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DEVELOPING AN ECOLOGICAL NETWORK AMONG THE SPAW-LISTED MPAs OF THE WIDER CARIBBEAN

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An Evaluation of Connectivity Between the SPAW-Listed Protected Areas to Guide the Development of a Functional Ecological Network of Protected Areas in the Wider Caribbean

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SUMMARY

Marine protected areas (MPA) are important tools used in marine conservation and ecosystem protection strategies at special places throughout the Caribbean. In addition to the role of MPAs in protecting and restoring declining marine communities and their habitats, ecological connections can extend the strategic importance of MPAs beyond their geographic borders. The linking of protected areas through their ecological connections and management strategies can create a functional network of conservation actions and allow the protected areas to work in unison to accomplish more than they would if they were ecologically and socially isolated from one another.

Each protected area that is listed under the Special Protected Areas and Wildlife Protocol (SPAW) of the Cartagena Convention in the Wider Caribbean focuses its resources on conserving local habitats and biological populations. However, a few species, through their migratory behavior or the distribution of their offspring, can take the benefits of these local conservation efforts to all parts of the Caribbean. In this way, an individual site in the SPAW network has a potential biological connection and ecological value to other protected areas in the region. This provides an incentive to better understand what connects different parts of the Caribbean ecosystem and for the SPAW sites to cooperate in strengthening those connections to improve how each SPAW site and their network relationships function.

Ecological connectivity in marine environments is the extent to which populations in different parts of a species' range are linked by the exchange of eggs, larvae recruits or other reproductive products, juveniles and adults. An analysis of some key ecological factors that interconnect the Caribbean's marine environment has been done here. An inventory of the physical and biological characteristics was compiled for the SPAW sites to include key species and an account of the primary habitats for those species. With this information as a guide, an analysis of connectivity between protected areas using published data on sea turtle migrations and the dispersal of coral and fish larvae from spawning events was done. This integration of biogeographic information and ecosystem processes was assessed for how it supports forming an alliance between the SPAW and other protected area sites based on ecological connectivity. The links between protected areas and their habitats created by marine species and the complex ecological processes of reproduction, transport and recruitment of their larvae show how a

network of protected areas has the potential to provide important ecological and conservation benefits for many components of the Wider Caribbean ecosystem.

In addition to supporting ecosystem integrity, physical and biological connectivity also brings threats to that integrity. Water-borne pathogens, the spread of invasive species and pollution have had dramatic impacts on marine communities in recent decades. The wide distribution of these impacts shows how collaborations between protected areas are important in rapidly identifying and facilitating effective responses to them. An ecological network of the SPAW protected areas is not only a network of ecosystem protections, but also a network of ecosystem sentinels that can report and coordinate responses to existing and new threats as they emerge.

Species, habitats and ecological connections can be used as a foundation on which to build management relationships between marine and terrestrial protected areas in the Caribbean. The following recommendations are a framework for establishing these relationships.

1. Establish Sub-regional Networks

The evaluation of ecological linkages shows that all parts of the Caribbean are connected, but the linkages are strongest at the sub-regional scale. Building network relationships between protected areas may be most efficient and provide the most relevance to country jurisdictions if they are initially focused at the sub-regional scale.

2. Fill Gaps in Species Inventories and Prepare an Interactive Habitat Atlas

The foundation on which to start building protected area network relationships is knowledge of the species and habitats found at each site in the network. Protected area sites should be engaged and assisted to fill gaps in their species and habitat data to allow a more complete inventory of the biological components and characteristics of each site and the network. These data should be combined with an online atlas of the sites to create an interactive database of comparable information about each site.

3. Invest in the Science of Ecosystem Connectivity and Marine Protected Areas

Protected area managers, and their policymakers, need efficient access to scientists and the data they produce to ensure research is designed to address management needs, management actions are based on sound science and managers are prepared to respond to climate change and other threats as they emerge. Developing a network of local, regional and global scientists to advise and respond to the needs of protected areas in the Caribbean should be part of the goals in creating a network of protected areas. The science of population dynamics, connectivity, and protected area performance in a changing climate should be made easily accessible to protected area managers. Investing in this science would build stronger ties between scientists and protected areas in the region, and help to cultivate and promote a new generation of Caribbean marine scientists and protected area managers.

4. Develop a Network Condition Evaluation

Most protected areas have some way of assessing the state of their protected resources and environment, and a review process for evaluating the effectiveness of the protected area's management. However, a method of comparing the status and trends in ecosystem condition across the network of sites should be developed in close consultation with the protected area managers. This reporting method would provide a tool for measuring the condition of natural resources and the strengths and weaknesses of management throughout the network. This network reporting system should not compete with or replace local monitoring or reporting procedures. It should expand the results of local reporting and apply them to an evaluation of the larger network.

5. Build Effective Communication and Outreach Mechanisms
The success of a protected area network requires an effective and lasting communication mechanism. Facilitating this communication is a critical to ensuring the network of sites is seen as relevant to managers and their stakeholders. It is also important for protected area managers to know that their local community values the purpose of their work. Community outreach should be used to inspire participatory engagement in protecting natural resources and to reflect local knowledge, cultural connections and livelihoods in how protected areas are established, managed and incorporated into networks.

Rather than a final analysis of ecological connectivity and design of a protected area networking strategy, the results and recommendations presented here should be starting points for building wider understanding and engagement for the SPAW-listed and other protected areas to work collaboratively to improve the shared ecosystem of the Wider Caribbean. UNEP, the SPAW protected areas and their partners should use the information presented to advance their conservation goals for the Caribbean and for its ecological connections throughout the Atlantic region.

Section 1: INTRODUCTION

An Interconnected Caribbean Ecosystem

The ecosystem of the Caribbean has evolved over millions of years through geological and biological processes that have shaped the islands and marine environments of the region. These processes have constructed diverse and complex habitats that generate the Caribbean's spectacular marine and terrestrial biodiversity. Preserving this rich biodiversity is essential to the future quality of the biological resources and the economies of the region. However, widespread threats to the integrity of Caribbean ecosystem are increasing in number and intensity. As a consequence, protecting biologically and physically diverse places in the Caribbean is an investment that preserves the functioning and resiliency of the ecosystem and the societies that depend on it.

The nations and territories of Wider Caribbean region have established protected areas and management strategies to sustain the resources and environments that intimately link their societies and economies to the ocean. However the Wider Caribbean ecosystem is not bound by political and institutional boundaries. Ocean currents, and the trans-boundary movement and reproduction of marine species, physically and ecologically connect the different places and nations of the Wider Caribbean.

As a result, the success of ocean protection measures anywhere in Caribbean is fundamentally linked to the condition of marine areas in other parts of the region. Species or their prodigy, and the factors that threaten their populations, move freely across the complex mosaic of territorial EEZs and national borders in the Caribbean. It is therefore essential that resource and protected area managers look beyond their jurisdictions to cooperate with the other nations of the region to improve the health of their shared ocean environment.

A Framework for Cooperation through a Network of Marine Protected Areas

The Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region, known as Cartagena Convention, is a regional legal agreement for the protection of the Caribbean Sea. Adopted in Cartagena, Colombia on 24 March 1983 and entered into force on 11 October 1986, the

Convention is supported by three technical agreements or "Protocols" on Land Based Sources of Marine Pollution, Oil Spills and Specially Protected Areas and Wildlife (SPAW.

Article 4 of the SPAW Protocol calls for establishment of protected areas as a mechanism for sustaining the natural resources of the Wider Caribbean Region. The Article provides for ecologically sound and appropriate use to conserve, maintain, and restore representative types of coastal and marine ecosystems and habitats and associated ecosystems critical to the survival and recovery of endangered, threatened, or endemic species of flora and fauna.

The SPAW Protocol is also designed to assists its Parties in develop cooperative programs to establish and manage protected areas and create "a protected area network" in the Wider Caribbean (Article 7(2)). To facilitate this, the European Commission – in partnership with the European Union, the Organization of African, Caribbean and Pacific States, and the Food and Agriculture Organization of the United Nations – has provided funds to the UN Environment Program Cartagena Convention Secretariat to promote cooperation between the SPAW-listed protected areas and create a "functional network of marine protected areas" in the Caribbean.

Developing regionally representative networks of marine protected areas is a priority in the Multilateral Environmental Agreements in African, Caribbean, and Pacific Countries Phase III project (ACP MEA III) and UNEP's Cartagena Convention Secretariat is working to develop a plan for the creation of a functioning MPA network in the Caribbean that will strengthen the interconnections of their habitats, species and conservation outcomes. Activities in this effort are to include:

- Developing scientifically sound guidelines for the analysis of connectivity and representativeness of marine protected areas;
- Identification of possible candidate areas for protection for regional networks;
- Activities to support management capacity of the marine protected areas and other area-based management measures.

As an initial step in creating this network, the Secretariat has undertaken a review of the ecological components that connect SPAW MPAs, as well as the existing cooperative efforts among a wider set of MPAs that are part of the Caribbean Marine Protected Area Management Network and Forum (CaMPAM). The analysis presented here is an overview of the ecological factors that interconnect the Caribbean's marine environment as a basis for building cooperation between SPAW and other MPAs of the region to enhance their roles in protecting ecosystem functions and populations of key species.

MPA Networks and Connectivity

Over the last two decades, linking marine protected areas into networks has become a goal in local and regional management efforts to conserve biodiversity, ecosystem functions and ecological services in marine environments (Grorud-Colvert et al 2014, Lagabrielle et al 2014, Knowles et al 2015). Networks of MPAs are envisioned to have ecological, economic and social benefits that are greater than the sum of those benefits coming from individual protected sites. They are also seen as more practical and acceptable than establishing single MPAs that incorporate large areas of the seascape. However, networks can be built on different kinds of relationships to achieve different goals. A clear understanding

of the goals for establishing a network of MPAs in the Caribbean will be fundamental to how it functions and to its success.

An MPA network can be defined as a collection of individual MPAs or reserves operating cooperatively and synergistically, at various spatial scales, and with a range of protection levels that are designed to meet objectives that a single reserve cannot achieve (IUCN-WCPA 2008). Grorud-Colvert et al (2014) define different types of networks based on their management needs and goals. These include:

- **Ad-hoc or Regional Networks:** a grouping of MPAs that are in proximity to each other but were not planned as a synergistic network.
- **Conservation Networks:** designed to have strict conservation goals in order to conserve the representative ecological characteristics of an area or ecosystem by protecting replicated sites that encompass habitats or species of interest.
- **Management Networks:** which manage and facilitate the economic uses of marine resources at a broader scale than a single-MPA approach would have afforded.
- **Social Networks:** based on human interactions across groups of people including MPA managers, stakeholders, decision-makers, and scientists who transfer knowledge, share best practices, and build capacity.
- **Connectivity Networks:** multiple marine reserves and other MPAs that are connected by the dispersal of larvae and/or movement of juveniles and adults with the general goal to maximize conservation and/or fisheries benefits from no-take areas.

A network of MPAs listed under the SPAW Protocol has characteristics in common with all the network types listed above. In addition, the SPAW sites all meet standards for ecosystem protection and management that are set by the listing process. These standards and the ecological processes that link their species, habitats and management challenges provide a basis on which to create a functional network of MPAs in the Caribbean.

As the concept of creating MPA networks has advanced, several basic principles for a functional and effective network design have been presented (IUCN-WCPA 2008, Brock et al 2012, Green et al 2013). These principles include *representation* (covering the full range of biodiversity, rare and threatened species), *replication* (protecting more than one example of a given feature), *connectivity* (ensuring linkages between sites through currents, migratory species and larval dispersal), and *adequacy* (having the appropriate size, spacing and shape).

The 35 sites presently listed under the SPAW Protocol form a network that to some degree incorporates these principles of representation, replication, connectivity and adequacy. The principle of connectivity is of primary consideration in the analyses that follows. A network based on ecological connectivity has the potential to expand the impact of each MPA to living marine resources beyond its borders, and elevate the importance of local management strategies for conserving the regional marine ecosystem.

Ecological connectivity in marine environments is the extent to which populations in different parts of a species' range are linked by the exchange of eggs, larvae recruits or other reproductive products, juveniles and adults (IUCN-WCPA 2008, Sale et al 2010). It is particularly important for designing MPA networks because it plays a fundamental role in the distribution, diversity, dynamics and resilience of species, populations and communities of marine life (Sale et al 2005, Cowen et al 2007, Olds et al 2016). A successful MPA network must therefore be managed to identify, maintain, and enhance connectivity among key species and sites within the network (Cannizzo et al 2020, Hilty et al 2020).

Sale et al (2010) summarized two ways in which connectivity can influence populations of species based on the rate of exchange of individuals and their genes between populations:

1) Evolutionary connectivity: the amount of gene flow occurring among populations over a timescale of several generations. It determines the extent of genetic differences among populations.

2) Demographic connectivity: an exchange of individuals among local populations that can influence population demographics and dynamics.

Connectivity can include:

- Exchange of offspring between populations through larval dispersal;
- Recruitment of juveniles and survival of these juveniles to reproductive age;
- Any large-scale movement of juveniles and adults between locations.

The evaluation of connectivity between the SPAW and other MPAs presented in the following sections is an analysis of how physical and ecological processes interconnect different parts of the Caribbean. In doing so, aspects of representation, replication and adequacy of the SPAW protected areas are inherently shown. With concepts of marine protected area networks and connectivity as a basis, examples of larval dispersal and migrations of turtles are used to put these concepts into practice for integrating the SPAW and other MPAs into a network or networks of Caribbean protected areas.

Before starting the analysis, a good understanding of the physical and biological characteristics and their setting of the protected areas is needed. To gain this, a basic atlas of the SPAW sites, an inventory of key species, and an account of the primary habitats for these species have been prepared. With this understanding, the analysis of connectivity between protected areas is possible within the biogeographic context of where the protected areas are and what they contain. The ultimate goal is to identify how this information can support forming an alliance between the SPAW sites that is based on ecological connectivity and to better understand the relevance of each site in sustaining the health and resiliency of the marine ecosystem of the Wider Caribbean.

Section 2: AN ATLAS OF SPAW-LISTED PROTECTED AREAS

A starting point for understanding the ecological relationships between the SPAW-listed protected areas is having good knowledge of the characteristics and setting of the sites, including the coastal and marine environments they include. The following atlas of the sites was prepared from satellite-based imagery contained in the Allen Coral Atlas (https://allencoralatlas.org) and the protected area boundaries presented in SPAW listing documents and the World Database on Protected Areas (https://www.protectedplanet.net/en). The atlas maps were prepared using graphic software, rather than from GIS files. They are therefore visual representations of the protected area boundaries and conditions, rather than usable for navigational or legal purposes. The maps are meant to provide a needed reference tool for understanding what is in the SPAW sites and for evaluating their ecological connections between marine, coastal and terrestrial environments of the Caribbean.

SPAW Atlas Contents:

1. Caribbean overview map and reference list of SPAW-listed sites
2. SPAW sites of Belize
3. SPAW sites of Cuba & Florida

4. Columbian islands and reef sites of the Seaflower Marine Protected Area
5. SPAW sites of the Columbian mainland.
6. SPAW sites of the Dominican Republic
7. SPAW sites of the Northern Antilles
8. Agoa Marine Mammal Sanctuary
9. SPAW sites of French Guiana
10. SPAW sites of the Southern Antilles
11. Flower Garden Banks National Marine Sanctuary

Section 3: HABITATS REPRESENTED BY SPAW PROTECTED AREAS

The following table is an evaluation of how representative the SPAW protected areas are of the primary habitats utilized by the protected species listed in Annexes I, II, and III of the SPAW Protocol. These habitats are based on the general description of the sites presented in the SPAW listing documents (http://palisting.car-spaw-rac.org) and from the imagery used to prepare the atlas.

The coastal and marine habitats of the Caribbean are highly complex and vary substantially locally and between different sites. The following somewhat arbitrary categorization of primary habitats is not meant to be comprehensive, but to help understand and compare the geographies of the SPAW sites. Combined with the analysis of SPAW protected and regulated species occurring in SPAW protected areas (Section 4), this comparison assesses to what extent the SPAW sites collectively represent the primary habitats of the Wider Caribbean ecosystem.

The habitat categories are:

- **Coral Reef**: Coral reef habitats can be subdivided into various zones based on depth (ie forereef, reef crest, backreef, lagoon etc). The coral reef habitat listed here includes those coral dominated communities and their associated highly diverse benthic habitats. These may also include deep-water mesophotic communities.

- **Seagrass**: Dense growths of seagrass, which are a diverse group of marine plants (angiosperms) with extensive root systems that anchor them into seafloor sediments. Beds of seagrass are often physically and ecologically closely associated with coral reefs.

- **Mangrove**: Mangrove species and other vegetation growing in saltwater estuaries, lagoons and coastal mudflats make up mangrove forests. Ecologically linked to other marine habitats, these tidal-influenced forests are inhabited by and support diverse populations of terrestrial, aquatic and marine organisms.

- **Estuary**: Areas where fresh and salt water converge in coastal environments. They are usually partially isolated from the ocean, and salinity can vary depending on the amount and proximity of freshwater input from land. Can include mangrove forests.

- **Rocky Intertidal**: While some type of rocky intertidal habitat occurs at most of the sites, identified here are sites where a significant portion of the coast is dominated by rocks and/or boulders. The physical geography, geological origin and age of island and continental shorelines will determine the extent of these rocky intertidal environments.

- **Beach**: Dynamic deposits of unconsolidated sediment moved by intertidal wave action. They can be important sites for nesting by turtles, and for recreation by people.

- **Forest**: Varying types of dense littoral (other than mangroves) and upland vegetation sustained by different soil types and amounts of rainfall.

Oceanic habitats (more than 200 m depth) are not included here, but make up the major proportion of the Wider Caribbean. Many of the SPAW sites include some oceanic habitat within their boundaries, but Seaflower and Agoa MPAs encompass particularly large oceanic areas.

PRIMARY HABITATS IN SPAW PROTECTED SITES	Coral Reefs	Seagrass	Mangrove	Estuary	Rocky Intertidal	Beach	Forest
Belize							
1 - Hol Chan Marine Reserve	■	■	■			■	
2 - Glover's Reef Marine Reserve	■	■	■			■	
3 - Port Honduras Marine Reserve	■	■	■	■		■	■
Cuba							
4 - Parque Nacional Guanahacabibes	■	■	■		■	■	■
5 - Parque Nacional Cayos de San Felipe	■	■	■			■	■
Colombia							
6 - Seaflower Marine Protected Area	■	■	■	■		■	
7 - Natural Park of Wetlands between the rivers León and Suriquí			■	■			■
8 - Sanctuary Cienaga Grande de Santa Marta			■	■			■
Dominican Republic							
9 - La Caleta Submarine Park	■	■			■		
10 - National Park Jaragua	■	■			■	■	■
11 - National Park Haitises			■	■			■
12 - National Park Sierra de Bahoruco							■
French West Indies							
13 - Réserve naturelle nationale de l'Amana Guyane			■	■		■	■
14 - Ile du Grand Connétable Guyane					■		
15 - Réserve naturelle nationale de Kaw-Roura Guyane			■	■			■
16 - Étangs des Salines Martinique				■		■	
17 - Versants Nord de la Montagne Pelée							■
18 - Parc National de la Guadeloupe	■	■	■	■	■	■	■
19 - Réserve Naturelle de Petite Terre	■	■	■		■	■	■
20 - Sanctuaire Agoa (ZEE Guadeloupe et Martinique)	■	■					
21 - Étangs Lagunaires de Saint-Martin			■	■			■
22 - Réserve Naturelle Nationale de Saint-Martin	■	■	■		■	■	■
Grenada							
23 - Molinière-Beauséjour Reserve	■	■	■		■	■	■
Dutch Caribbean							
24 - Bonaire National Marine Park	■	■	■			■	■
25 - The Quill and Boven National Park St. Eustatius							■
26 - St Eustatius National Marine Park	■	■	■		■	■	
27 - Saba Bank National Park	■	■					
28 - Saba National Marine Park	■	■			■		
29 - Mt. Scenery National Park Saba							■
30 - Man O War Shoal Marine Park	■	■					
Saint Vincent and the Grenadines							
31 - Tobago Cays Marine Park	■	■	■			■	■
United States of America							
32 - Dry Tortugas National Park	■	■	■			■	
33 - Florida Keys National Marine Sanctuary	■	■	■			■	
34 - Everglades National Park		■	■	■	■	■	■
35 - Flower Garden Banks National Marine Sanctuary	■						
NUMBER OF SPAW SITES CONTAINING HABITAT	22	22	22	11	11	19	21

This table shows the importance of coral reef, seagrass and mangrove habitats among the SPAW sites. These habitats are ecologically closely linked where they occur within the same protected area. For example, fish move between coral reef, seagrass and mangrove habitats to forage, for shelter and at different stages of their lifecycles. Beach and forest habitats are also important at the majority of the sites and are linked respectively by the reproduction and migrations of turtles and birds throughout the

Caribbean. Color shading indicates the setting of the sites: Green – coastal wetland, Blue – entirely marine, Brown – entirely terrestrial.

These data are a relatively simple characterization of the seascape of the protected areas that integrates the physical features and living communities of an area. This comparison of habitats is an initial foundation on which to start building relationships between different protected areas to address common management strategies for their shared habitats. It helps to bring attention to the species that utilize the habitats and the need to protect the biological connections between habitats across a protected seascape and between protected areas.

Section 4: SPECIES REPRESENTED AT SPAW PROTECTED AREAS

In order to evaluate how representative the SPAW protected areas are of the species identified in Annexes I, II and III of the SPAW Protocol, the reported presence of the species in the listing documents for each SPAW site was compiled into the following table. This compilation is an objective documentation of what was reported in the documents. No attempt has been made to fill what may be gaps in reporting.

It is obvious that detailed reporting has not always occurred for some of the species. For instance, 62% of the sites report having coral reef habitats, but approximately only 30 – 40% of sites report specific coral species or families that are in the SPAW Annexes. This is not to discount the intuitive understanding that several if not all coral species exist where coral reefs are reported as important habitats at a site. For instance Florida Keys National Marine Sanctuary (#33) does not report specific corals as present. Reporting gaps may also exist for the other listed species, such as certain birds and marine mammals. These groups of species are not always likely to be subject to accurate identification or dedicated field surveys during periods of infrequent or rare sightings within a protected area. Additions to the SPAW Annexes since sites were listed may also account for some of the gaps.

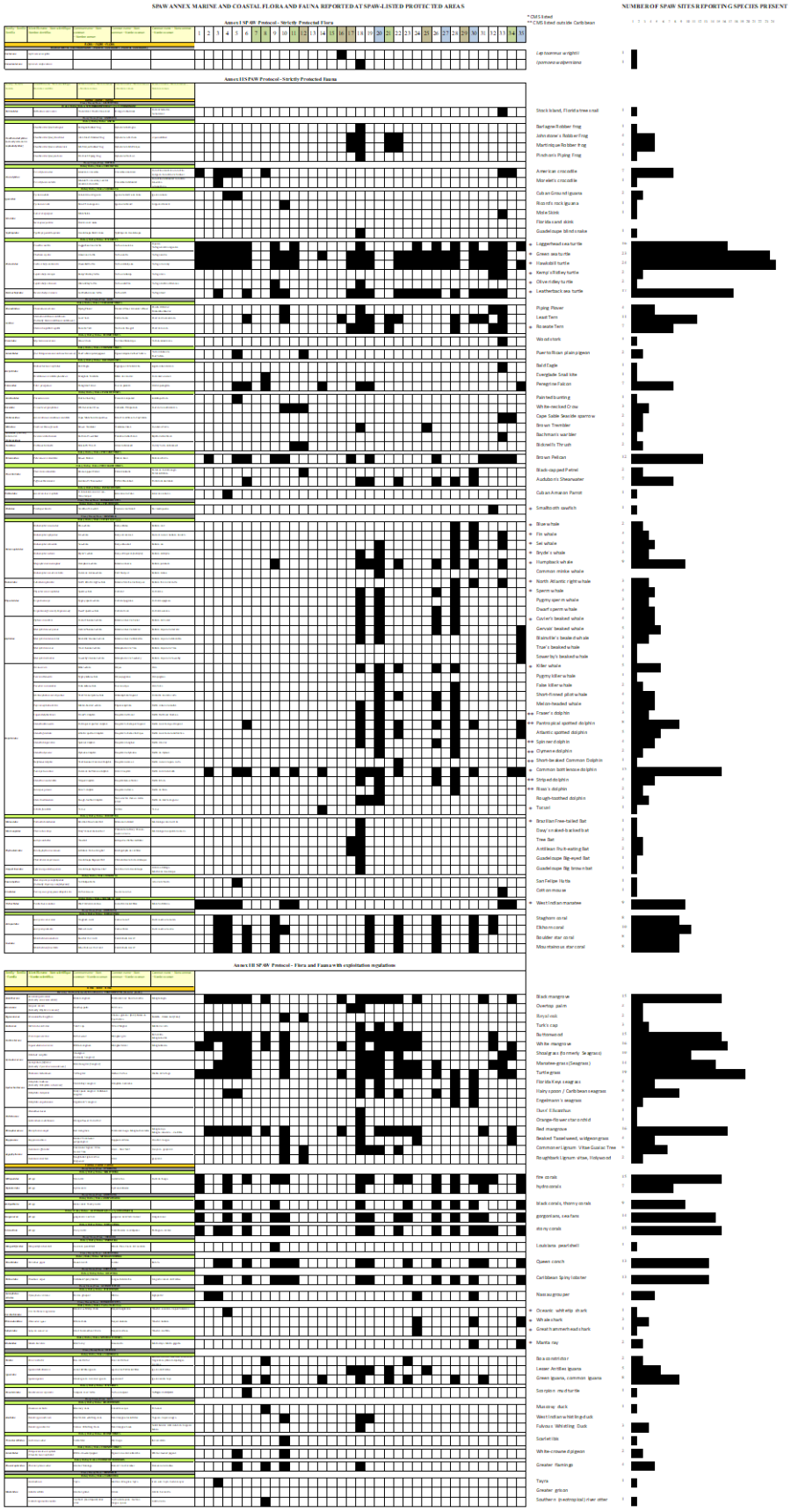
It should be noted that the SPAW listing guidelines ask which of the IUCN Red Listed species are present at a site. The listing documents for some of the sites include these IUCN species that aren't specifically listed in the SPAW annexes. However, this documentation of the distributions of the species of marine and terrestrial wildlife listed in the SPAW Annexes (133 of the 300+ species in the annexes) provides a useful assessment of the key groups of species that are most common among the protected sites.

See separate pdf of the table for clarity.

Key to the sites in the table (same as table in Section 3):

1 - Hol Chan Marine Reserve
2 - Glover's Reef Marine Reserve
3 - Port Honduras Marine Reserve
4 - Parque Nacional Guanahacabibes
5 - Parque Nacional Cayos de San Felipe
6 - Seaflower Marine Protected Area
7 - Natural Park of Wetlands between the rivers León and Suriquí
8 - Sanctuary Cienaga Grande de Santa Marta
9 - La Caleta Submarine Park
10 - National Park Jaragua
11 - National Park Haitises
12 - National Park Sierra de Bahoruco
13 - Réserve naturelle nationale de l'Amana Guyane

14 - Ile du Grand Connétable Guyane
15 - Réserve naturelle nationale de Kaw-Roura Guyane
16 - Étangs des Salines Martinique
17 - Versants Nord de la Montagne Pelée
18 - Parc National de la Guadeloupe
19 - Réserve Naturelle de Petite Terre
20 - Sanctuaire Agoa (ZEE Guadeloupe et Martinique)
21 - Étangs Lagunaires de Saint-Martin
22 - Réserve Naturelle Nationale de Saint-Martin
23 - Molinière-Beauséjour Reserve
24 - Bonaire National Marine Park
25 - The Quill and Boven National Park St. Eustatius
26 - St Eustatius National Marine Park
27 - Saba Bank National Park
28 - Saba National Marine Park
29 - Mt. Scenery National Park Saba
30 - Man O War Shoal Marine Park
31 - Tobago Cays Marine Park
32 - Dry Tortugas National Park
33 - Florida Keys National Marine Sanctuary
34 - Everglades National Park
35 - Flower Garden Banks National Marine Sanctuary



The bar chart to the right of the matrix compares the relative number of species reported among all the SPAW sites. An arbitrary line of 7 sites reporting a species highlights those species that are most prevalent across the sites. These include sea turtles, some marine mammals, corals, the queen conch

Stombus gigas, the Caribbean spiny lobster *Panulirus argus*, sea grasses, mangroves, and a number of birds and reptiles. These species represent direct ecological linkages between the SPAW protected areas and are prime candidates for establishing common management strategies among the sites.

In addition to showing SPAW Protocol annex species, species that are also listed under the Convention on the Conservation of Migratory Species of Wild Animals (CMS) are indicated (*), some of which are listed by CMS but only for certain subpopulations outside the Caribbean (**). Showing those species that are listed by CMS and are also reported at SPAW sites emphasizes the potential for these migratory species to directly connect the protected areas through their reproductive migrations and foraging behaviors throughout the wide ranges where they are found in the Caribbean and Atlantic. This is in spite of not all sites reporting their presence.

As more data and reporting that further refines the distribution of all the species in this table, as well as unreported species listed in the SPAW annexes that are not shown, the functional strength of the ecological connections between protected areas through these species will become better known. These distributions will be important in forming cooperative conservation plans among the SPAW sites.

Section 5: CONNECTIVITY OF SPAW-LISTED PROTECTED AREAS THROUGH SEA TURTLE NESTING AND CONSERVATION

Sea Turtles are highly migratory during all their life-history stages. They rely on marine and coastal habitats within the EEZs of all nations and territories of the Wider Caribbean and these habitats are critical for turtle dispersal, foraging, refuge, mating, migration and nesting (Eckert and Eckert 2019). As a result, populations of turtles in any part of the Caribbean are influenced by threats imposed on turtles and their habitats hundreds or even thousands of kilometers away. Cooperative species protection and habitat management strategies between nations are therefore essential to ensure local sea turtle conservation policies are effective. Because of their distant migratory movements, numerous threats to their survival, and the widely held desire by the people of the Caribbean to protect sea turtles, turtle species are icons for the interconnected nature of the Caribbean ecosystem, for the threats to its integrity, and for management efforts in marine protected areas throughout the region.

The majority of the nations and territories of the Wider Caribbean protect sea turtles from exploitation. All six of the sea turtle species found in the Caribbean are on the IUCN Red List of Threatened Species and protected by the international conservation accords such as the SPAW Protocol, the Convention on Migratory Species (CMS), and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Although some Caribbean nations allow the harvest of turtles for what is considered “traditional or subsistence use” and illegal harvest is often reported in the region, national and international regulations, as well as important changes in attitudes regarding conservation of turtles, have allowed sea turtle populations to gradually recover from historic declines caused by the exploitation of turtle eggs, juveniles and adults. Many threats to turtle populations still exist however, including fisheries bycatch, fishing gear entanglement, degradation of foraging habitats, coastal development, water quality declines and climate change.

Sea turtles migrate between areas where they breed, nest and forage. Effective protection strategies for turtles in the Caribbean must therefore be a cooperative and coordinated effort across the many jurisdictional borders of the region. The hubs of the migratory pathways and for critical protections of turtles are the nesting beaches, which are central in the lifecycles of female and juvenile turtles. Figure 5.1 is reproduced from Eckert et al 2020. It shows the distribution of turtle nesting by species location and abundance of nesting crawls across the Caribbean. These distinctive nesting hubs are connected to other parts of the region through the migrations of the turtles from these sites to and through their

foraging ranges. Figure 5.2 shows these ranges derived from tracking data and the management units presented in Eckert et al (2020). These management units were developed by Wallace et al (2010) to coordinate the biogeographic application of conservation strategies for turtle species beyond their nesting sites.

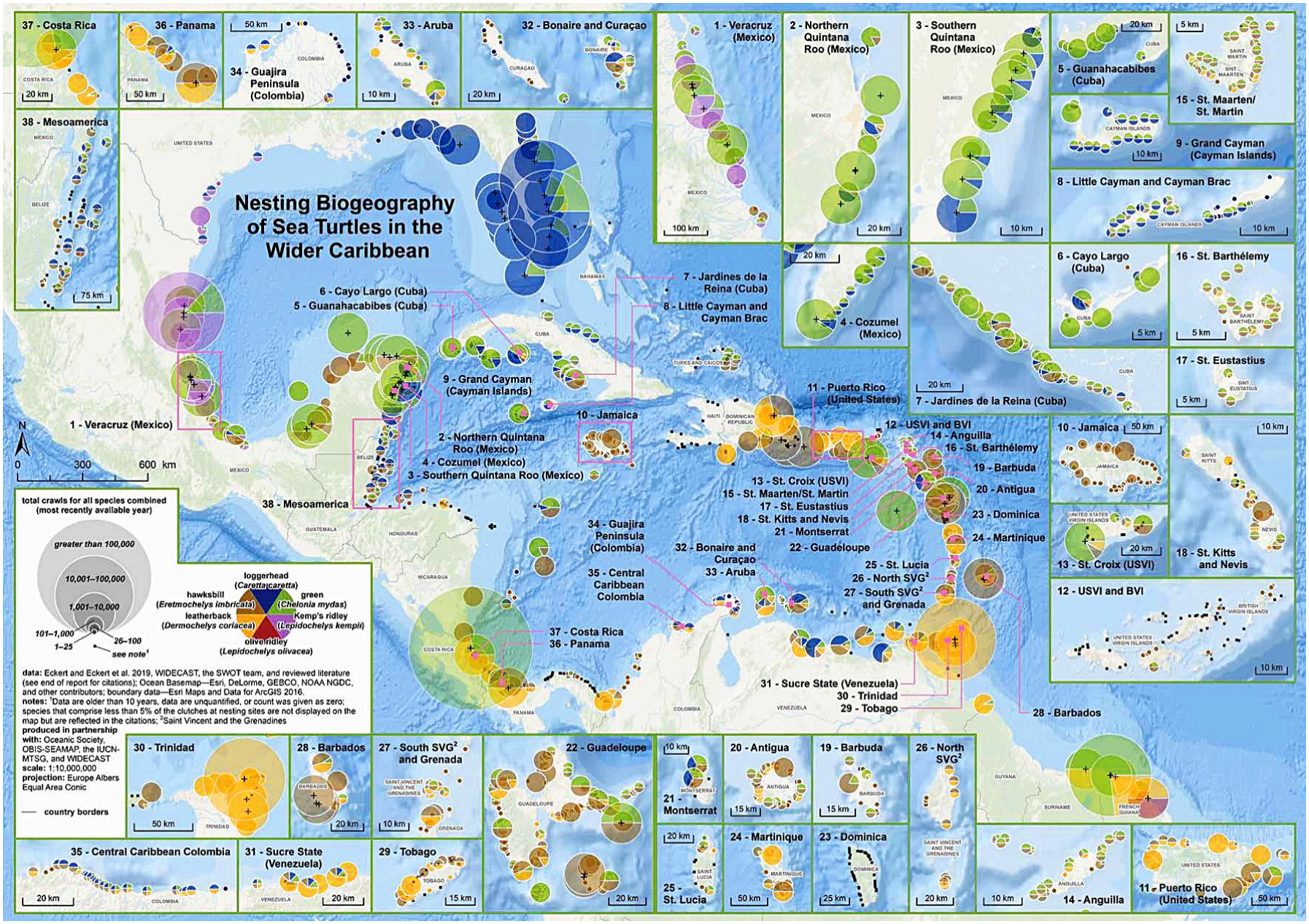


Figure 5.1. Turtle nesting sites in the Caribbean showing relative abundance of crawls by turtle species. Reproduced from Eckert et al (2020) Sea Turtles of the Caribbean in the State of the World's Sea Turtles 2020 Report https://www.seaturtlestatus.org/swot-report-vol-15.

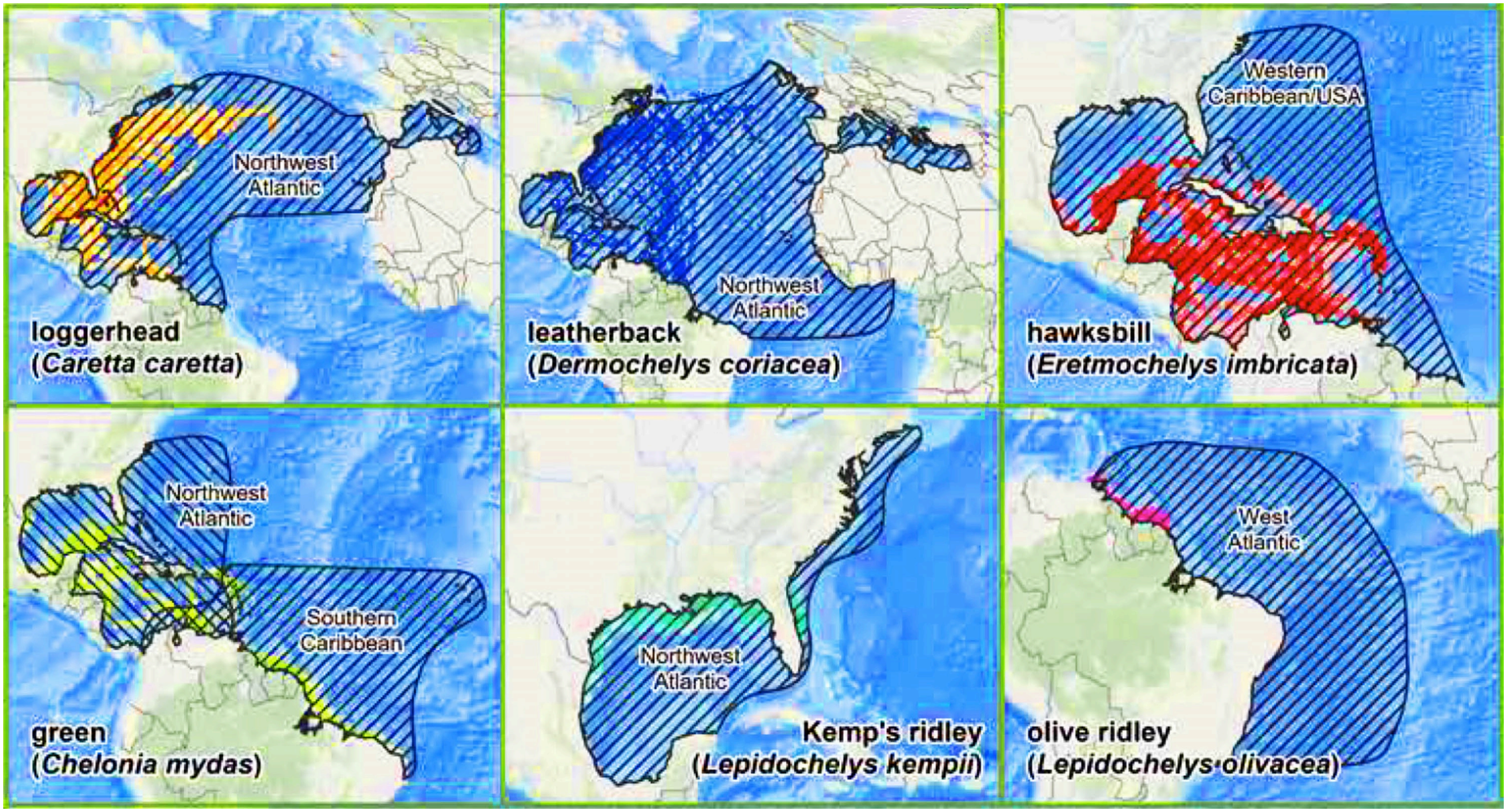
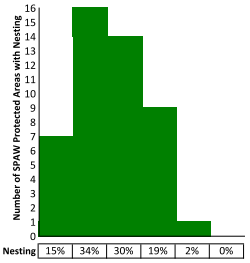


Figure 5.2. Regional Management Units (cross-hatched areas) for sea turtle species in the Atlantic developed by Wallace et al 2010 based on telemetry, genetics, tagging and nesting data. Migration corridors and foraging areas based on satellite telemetry data are shown by different colors for each species. This figure is a compilation of maps that are in Eckert et al (2020).

Figure 5.3 below evaluates the role that SPAW sites play in protecting turtle nesting sites, and through these protections, how the sites help to sustain turtle populations over their foraging ranges.

SEA TURTLES NESTING IN SPAW-LISTED PROTECTED AREAS	Loggerhead	Green	Hawksbill	Leatherback	Olive Ridley	Kemp's Ridley
Belize						
1 - Hol Chan Marine Reserve						
2 - Glover's Reef Marine Reserve						
3 - Port Honduras Marine Reserve						
Cuba						
4 - Parque Nacional Guanahacabibes						
5 - Parque Nacional Cayos de San Felipe						
Colombia						
6 - Seaflower Marine Protected Area						
7 - Natural Park of Wetlands between the rivers León and Suriquí						
8 - Sanctuary Cienaga Grande de Santa Marta						
Dominican Republic						
9 - La Caleta Submarine Park						
10 - National Park Jaragua						
11 - National Park Haitises						
12 - National Park Sierra de Bahoruco						
French West Indies						
13 - Réserve naturelle nationale de l'Amana Guyane						
14 - Ile du Grand Connétable Guyane						
15 - Réserve naturelle nationale de Kaw-Roura Guyane						
16 - Étangs des Salines Martinique						
17 - Versants Nord de la Montagne Pelée						
18 - Parc National de la Guadeloupe						
19 - Réserve Naturelle de Petite Terre						
20 - Sanctuaire Agoa (ZEE Guadeloupe et Martinique)						
21 - Étangs Lagunaires de Saint-Martin						
22 - Réserve Naturelle Nationale de Saint-Martin						
Grenada						
23 - Molinière-Beauséjour Reserve						
Dutch Caribbean						
24 - Bonaire National Marine Park						
25 - The Quill and Boven National Park St. Eustatius						
26 - St Eustatius National Marine Park						
27 - Saba Bank National Park						
28 - Saba National Marine Park						
29 - Mt. Scenery National Park Saba						
30 - Man O War Shoal Marine Park						
Saint Vincent and the Grenadines						
31 - Tobago Cays Marine Park						
United States of America						
32 - Dry Tortugas National Park						
33 - Florida Keys National Marine Sanctuary						
34 - Everglades National Park						
35 - Flower Garden Banks National Marine Sanctuary						

Turtles Nesting in Country
Turtles Nesting at SPAW Site
Nesting Absent or Unconfirmed
Coastal Wetland (No Nesting Beaches)
Entirely Marine (No Nesting Beaches)
Entirely Terrestrial (No Nesting Beaches)



	Loggerhead	Green	Hawksbill	Leatherback	Olive Ridley	Kemp's Ridley
Percent of Total SPAW Protected Areas with Nesting	15%	34%	30%	19%	2%	0%
Percent of Total Caribbean Species-Specific Nesting Sites	15%	27%	38%	18%	1%	2%

Figure 5.3. Sea turtle nesting at SPAW sites prepared from data provide by the SPAW listing documents and by the Wider Caribbean Sea Turtle Conservation Network's (WIDECAST) database of sea turtle nesting in the Caribbean (Eckert and Eckert 2019). The matrix indicates that the SPAW nations and territories have nesting beaches within their SPAW protected areas for most of the turtle species that nest within their territorial boundaries. Other beaches in these nations and territories, which are outside SPAW protected areas, are also places where turtles nest and may have some form of protection, but these sites are not included in this figure. The bar graph at the bottom shows the total number of nesting beaches for each turtle species that are collectively within SPAW sites. Numbers below the bar graph show the percentages for each species nesting in the SPAW sites and compares it to the total species-specific nesting sites for the entire Caribbean. This Caribbean-wide data comes from Eckert and Eckert (2019) who document a total of 1,341 nesting sites in the Wider Caribbean. However, those nesting sites are often associated with multiple species, so the species-specific nesting site total of 2,667 is used to compare percentages between SPAW nesting sites and those across the entire region. The percentage numbers are similar, which suggests the nesting sites within SPAW protected areas generally reflect the proportion of nesting sites used by each species throughout the region. However, this is not to suggest that nesting site protections across the region is adequate for all species.

These results combined with tracking data shown in Figure 5.2 indicate that individual turtles migrate from nesting sites to local and distant foraging areas, making journeys that can span the entire Caribbean basin and beyond. For example, Blumenthal et al (2006) used satellite tags to track green, loggerhead turtles from the Cayman Islands to foraging areas in Belize, Florida, Guatemala, Honduras, Mexico, and Nicaragua. Data from Iverson et al (2020) tracked a loggerhead turtle from the Dry Tortugas to Nicaragua. Figure 5.4 shows data from Becking et al (2016) who tracked green, loggerhead and hawksbill turtles making migratory journeys of 197 to 3135 km from breeding sites in Bonaire to foraging sites 176 to 2202 km away in various widely-dispersed locations. Long distance migrations of loggerhead and leatherback populations can even connect these species to habitats and populations on the opposite side of the Atlantic as is shown by the planning units for these species in Figure 5.2. These data establish extensive links from the nesting hubs at SPAW and other protected areas to diverse locations in other parts of the Caribbean and Atlantic.

Section 6. CONNECTIVITY ANALYSIS OF THE SPAW MARINE PROTECTED AREAS USING MODELS OF LARVAE PRODUCTION, DISTRIBUTION AND SETTLEMENT PATTERNS ON CORAL REEFS IN THE WIDER CARIBBEAN

The connectivity of places in the ocean is either passive or active (Cannizzo et al 2020). Passive connectivity occurs when organisms, nutrients and materials are moved by physical processes, like the transport of larvae via ocean currents (Figure 6.1). Active connectivity occurs when organisms move themselves from place to place. The scales at which these movements occur can vary substantially in space and time. Animals can utilize both during their development and lifecycles, and larvae of some species have the ability to be both passive and active.

The amount of time larvae of marine fishes and invertebrates spend in the plankton before settlement is a measure of potential connectivity. It will determine the scale at which connectivity operates, which varies from the small scale (minutes or hours where larvae settling close to their origin) to scales that can span months with currents dispersing larvae across entire ocean basins (Cowen et al 2006, Jones et al 2009, Green et al 2014).

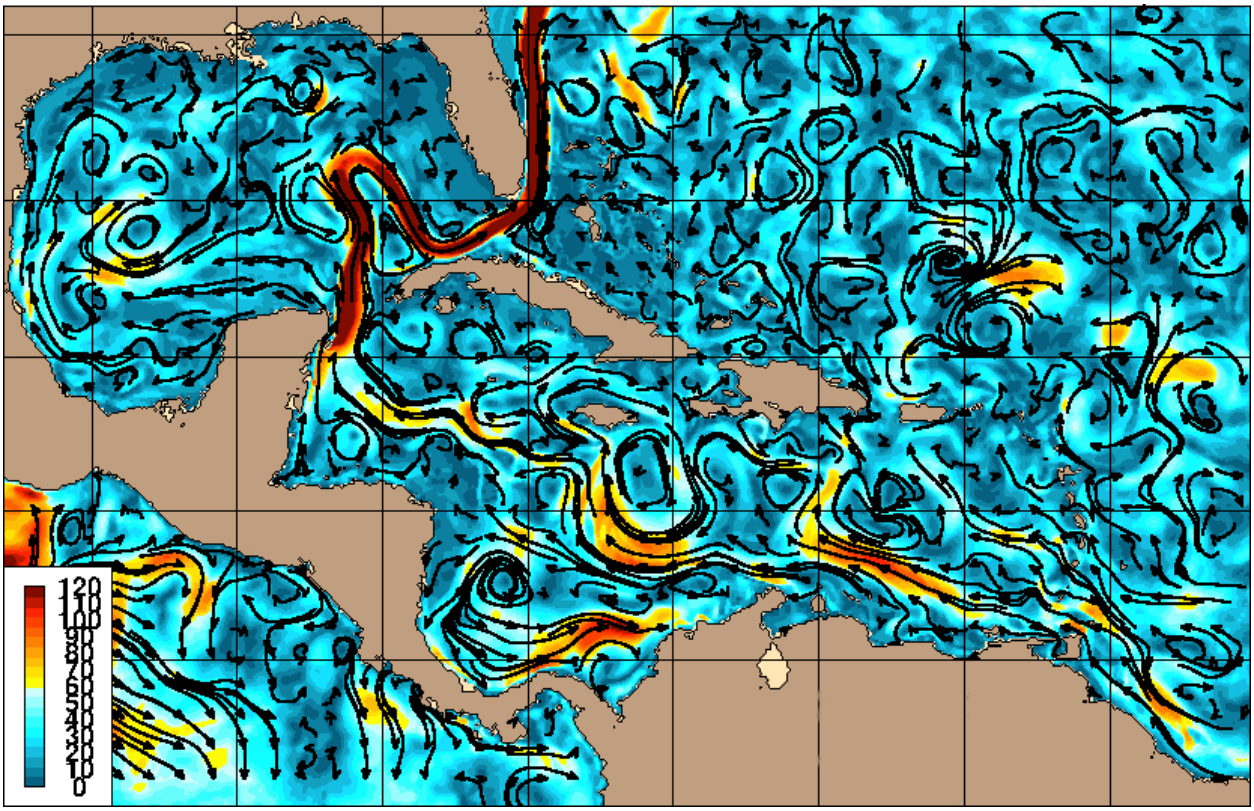


Figure 6.1. Hybrid Coordinate Ocean Model (HYCOM) of ocean circulation in the Caribbean showing speed (color: cm/sec) and direction (arrows) of currents. This snapshot is for August 18, 2020 and shows the complex pattern of circulation that is fundamental in physically distributing larvae and other water-borne impacts between locations and marine populations throughout the Caribbean. Image from HYCOM Consortium for Data-Assimilative Ocean Modeling, US Naval Research Laboratory: https://www7320.nrlssc.navy.mil/GLBhycomcice1-12/

Many species of corals throughout the Caribbean, as in other parts of the world, undergo synchronous spawning events at particular times of the year (Szmant 1986, Gittings et al 1992). While the timing of these events can vary between species and be influenced by a number of environmental factors (van Woesik et al 2006, Levitan et al 2011), they mainly occur in the Caribbean during August and September. These synchronized mass spawning events increase the probability of reproductive success in coral populations. Water currents carry the coral larvae produced during these events to sites where they settle and begin new coral colonies. The settlement may occur on the same reef, or at reef sites hundreds of kilometers from a larvae's parent colony. This process of reproductive spawning, transport and settlement is fundamental

in determining the distribution and resiliency of coral reef communities. It is also fundamental in the spatial and temporal scale of ecological connectivity between coral reef populations (Steneck et al 2009, Sale et al 2010).

Research into this reproductive process has been the focus of numerous studies seeking to understand connectivity between different coral reef fish, coral and other reef dwelling populations, and within and between marine protected areas (Palumbi 2004, Cowen et al 2006 & 2007, Jones et al 2007, Grober-Dunsmore and Keller 2008, Schill et al 2015). Given the importance of protecting and sustaining coral reef habitats in the majority of the SPAW and other marine protected areas in the Caribbean, an understanding of the connectivity between MPAs through this reproductive process will be central in determining the wider ecological benefits of coral reef conservation strategies at each of the SPAW sites.

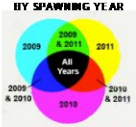
Schill et al (2015) undertook a detailed analysis of coral reef connectivity through larval transport modeling as a way to inform establishing MPA networks in the Caribbean. The results of this study provide a valuable dataset and framework for assessing how the existing SPAW sites are potentially interconnected by larval production and coral recruitment. The research used regional ocean circulation data for the period 2008 to 2011, combined with an understanding of coral reproduction and larval biology (spawning frequency, pelagic larvae duration, rate of mortality, settlement probability), to model larvae dispersal patterns between coral reef areas within different national jurisdictions. Their results show the variety of geographic connectivity relationships between sources and destinations of coral larvae across the Caribbean.

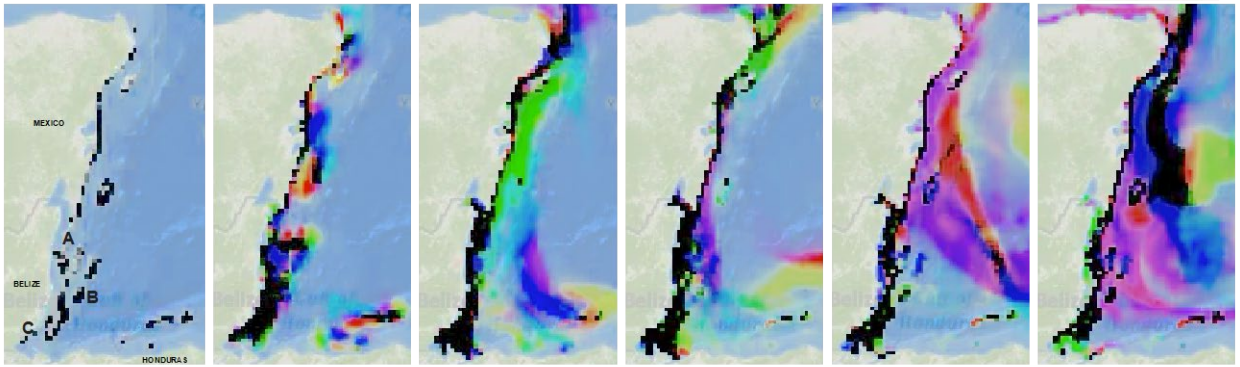
In order to visualize how spawning events and current patterns interact to distribute coral larvae over key parts of the Caribbean, animations from the above study were edited to show snapshots of probable larvae concentrations at specific time intervals following spawning events. Figure 6.2 presents simulated coral larvae distribution over 30 days during three different years in the Mesoamerican Barrier Reef region of Mexico, Belize and Honduras, and in the Lesser Antilles. These areas were chosen to illustrate because they contain several SPAW-listed sites. The amount of larvae produced by the model is based on the geographic area of coral reef habitat at the sources (black areas at day zero). Over subsequent snapshot intervals, the predicted distribution and concentration of larvae are indicated by different colors for each of three annual spawning events.

SPAW MARINE PROTECTED AREAS
A. Hol Chan Marine Reserve
B. Glover's Reef Marine Reserve
C. Port Honduras Marine Reserve
D. Réserve Naturelle de Saint-Martin
E. Saba National Marine Park
F. Saba Bank National Marine Park
G. St Eustatius National Marine Park
H. Parc National de la Guadeloupe
I. Réserve Naturelle de Petite Terre

VISUALIZATION OF CORAL LARVAE DISTRIBUTION AND CONCENTRATION MODELED OVER 30-DAYS FOLLOWING SIMULATED CORAL SPAWNING EVENTS IN 2009, 2010 AND 2011

KEY TO LARVAE DISTRIBUTIONS BY SPAWNING YEAR





Day 0 | Day 1 | Day 5 | Day 10 | Day 20 | Day 30

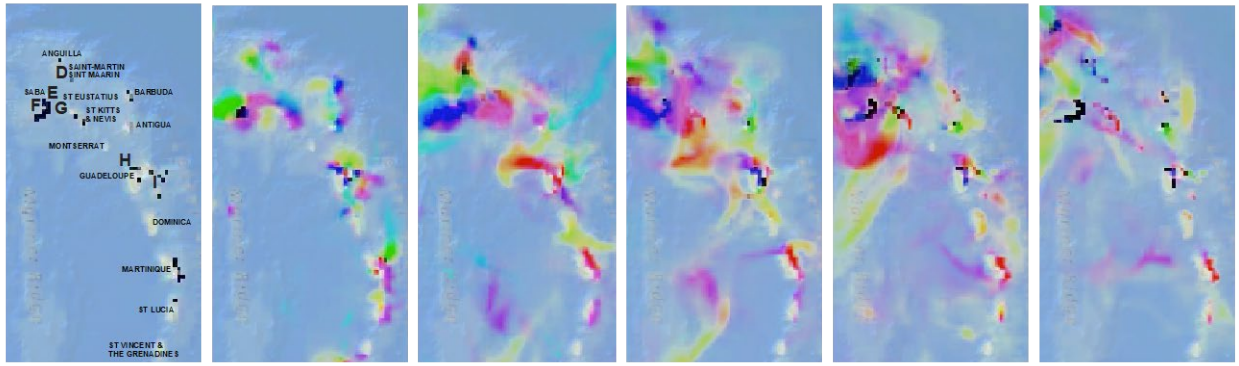


Figure 6.2. Coral spawning events simulated for three different years (data extracted from Schill et al 2015): Blue = 2009, Red = 2010, Yellow = 2011. Underlying ocean current data is from NOAA's Real-Time Ocean Forecast System. Color key at upper right shows blending of colors to illustrate areas where the trajectories of the products from spawning events overlap or diverge between years. Black areas are the coral reef sources at Day 0, and where potential settlement locations by all three spawning events overlap at subsequent periods up to 30 days. These black colored reef areas are the locations predicted by the model to have the highest probability of new coral colony recruitment. The locations of SPAW sites are shown at Day 0 with a key for the sites in the upper left.

This presentation of the study's results shows that the larvae distribution and settlement probability following any spawning event will vary significantly between sites and years. However, the results indicate that some locations have higher probabilities of receiving larvae from local and distant sources. This is shown by the range of colors and particularly by the black areas where larvae settlement is most likely to occur and maintain a strong connection with spawning sources over time. From these data, interpreting the relative strength of the connections between the places that give and receive larvae across the Caribbean region starts to be possible.

As part of their analysis, Schill et al (2015) assessed the strength of the connections between different parts of the Caribbean based on the amount of coral larvae produced and received by EEZ jurisdictions. In order to evaluate how these results can be applied directly to MPAs that are SPAW sites, the results were reinterpreted to consider how EEZ's with SPAW MPAs in different locations are likely to contribute and receive larvae.

The matrixes below (Figures 6.3, 6.4 & 6.5) present a dissection of the model output, which identified relative connection strengths between Caribbean EEZs based on larval production, transport and settlement. EEZs with and without SPAW sites were extracted and presented to show the relative connectivity between jurisdictions with SPAW sites, and between jurisdictions with and without SPAW sites. The resulting matrixes and graphs are a measure of how SPAW sites are connected to each other by the output and receipt of reproductive products, and how the SPAW sites are connected to other parts of the Caribbean through these products. These data will be useful in targeting how the SPAW sites are developed into a MPA network, and how the SPAW sites should be working with other MPAs to ensure resiliency of their coral populations.

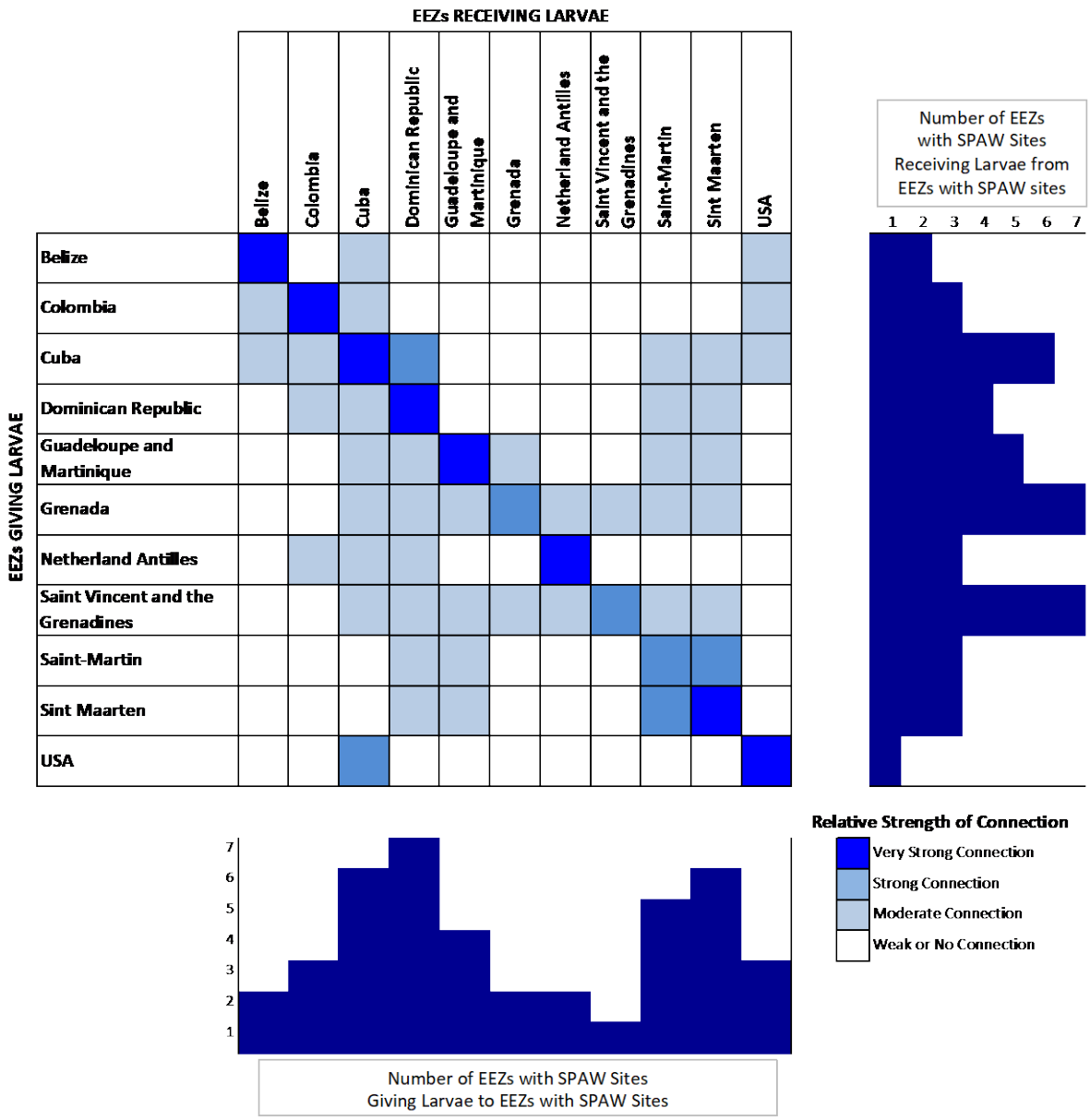


Figure 6.3. Coral larvae connectivity between country EEZs with SPAW-listed marine protected areas. Country EEZs produce and export (giving) coral larvae are shown on the right y-axis and country EEZs receiving coral larvae are shown on the top x-axis. Very strong connections are obvious where coral larvae are produced and received locally and where EEZs are geographically adjacent or close. This is shown by the darker blue fields, which indicate the potential for self-seeding of reefs within an EEZ or reefs within a SPAW site. Strong and moderate connections are indicated where larvae are potentially exported beyond their origin EEZ's border to be received in other EEZs. The bar graph at the bottom shows the number of EEZs contributing larvae. Bar graph on right shows the number of EEZs receiving larvae. These data show the relative importance of Cuba, the Dominican Republic, Guadeloupe/Martinique, Grenada and Saint Vincent & the Grenadines in potentially contributing larvae to other SPAW sites, and Cuba, the Dominican Republic and Saint Martin/Sint Maarten in receiving larvae from other SPAW sites. The data also shows how Saint-Martin and Sint

Maarten have strong connectivity that gives and receives larvae between the adjacent seascapes they share.

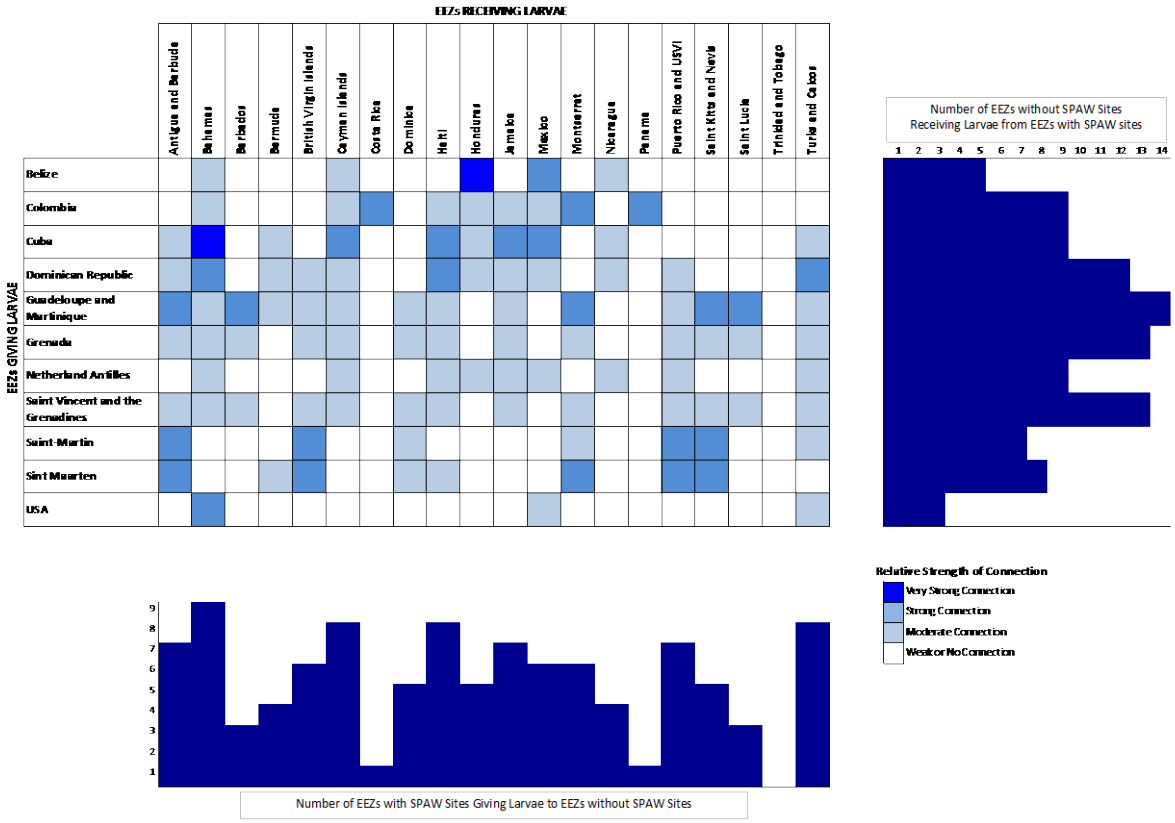


Figure 6.4. Coral larvae connectivity between country EEZs with SPAW-listed marine protected areas giving larvae to other country EEZs without SPAW-listed MPAs. Belize and Cuba have very strong connections to the Bahamas and Honduras respectively. Cuba and Belize both have large coral reef areas and the model predicts their reefs will export larvae. However, as shown in the graph on the right, coral reefs at SPAW sites in the Dominican Republic, Guadeloupe and Martinique, Grenada and Saint Vincent and the Grenadines have the potential to influence larvae recruitment in the largest number of EEZs without SPAW sites. The graph at the bottom shows the relative contribution of larvae from SPAW sites to each of the EEZs that don't have SPAW sites. Coral reefs in Costa Rica, Panama and Trinidad and Tobago receive larvae from a relatively small number of SPAW sites compared to the other EEZs without SPAW sites.

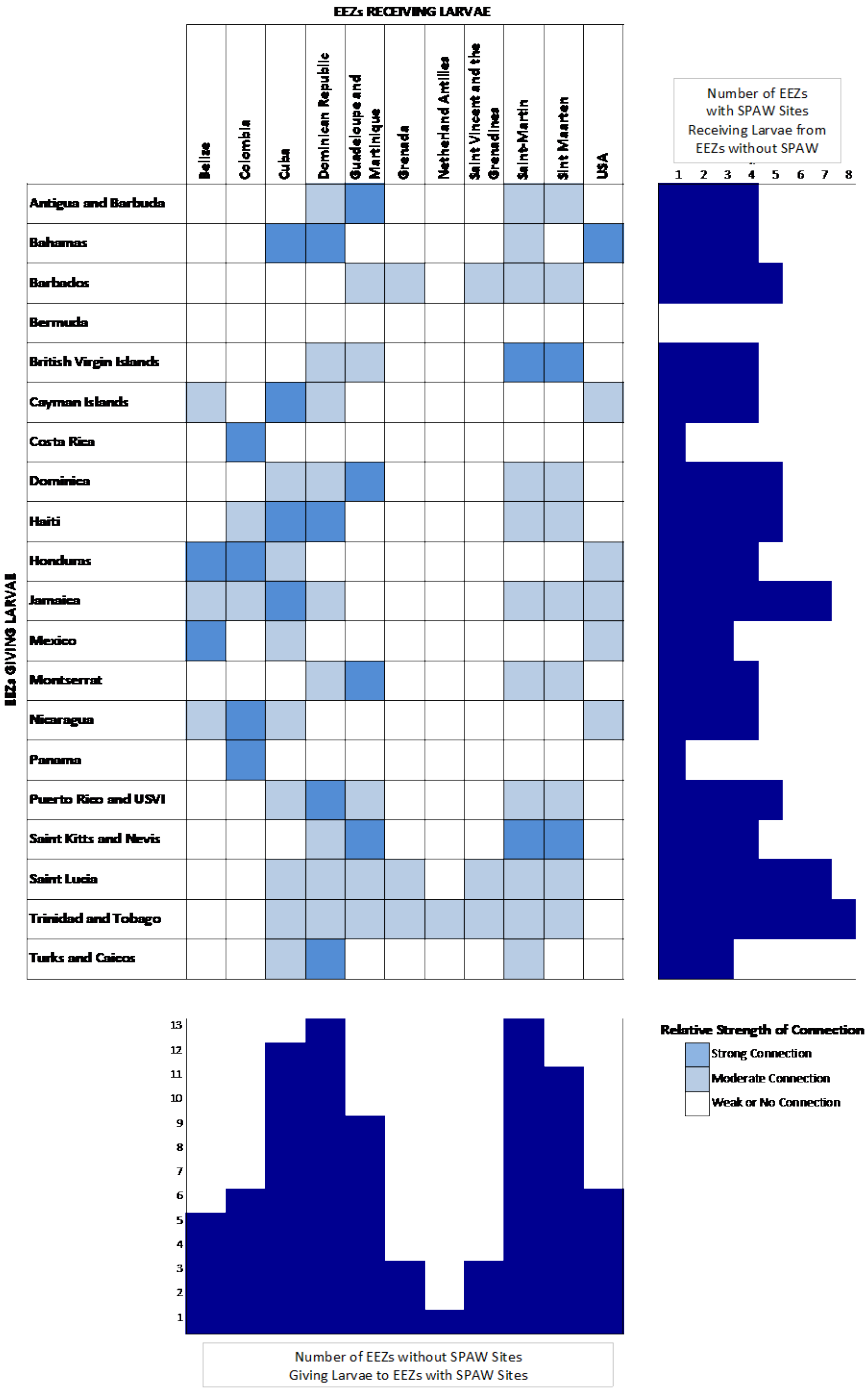


Figure 6.5. Coral larvae connectivity between countries without SPAW-listed marine protected areas giving larvae to countries with SPAW-listed MPAs. The model results show the importance of geographic proximity in the strength of the connections, but larvae from relatively distant locations can contribute to coral populations in SPAW sites. For example, larvae originating in Saint Lucia have the potential to settle on Cuban reefs. The graph to the right indicates that Jamaica, Saint Lucia and Trinidad & Tabago are potentially exporting to the largest number of SPAW sites, while larvae originating in Bermuda, Costa Rica and Panama mostly settle in areas without SPAW sites. The graph at the bottom highlights the potential

strong links that Cuba, the Dominican Republic and Saint-Martin/Sint Maarten have to countries that don't have SPAW sites. Larvae settling in the Netherland Antilles come from the fewest number of areas without SPAW sites.

Other coral reef populations have been used to investigate connectivity through larval distribution modeling (Treml et al 2012). Cowen et al (2006) analyzed connectivity in the Caribbean through larval dispersal from spawning of coral reef fishes. Their study evaluated the spatial scales over which fish larvae may be dispersed by currents, but included variability in larval concentrations and distributions over time resulting from reproductive timing, pelagic larval duration and larval swimming behavior. As in Schill et al (2015), Cowen et al (2006) used this understanding of the factors influencing larval production, transport and settlement to assess the level of connectivity, but they also included how these factors influence the degree to which larval dispersal is able to maintain ecological and genetic connectivity between coral reef fish populations in different parts of the Caribbean.

Figure 6.6 shows part of the output from Cowen et al (2006) modeling results. These data show the dominance of "self-recruitment" of fish populations. Retention of most of the produced larvae causes recruitment to be mainly local in scale. Cowen et al (2006) indicate that ecologically significant numbers of settling larvae are sourced from reef areas separated by only 50 to 100 km distance, with the majority of larvae locally retained. They show how the levels of larval exchange indicated by these results provide a basis for biogeographic breaks in the genetic structure of fish and other reef populations in the Caribbean. However, the data in Figure 6.6 reveals certain reef areas have potential connections through recruitment of larvae from more distant sites even if these connections may be defined by low numbers of settling larvae. In addition, stochastic events such as hurricanes, that can modify the underlying current patterns, may allow for periodic intense exchange between distant coral reef populations. This would potentially reduce the isolation of reefs from one another for short, but ecologically consequential, periods of time.

The combination of stable weak connections with random strong larval exchange between different areas of the Caribbean over time may provide for connectivity that is ecologically relevant to sustaining fish and other species on coral reefs in particular parts of the region. It also provides a basis for building management relationships between protected areas in certain part of the Caribbean.

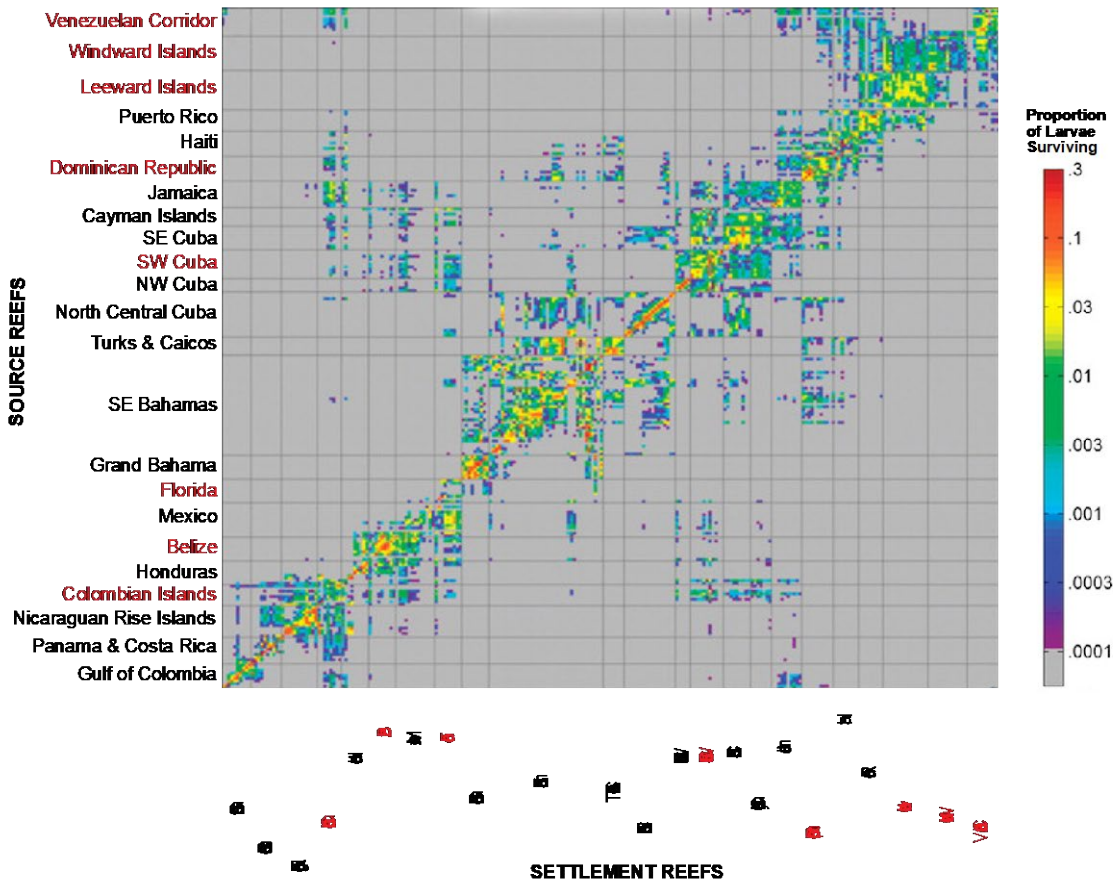


Figure 6.6. Connectivity matrix modified from Cowen et al (2006) modeling results that show the strength of the connections between coral reef fish larvae sources and destinations in different parts of the Caribbean. The model used biophysical parameters for fish species and ocean circulation models generated over five years and divided coral reef sites into 260 model habitats (9 km x 50 km in size) in the Caribbean. The colors within the matrix indicate the level of probability for virtual larvae sources (y-axis) to settle at destinations (x-axis) after a 30-day pelagic larval duration and the onset of active larval movement (swimming) after 15 days. The gray lines group the reef habitat used in the model into sub-regions and indicate the relative amount of reef area contributing and receiving larvae within sub-regions. Sub-regions with SPAW sites are highlighted in red in the axes. As shown in the model results produced by Schill et al (2015) for coral, fish populations are dominated by self-seeding, which is shown by a high proportion of larvae produced settling on or near their source (the concentration of red and yellow color along the diagonal in the matrix). The proportion of produced larvae surviving and settling will determine if recruitment will maintain fish populations at a settlement reef. This limits the connection strength indicated between source and settlement reefs, but the cumulative strength of multiple sources contributing larvae to a settlement site may be ecologically significant. For example, looking vertically from the bottom x-axis, the model suggests southwest Cuba (SPAW site Guanahacabibes) may be accumulating larvae from the Colombian Islands (SPAW site Seaflower), Belize (SPAW sites Hol Chan, Glovers & Port Honduras), Mexico, other Cuban reefs, Cayman Islands and Jamaica. The Colombian Islands (SPAW site

Seaflower) may accumulate larvae from sources in Gulf of Colombia, Panama & Costa Rica, Nicaraguan Rise Islands, Cuban reefs, Jamaica, the Dominican Republic, and Haiti. Looking horizontally from the left x-axis, the Venezuelan Corridor (SPAW site Bonaire) may be contributing larvae as far as the Colombian Islands, Jamaica, Dominican Republic, Haiti, and Puerto Rico. Other sub-regional interconnections may also be highlighted in groups of source-settlement relationships shown in the matrix and help to focus attention on important long-term ecological links within and between the sub-regions of the Caribbean.

As part of their analyses, Schill et al (2015) evaluated the importance of particular coral reefs in maintaining connectivity in the region. Their analysis of "betweenness centrality" identified particular sites that act as bridges, or "stepping stones," between sites (Figure 6.7). These data show that although two sites may not have strong direct connections between them through larvae production and settlement, they can have important connections through other reefs that link their biological populations over many generations of reproduction. In this way, different strengths of connectivity work together to build ecological and evolutionary bonds between different areas of the Caribbean and to maintain the robustness of the reef communities they support throughout the region.

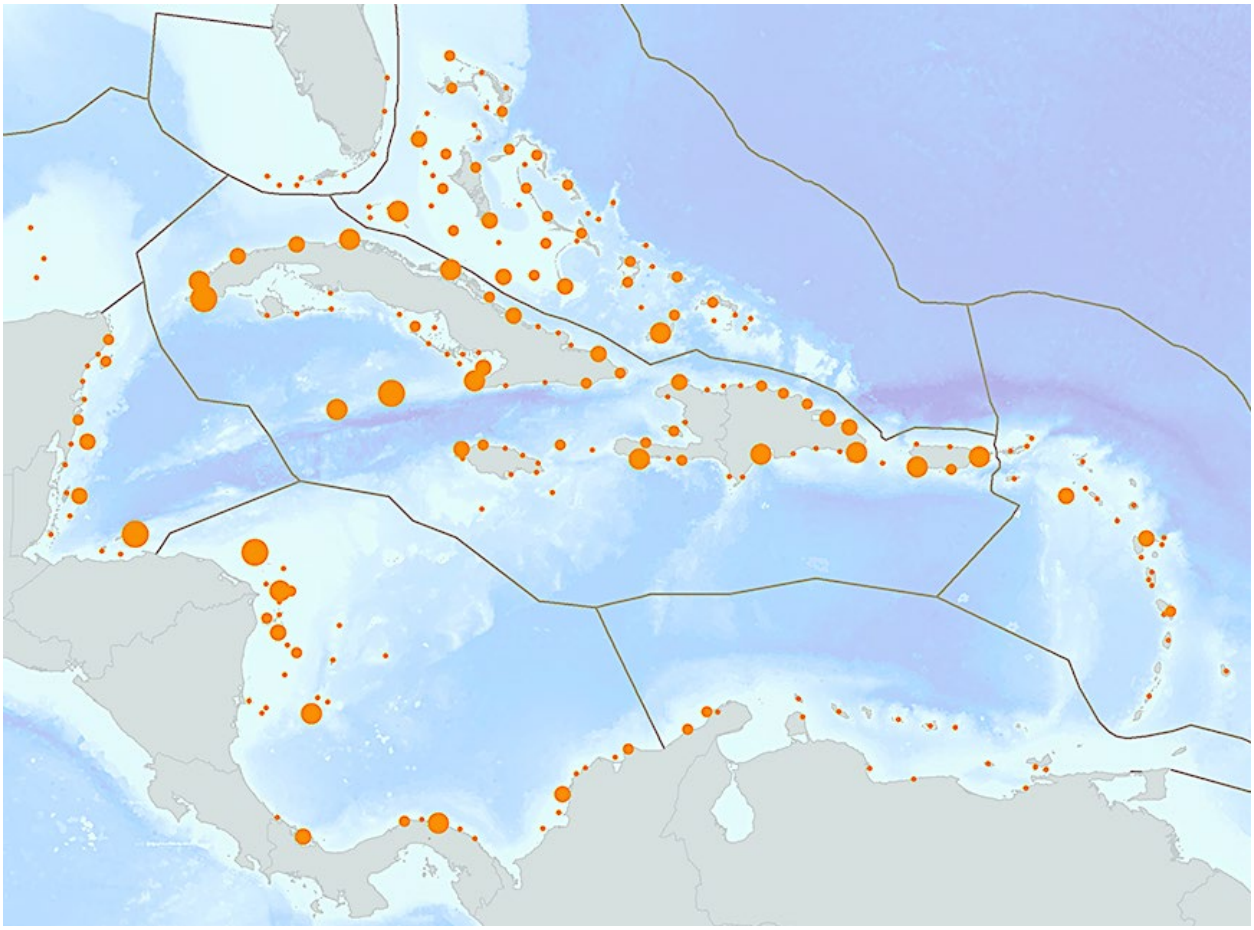


Figure 6.7. Relative betweenness centrality by coral reef unit measured by Schill et al (2015) showing important ecological bridges in the Caribbean. The circles represent sites of

interconnection between reefs that export and receive coral larvae. The larger the circle, the greater the importance of the reef as a bridge, or "stepping stone," between sites. The bridges mean that coral populations at the site have connections to larvae coming from sources and also have connections to other locations through the bridge-site's export of larvae. SPAW sites occurring where reefs rank high as important bridges or "stepping stones" include Seaflower, Guanahacabibes, Saba Bank, and Guadeloupe MPAs. Dark lines on the map are boundaries of designated Ecoregions in the Caribbean (Spalding et al 2007).

To further explore and visualize the potential for individual MPAs to export and receive larvae to and from other coral reef areas, three SPAW sites in different parts of the Caribbean were selected to analyze in detail. With the assistance of Dr. Jorge Brenner, one of the authors of Schill et al (2015), connectivity data were extracted from their modeling results for Glover's Reef, Guanahacabibes, Bonaire and Guadeloupe. Figure 6.8 through Figure 6.15 show the strength of connectivity to and from other reef sites in the region as revealed by the modeling results for coral larvae originating at each site, and for coral larvae received at each site. The straight lines represent the strength of the connections between larvae source and settlement sites, but the actual pathways vary in length and trajectory because they are defined by circulation patterns. This analysis, which is possible to do for other coral reef areas in the region, refines the analyses shown in Figures 6.3 through 6.5 and provides a tool for further evaluating the ecological bridges created by particular reefs and MPAs (Figure 6.7). As shown previously, larval sources and destinations in close proximity to the analyzed sites show the strongest connections, but the data show that ecological exchange with distant reefs is possible. They also show how complex local current patterns often allow for the interchange of larvae between sites, where they give and receive larvae to each other. These presentations of the modeled data help to improve understanding of how particular places in the Caribbean are linked through the geographic distribution of reproductive products, and can be used in designing research and management relationships between different MPAs.

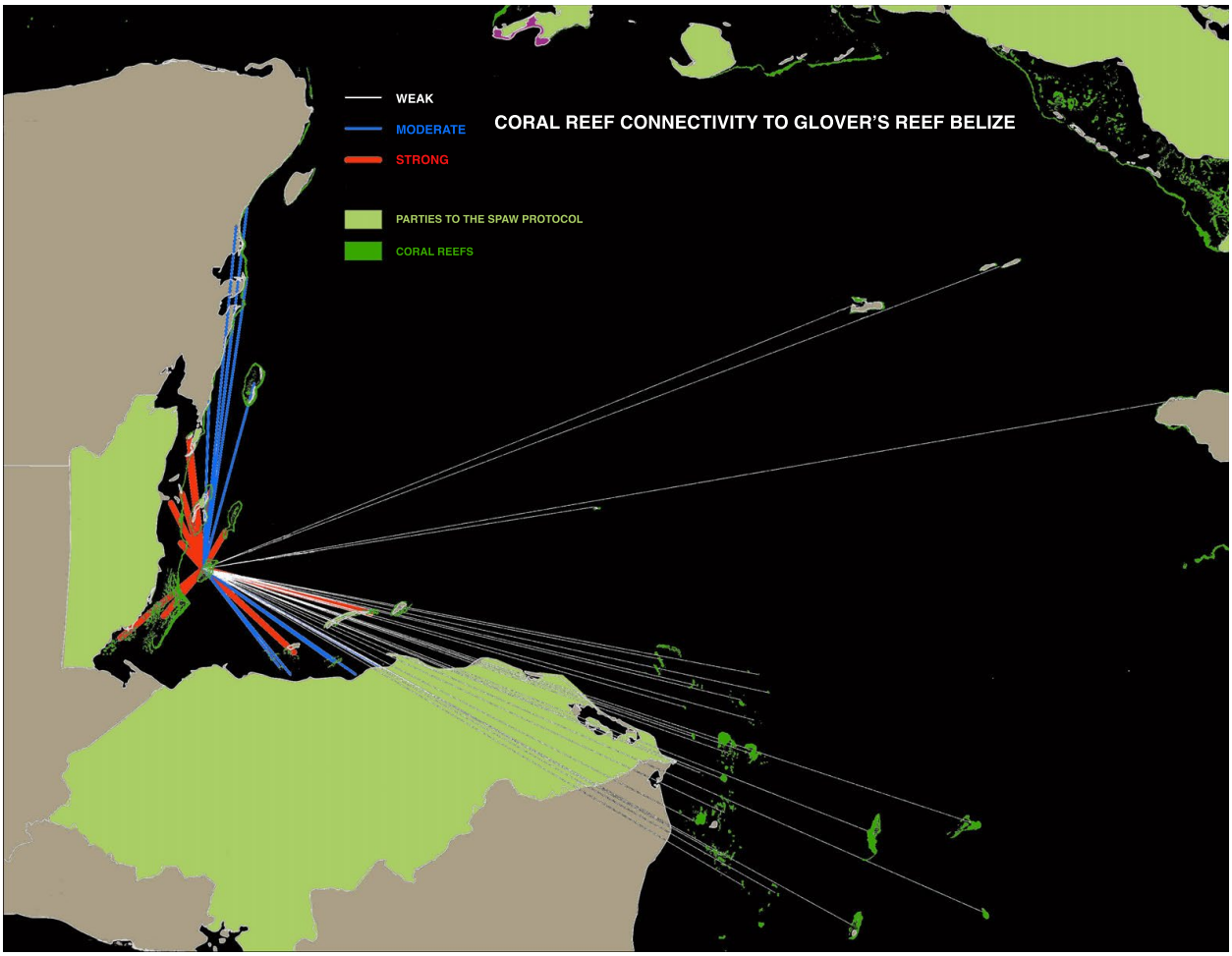


Figure 6.8. Relative strength of coral reef connectivity showing sources of coral larvae received by Glover's Reef, Belize based on results of larvae dispersal modeling.

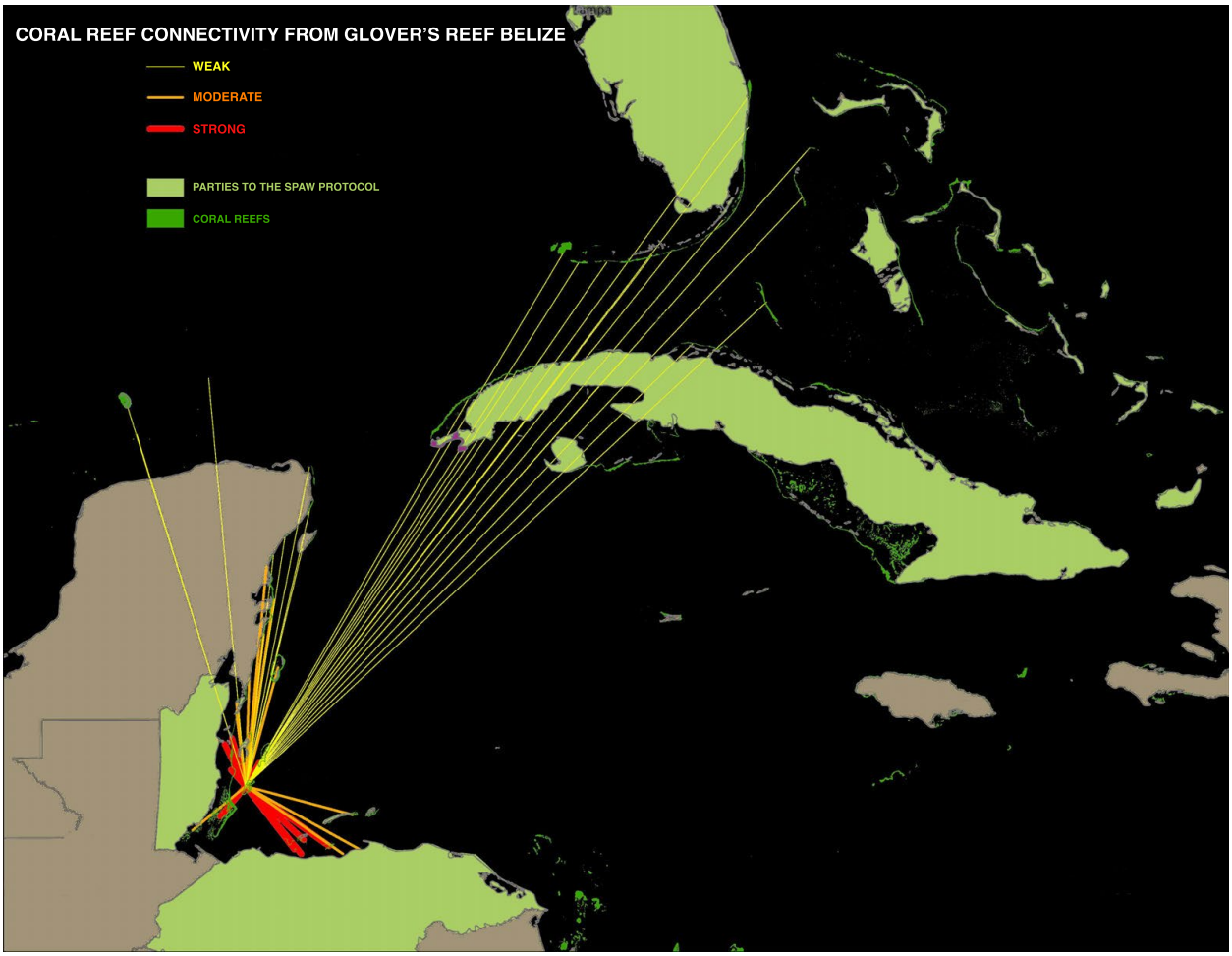


Figure 6.9. Relative strength of coral reef connectivity showing destinations of coral larvae exported by Glover's Reef, Belize based on results of larvae dispersal modeling.

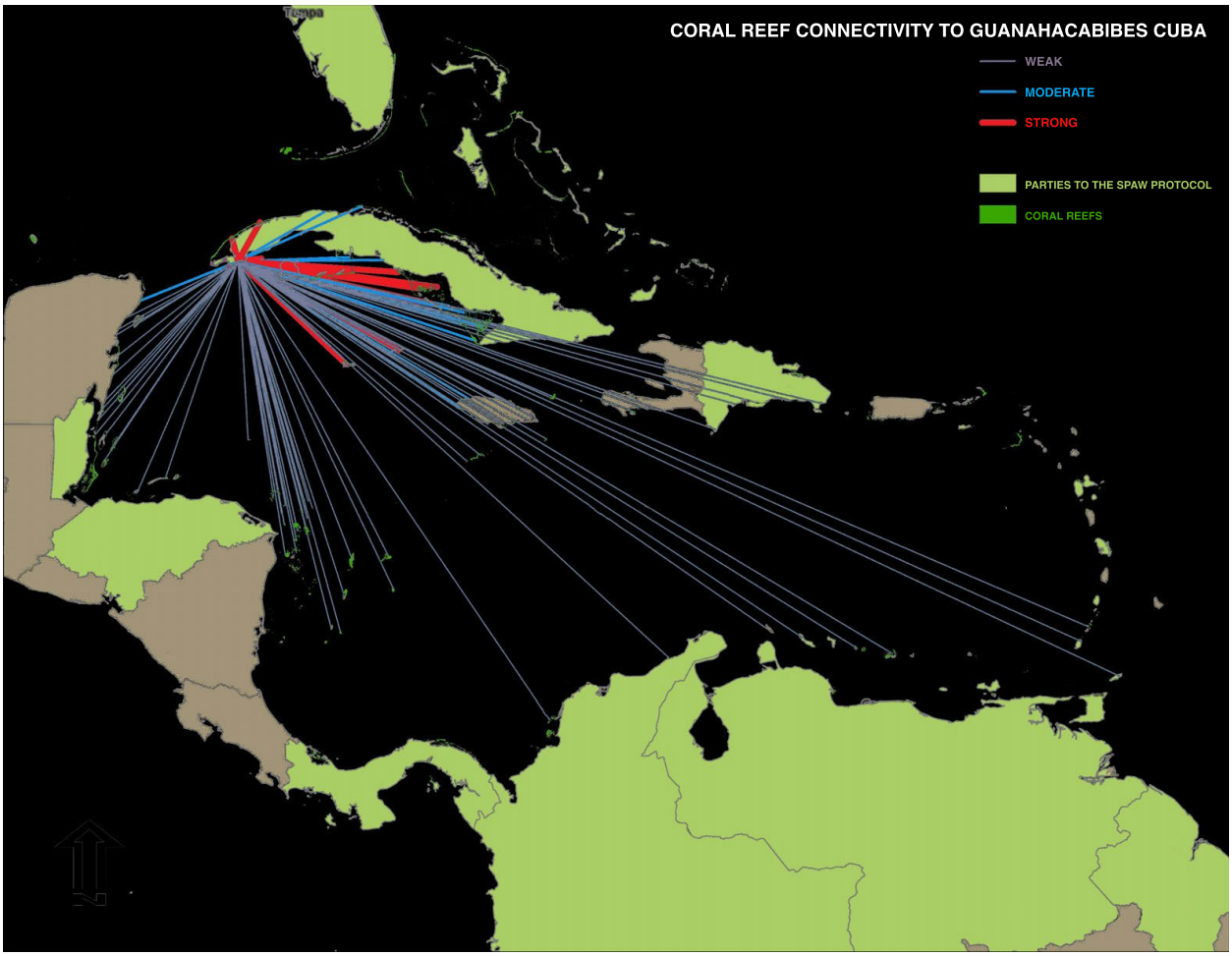


Figure 6.10. Relative strength of coral reef connectivity showing sources of coral larvae received by Guanahacabibes, Cuba based on results of larvae dispersal modeling.

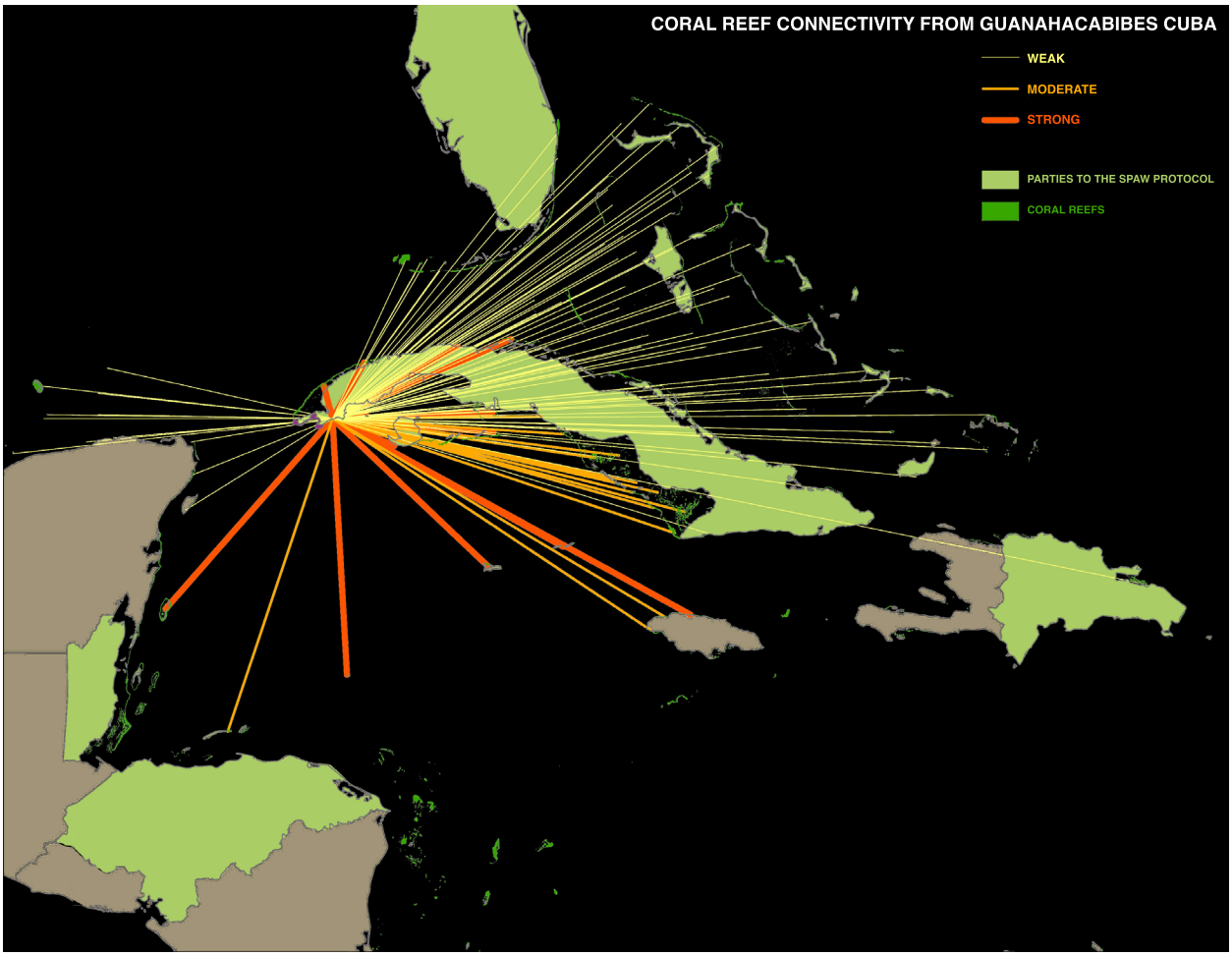


Figure 6.11. Relative strength of coral reef connectivity showing destinations of coral larvae exported by Guanahacabibes, Cuba based on results of larvae dispersal modeling.

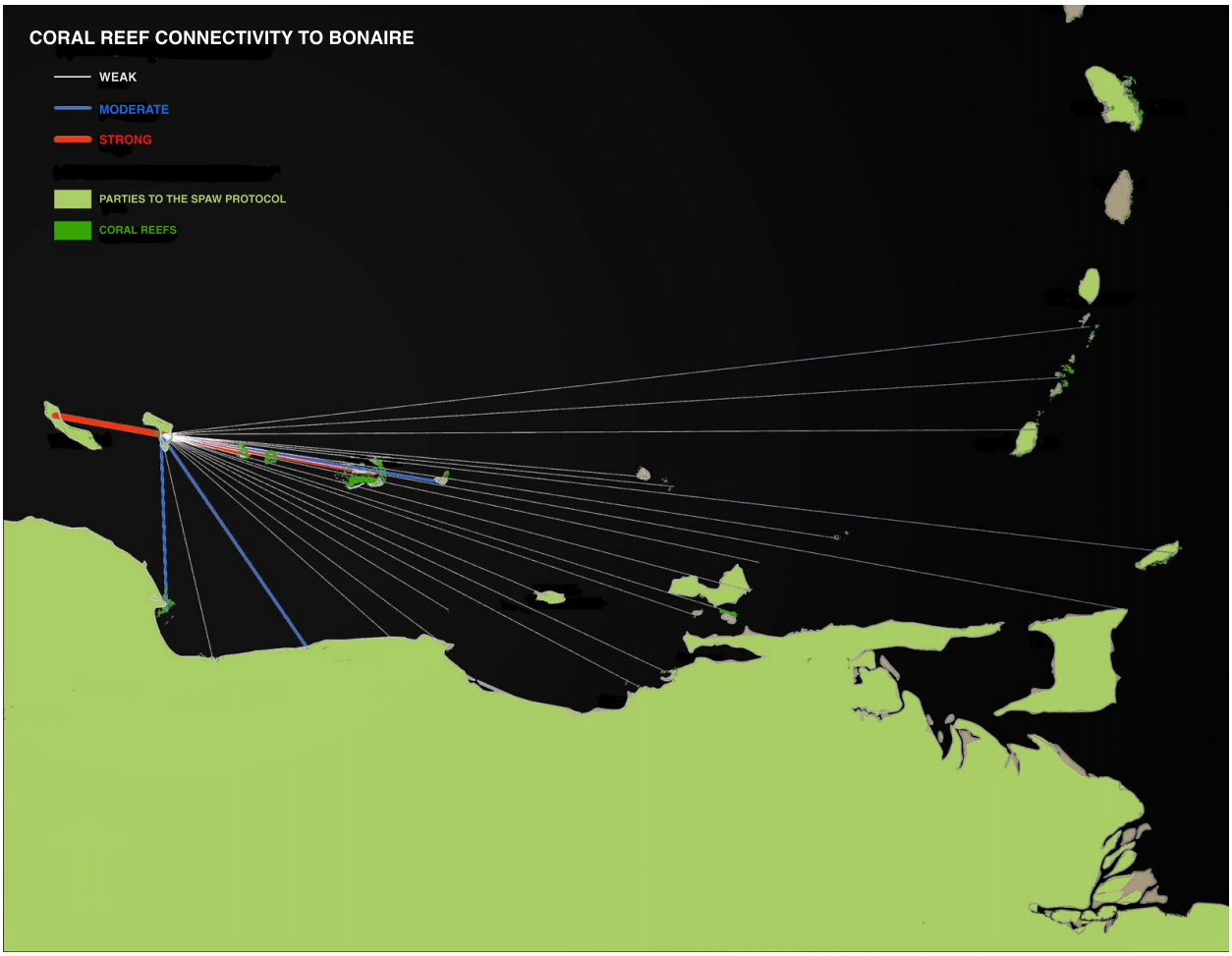


Figure 6.12. Relative strength of coral reef connectivity showing sources of coral larvae received by Bonaire based on results of larvae dispersal modeling.

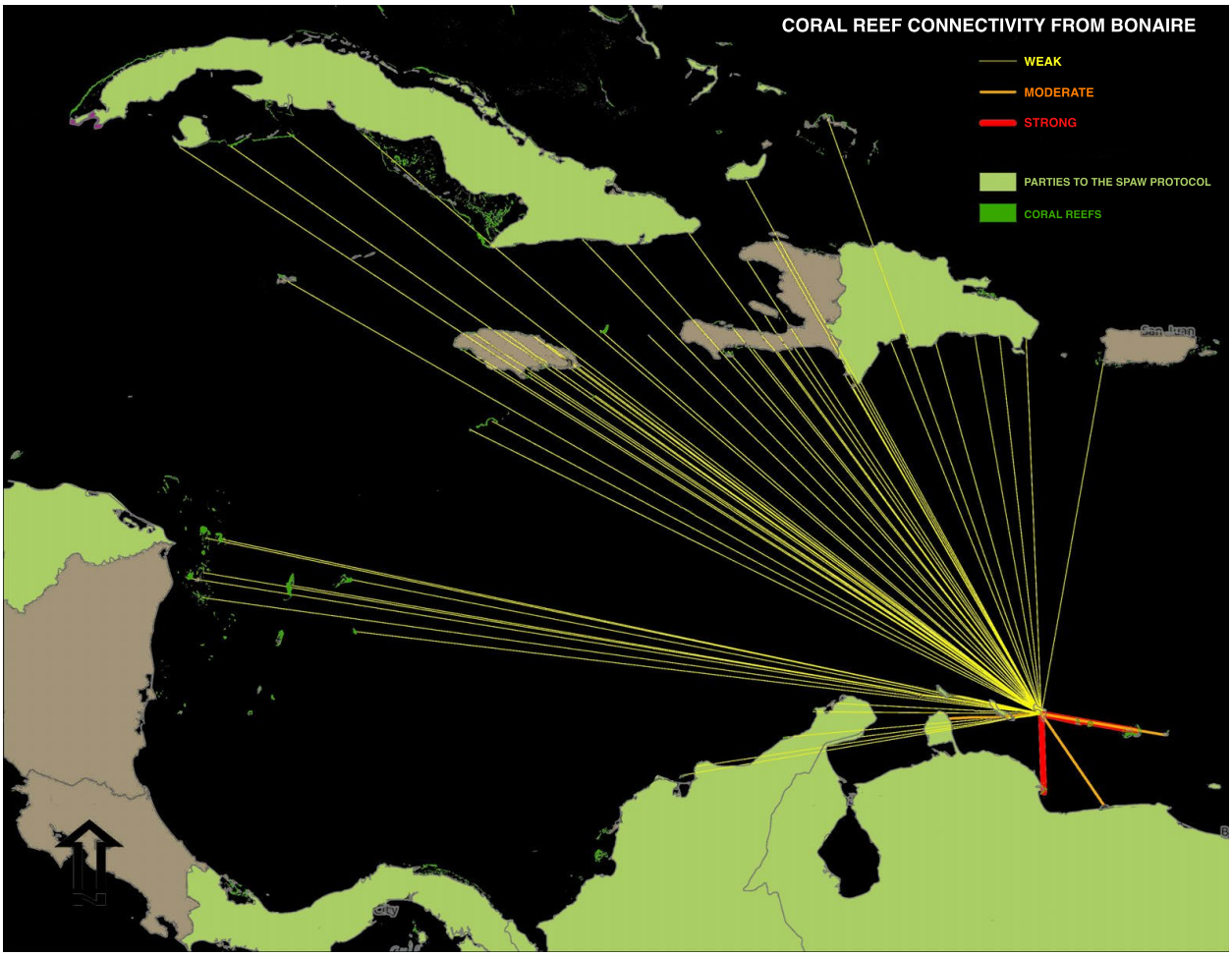


Figure 6.13. Relative strength of coral reef connectivity showing destinations of coral larvae exported by Bonaire based on results of larvae dispersal modeling.

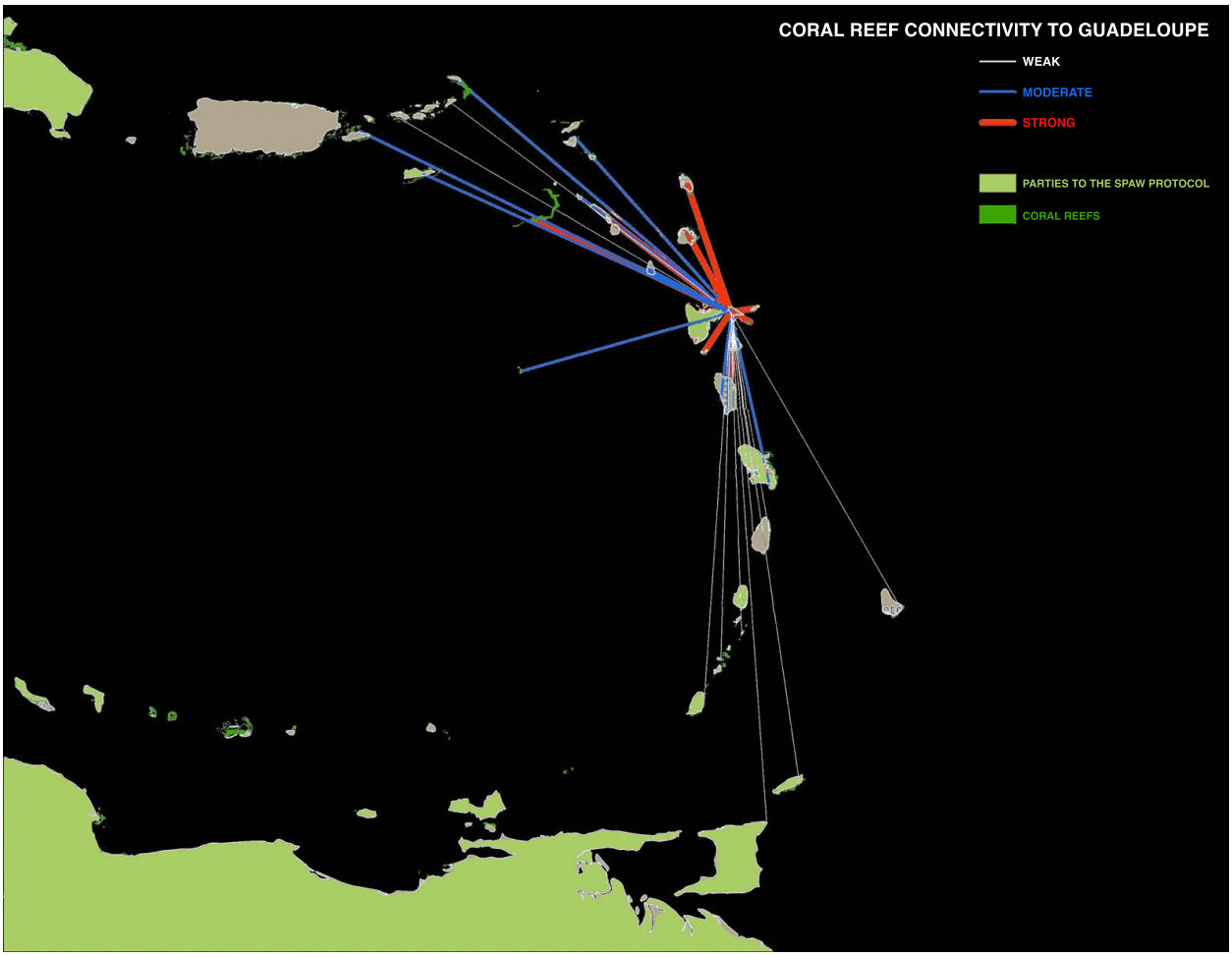


Figure 6.14. Relative strength of coral reef connectivity showing sources of coral larvae received by Guadeloupe based on results of larvae dispersal modeling.

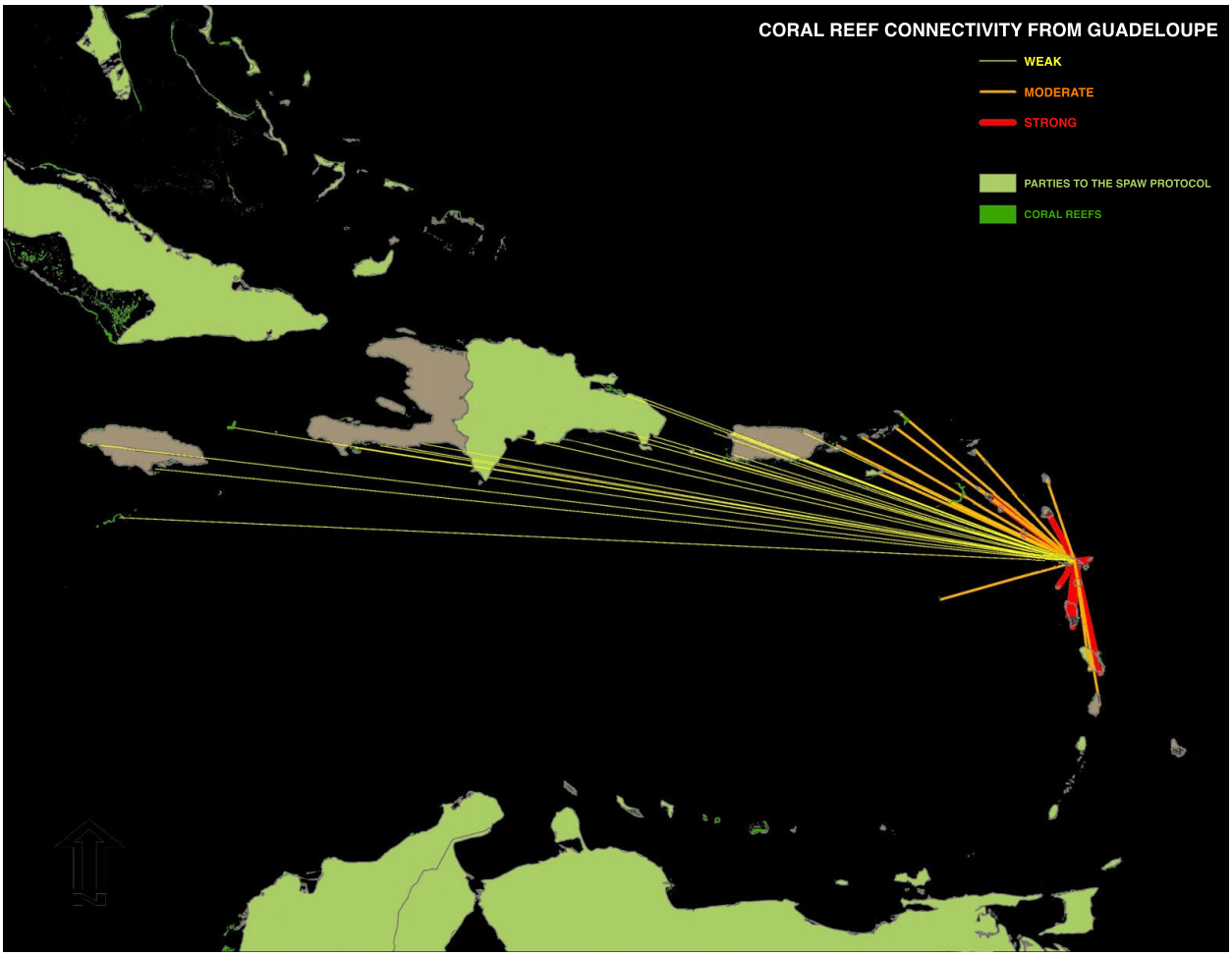


Figure 6.15. Relative strength of coral reef connectivity showing destinations of coral larvae exported by Guadeloupe based on results of larvae dispersal modeling.

The connections created by these complex ecological processes of reproduction, larval transport and recruitment on coral reefs highlight the ecological dependence and influence different coral reef areas and marine protected areas have on each other. Conditions that decrease the reproductive health of reef species and the larvae they produce in one place will have an impact on the health of coral reefs that receive their larvae. If a SPAW site, or any other MPA, can maintain or improve this reproductive health and the survival of the resulting larvae then it and other coral reef areas benefit.

Whether or not a coral reef is in a SPAW-listed marine protected area has no real ecological basis for the coral reef's ability to export or import larvae to and from other coral reefs of the Caribbean, unless however the protected area provides for enhanced larvae production and settlement. The data presented show how coral reefs, and any marine protected area that contains coral reefs, have potentially important links to other coral reef areas of the Caribbean. The reproductive condition of coral reef populations in the territorial waters of a country or in an MPA will influence the amount of larvae produced by those populations. How those produced larvae will influence other coral communities inside or outside that country or MPA will depend

on what happens to the larvae after a spawning event. Numerous physical and biological factors, including water conditions that influence larvae survival, will determine the fate of larvae produced by spawning events. However, the more larvae a marine protected area is able to produce, and if environmental factors in the region are favorable for larvae survival, the contribution a protected area will have on larvae arriving at other MPAs will be strengthened.

This concept of MPA connectivity through coral reef larvae production and distribution emphasizes the important role that a network of MPAs has in ensuring that all sites in the network realize ecological dividends from the protection investments made at single sites in the network. The data presented here show the potential impact that preservation and restoration efforts at the existing SPAW sites have beyond their borders, and how other MPAs potentially impact the SPAW sites. The resiliency of coral reef populations within a SPAW MPA will be higher if its number of sources for larvae is higher. Working collaboratively with other MPAs, whether they are part of SPAW or not, will help to ensure connections to larvae sources and destinations are maintained.

Section 7: OTHER ECOSYSTEM CONNECTIONS BETWEEN CARIBBEAN PROTECTED AREAS

In addition to the assessments of ecological connectivity through the migration of sea turtles from nesting to feeding areas (Section 5) and the distribution and recruitment of larvae by reefs in the region (Section 6), it is also considered important to at least highlight marine mammal and bird migrations in connecting distant parts of the Wider Caribbean and beyond. Although an in-depth analysis isn't presented below, the ecological and conservation significance of whale and bird populations is recognized as a priority for establishing protected area networks and linking protection programs and policies for terrestrial and marine habitats across the region.

Marine Mammals

Several marine mammal sanctuaries in the Caribbean have developed "Sister Sanctuary" relationships with Stellwagen Bank National Marine Sanctuary in the United States (Wenzel et al 2018) (Figure 7.1). This initiative has been formally recognized by the SPAW Protocol as the Marine Mammal Protected Areas Network with the purpose to cooperate in humpback whale research, monitoring, protection strategies and management programs. Humpback whales seasonally migrate from summer feeding areas at Stellwagen Bank and the North Atlantic to winter breeding sites in the Caribbean. The SPAW-listed Agoa Marine Mammal Sanctuary in the French Antilles, together with the US, Dutch, Dominican Republic and Bermuda sanctuaries (Figure 7.2) protect whale populations at both ends of their seasonal migrations. However, the cooperative international relationships bring needed attention to expanding conservation programs and policies to include the migratory pathways these whales take between the sanctuaries. As a result, this network of sanctuaries for marine mammals is a model for building other protected area relationships to ensure conservation benefits are not only achieved within the protected area boundaries, but also within the habitats traversed by migratory species that connect protected areas across the Caribbean (Figure 7.3).

The Important Marine Mammal Area initiative of IUCN's Marine Mammal Protected Areas Task Force has been established to bring wider protections to marine mammal populations around the globe (https://www.marinemammalhabitat.org/immas/). Working with this and other marine mammal protection initiatives to highlight Caribbean marine mammal connections may be an opportunity to make marine mammals umbrella species for all Caribbean MPAs. An ongoing review of the Marine Mammal Action Plan, adopted by the SPAW Protocol in 2008, is likely to provide a framework for integrating marine mammal conservation into an expanded network of SPAW and other MPAs in the Caribbean.

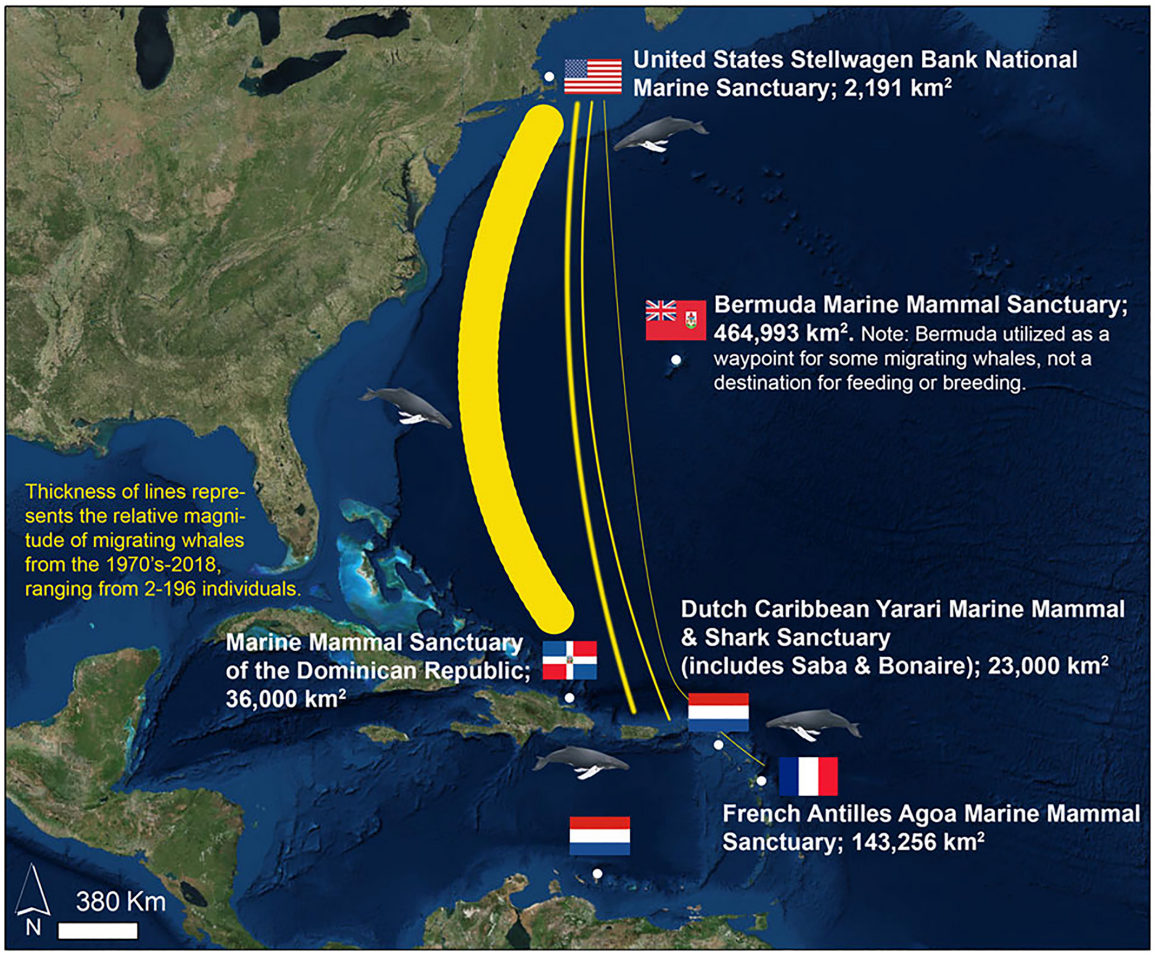


Figure 7.1. Sister Sanctuary Network for the Conservation of North Atlantic Humpback Whale Populations. From Wenzel et al (2018).

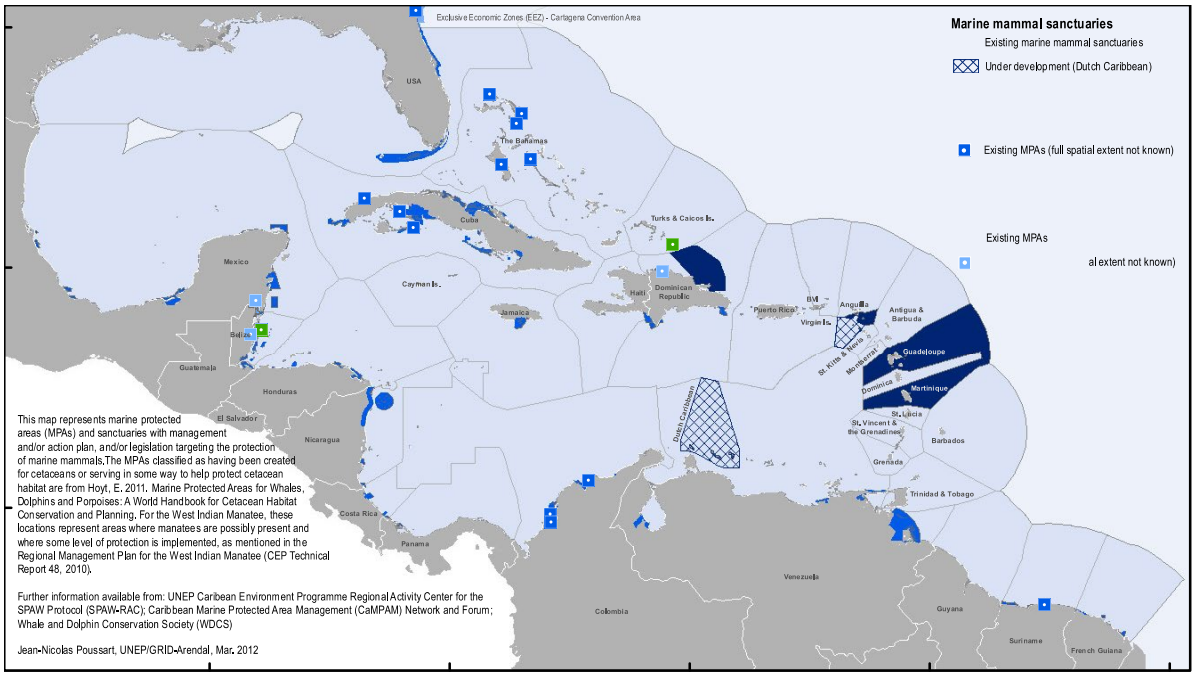


Figure 7.2. Marine Protected Areas of the Caribbean that have specific legislative and/or management policies for marine mammal protections prepared in 2012 by the Spain-UNEP WebLife Project (http://www.ancien-site.car-spaw-rac.org/?Scenarios-for-marine-mammal) The Dutch Caribbean has subsequently established the Yarari Marine Mammal and Shark Sanctuary in 2015, which includes Saba, Saba Bank and Bonaire EEZs.

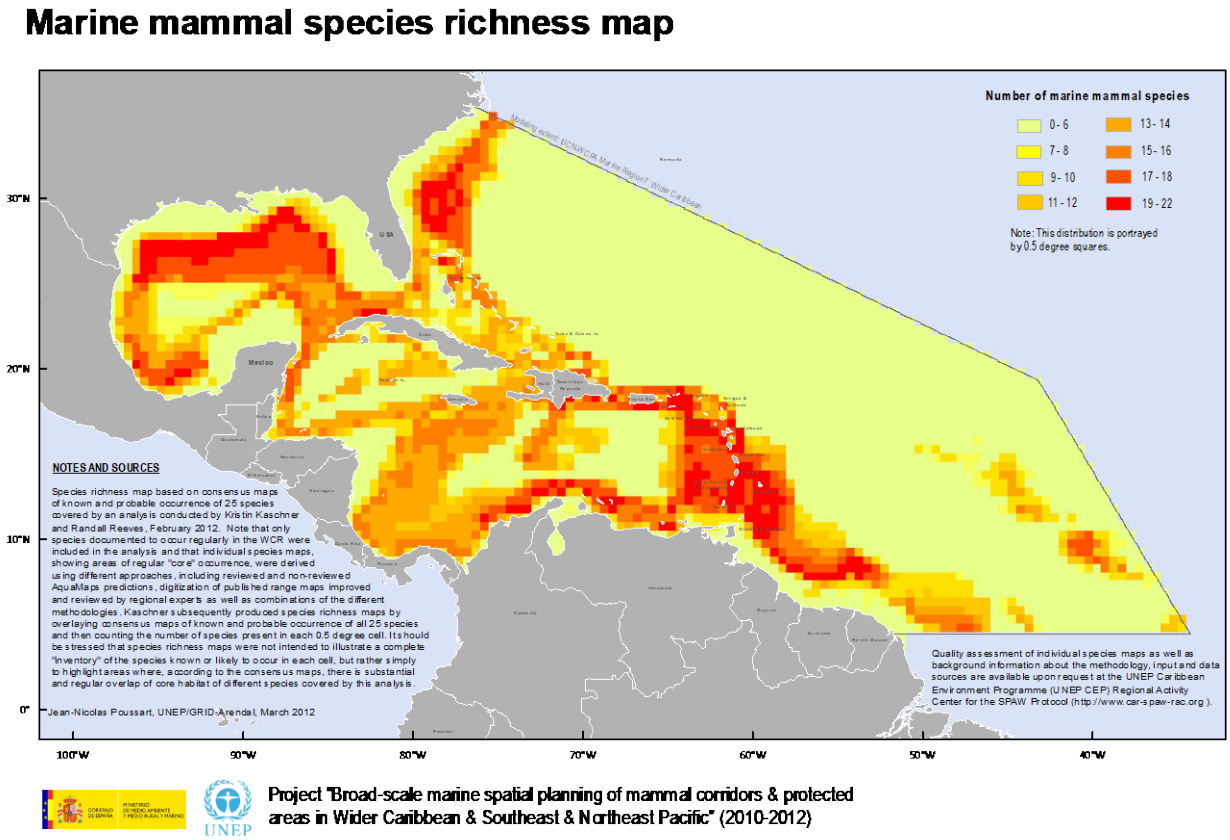


Figure 7.3. Distribution of 25 marine mammal species in the Caribbean. These data were part of the Spain-UNEP LifeWeb Project (http://www.ancien-site.car-spaw-rac.org/?Scenarios-for-marine-mammal) to support development of transboundary marine mammal management actions for the Wider Caribbean.

Migratory Birds

Any assessment of migratory species in the Caribbean would not be complete without consideration of the important Caribbean flyway for bird populations. Billions of migratory birds seasonally move between North and South America and the tropical shores and islands of the Caribbean (Faaborg et al 2010). The large expanses of the Gulf of Mexico and Caribbean Sea are challenging bridges for many of these migrations for which species have evolved diverse strategies to cross (La Sorte et al 2016). For some species, the Caribbean islands are important stopover sites and destinations in these migrations, and the terrestrial habitat conservation measures within Caribbean protected areas are essential to the survival of birds making these annual movements. The Cornell Lab of Ornithology maintains an extensive database (https://ebird.org/) in conjunction with Birds Caribbean (https://www.birdscaribbean.org, Gerbracht and Levesque 2019) of bird biogeography in the region. These data are a valuable tool for highlighting migratory connectivity of key Caribbean locations and potential gaps in protection over the range of different bird species. Brenner et al (2016) used the convergence of

data for bird (and marine) species and threats due to wetland and forest loss in their analysis of migratory corridors (https://maps.migratoryblueways.org) in the Gulf of Mexico (Figure 7.3). Expanding this analysis for the Caribbean using the ebird.org data would show how habitat integrity at key sites in the Wider Caribbean has ecological significance to essential biodiversity conservation programs throughout North and South America.

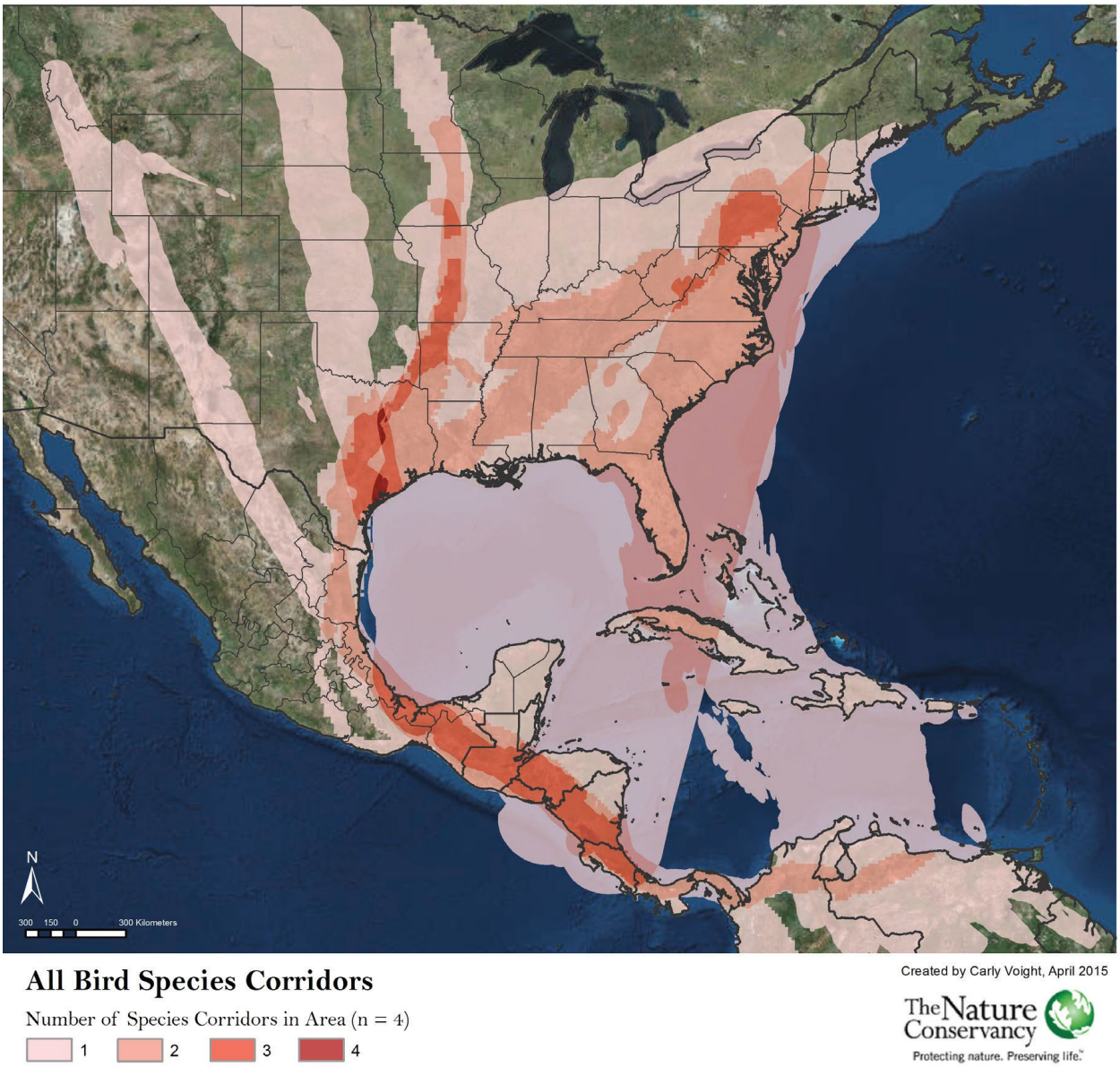


Figure 7.3. Combined data from Brenner et al (2016) for four satellite-tracked bird species. This shows the broad migratory corridors between summer breeding areas in North America and wintering areas in Central and South America. The interactive data and maps can be viewed here: https://maps.migratoryblueways.org.

Section 8: CONNECTIVITY OF ECOSYSTEM THREATS

In addition to supporting ecosystem integrity, physical and biological connectivity also brings threats to that integrity. Water-borne pathogens, the spread of invasive species and pollution have had dramatic impacts on marine communities in recent decades. The examples given here are not meant to be comprehensive, but they show how shared management challenges and direct connections presented by these and other human and climate induced threats make establishing networks of sites important in rapidly identifying and facilitating collaborative responses to them. An ecological network of the SPAW protected areas is not only a network of ecosystem protections, but also a network of ecosystem sentinels that can report and coordinate responses to existing and new threats as they emerge.

In the Caribbean, the mass die-off of the long-spined sea-urchin *Diadema antillarum* in 1983-1984 was particularly consequential (Lessios et al 1984). The mortality of urchins spread rapidly throughout the Wider Caribbean eliminating nearly all populations of the species within a year of its first appearance in Panama in January 1983. The loss of this keystone herbivore significantly transformed the character of Caribbean coral reefs by increasing the widespread abundance of benthic algae populations. The specific pathogen responsible for the disease has not been conclusively identified, but its impact was significant. Its rapid rate of spread followed water current patterns and killed on average 98% of all the *D. antillarium* in its wake (Lessios 1988).

Numerous coral diseases have also been described since the 1970s. These diseases, exacerbated by ocean temperature increases and coral bleaching due to climate change, have contributed dramatically to the decline in coral populations in the Caribbean, particularly *Acropora* species, and have often spread rapidly from one location to another (see review by Bruckner 2009). Most recently, a new disease outbreak, termed stony coral tissue loss disease (SCTLD), has spreading through the region impacting numerous coral species (Precht et al 2016, Aeby et al 2019, Doyle and O'Sullivan 2020). Ocean currents are important in the spread these coral diseases locally, but divers and ship ballast water may also be facilitating their more widespread occurrence. In response to the severe spread of this disease a Caribbean-wide research and coordinated response strategy has been proposed (Skrivanek and Wusinich-Mendez 2020).

Invasive species exemplify how connectivity of biological systems can bring rapid change to marine ecosystems. The introduction of the Indo-Pacific lionfish is an important example. This fish has spread throughout the Western Atlantic and Caribbean since it was first found in the region in the 1980s (Johnston et al 2017). These fish have been recorded to occur in densities greater than 390 fish per hectare (Green and Côté 2009) and their voracious feeding can reduce prey biomass and biodiversity with significant impacts on coral reef fish, crustacean and mollusk populations (Albins and Hixon 2013). Dispersal modeling has shown how currents spread lionfish larvae between regions of the Wider Caribbean and suggests that targeted removal of these invasive fish from key larval source locations could provide some measure of control on their populations (Johnston and Purkis 2015, Johnston et al 2017). Another invasive species that has spread throughout the Caribbean and Gulf of Mexico is the orange cup coral *Tubastraea sp*. Introduced in Puerto Rico and/or Curaçao in the 1930s, probably on ship hulls, the larvae of this azooxanthellate coral have been dispersed widely by currents to colonized natural and artificial substrates and compete with native benthic communities (Creed et al 2017).

Pollution is a significant threat to the health of the Caribbean ecosystem and its human communities. The intimate association of coastal and island environments with the ocean through watersheds and ocean currents mean that nowhere in the Caribbean is isolated from land-based and other sources of water-borne pollution. Nutrient, chemical, oil, plastic and other pollutants are considered significant threats to the people and natural resources of all the nations of the Caribbean (Diez et al 2019).

The LBS Protocol of the Cartagena Convention is a key agreement to limit pollution in the Wider Caribbean through obligations and regional cooperation among the Contracting Parties (https://www.unenvironment.org/cep/what-our-pollution-or-lbs-protocol). This agreement, together with its sister agreement on combating oil spills supported through the Assessment and Management of Environmental Pollution (AMEP: https://www.unenvironment.org/cep/what-we-do/assessment-management-environmental-pollution-amep-programme), is a framework on which to integrate the protections provided by the SPAW Protocol into a comprehensive Caribbean-wide environmental and resource protection strategy through a network of focal points created by the SPAW-listed protected areas. With physical and ecological connectivity at the core of this framework, the actions taken by the protocols of the Cartagena Convention are mutually supportive and mirror the ecological linkages between species, habitats and the environmental conditions that sustain them.

Section 9: RECOMMENDATIONS

This evaluation of the physical and ecological processes that interconnect the SPAW and other protected areas in the Caribbean is a basic blueprint for building alliances based on ecological connectivity. It is meant to be the beginning of a process to better understand the relevance of each protected area in sustaining the condition and resiliency of the marine ecosystem of the Wider Caribbean. The species, habitats and ecological connections that have been highlighted are just a few of the ecosystem elements that can be used as a foundation on which to start building management relationships between marine and terrestrial protected areas.

To begin constructing those relationships, the following actions are recommended. These actions should be implemented in collaboration with protected area managers and their representatives. The CaMPAM Caribbean Marine Protected Area Management Network and Forum (presently under review by UNEP-CEP) and MPAConnect (https://www.gcfi.org/initiatives/mpa-capacity-program) have previously supported communication and capacity among MPA practitioners in the Caribbean and these programs should be jointly engaged to help facilitate these actions.

1. Establish Sub-regional Networks

The evaluation of ecological linkages shows that all parts of the Caribbean are connected, but the linkages are strongest at the sub-regional scale. Building network relationships between protected areas may be most efficient and provide the most relevance to country jurisdictions if

they are initially focused at the sub-regional scale. These sub-regional networks can be the basis for linking the Caribbean into a larger network of these sub-regional relationships (Figure 9.1)

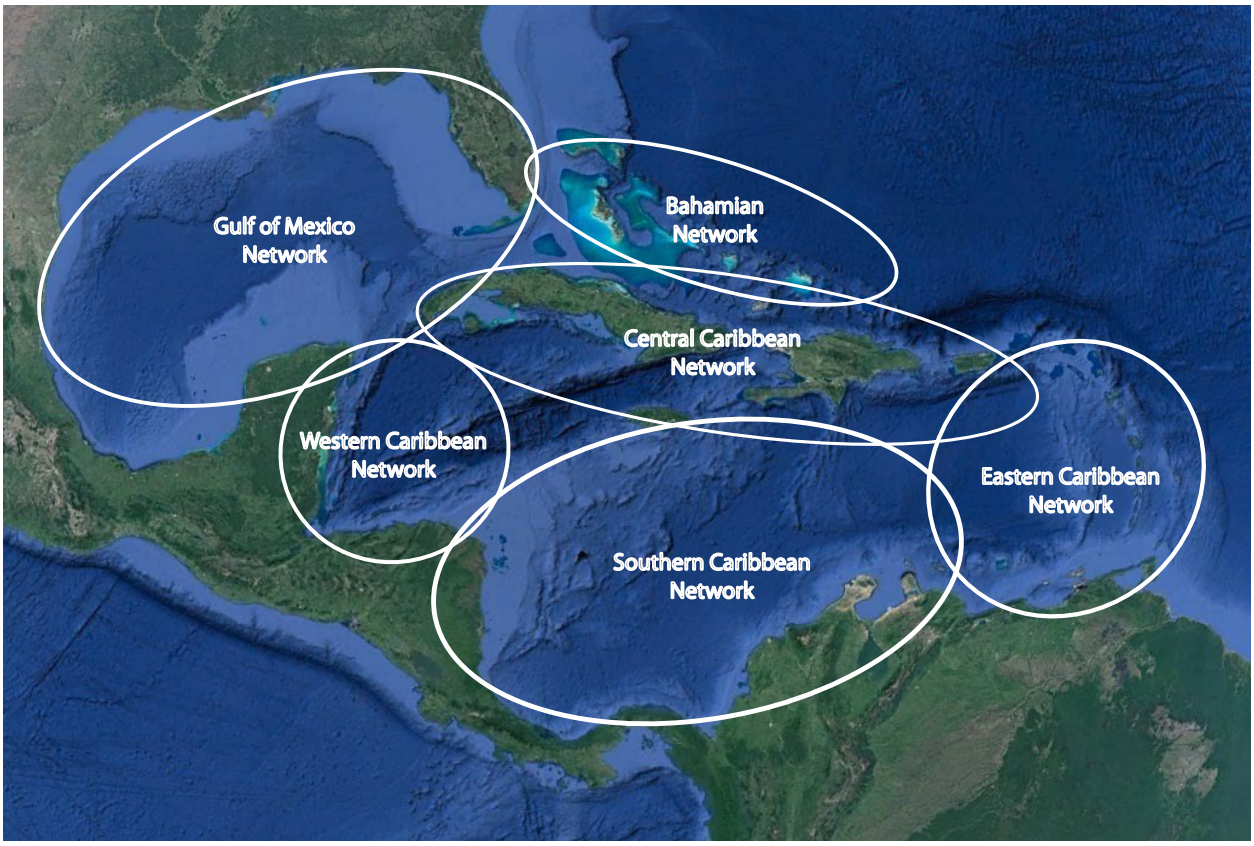


Figure 9.1. Conceptual grouping of protected areas into sub-regional networks. These groupings should be developed by the marine and terrestrial protected areas they incorporate and by utilizing what is known about ecological connectivity between them. The boundaries overlap to indicate that they are arbitrary in concept and that some protected areas can be considered to be part of more than one sub-regional network.

The protected areas within each sub-region should determine how these relationships are assembled and the extent of their geographic scope. The Ecoregions that were developed by Spalding et al (2007) for the Caribbean could also be used as a basis for these networks. Some sub-regional collaborations already exist and should be used to help form the relationships. A few of these include:

- The Dutch Caribbean Nature Alliance (https://www.dcnanature.org), a regional network of protected areas for Aruba, Bonaire, Curaçao, Saba, St. Eustatius and St. Maarten.

- Healthy Reefs Initiative (https://www.healthyreefs.org/cms), a collaboration between Mexico, Belize, Guatemala and Honduras to promote the integrity of the Mesoamerican Reef Ecosystem

- Caribbean Biological Corridor Initiative (http://cbcbio.org), an intergovernmental initiative by Cuba, Haiti, Dominican Republic and Puerto Rico for implementing projects to conserve and manage shared terrestrial and marine biodiversity.

- RedGolfo – Gulf of Mexico Marine Protected Area Network (http://www.cubamar.org/redgolfo, Gil-Agudelo et al 2020), an initiative between MPAs in Mexico, Cuba and United States and proposed as a project of the GEF-funded Gulf of Mexico Large Marine Ecosystem Program (https://iwlearn.net/learning/twinning/twinning-exchanges/creating-a-trilateral-cooperation-between-cuba-mexico-and-the-usa-28-november-2-december-2017).

The SPAW-listed protected areas could take on roles as coordinating "hubs" in sub-regional "clusters" of MPAs (Figure 9.2). This would create a more inclusive network of protected areas incorporating sites that are not listed under SPAW, but are important to the SPAW sites through their ecological connections. This could also help to bring new protected areas to the SPAW listing process by highlighting their ecological value to regional conservation efforts.

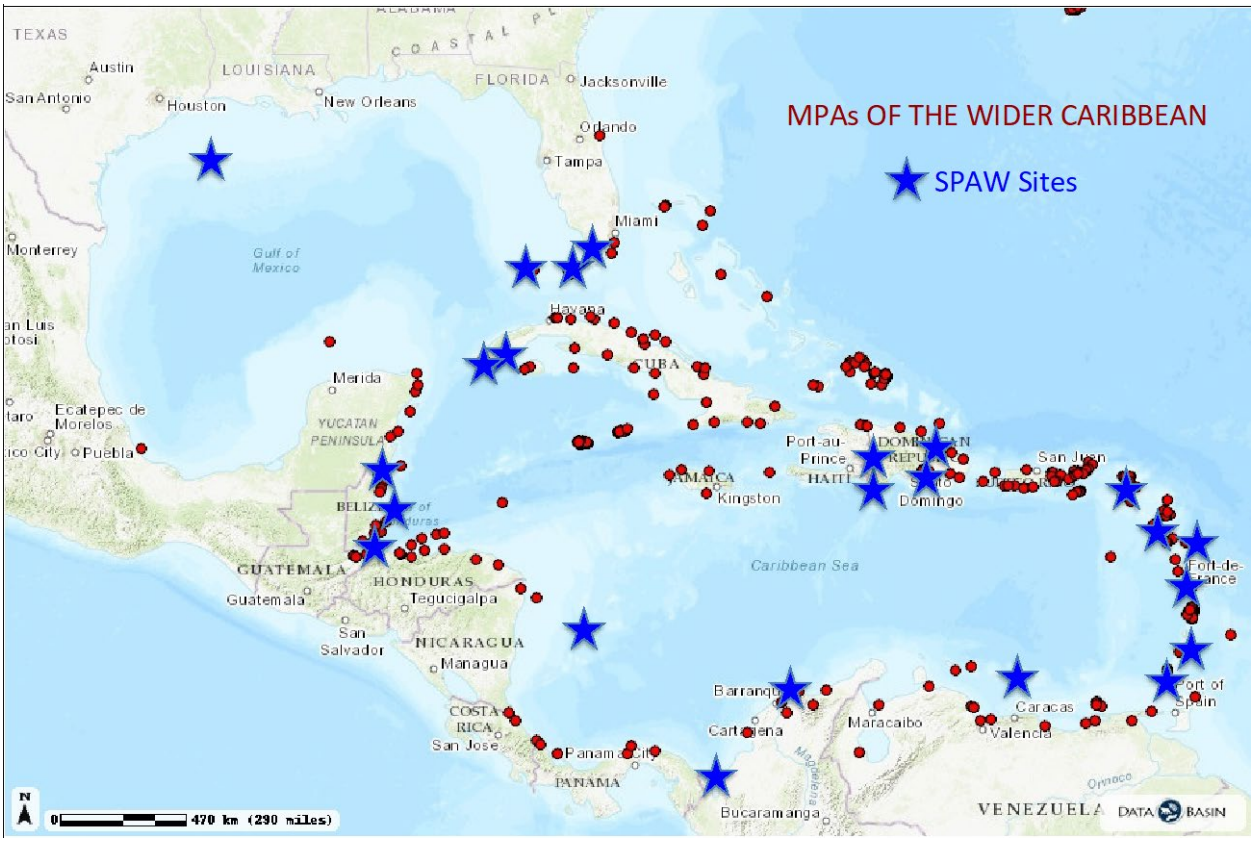


Figure 9.2. Caribbean marine protected areas (red dots) and SPAW protected areas (blue stars), which could coordinate network relationships between sub-regional clusters of protected areas. Base map of Caribbean MPAs from databasin.org (https://databasin.org/datasets/aecb22a5c5e44de29ec5bdcd6bfac186/).

Developing network relationships among marine protected areas in the Wider Caribbean to cooperatively sustain and improve marine environmental conditions and living marine resources has important application to the goals of the Caribbean and North Brazil Shelf Large Marine Ecosystem project (CLME+ https://clmeplus.org). This GEF-funded, UNDP-implemented initiative between 25 countries and 8 overseas territories of the Caribbean is broadly focused on strategies and actions to improve trans-boundary governance and management of shared living marine resources, particularly those related to fisheries. Its regional-level approach to ecosystem-based management of marine resources is an important objective that is obviously shared with a coordinated network of marine protected areas in the Caribbean. Partnering with the large scope of the CLME+ program will ensure that the ecological benefits of a SPAW marine protected area network are realized in the outcome of the CLME+ program's strategic plans.

2. Fill Gaps in Species Inventories and Prepare an Interactive Habitat Atlas

The foundation on which to start building protected area network relationships is knowledge of the species and habitats found at each site in the network. The inventories and habitat descriptions that have been presented in Sections 3 & 4 are an initial assemblage of comparable data across the network of SPAW sites. Sites should be engaged and assisted to fill gaps in the data to allow a more complete inventory of the biological components and characteristics of each site and the network. These data should be combined with an online atlas of the sites that builds on what is presented in Section 2 to create an interactive database of comparable information about each site. The Allen Coral Atlas project (https://allencoralatlas.org) and The Nature Conservancy's Caribbean Benthic Habitat Mapping Project (https://tnc.maps.arcgis.com/apps/opsdashboard/index.html#/7655ed9235554926807f7f587376c1ae) have used satellite imagery to assess and visualize the distribution of key coral reef habitat types in many parts of the Caribbean. The interpretations of satellite imagery incorporated in these projects, combined with local knowledge of habitats, could be used to display quantitative habitat data at the MPA scale and allow comparisons to be made between network sites. Combining these maps with species inventories and other data, such as bathymetry and characteristics of deep-water habitats, would provide a valuable reference tool for understanding what is in SPAW and other protected area sites and allow protected area managers to better understand what their sites have in common.

3. Invest in the Science of Ecosystem Connectivity and Marine Protected Areas

Sections 5-7 have presented just a small selection of results from the large amount of research that has been published about ecological connectivity in the Caribbean and elsewhere. However, those few studies show how the movement of species and their offspring is essential to the survival of biological populations and to designing effective conservation actions that can have a meaningful impact beyond where they occur. Research also shows that understanding and tracking ecological connectivity is important in preparing for and responding to impacts that threaten marine populations throughout the Caribbean (Section 8). This is particularly true for the challenges that climate change impacts bring to protected areas. Understanding ecosystem

connectivity will be fundamental in managing species populations and their habitats to build resiliency to climate change inside and outside protected area boundaries.

Protected area managers, and their policymakers, need efficient access to scientists and the data they produce to ensure research is designed to address their needs and that management decisions are based on sound science.

A significant amount of modeling and tracking data has already been produced that will be valuable in designing how networks of marine protected areas function. These data should be assembled into an interactive database that can be used to further assess ecological connections and their strengths throughout the region. In addition to working with the models produced by Schill et al (2015), Cowen (2006) and others for invertebrate and fish larvae in the Caribbean, databases of the distribution and movement of species should be part of a protected area network toolkit for exploring biological connections and corridors. A few of these databases include:

- WIDECAST – Wider Caribbean Sea Turtle Conservation Network (https://www.widecast.org), maintains data on nesting locations and facilitates regional conservation and management of sea turtle populations.

- SWOT – State of the World's Sea Turtles (https://www.seaturtlestatus.org), compiles and publishes global sea turtle migratory, nesting and conservation data.

- Migratory Connectivity in the Ocean (https://mico.eco), tracking data for fish, seabird, sea turtles and marine mammals around the world.

- AquaMaps (https://www.aquamaps.org), a global database on the distribution of fishes, marine mammals and invertebrates.

- IMMA E-Atlas (https://www.marinemammalhabitat.org/imma-eatlas/), a product of IUCN's Important Marine Mammal Area initiative and Marine Mammal Protected Areas Task Force. It has established regional groups dedicated to wider protections of marine mammal populations around the globe. However, it presently lacks representation for the Caribbean. Integrating the data and maps produced for Caribbean marine mammal corridors in the LifeWeb Initiative (http://www.ancien-site.car-spaw-rac.org/?-Maps-and-reports-) and from other sources with the IMMA atlas is needed.

- Global Shark Movement Project (https://www.globalsharkmovement.org), a database and research program that assembles global tracking and environmental data on shark populations and their movements.

- eBird (https://ebird.org), an extensive global interactive database of sightings, movements and biology of bird species and populations maintained by Cornell University.

An effort to assemble some of these data into a comprehensive analysis of migratory corridors for the Gulf of Mexico was done by Brenner et al (2016) (https://maps.migratoryblueways.org).

Expanding this analysis to the Wider Caribbean would significantly improve access to the regional information contained within these diverse data sites.

Developing a network of local, regional and global scientists to advise and respond to the needs of protected areas in the Caribbean should be part of the goals in creating a network of protected areas. CARICOMP was a cooperative international scientific network and monitoring effort by marine laboratories throughout the Caribbean from 1985 to 2007 (Cortes et al 2019). It coordinated standardized monitoring of marine and coastal productivity and condition by local scientists. Reviving this network could provide an important resource of local knowledge, long-term monitoring data and established relationships of scientists with local governments. These laboratories, their association with regional academic institutions and scientists, and their use of local and regional protected areas as study sites, would help to cultivate and promote a new generation of Caribbean marine scientists and protected area managers.

Networks of protected areas are networks of sentinels that can identify and report threats when they emerge. Access to good science will allow a network to rapidly recognize these threats and their origin. It will also help to accurately target a collective response.

4. Develop a Network Condition Evaluation

All the SPAW-listed protected areas have some form of assessment for documenting the state of their protected resources and environment, and a review process for evaluating the effectiveness of the protected area's management. However, differences in the way these assessments and evaluation are done and reported limit the ability to compare the status and trends of resource and environmental conditions across the network of sites. A few innovative and informative "report cards" have been developed for some parts of the Caribbean based on key indictors of ecosystem health. Some of these reporting programs include:

- Mesoamerican Reef Report Card (https://www.healthyreefs.org/cms/report-cards/) produced by the Healthy Reefs Initiative. Six report cards have been developed since 2008 that use a Reef Health Index based on coral cover, macroalgae abundance, and fish populations. These series of reports on the health of reefs in Mexico, Belize, Guatemala and Honduras allow an evaluation of ecosystem trends over time in context to the success of management strategies and conservation initiatives in response to ongoing and new threats to the integrity of reef and associated communities.

- Eastern Caribbean Report Cards (accessible here: https://www.agrra.org/resources/) produced in 2016 by the Nature Conservancy for Antigua & Barbuda, Dominica, Grenada, St Kitts & Nevis, St Lucia and St Vincent & the Grenadines. These individual country reports also used the Reef Health Index indicators to display scores based on local monitoring data collected as part of the ECMMAN Project (https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/Caribbean/science/management/Documents/ECMMAN%20Project%20Accomplishments%20(2013-2017).pdf)

- Other "report card" initiatives have been established in the Bahamas (http://www.perryinstitute.org/category/coral-reef-publication/) and Cayman Islands (https://reefresearch.org/wp-content/uploads/2020/06/HRR-Card-Final-2020.pdf).

- The Atlantic and Gulf Rapid Reef Assessment Program (https://www.agrra.org), while not a "report card," is a widely used monitoring protocol for providing the data that is used in preparing the above reports. Its database is a useful tool for evaluating coral reef condition across the region.

- Twelve countries of Latin America have conducted a "coordinated audit" of terrestrial and marine protected areas through Latin American and Caribbean Organization of Supreme Audit Institutions (OLACEFS) based on a set of common indicators using the Protected Areas Implementation and Management Index (INDIMAPA) tool (https://www.olacefs.com/auditorias-coordinadas/). The process uses data from each country to identify the strengths and weaknesses in the management of protected area resources.

The processes used to produce these ecosystem report cards, while delivering valuable measures of resource and management conditions that are visually engaging, often require expenditure of significant time and resources and may require specific data collection protocols beyond what are already used at a site. Such a reporting system may not be practical for repeated assessment of status and trends in ecosystem condition for a large network of diverse protected areas.

An alternative system of reporting on the condition of the SPAW network of sites could be developed from procedures used by NOAA's Office of National Marine Sanctuaries in the United States (https://sanctuaries.noaa.gov/science/condition/). These procedures summarize local monitoring data and expert knowledge of water quality, habitats and living resources, and the human activities that affect them, without requiring new data or specific indicators to be measured. The process recognizes that the physical and biological structure of the ecosystem at each reported site may differ, but that answers to a series of common evaluation questions based on information that is already known by local scientists, managers and other stakeholders, can produce a local evaluation of ecological criteria and compare the results across a diverse network of protected areas. This wide applicability gives the network a tool for measuring its collective progress toward maintaining and improving the natural resources and the services they provide throughout the network. At the same time, the strengths and weaknesses across the system can be determined, which can help to direct resources to sites where they are most needed. This network reporting system would not compete with or replace local monitoring or reporting procedures. It would expand the results of local reporting and apply them to an evaluation of the larger network.

No matter what type of reporting method is used to compare the status and trends in ecosystem condition and the effectiveness of management across the network of sites, it should be developed in close consultation with the SPAW site managers. This will ensure a full understanding of, participation in, and support for the design and production of the local and regional evaluations.

5. Build Effective Communication and Outreach Mechanisms

The functional success of a protected area network will hinge not only on the strength of its ecological connections, but also, and possibly most importantly, on the strength of its human connections. Implementing any of the recommendations made above will require an effective and lasting communication mechanism that maintains protected area managers and the SPAW Protocol Secretariat in professional and personal relationships. Facilitating these relationships is a critical part of designing what the network of sites can and will achieve. Since 1997, the Caribbean Marine Protected Areas Network and Forum (CaMPAM) (http://campam.gcfi.org, Bustamante et al 2018) has worked to connect SPAW and other protected area managers and stakeholders through the sharing of information, capacity trainings, grants and collaboration on regional projects. MPAConnect (https://www.gcfi.org/initiatives/mpa-capacity-program) has also pioneered a program for building capacity among Caribbean MPA managers through peer-to-peer engagement in training programs that target the specific needs of protected areas. MPAConnect maintains an interactive database of its 31 MPAs that displays site information and status of collaborative projects. CaMPAM is undergoing a review to determine its future direction. This is an opportunity to explore how these two programs can work together with the SPAW sites to improve communication among Caribbean protected area stakeholders, and show how building protected area networks based on ecosystem and management connections has tangible relevance to each of its members.

In addition to knowing that other protected areas value the conservation achievements at each of the sites in the SPAW network, it is also important for protected area managers to know that their local community values their achievements. Partnering with local and regional organizations that promote participatory engagement in protecting natural resource is needed to ensure local knowledge, cultural connections and livelihoods are reflected in how protected areas are established, managed and incorporated into networks. A network of Caribbean protected areas should work with community-based programs, such as the Caribbean Natural Resources Institute (https://canari.org), to help people understand how their natural environment, and their relationship to it, is interconnected to places and people in other parts of the Caribbean and beyond. Community pride in those connections, and in the role local conservation efforts play in strengthening them, will be key to the success of this or any other program designed to keep intact the interconnected ecological mosaic of the Wider Caribbean.

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