserve	L	NA	H	L	L	NA	NA	L	VH	H
	Aride Special Reserve	L	L	M	L	H	H	VH	L	NA	L
	Baie Ternay Marine National Park	H	M	L	L	M	L	H	L	NA	L
	Cousin Special Reserve	L	M	M	L	H	M	VH	L	NA	L
	Curieuse Marine National Park	H	VH	L	L	M	H	H	H	L	L
	Ile Cocos Ile La Fouche Ilot Platte Protected Area	H	M	L	L	H	M	VH	L	NA	L
	Mahé (Anse Faure-Fairy Land) Shell Reserve	L	VH	L	L	L	L	M	VH	NA	L
	Port Launay Marine National Park	M	VH	L	L	H	M	H	H	L	L
	Silhouette Marine National Park	VH	VH	L	L	H	H	M	L	NA	M
	Ste Anne Marine National Park	H	VH	L	L	M	H	H	H	NA	L

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Appendix A. Web Map and Data Catalogue

Links to Web Maps and Associated Map Layers

Link to Open All Maps in a Single Browser Window

Map	Theme	Layer (Link to URL)	Description
Artisanal Shelf Fishery	Base map	Gazetteer	This layer identifies geographic place names of Seychelles.
	Base map	Archipelago Subregions	This layer is comprised of polygons that identify the general locations of Seychelles' archipelagic areas.
	Base map	Coastline	This layer contains polygons representing the coastlines of Seychelles' islands and atolls
	Base map	EEZ Boundary	This layer depicts Seychelles' Exclusive Economic Zone Boundary.
	Model Output	Artisanal Shelf Fishery VMS, Relative Selectivity Among Shelf Areas	This layer depicts the Resource Selection Relative Selectivity Index (RSI), based on the percent of fishing effort that occurred within particular seafloor geomorphic habitats divided by the percent availability, or total areal extent, of that type (Thomas & Taylor, 1990). An index value of 1.0 indicates fishing effort in proportion to availability, while indices >1 show relative degrees of preference and values <1 show areas fished less than their proportional availability (i.e., relative avoidance).
	Model Output	Artisanal Shelf Fishery VMS, Relative Selectivity Among Shelf and Habitat Areas	
	Input Data	Seychelles MSP Zoning Design Milestone3 (26March2020)	Seychelles MSP Milestone 3 – Gazetted Marine Protection Areas. The Seychelles MSP Milestone 3 areas were gazetted on 26 March 2020 at Statehouse. The completion of the Seychelles marine spatial plan will continue beyond 2021. See www.seymsp.org for more information.
	Input Data	Protected Areas Pre - MSP	This feature layer depicts the designated marine and terrestrial protected areas in Seychelles. This does not include the newly gazetted protected areas that are outcomes of

			the Seychelles Marine Spatial Plan (i.e. MSP Milestone 3).
	Input Data	Daw et al 2011 Survey (Where People Fish)	This layer depicts artisanal fishers survey results (Daw et al. 2011; Where People Fish).
	Model Output	Artisanal_Outboard_Fishery_Model_Distance_Selectivity_Function	This layer depicts an intermediate Artisanal Outboard Fishery Model output, the Distance Selectivity Function. This layer identifies the relative selectivity of areas, based on their distance from landing sites, and calibrated using artisanal fishers survey results from Daw et al. 2011.
	Model Output	Artisanal_Outboard_Fishery_Model_Daw_RSI_Distance_RSI_Combined	This layer depicts an intermediate Artisanal Outboard Fishery Model output, where the Distance Selectivity Function is combined with the geomorphic class selectivity selectivity index. This layer identifies the relative selectivity of areas, based on their distance from landing sites, and calibrated ussing artisanal fishers survey results from Daw et al. 2011.
	Model Output	Artisanal Outboard Fishery Model Geomorph Class Selectivity	This layer depicts Artisanal Outboard Geomorphic Class Selectivity. An index value of 1.0 indicates fishing effort in proportion to availability, while indices >1 show relative degrees of preference and values <1 show areas fished less than their proportional availability (i.e., relative avoidance).
	Input Data	Artisanal Vessel Location Density (On-shelf; 2011-2015; 2k radius)	This layer depicts the spatial density of artisanal Vessel Monitoring System locations, within a 2 km search window around each location (NON-Cucumber Vessels on Shelf Habitats, 2011-2015).
	Base map	World Ocean Reference	This vector tile layer is designed to be used as annotation for features on the World Ocean Base map, this reference layer includes marine water body names, undersea feature names, and derived depth values in meters. Land features include administrative boundaries, cities, and inland water names.

	Base map	GEBCO_2020 Bathymetric Contours (NOAA NCEI Visualization)	This layer provides labeled bathymetric contours derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
	Base map	GEBCO_2020 Grayscale Basemap (NOAA NCEI Visualization)	This layer provides a grayscale basemap derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
Blue Carbon	Base map	Gazetteer	This layer identifies geographic place names of Seychelles.
	Base map	Archipelago Subregions	This layer is comprised of polygons that identify the general locations of Seychelles' archipelagic areas.
	Base map	Coastline	This layer contains polygons representing the coastlines of Seychelles' islands and atolls.
	Base map	EEZ Boundary	This layer depicts Seychelles' Exclusive Economic Zone Boundary.
	Input Data	Seychelles MSP Zoning Design Milestone3 (26March2020)	Seychelles MSP Milestone 3 – Gazetted Marine Protection Areas. The Seychelles MSP Milestone 3 areas were gazetted on 26 March 2020 at Statehouse. The completion of the Seychelles marine spatial plan will continue in 2020. See www.seymsp.org for more information.
	Input Data	Protected Areas Pre - MSP	This feature layer depicts the designated marine and terrestrial protected areas in Seychelles. This does not include the newly gazetted protected areas that are outcomes of the Seychelles Marine Spatial Plan (i.e. MSP Milestone 3).
	Input Data	Mangrove Wetlands (GoS-UNDP-GEF; Klaus 2015)	This layer depicts the distribution of wetland and mangrove habitats across Seychelles' EEZ.
	Model Output	Mangrove Blue Carbon	This layer depicts estimated amounts of mangrove blue carbon, summed by individual mangrove forest polygons.
	Model Output	Seagrass Blue Carbon	This layer depicts estimated amounts of seagrass blue carbon, summed by individual seagrass bed polygons.

	Base map	World Ocean Reference	This vector tile layer is designed to be used as annotation for features on the World Ocean Base map, this reference layer includes marine water body names, undersea feature names, and derived depth values in meters. Land features include administrative boundaries, cities, and inland water names.
	Base map	GEBCO_2020 Bathymetric Contours (NOAA NCEI Visualization)	This layer provides labeled bathymetric contours derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
	Base map	GEBCO_2020 Grayscale Basemap (NOAA NCEI Visualization)	This layer provides a grayscale basemap derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
	Base map	World Imagery	This layer provides one meter or better satellite and aerial imagery in many parts of the world and lower resolution satellite imagery worldwide.
Coral Reef Recreation and Tourism	Base map	Gazetteer	This layer identifies geographic place names of Seychelles.
	Base map	Archipelago Subregions	This layer is comprised of polygons that identify the general locations of Seychelles' archipelagic areas.
	Base map	Coastline	Polygons representing the coastlines of Seychelles' islands and atolls.
	Base map	EEZ Boundary	This layer depicts Seychelles' Exclusive Economic Zone Boundary.
	Input Data	Selected Dive Sites	This layer depicts frequently used scuba dive sites in Seychelles. Attributes include the commonly used name for each site.

	Input Data	On-Reef Photo User Days	Estimates of tourism activities on coral reefs were derived from locations of underwater photos and the location of dive sites. Microsoft Lobe, a free desktop AI/ML tool was used to classify photos from Flickr and return photos that depicted underwater scenes. Underwater photos were then standardized to Photo User Days ("PUDs") as an indication of the intensity of image-uploads from any location. The PUDs thus generate a score of the number of images, but with a filter to ensure that only one image per user per day can be counted across a 500m resolution grid spread across the region.
	Input Data	On-Reef Photo User Days (100m buffer)	Polygons representing 100m buffer areas surrounding the On-Reef Photo User Days locations.
	Input Data	Dive Sites (100m buffer)	Thi slayer depicts 100m buffer areas surrounding known dive sites.
	Input Data	Dive Shops	This layer identifies the locations of retail dive shops in Seychelles.
	Input Data	Tourism Accomodations	This feature layer depicts the locations of tourism accommodations in Seychelles. These data are provisional and considered draft. Attribute data include the type and size of each establishment (# of beds), addresses, and contact information.
	Input Data	Seychelles MSP Zoning Design Milestone3 (26March2020)	Seychelles MSP Milestone 3 – Gazetted Marine Protection Areas. The Seychelles MSP Milestone 3 areas were gazetted on 26 March 2020 at Statehouse. The completion of the Seychelles marine spatial plan will continue in 2020. See www.seymsp.org for more information.
	Input Data	Protected_Areas_Pre - MSP	This feature layer depicts the designated marine and terrestrial protected areas in Seychelles. This does not include the newly gazetted protected areas that are outcomes of the Seychelles Marine Spatial Plan (i.e. MSP Milestone 3).

	Base map	World Ocean Reference	This vector tile layer is designed to be used as annotation for features on the World Ocean Base map, this reference layer includes marine water body names, undersea feature names, and derived depth values in meters. Land features include administrative boundaries, cities, and inland water names.
	Model Output	On-Reef_Tourism_Intensity	Photo images and dive-sites were both used to generate a weighted map of the intensity of on-reef tourism activities to get a measure of a cultural ecosystem service. To create a weighted map, each point location of # of PUD images or dive intensity was buffered by 1km, and the total reef area within that 1 km radius was calculated for each point. Each point's score (# of PUDs or dive intensity) was then divided by the total area of the buffer to spread the intensity based on the total area of reef tract. A point density analysis was then performed on each of these input layers based on that value and these two layers were summed to provide an intensity score which incorporated overlapping scores where PUDs and/or dive sites were generating overlapping scores. This layer was then clipped to the map of coral reefs such that every 100m tract of reef received a unitless use-intensity score.
	Model Output	On-Reef Tourism Expenditures	The On-Reef Tourism Expenditures model provides mapped estimates of the annual dollar expenditure and contribution of coral reefs to the tourism sector from on-reef tourism activities such as snorkeling and SCUBA. Values were assigned based on reef use intensity determined by proximity to dive sites and underwater photography. Values are expressed in $USD, per hectare, per year.

	Model Output	On-Reef Visitation Value	A series of indicators were developed to give a clear indication of the proportion of persons enjoying on-reef activities or their equivalent spending. These indicators were drawn from visitor exit surveys (National Bureau of Statistics, 2017); the ratio of underwater PUDs to total Flickr photos; and the ratio of dive shops (derived from DiveBoard and supplemented with data from TripAdvisor and Diveary) to the number of hotel rooms (Global Accommodation Reference Database cross-referenced to data provided by Ministry for Habitat, Infrastructure and Land Transport (MHILT)). Using this approach, comparing these indicators to similar indicators from around the world and informed by further academic studies on the relative importance of on-reef activities in certain countries, the team determined that the value of on reef tourism activities on coral reefs, for overall tourism in the Seychelles, was 9% of the annual tourism expenditures and visitor arrivals. The values for coral-reef associated arrivals and expenditures were distributed across the coral reefs weighted by the intensity maps to arrive at the final version of the maps, in which each 100m tract of coral reef has an associated tourism expenditure and visitation value.
	Base map	GEBCO_2020 Bathymetric Contours (NOAA NCEI Visualization)	This layer provides labeled bathymetric contours derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
	Base map	GEBCO_2020 Grayscale Basemap (NOAA NCEI Visualization)	This layer provides a grayscale basemap derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
Other Nature	Base map	Gazetteer	This layer identifies geographic place names of Seychelles.

Dependent Tourism	Base map	Archipelago Subregions	This layer is comprised of polygons that identify the general locations of Seychelles' archipelagic areas.
	Base map	Coastline	Polygons representing the coastlines of Seychelles' islands and atolls.
	Base map	EEZ Boundary	This layer depicts Seychelles' Exclusive Economic Zone Boundary.
	Input Data	eBird Birdwatching Locations	This layer depicts birdwatching locations extracted from the eBird database (ebird.org).
	Input Data	Mangrove Tourism Locations	This layer depicts locations of tourist attractions that are in proximity to mangrove habitats
	Input Data	Mangrove Extent (Klaus2015)	This layer depicts the extent of mangrove habitats, as identified by Klaus, 2015.
	Input Data	Seychelles MSP Zoning Design Milestone3 (26March2020)	Seychelles MSP Milestone 3 – Gazetted Marine Protection Areas. The Seychelles MSP Milestone 3 areas were gazetted on 26 March 2020 at Statehouse. The completion of the Seychelles marine spatial plan will continue in 2020. See www.seymsp.org for more information.
	Input Data	Protected Areas Pre - MSP	This feature layer depicts the designated marine and terrestrial protected areas in Seychelles. This does not include the newly gazetted protected areas that are outcomes of the Seychelles Marine Spatial Plan (i.e. MSP Milestone 3).
	Base map	World Ocean Reference	This vector tile layer is designed to be used as annotation for features on the World Ocean Base map, this reference layer includes marine water body names, undersea feature names, and derived depth values in meters. Land features include administrative boundaries, cities, and inland water names.
	Model Output	Birder Observer Days	This layer depicts an estimate of birdwatching effort, based on data uploaded by users of the internationally popular eBird app. Numbers represent birdwatching intensity, with the score being the sum of "observer-day" uploads per 500m grid cell (ie. capturing only

			one observation per observer per day per cell).
	Model Output	Birding Species Importance	This layer depicts an estimate of the importance of each grid cell unit to birdwatching based on the species importance score of birds seen in this area (based on eBird observation data). The species importance score is a sum of 3 metrics applied to each species (endemism, threat status, and charisma); this score is multipled by the number of observations of this species, and weighted observations for all species are summed within a grid cell.
	Base map	GEBCO_2020 Bathymetric Contours (NOAA NCEI Visualization)	This layer provides labeled bathymetric contours derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
	Base map	GEBCO_2020 Grayscale Basemap (NOAA NCEI Visualization)	This layer provides a grayscale basemap derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
Nature Dependent Beaches	Base map	Gazetteer	This layer identifies geographic place names of Seychelles.
	Base map	Archipelago Locator Boxes	This layer is comprised of polygons that identify the general locations of Seychelles' archipelagic areas.
	Base map	Coastline	Polygons representing the coastlines of Seychelles' islands and atolls.
	Base map	EEZ Boundary	This layer depicts Seychelles' Exclusive Economic Zone Boundary.
	Input Data	Flicker Photo User-Days Locations	Locations of photos provided by Flickr. Estimates of nature dependent tourism activities on beaches were derived from locations of photos depicting scenes with nature-associated characteristics.

	Input Data	TripAdvisor Photos by Attraction by Member Locations	This layer depicts TripAdvisor photo locations related to nature dependent beaches, as logged by unique users.
	Input Data	TripAdvisor Reviews Locations	This layer depicts locations associated with attraction reviews provided by TripAdvisor.
	Model Output	TripAdvisor Photos by Attraction by Member (100m buffer)	This layer depicts 100m buffer areas around TripAdvisor photo locations that were related to nature dependent beaches, as logged by unique users.
	Model Output	Flicker Photo User-Days (100m buffer)	This layer depicts 100m buffer areas around Flickr photo locations that were related to nature dependent beaches, as logged by unique users.
	Model Output	TripAdvisor Reviews (100m buffer)	This layer depicts 100m buffer areas around locations of attraction reviews provided by TripAdvisor.
	Input Data	MSP Zoning Design Milestone3 (26March2020)	Seychelles MSP Milestone 3 – Gazetted Marine Protection Areas. The Seychelles MSP Milestone 3 areas were gazetted on 26 March 2020 at Statehouse. The completion of the Seychelles marine spatial plan will continue in 2020. See www.seymsp.org for more information.
	Input Data	Protected Areas Pre - MSP	This feature layer depicts the designated marine and terrestrial protected areas in Seychelles. This does not include the newly gazetted protected areas that are outcomes of the Seychelles Marine Spatial Plan (i.e. MSP Milestone 3).
	Base map	World Ocean Reference	This vector tile layer is designed to be used as annotation for features on the World Ocean Base map, this reference layer includes marine water body names, undersea feature names, and derived depth values in meters. Land features include administrative boundaries, cities, and inland water names.

	Model Output	Nature Dependent Beach Expenditures	This layer depicts mapped estimates of the annual dollar expenditure of which can be assigned to natural elements of the beach to the tourism sector. Natural importance was assigned based on the numbers and locations of photos with visual signature of natural value (e.g., clear water, white sand, vegetatio and forested hills). Values are expressed in $USD.
	Model Output	Nature Dependent Beach Visitation Value	This layer depicts mapped estimates of the annual visitor numbers who are present due to the natural values of the beach. Natural importance was assigned based on the numbers and locations of photos with visual signatures of natural value (e.g., clear water, white sand, vegetation, and forested hills. Values are expressed in visitor numbers/ha, representing the additionality of tourists who are present in the country because of these natural values.
	Model Output	Nature Dependent Beaches Tourism Intensity	Photo images were used to generate a weighted map of the intensity of nature dependent beach tourism activities to get a measure of a cultural ecosystem service. Every 100m tract of beach (grid cell) received a unitless use-intensity score.
	Base map	GEBCO_2020 Bathymetric Contours (NOAA NCEI Visualization)	This layer provides labeled bathymetric contours derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
	Base map	GEBCO_2020 Grayscale Basemap (NOAA NCEI Visualization)	This layer provides a grayscale basemap derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
Coastal Protection	Base map	Gazetteer	This layer identifies geographic place names of Seychelles.
	Base map	Archipelago Subregions	This layer is comprised of polygons that identify the general locations of Seychelles' archipelagic areas.

	Base map	Coastline	Polygons representing the coastlines of Seychelles' islands and atolls.
	Base map	EEZ Boundary	This layer depicts Seychelles' Exclusive Economic Zone Boundary.
	Model Output	Coastal Protection - Exposure Index	This layer depicts the coastal exposure index, created by combining the ranks of six biological and physical variables at each shoreline point. Ranks vary from very low exposure (rank=1) to very high exposure (rank=5), based on a mixture of user- and model-defined criteria. This ranking system is based on methods developed by DiPaola et al. (2011).
	Model Output	Coastal Protection - Exposure x People	This layer depicts the index of shoreline exposure multiplied by the coastal population at <30m elevation, values assigned to each shore point.
	Model Output	Coastal Protection - Habitat Role index	This layer depicts the relative protective value of reefs at each shore point, estimated as the difference between the weighted average rank of exposure variables with (Exposure_Index) and without (Exposure_NoHab) consideration of the reef habitat rank.
	Model Output	Coastal Protection - Habitat Role_x_People	This layer depicts a weighted index of the relative protective function of reefs (HabRole) multiplied by the coastal population at <30m elevation.
	Input Data	Coastal Protection - Average width of reef crests & flats (m)	This layer depicts the average cross-reef distance of reef crests and reef flats based on the geomorphological characterization in Allen Coral Atlas.
	Input Data	Coral Reef (UNEP WCMC 2010 from Klaus 2015)	This layer depicts coral reef extent (as identified by Klaus, 2015).
	Input Data	Coral Reef Mahe (MACCE)	This layer depicts coral reef extent (as identified by MACCE, 2015).
	Input Data	Seychelles Allen Coral Atlas Geomorphology (polygons)	This layer depicts the Allen Coral Atlas Geomorphology Classification (2021)

	Input Data	Seychelles MSP Zoning Design Milestone3 (26March2020)	Seychelles MSP Milestone 3 – Gazetted Marine Protection Areas. The Seychelles MSP Milestone 3 areas were gazetted on 26 March 2020 at Statehouse. The completion of the Seychelles marine spatial plan will continue in 2020. See www.seymsp.org for more information.
	Input Data	Seychelles Protected Areas Pre-MSP	This feature layer depicts the designated marine and terrestrial protected areas in Seychelles. This does not include the newly gazetted protected areas that are outcomes of the Seychelles Marine Spatial Plan (i.e. MSP Milestone 3).
	Base map	World Ocean Reference	This vector tile layer is designed to be used as annotation for features on the World Ocean Base map, this reference layer includes marine water body names, undersea feature names, and derived depth values in meters. Land features include administrative boundaries, cities, and inland water names.
	Input Data	Seychelles Allen Coral Atlas Benthic Coral Class	This layer depicts the Allen Coral Atlas Benthic Coral Classification (2021).
	Base map	GEBCO_2020 Bathymetric Contours (NOAA NCEI Visualization)	This layer provides labeled bathymetric contours derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.
	Base map	GEBCO_2020 Grayscale Basemap (NOAA NCEI Visualization)	This layer provides a grayscale basemap derived from the General Bathymetric Chart of the Oceans (GEBCO) GEBCO_2020 global land and seafloor elevation dataset.