

Economic Valuation of Ecosystem Services in Bahamian Marine Protected Areas



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Prepared by the Natural Capital Project



Katie Arkema, PhD

Dave Fisher

Katherine Wyatt

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Acronyms

AIS: Automatic Identification System

BPAF: Bahamas Protected Areas Fund

BREEF: Bahamas Reef Environment Educational Foundation

BNT: Bahamas National Trust

CBD: United Nations Convention of Biological Diversity

CTI: Centre for Training and Innovation

ECLSP: Exuma Cays Land and Sea Park

EEZ: Exclusive Economic Zone

CCI: Caribbean Challenge Initiative

MMA: Marine Managed Area

MPA: Marine Protected Areas

NatCap: Natural Capital Project

NBMR: North Bimini Marine Reserve

NP: National Park

PoWPA: Programme of Work on Protected Areas

SWMMA: Southwest New Providence Marine Managed Area

TEEB: Economics of Ecosystems and Biodiversity

TNC: The Nature Conservancy

Executive Summary

Marine Protected Areas for People and the Environment

The marine and coastal environment of The Bahamas provides habitat for a diversity of animals and plants and numerous benefits for the Bahamian people. Yet coral reefs, mangroves, sand flats, beaches and other ecosystems across the archipelago suffer from a growing intensity of activities in the coastal zone, putting at risk the fisheries, tourism, storm protection, and other benefits from nature that underlie the country's economy and ensure human wellbeing.

The Bahamas has the opportunity to protect and manage coastal and marine ecosystems and the wealth of economic benefits they provide to Bahamians and beyond.

Bahamas Protected is a three-year initiative to effectively manage and expand the Bahamian marine protected areas (MPA) network to safeguard the economic value of marine ecosystems. It aims to support the Government of The Bahamas in its commitment to the Caribbean Challenge Initiative in which 11 countries pledged to protect 20% of marine and coastal habitat by 2020 with sustainable financing for effective management. Bahamas Protected is a joint effort between The Nature Conservancy (TNC), Bahamas National Trust (BNT), Bahamas Reef Environment Educational Foundation (BREEF), and other stakeholders, with major funding from Oceans 5. As a component of Bahamas Protected, the Natural Capital Project was contracted to quantify the economic value of ecosystems within the Bahamian MPAs and the influence of alternative management scenarios on future benefits.

Valuing nature's bounty to promote marine protection

Traditional approaches to MPA management focus on ecological considerations, such as a sufficient diversity and proximity of habitats. While such factors are essential for sustaining species, they may miss the societal importance of MPAs. Increasingly, conservation practitioners, governments, and other stakeholders are considering the benefits that nature provides to people, or 'ecosystem services.' Diverse, functioning ecosystems provide myriad benefits that can be sustained through protected area management. Nearshore habitats bolster the stocks of fisheries, beaches and reefs draw tourists, and coastal forests and seagrasses buffer storm waves, mitigate climate, and promote water quality.

Based on the Natural Capital Project's previous work in The Bahamas and throughout the Caribbean, we quantified the economic value of four key ecosystem services within the existing MPA network (Fig ES-1). We take two distinct, but complementary approaches. For the current MPA network, we estimate gross value of ecosystem services provided at each site as compared to no service provision. For New Providence and Andros, we include risk of human activities to ecosystems and services. Coupled with costs, this information could be leveraged to estimate the net value of Bahamian MPAs.

Nursery habitats to support lobster fisheries



- \$23.5 million in export value annually
- 6 million lbs. catch annually

Vibrant tourism



- \$67.6 million in expenditures annually
- 383,000 visitor-days annually

Communities protected from coastal hazards



- Reduced exposure to 39,000 people and \$806 million in annual income

Carbon storage for climate mitigation



- \$5 billion in avoided carbon emissions
- 400 million tons CO₂ in mangroves & seagrass

Figure ES-1. Economic value of four ecosystem services provided by The Bahamas MPA network.

Additional services that would likely increase the overall value of the network (Hargreaves-Allen 2016) include:

- Fisheries support worth \$268/km²/year from coral reef, mangrove, seagrass, and tidal creek
- Freshwater supply worth \$15.5/km²/year from tidal creek
- Water and water quality services worth \$508/km²/year coral reef, mangrove, seagrass, and tidal creek
- Cultural and aesthetic services worth \$324/km²/year from coral reef, seagrass, beach, tidal creek, and open water

Spatial variation in the value of ecosystem services provided by the MPA network

TNC, BNT, Dr. Venetia Hargreaves-Allen, and others have assembled considerable information about the economic value of ecosystems, species, and MPAs in The Bahamas. The Natural Capital Project built on this knowledge by estimating spatial variation in the economic value of ecosystem services within the existing MPA network. It is important to note that we do not analyze the marginal benefit of MPA implementation itself.

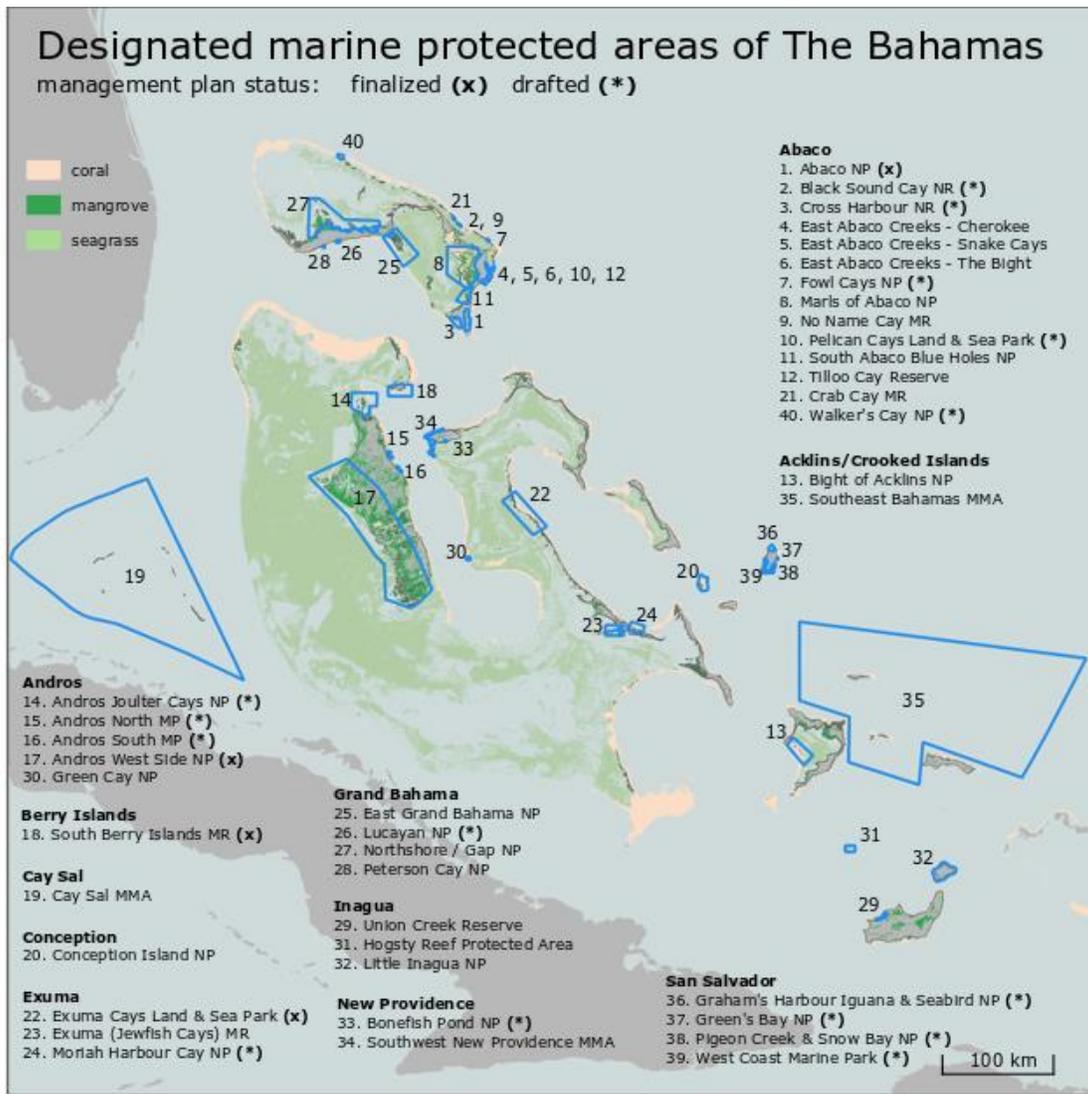


Figure ES-2. Designated marine protected areas of The Bahamas. NP=National Park, MP=Marine Park, MR=Marine Reserve, MMA=Marine Managed Area.

The value of ecosystem services within individual MPAs vary greatly across the network as a function of ecological, social, and economic factors. These differences can be used to inform management.



The Andros West Side National Park, Marls of Abaco National Park, and Cay Sal Marine Managed Area contain a higher proportion of their region’s mangroves and seagrass than other protected areas in those regions and thus exemplify priority areas for management to ensure the economic benefits of fisheries into the future. The economic value of nursery habitat for spiny lobster within MPAs depends on the extent of nursery habitat, and proximity to adult, shallow shelf habitat, as well as other factors such as larval recruitment.



The higher tourism expenditures attributable to Southwest New Providence Marine Managed Area and Exuma Cays Land & Sea Park illustrate the importance of infrastructure and access for supporting tourism and highlight how investing in protection and management of coral reef and fish communities can foster a world-renowned location for tourism.



Half the population of San Salvador and 1/3 the population of the Berry Islands are at lower risk from coastal hazards due to ecosystems within MPAs. More than 30,000 people on New Providence live in areas partially protected by corals in SWMMA and coastal forests in Bonfish National Park. The economic value of coral reefs, seagrass beds, mangroves, and coppice within MPAs for reducing the storm risk of coastal communities depends on exposure (e.g., shallow, wide shelves are associated with storm surge) and proximity to coastal populations.



Habitats in Andros West Side National Park and Marls of Abaco store the most carbon in the network, valued at more than \$3.5 billion and \$500 million in avoided carbon emissions, respectively. The economic value of carbon sequestration within MPAs varies spatially, due to size (i.e. area of carbon-storing habitat), relative abundance of seagrass vs mangroves (mangroves store more carbon per unit area), and abiotic factors (e.g., precipitation, temperature).

Table ES-1. Value of four ecosystem services provided by existing marine protected areas in The Bahamas.

Ecosystem Service	Values provided by ecosystems within the existing MPA network	Factors that influence spatial variation in ecosystem service value (not comprehensive)
Tourism	383,000 visitor-days and \$67.6 million in expenditures annually	Island differences in visitation, expenditure, habitat extent, access, infrastructure
Coastal protection	Reduced exposure to 39,000 people and \$806 million in income annually	Habitat type and quality, coastal elevation, shoreline type, surge potential, wave characteristics, sea-level rise, proximity of habitats in MPA to coastal population
Nursery habitat for spiny lobster	6 million lbs. and \$23.5 million in revenue from the lobster fishery is attributable to nursery habitat annually	Habitat type and extent, larval recruitment to nursery habitat, proximity of nursery habitat to shallow shelf habitat for adults
Carbon storage for climate mitigation	400 million tons of CO ₂ stored and \$5 billion in avoided damages from emissions globally	Relative abundance of mangroves and seagrass, carbon stored in soil and aboveground biomass (based on climate).

Island-scale valuation of ecosystem services to inform future management

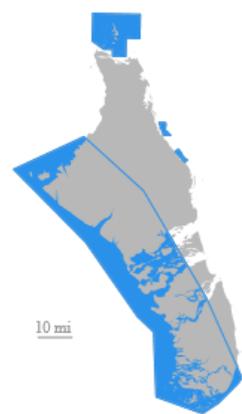
The economic value of ecosystem services provided by habitats within the current network differs among MPA sites, as does management status. Some MPAs have finalized management plans and others have plans in the development stage. In the island-scale analyses below, we explore in greater depth the value of ecosystem services provided by habitats and implications for management. For New Providence and Andros, we include current risk of human activities to habitats and services. Results for these cases provide insight into potential gains if MPAs were to fully protect habitats.

Exuma Cays Land and Sea Park is the oldest marine protected area in The Bahamas and the only one managed as a no-take area. The fisheries, tourism, and carbon storage and sequestration values indicate the importance of continued investment into the ECLSP for enforcement, boats, infrastructure and more to maintain these benefits now and into the future. Within the park, our analysis estimates



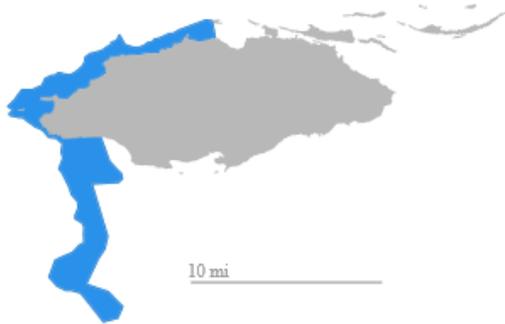
- Visitors spend \$6.6 million annually from 23,000 visitor-days.
 - Nursery habitat supports \$1 million in export value of spiny lobster annually and 240,000 lbs. in catch.
 - Coral, seagrass, and mangrove protect much of the Exuma Cays coastline and reduce the risk of coastal hazards for people along the southern extent of the Cays (low population precludes assigning a coastal protection value to ecosystems within ECLSP).
 - Seagrass and mangroves prevent over \$130 million in avoided damages due to emissions by storing more than 10.7 million tons of carbon.
- Previous studies indicate increased biomass and reproductive capacity for lobster, Nassau grouper, and queen conch within the park and that improved fisheries outside the park, along with increased high-end tourism and property values within the park, has generated over \$9 million in direct and measurable economic impact in a single year.

Andros' West Side National Park, Joulter Cays, North and South Marine Parks, and Barrier Reef provide a wealth of natural resources. The Sustainable Development Master Plan for Andros informs investments in infrastructure and education to support livelihoods, while safeguarding the ecosystems that underlie the island's economy and human wellbeing. The Master Plan would



- Increase tourism expenditures from \$113 million currently to \$170 million, an increase of more than 35% in Mangrove Cay and North Andros and 10% and 20% in South and Central Andros, respectively. In contrast, intensive development would concentrate tourism in the North and South districts, further exacerbating the unequal distribution of wealth.
 - Increase the value to the lobster fishery provided by nursery habitats in Andros MPAs by \$6.5 million, from \$14.5 to \$21 million annually.
 - Protect more than 60% of the populated coast of Andros (up from 50%, \$2.4 million, currently protected). Unregulated development and destructive fishing practices would more than triple the number of people at risk from flooding and erosion.
 - Increase carbon storage assets, worth \$6 billion in Andros West Side National Park, by 3% and safeguard against \$550 million in damages possible under more intensive development.
- Previous studies show that natural resources on Andros generate \$155.6 million in direct economic revenue (2015 dollars), including \$52,000 from fishing and roughly \$25,000 from crabbing and sponging (Hargreaves-Allen 2010).

Southwest New Providence Marine Managed Area borders the most populated island in The Bahamas. Habitats within SWMMA provide benefits to a multitude of users, yet the cumulative risk from human activities—development, dredging, oil leakage, tourism, invasive species, fishing, and marine transportation—threatens to reduce the services the area provides. Our risk-based analysis for SWMMA estimates that



- Visitors currently spend an estimated \$14 million annually, yet this could be increased by 14% if habitats faced lower risk of degradation.
- Risk from current activities reduces, by 50%, the contribution of nursery habitat for lobster, a loss of \$127,000 (from \$259,600 if habitats faced no risk of degradation from human activities).
- 6% of New Providence’s population (and 12% of its income) is at greater risk from storms as a result of current risk to habitats. Habitats around New Providence could

protect up to 30,000 people if they faced no risk.

- Habitats in SWMMA could store up to 2.45 million tons of carbon, but are compromised by risk from current activities, storing only 1/2 as much than if they faced no risk, at a global cost of \$16 million.
- Restoring ~6 km² of coral within the park could result in \$662,000 more in visitor-expenditure annually and would protect an additional 22,000 people and \$606 million in annual income.

North Bimini Marine Reserve (NBMR) was approved in 2010 but never officially gazetted. Management actions that reduce the risk of degradation have the potential to benefit not only the seagrass, mangroves, coral, and species, but also the people of Bimini that rely on these ecosystems for their sustenance, livelihood, and safety. Within the reserve



- An estimated 19,500 tourists visit each year, spending \$3.3 million.
- Nursery habitat supports nearly \$300,000 in lobster export value and 76,505 lbs. of catch annually.
- Mangroves, seagrass, and even the little bit of coral within the reserve reduce the risk to coastal hazard for nearly half of the population of north Bimini (3,000 people), with reduced exposure to \$31.2 million in income annually.
- Mangroves and seagrasses store over 3.5 million tons of carbon, worth \$46.2 million in avoided damages.

Eleuthera does not currently have any MPAs, yet adjacent habitats provide important benefits, demonstrating the potential value of MPA designation. These metrics could be used to engage diverse stakeholders (e.g. residents, fishers, and tour guides) around MPA designation. Benefits include



- \$30 million in visitor-expenditures are generated in Northern Eleuthera, followed by \$17 million and \$11.5 million in Central and Southern Eleuthera, respectively.
- \$5.7 million annually in lobster export value (from 1.5 million lbs. in catch) is attributable to nursery habitat around Eleuthera.
- All 11,000 people living on the island benefit from the reduction in coastal hazards marine ecosystems provide, especially along the high hazard areas to the north, the eastern side of the island, and Southern Eleuthera.
- Mangroves and seagrass store more than 120 million tons of carbon, worth more than \$1.5 billion in avoided damages.

Implications of findings for MPA policy, planning, and management

According to our analysis, visitation within MPAs provides \$67.6 million annually in tourism expenditures, 2.6% of overall expenditures in 2015. Ecosystems within the existing MPA network are worth more than \$23.5 million annually in nursery habitat values for spiny lobster. The nursery habitat within the MPA network contributes to 50% of the overall value of the lobster fishery, which in turn provides more than 1,300 active lobster jobs (Sealey 2011). In addition, ecosystems in the network reduce the risk of coastal hazards, such as Hurricanes Mathew and Joaquin, to nearly 40,000 people living along coastlines throughout the country and \$806 million in annual income. Mangroves and seagrass within the MPA network store 400 million tons of carbon, worth \$5 billion in avoided emissions globally.

- Effective management is important for maintaining and growing the economic value of the ecosystem services within the existing network of MPAs, as the examples of SWMMA and Andros show. Only four out of the 40 existing MPAs have management plans finalized; 15 sites have draft plans. Without effective management and financing to protect coastal and marine ecosystems, The Bahamas puts at risk the economic value of its fisheries and tourism sectors and increases its vulnerability to hurricanes and climate change.
- The economic value and benefits of coastal and marine ecosystems for all Bahamians illustrates the importance of considering MPA management within the context of comprehensive planning processes. Vision 2040 and the Integrated Coastal Zone Management processes on a national scale, and sustainable development planning on a local scale, provide opportunities to incorporate MPA management.
- By maintaining the economic value of ecosystem services provided by functional habitats, well-managed MPAs can help The Bahamas achieve several of its international commitments, such as those under the Convention on Biological Diversity. Additionally, several Sustainable Development Goals are related to MPAs including, healthy oceans (Goal 14), poverty alleviation (Goal 1), hunger (Goal 2), health (Goal 3), climate action (Goal 13), and sustainable cities and communities (Goal 11).
- An analytical ecosystem services approach can be used to model and quantify the gross economic value of possible sites for future protection under the 20-by-20 challenge. Taken in conjunction with information about costs of implementation and threats to habitats that provide services, the economic value of ecosystem services can help to ensure that management strategies maximize net benefits to MPA-adjacent communities and all Bahamians.
- By fostering an iterative process between ecosystem service valuation and stakeholder engagement, Bahamas Protected has the opportunity to understand how management decisions made today will influence the sustainability and economic value of ecosystems into the future, to enhance information exchange, transparency, and positive participant interaction, and to ensure local support and management of new sites in the Bahamian MPA network.

Conclusion

The economic value of ecosystem services and the livelihoods they support indicate the importance of managing the MPA network now in order to help safeguard against the loss of economic and societal benefits to Bahamians, the Caribbean, and people world-wide in the future. Please see the complete report for the full analysis of spatial variation in ecosystem services provided by habitats within the MPA network and island-scale valuation of ecosystem services to inform management.

1. Introduction

Background

The marine and coastal ecosystems of The Bahamas provide habitat to a diversity of animals and plants and numerous benefits to the Bahamian people. Thousands of miles of beach, extensive sand flats, barrier and fringing reefs, and the highest density of blue holes in the world are home to many species, including turtles, flamingos, and coral reef fish (Thurlow and Palmer 2007), and draw more than 6 million tourists annually (Ministry of Tourism 2015). Several commercial, recreational and subsistence fisheries support livelihoods and provide sustenance to the Bahamian people (Hargreaves-Allen 2010, Department of Marine Resources 2014). While these coastal and ocean activities are critical to The Bahamian economy and well-being of its people, they also pose risks to the very ecosystems that make them possible. For example, coastal development for tourism and housing can lead to mangrove clearing and pollution; over-fishing threatens economically and ecologically important fish as well as the coral reefs they depend upon (Halpern et al. 2008). Hurricanes such as Joaquin and Mathew underscore the dangers settlements and cities face with rising seas, a growing intensity and frequency of storms, and loss of natural resources that buffer shorelines (Arkema et al. 2017, Sullivan Sealey et al. 2017).

To safeguard coastal and marine ecosystems in the Bahamian archipelago and throughout the Caribbean, The Government of The Bahamas and governments of ten other countries and territories have committed to the Caribbean Challenge Initiative (CCI). This regional agenda involves protecting and effectively managing 20% of marine and coastal ecosystems in each country by 2020 (the '20-by-20' goal) and ensuring that the conserved areas are effectively managed into the future inclusive of a reliable, long-term finance structure. To meet this target, The Bahamas continues to expand on its existing network of Marine Protected Areas (MPAs) since 2008, which currently covers 10% of nearshore and marine environments. The goal of the initiative is not only to expand coverage of protected sites. Effective implementation and management of the protected areas will be needed to fulfill national conservation objectives, mitigate and adapt to projected climate change impacts, and to ensure the sustainability of ecosystems and the benefits they provide to Bahamian people and beyond.

Bahamas Protected is a three-year initiative to effectively manage and expand the Bahamian marine protected areas (MPA) network. It aims to support the Government of The Bahamas in meeting its commitment to the Caribbean Challenge Initiative (CCI). Bahamas Protected is a joint effort between The Nature Conservancy, the Bahamas National Trust, the Bahamas Reef Environment Educational Foundation and multiple national stakeholders, with major funding from the international philanthropic organization, Oceans 5. One component of Bahamas Protected is the quantification of ecosystem services provided by coastal and marine ecosystems to make the economic case and build awareness and support for MPA declaration.

Economic Valuation of Ecosystem Services within Bahamian Marine Protected Areas

Traditional approaches to MPA planning have focused on ecological goals and habitat parameters (Carr 2000). While ecological considerations are essential for conserving sufficient area and diversity of habitats in close enough proximity to ensure the sustainability of critical species and habitats, they may miss the importance of conserving and managing ecosystems for human communities. Increasingly, conservation practitioners, government agencies, coastal planners, and other stakeholders are

considering the benefits that nature provides to people, or ‘ecosystem services’, in their approaches to coastal and marine management (Arkema et al. 2015, Langridge et al. 2014, White et al. 2012). Using an ecosystem services approach to inform planning and management of MPAs can help generate social support from adjacent residents (Hamu et al. 2004, Abecasis et al. 2013) and ensure that the MPAs meet community expectations and align with residents' livelihood and culture (Meyer and Helfman 1993, Hayes et al. 2015).

Globally, the ecological, economic, and social impacts of MPAs vary widely (Lester et al. 2009, Mascia et al. 2017, Gill et al. 2017). MPAs often increase the biomass, density, size, and diversity of otherwise exploited species within park boundaries, with corresponding indirect effects on other species and adjacent areas such as increased larval recruitment and spillover of adult fish (Abesamis and Russ 2005, Amargo et al. 2010, and Januchowski et al. 2013). However, outcomes from MPA establishment vary considerably among different sites. A recent study suggests a strong relationship between achievement of conservation objectives and effective management, adequate staffing, and sufficient financial resources (Gill et al. 2017). One of the largest and most financially viable MPAs in the world is the Great Barrier Reef Marine Park (GBRMP), with economic value of more than \$5.5 billion per year in benefits to local economies and employment estimated at 53,800 jobs. Moreover, the expansion of no-take zones in GBRMP in 2004 appears to have contributed to widespread recovery of depleted fish stocks (McCook et al. 2010). MPA establishment in other regions has also had positive economic benefits (Somonte et al. 2010, Hargreaves-Allen 2012, Schuhmann and Mahon 2015, Hargreaves-Allen and Pendleton 2016). The social impacts of MPAs are widely debated and less well-understood (Mascia et al. 2017).

In The Bahamas, several previous studies have assembled considerable information about the economic value of ecosystems, species, and MPAs (Hargreaves-Allen 2010, 2011, 2016, Micheletti 2016). Our review of the past literature (see below) suggests that flats and estuaries, coral reefs, and mangroves are the most highly valued habitats, ranging in value from more than 30,000 to more than one million per square kilometer per year (adjusted to 2015 values). These habitats vary in the services they provide; for example, coral reefs are important for tourism and coastal protection, but have not been shown to contribute substantially to carbon storage and sequestration. While mangroves, tidal creeks and flats provide important fisheries and carbon storage and sequestration values. These studies are useful for producing total economic value of ecosystems for multiple ecosystem services and raising awareness about the importance of protecting coastal and marine ecosystems for people as well as the environment. However, economic values of ecosystem services vary spatially with differences in ecological, social, and economic factors. For example, coastal protection values tend to be higher where coral reefs are in shallow water near wide swaths of mangroves and fronting populated areas versus places where corals are deep, mangroves are sparse, and there are few buildings. Given this variation, what is needed to inform the management and declaration of MPAs is a better understanding of the economic value of ecosystems across the diverse network of MPAs and how management decisions made today will influence ecosystem services provided to Bahamians in the future.

To quantify the economic value of ecosystems within the marine protected area network, the Bahamas Protected project collaborated with the Natural Capital Project (NatCap). NatCap works with leaders of countries, companies, communities, and organizations worldwide to develop practical tools and approaches to account for nature's contributions to society to enable them to take action for a more sustainable future. NatCap has developed a suite of ecosystem service models, called InVEST, that connect habitat quality to ecosystem services and produces metrics in biophysical, economic and social

terms. We have tested several of the service models for coastal and marine ecosystems in The Bahamas over the last two years to inform a master plan for Andros Island (Arkema et al. 2016, BRL Ingénierie 2017).

For the current project, we used InVEST to model the value of four ecosystem services within the existing MPA network. This approach captures the gross value of ecosystem services rather than the net benefit of MPA designation. Gross value reflects the value of the ecosystem service relative to if no service were provided and is a necessary step towards estimating the value of MPA management against the counterfactual of no management. Determining the net benefit of MPA designation requires information about the cost of implementation and management as well as the marginal benefit of protection status. The marginal benefit of protection status varies depending on the threat of degradation. For example, those places facing greater threats to ecosystems (and the services they provide) will receive greater marginal benefits from protection than those in remote places facing no threat. Our island-scale analyses around New Providence and Andros begin to address this issue. At these locations, we include the current risk of human activities, such as coastal development and transportation by water, to habitats and services. By including an assessment of risk from current human activities in these regions, our analyses provide some insight into the potential gains if MPA designation and implementation were able to fully protect habitats. This information comes closer to demonstrating the marginal value of MPAs for ecosystem service provision, and coupled with information on costs, could be leveraged in a cost benefit analysis to estimate the net social welfare impact of MPAs in The Bahamas.

NatCap worked with the Bahamas Protected project to leverage our in-country experience and economic models to quantify the economic value of ecosystem services within Bahamian MPAs to inform the 20-by-20 goal. In particular, we (1) reviewed past studies of economic value of marine ecosystems, species, and MPAs in The Bahamas, (2) used open-source software to quantify the economic value of ecosystem services within the existing network of MPAs, (3) explored management issues and quantified ecosystem services at an island scale for five regions with MPAs of varying management regimes, (4) suggested future directions for using an ecosystem services approach to inform declaration of new MPAs, and (5) provided a final report, including a written summary, synthesis and graphics to support communication about the biophysical, economic and social value of ecosystem services within MPAs in The Bahamas and suggest policy implications. The following document is organized into five main sections the report on our findings for each of the five objectives above, beginning with a section reviewing the four priority ecosystem services we analyzed that reflect shared Bahamian values for ecosystem services provided by coastal and marine systems.

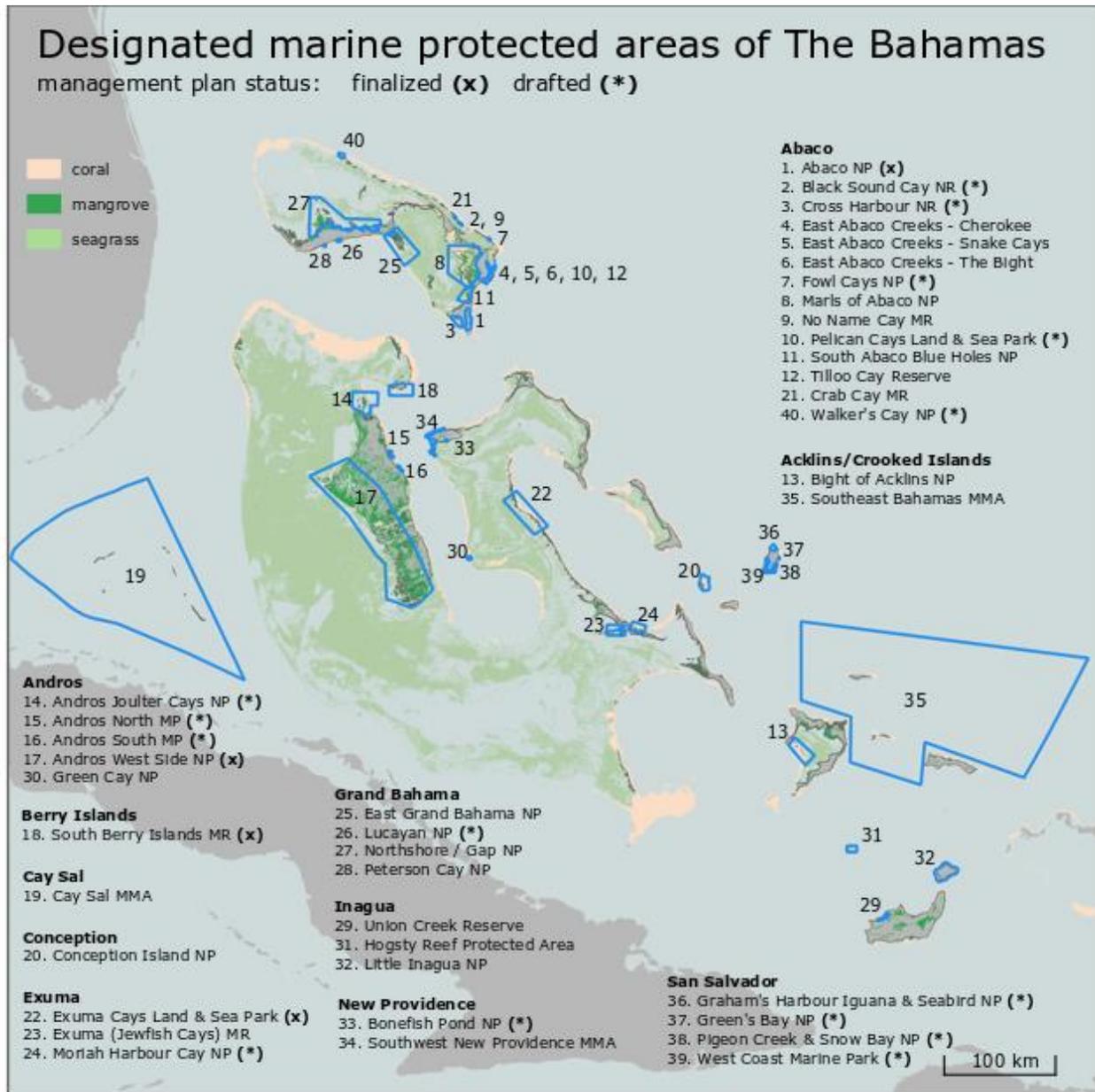


Figure 1. Bahamas marine protected areas network. Important habitats for providing ecosystem services are also shown: Seagrass beds (light green), mangrove forests (dark green), corals (light pink). NP=national park, MMA= Marine Managed Area, MR= Marine Reserve, MP=Marine Park.

2. Priority ecosystem services

Based on conversations with the core team, as well as the Natural Capital Project's previous work in The Bahamas and throughout the Caribbean, we identified four benefits that reflect some of the most important shared values of Bahamians. Because of their importance for the national economy, livelihoods, and sustenance, fisheries and tourism related values are often the benefits from nature that first and foremost resonate with stakeholders. After hurricane Joaquin in 2015 and hurricane Matthew in 2016, stakeholders, decision-makers, NGOs, and coastal planners, are showing increased interest in

the role of ecosystems in providing a natural buffer from storm impact, flooding, and sea-level rise. Finally, while the importance of ecosystems as carbon sinks is relatively new and not often mentioned by stakeholders during initial conversations about their values for coastal and marine ecosystems, the fact that small island, Caribbean nations are at the forefront of threats from climate change, makes the benefits of climate mitigation provided by blue carbon all the more relevant.



Fishing vessel and tourist destination along the coast of Andros (photo by Jacklyn Mandoske).

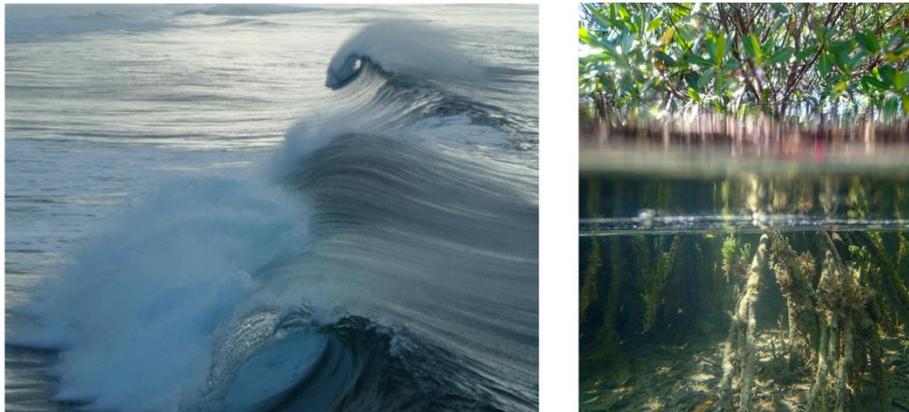
Nursery habitats for spiny lobster fishery

Fishing is an especially important activity for Bahamians, as people country-wide depend on fisheries for income and sustenance. National and foreign fishing pressure, along with poorly conducted and excessive coastal development and pollution could degrade nursery habitats for economically important fishes, potentially threatening this valuable resource. Nationally, the most valuable export fishery is the spiny lobster. From 1997 to 2014, The Bahamas exported an average of 6 million lbs. of lobster tails (equivalent to 16.9 million lbs. whole lobster), with an average value of \$66 million (Department of Marine Resources). Spiny lobster depends on nearshore habitats, including seagrass, mangroves, and other nearshore vegetation like the red algae, *Laurencia*, during their early life stages. Impacts to these habitats can have consequences for the productivity of the fishery as a whole. We focused our analysis on spiny lobster, seagrass, and mangroves because it is the most valuable export fishery, because country-wide datasets of seagrass and mangroves exist (we lack such datasets for *Laurencia*), and because the Department of Marine Resources releases periodic reports with the necessary parameters to model this species quantitatively and to estimate the economic value of nursery habitats in MPAs.

Tourism and recreation

Tourism is a major part of the economy of The Bahamas. In 2015, over 6 million foreigners visited The Bahamas and contributed \$2.5 billion to the economy. Based on exit survey reporting, the three most popular tourist activities are beach-going, rest and relaxation, and snorkeling (Ministry of Tourism 2015). Significant portions of tourists also listed diving, deep-sea fishing, bonefishing, and birdwatching as reasons for their trip. These activities, as well as the reputation of The Bahamas as a destination, are dependent on the natural beauty and healthy natural resources provided by marine and coastal ecosystems such as coral reefs. A recent valuation of the world's coral reefs estimated that reef-associated visits in The Bahamas generate over \$500 million in visitor expenditures, approximately 18.5% of the country's total tourist expenditures and 6.3% of GDP (Spalding et al. 2017).

Since ten percent of the archipelagic zone is currently designated in a network of protected areas—with more designations to come—tourists are already spending time and money, and gaining valuable experiences, within the MPA network, whether they are aware of it or not. Therefore, accurately estimating the economic value of tourism to these places, and the social value of the experiences of tourists and locals, depends first on accurately measuring the popularity, or visitation rates, of these places. Estimating visitation rates and expenditures related to site-visits within each individual MPA has not been done before this analysis, and is a necessary first step to understanding the tourism value of the network as a whole.



Waves breaking on the shoreline and mangrove root systems (photo by Jaclyn Mandoske).

Coastal protection provided by natural buffers

Sea level rise, storm surge, and flooding are major issues throughout the Caribbean (Simpson et al. 2010, IPCC 2014). The Bahamas’ low-lying nature makes it particularly vulnerable. Hurricanes Joaquin and Matthew demonstrated this vulnerability (ERM 2017, Sullivan Sealey et al. 2017) and recent analyses project over \$1 billion in average annual losses due to inland and coastal flooding in the future (ERM 2017). Seawalls have historically been used to mitigate these effects, but are expensive to build and maintain and often have adverse and unintended consequences (Burgess et al. 2004, Hillen et al. 2010). Marine and coastal habitats—primarily coral reefs, seagrass, and coastal forests—can attenuate waves and surge associated with storms, in some cases mitigating flooding and coastal erosion (Barbier et al. 2008, Zhang et al. 2012, Spalding et al. 2014). Understanding where and to what extent natural habitats may be providing valuable coastal protection services is important for communities seeking to manage coastal resources. Identifying where habitat in existing MPAs is particularly important for helping to reduce the risk of coastal hazards to people and property can help to prioritize the development of effective management plans for high priority MPAs.

Carbon storage and sequestration

Mangroves and seagrasses have been widely recognized as major carbon sinks that can store and sequester carbon for decades to millennia (Chmura et al. 2003). Carbon stored and sequestered by coastal ecosystems is increasingly being referred to as “blue carbon” due to their significant contribution as a carbon sink (McLeod et al. 2011). The ability of coastal ecosystems to contribute substantially to

carbon storage is largely due to the carbon content in the soils, as well as high rates of carbon burial in soils (Mclead et al 2011). Furthermore, land use changes that degrade or destroy coastal habitats have the potential to release large amounts of stored carbon into the atmosphere (Donato et al. 2011). Land use changes currently account for 8–20% of global greenhouse gas emissions (Pendleton et al. 2012), and since carbon released from coastal habitats is often not accounted for in national greenhouse gas inventories (Crooks et al. 2011), it may be a significant further source of carbon emissions. As research on climate change mitigation has grown, there has been increasing attention on maintaining and restoring wetlands, mangroves, and seagrass for their carbon storage and sequestration services through strengthening policy and practical management decisions (Crooks et al. 2011), such as declaration and management of MPAs. Further, emerging carbon markets and the REDD+ program¹ offer opportunities for The Bahamas to capitalize on the protection of these habitats.

3. Literature review of past work on economic values of ecosystems, species, ecosystem services, and MPAs in The Bahamas

Background and objectives

A wealth of research has been done throughout the world, Caribbean, and The Bahamas to understand and quantify the benefits that natural capital—habitats, ecosystems, species, and more—provide to people. Constanza and others (1997, 2014), Daily (1997), Barbier and others (2011), and De Groot and others (2012) ignited the global conversation around the value of the world’s ecosystem services and natural capital. In the subsequent years, local, regional and national studies around the world have improved the methodology for valuing habitats and the ecosystem services they provide². A key lesson is that the value of ecosystem services varies spatially with differences in ecological, social, and economic factors (Ruckelshaus et al. 2015). Scientists and economists are increasingly aiming to account for these differences to inform management of natural resources, including marine protected areas.

Our objective was to review the available information on the economic value of species, habitats, and marine protected areas in The Bahamas. We completed this work with the hope that our compilation and synthesis would inform current activities within The Bahamas Protected project and provide context for our analysis of the economic value of ecosystem services provided by the existing network.

Methodology

We surveyed the peer-reviewed and grey literature using existing ecosystem service databases, primary literature searches, google scholar searches, searches for reports by local experts, recommendations from partners, and the citations found within each publication. We used Hargreaves-Allen’s literature review for the Integrated Coastal Zone Management plan as a starting point, referencing the global and regional studies and thoroughly incorporating the handful of Bahamian studies. We focused on studies that were specific to The Bahamas² and included metrics that quantified the value of habitats or ecosystem services with the country. Values did not need to be monetary, but they did need to include demand from people for the services (i.e., we did not include in this review the wealth of strictly

¹ REDD stands for countries efforts to reduce emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests and enhancement of forest carbon stocks.

² For a review of regional valuation studies, please see Schuhmann and Mahon 2015. For a review of global valuation studies, please see Torres and Hanley 2016.

ecological studies of coastal and marine ecosystem services in The Bahamas. Such a review would have been beyond the scope of this study).

We cataloged publications and reports based on the habitats and services included. We then summarized results for the most relevant habitats and ecosystem services. We selected which habitats and services to further explore based on the availability of previous work, the types of metrics reported (e.g., monetary, numbers of people affected), and the priorities identified by the core team. We adjusted reported values by inflation in order to report all values in 2015 Bahamian dollars.

Results and interpretation

Twenty-three studies met our criteria for selection and were included in our database. The majority of these studies are not otherwise compiled in known global, regional, or national databases of ecosystem service values. For example, Economics of Ecosystems and Biodiversity (TEEB)—the global initiative to recognize, demonstrate, and capture the value of nature—has created a database³ of valuation studies to further its mission, yet none of the 37 Caribbean studies included are specific to The Bahamas. Similarly, the Marine Ecosystem Services Partnership database⁴ includes 45 studies from the Caribbean and only four are from The Bahamas⁴. Despite limited representation in global databases, the 23 Bahamas-specific studies included indicate the rich history and knowledge around certain ecosystem services in The Bahamas.

The 23 studies included represent a range of locations, approaches, metrics, and priorities. Roughly half of the studies were conducted for the entire Bahamas and the remaining half were specific to islands or island groups. Four studies focused on Eleuthera, three on Exuma, two on Abaco, one on New Providence, and one on Andros. The majority of these studies use a benefits transfer approach and present the value of habitats or services per unit area. Other studies, especially those related to fisheries catch, measured economic export value or estimated the number of jobs. Half of the studies included the value of habitats or ecosystems in their analysis (see database). Mangroves were the most commonly included ecosystem, followed closely by coral and then seagrass (Figure 2). All but one study included valuation of at least one ecosystem service. Fisheries were mostly commonly quantified and valued, followed by tourism and then, more distantly, by climate mitigation, cultural value, biodiversity, and water quality (Figure 2). In some cases, values could be readily compared between studies, while in others cases, metrics were not appropriate to further summarize. Based on the focus of this consultancy, the number of relevant studies, and the types of metrics included, we selected ecosystems and services to further summarize below. Please see the associated database to see the full range of metrics and values for each habitat and service.

³ <http://www.teebweb.org/publication/tthe-economics-of-ecosystems-and-biodiversity-valuation-database-manual/>

⁴ <http://www.marineecosystems-services.org/databases>

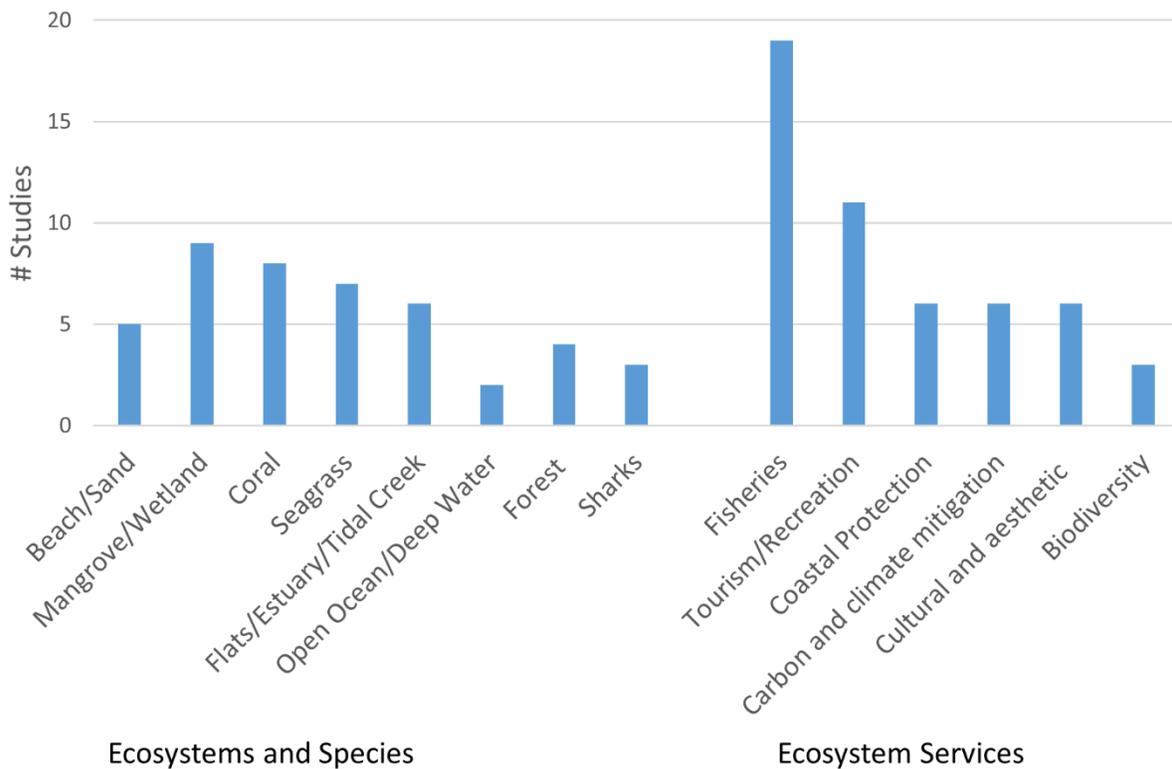


Figure 2. Number of valuation studies including different habitats and ecosystem services in The Bahamas.

Past analyses of habitat and ecosystem valuation

Of the habitats and ecosystems included in previous valuation studies, flats and estuaries were valued most highly, followed by coral reefs and mangroves. Values for tidal creeks (including tidal flats and estuaries) ranged from \$35,000 to \$1.75 million km²/year. The greatest value (and variability in value) of tidal creeks comes from their ability to protect coastline, which can provide values of \$150,000 to over \$1.5 million/km²/year. Tidal flats also provide important values for fisheries support and carbon sequestration (Hargreaves-Allen 2016). The range of values for coral value and mangrove (including tidal mangrove creeks) are similarly wide: from \$44,500 - \$1.35 million/km²/year for coral and \$850,000 - \$1.2 million/km²/year for mangrove (Figure 3). Again, the estimated greatest value (and variation in value) for these habitats comes from coastal protection (e.g., \$38,500 - \$1.3 million/km²/year for coral). In addition to coastal protection value, coral is important for its contribution to divers, snorkelers and recreation more broadly (\$198,000 km²/year). Commercial and subsistence fisheries are also dependent on coral and this fisheries support is estimate at \$31,000-91,000 km²/year (Hargreaves-Allen 2016). Mangroves derive additional value through providing nursery habitat for fisheries and storing and sequestering carbon. Past studies have valued seagrass and forests (including pine, coppice, and shrub) at far lower values. Seagrass has been valued from \$500-150,000/km²/year and forests values are clustered around \$72-74,000/km²/year (Figure 3). Unlike other habitats, seagrass derives most of its value for its role in carbon sequestration.

For each habitat, the largest economic values come from the most recent benefits-transfer analysis, which used improved methodology at a national scale to inform the Integrated Coastal Zone

Management plan. This approach included the array of services provided by each habitat (an update to previous work where values were not available), while simultaneously reducing double counting by “considering overlap, trade-off, and synergy between different services” by only including final (rather than intermediate) services and matching studies based on many criteria (Hargreaves-Allen 2016).

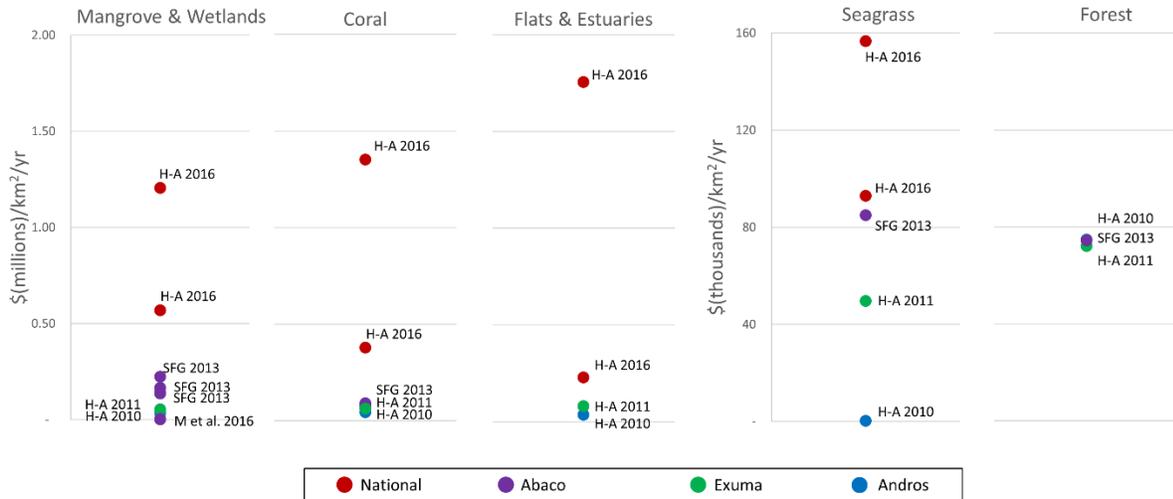


Figure 3. Economic valuation of habitats as determined by different studies (adjusted to 2015 values). Sources are adjacent to the data point: SFG 2013 is Clavelle and Jylkka 2013 (as reported for the Sustainable Fisheries Group), H-A is Hargreaves-Allen, and M. et al. is Micheletti et al. 2016

Past analyses of ecosystem service valuation

Fisheries

Of all of the ecosystem service values found throughout the literature and published data, fisheries catch and export value are the most readily available, with some studies also reporting associated employment. Yet, reported catch and export value are likely substantial underestimates of the value of fisheries for The Bahamas. Though time, the lobster fishery has been the most prolific, bringing in 2,301 metric tons per year from 2006 to 2009 (Dept. of Marine Resources in Hargreaves-Allen 2010) with an export value of over \$64.5 million. However, Smith and Zeller (2016) suggest that lobster catch during that time was likely closer to 10,500 metric tons, 4.5 times the reported landings. Reef fish are reported as the second most valuable fishery, bringing in nearly \$60 million in export value (FAO 2009, Hargreaves-Allen 2010). Individual scalefish species, conch, crab, and sponge contribute substantially, \$0.5-10 million in export value annually each. In addition, much of catch of these species are traded locally and not reported in national export statistics (e.g. land crab on Andros island; Hargreaves-Allen 2010). An estimated 33,100 metric tons per year (1950-2010 average) are caught in the subsistence fishery (Smith and Zeller 2016), providing food security to countless Bahamians. If reconstructed values for other sectors are any indication, the value of fisheries—commercial, recreation, and subsistence—are likely much larger than reported at the national scale.

In addition to the commonly published catch and export value, a few studies help to demonstrate the importance of the fishing industry for employment. Gittens and Braynen (ND) estimate there to be over 4,000 Bahamian fishing vessels and Micheletti et al. (2016) estimate there to be 800 around Great Abaco alone. FAO (2009) report there to be 9,300 people employed in the industry while Hargreaves-Allen (2010) reports there to be 3,800 part-time fishers and an additional 52 vendors, processors, and

exporters. Further, Sullivan Sealey (2011) estimate roughly 1,300 active lobster fishers throughout the islands, with the most around Grand Bahama, Spanish Wells, Abacos, and New Providence. As with catch, these values are likely underestimates. In whole, the fishery industry is a vital component of Bahamians livelihoods.

Tourism

With over 4.5 million visitors annually, contributing over 60% to the national economy, tourism is vital to The Bahamas (Ministry of Tourism in Hargreaves-Allen and Pendleton 2010). Stopover visitors in 2007 spent over \$402 million (Hargreaves-Allen and Pendleton 2010). Yet, these national statistics miss some of the implied revenue, aggregated economic impacts, and the livelihoods supported. The implied revenue from nature based tourism on Andros alone is over \$24.5 million, with bonefishing lodges contributing the greatest amount (Hargreaves-Allen 2010). Demonstrating that the economic impacts extend beyond visitor expenditure, expenditure for guided and non-guided fishing is over \$75 million annually, while the estimated aggregated economic impact is over double that (Fedler 2010). Expenditure related to sharks—for cinema, research, diving and more—is over \$50 million annually; the aggregated economic impact is, again, well over double at nearly \$115 million annually (Haas 2017). As with fisheries, tourism also supports the livelihoods of Bahamians, though these data are limited. On Andros alone, nature-based tourism supports an estimated 518 people on an island with a population of roughly 8,000 (Hargreaves-Allen 2010). Across the country, there are over 300 fishing guides (Fedler 2010). These samples offer just a glimpse of the value of tourism to The Bahamas, both in terms of visitor expenditure, but also aggregated economic impact and livelihoods.

Coastal protection

While fewer studies examine the role of natural habitats in protecting people, livelihoods, and income from storms and erosion, the value of coastal protection is consistently high. Most recently, coastal habitats have been estimated to provide \$3.9 billion per km² in coastal protection and nearly \$120 million in erosion control (Hargreaves-Allen 2016). Though determined using older methodology, habitats on Exuma and Andros were estimated to provide over \$8.5 and \$6.8 million per km², respectively, in disturbance regulation (Hargreaves-Allen 2011, Hargreaves-Allen 2010). In past work on Andros for the creation of the Master Plan, the Natural Capital Project found that natural habitats protected over 95 km of shoreline, and 50% of the coastal population and annual income. On east Great Abaco, the disturbance protection from coastal habitats provided an avoided cost of \$1,137 for communities and \$1,348 in avoided costs for government. The erosion protection provided an additional \$33,423 in avoided costs for government (Micheletti et al. 2016). Studies including coastal protection—though limited in number—ubiquitously find the role of habitats in protecting shorelines from storms and erosion to be one of the most valuable.

Climate mitigation and carbon storage

Relatively little work has previously been done to evaluate and estimate the value of natural capital in climate mitigation and carbon storage. In a study of four sites on Eleuthera, dwarf mangroves were found to store 11.12 Mg/ha, though the amount of carbon varied widely between samples and sites (Baretto et al. 2015). In a more comprehensive study, habitats in The Bahamas were found to be worth nearly \$4,000 per km² per year for carbon sequestration (Hargreaves-Allen 2016). There may be fewer studies on carbon storage because of the difficulty of measuring carbon in specific locations, as well as the uncertainty and volatility of carbon markets and the social cost of carbon. Yet, we know that coastal

habitats like mangrove and seagrass play an important role in storing and sequestering CO₂ and that the globally felt social cost of emitted carbon is high (IWG 2016).

4. Spatial variation in ecosystem services within the current network of MPAs

Previous studies of economic valuation for coastal and marine ecosystem services in The Bahamas have been useful for valuing a suite of services provided by different habitats and raising awareness about the importance of these ecosystems for supporting the economy of the country and well-being of its people. To build on this previous work and further inform the management of a diverse network of current and future MPAs extending across a country of islands varying in their ecological, social, and economic context, we used a suite of production function models called InVEST (Sharp et al. 2017) to value ecosystem services provided by coral reefs, mangroves, seagrasses and other habitats (e.g., beaches, tidal flats etc.) within MPAs (Guerry et al. 2012). A production function approach links differences in time and space in the ecological structure and function of ecosystems with variation in services that ecosystems provide to people (Tallis and Polasky 2009). These models have been used elsewhere in the Caribbean (Arkema et al. 2015, 2017) and around the world to inform a diversity of coastal and marine management decisions (Ruckelshaus et al. 2015). We used these production functions to value the benefits from coastal habitats within the existing MPA network (covering 10% of The Bahamas territory) for lobster catch and export value, visitation and expenditure, protection from storms and erosion, and carbon storage for climate mitigation. As we describe in the introduction, this approach captures the gross value of ecosystem services, rather than the net benefit of MPA designation and implementation, which would require information about the cost of MPA implementation and management, as well as the marginal benefits of protection. Further, because habitats within MPAs provide additional services (e.g., additional fisheries, filtration for freshwater, and cultural value, among others), the values we report make up only part of the total economic value ecosystem services within with the MPA network.



Photo by Jaclyn Mandoske.

Nursery habitats for spiny lobster fishery

Approach

The InVEST Fisheries Production model produces estimates of fisheries landings and economic yields under different scenarios of habitat quality and harvest regulations (see Sharp et al. 2015, Arkema et al. 2015). The model takes information on the life history of the species, recruitment, migration, harvest mortality, and habitat dependencies and outputs estimates of landings and value at a national scale using a Beverton-Holt spawner-recruitment relationship, parameterized for steepness. These parameters are set nationally and therefore assume the uniform life history traits. Carrying capacity is set by the availability of nursery habitat, which is represented by spatially explicit mangrove and seagrass data. The lobster production model assumes that larvae are mixed during their extended pelagic period, and eventually settle in nursery habitat in proportion to its availability across the region (i.e. an island with 12% of nursery habitat will get 12% of recruits). The model also outputs estimates of the contribution of different nursery areas to total production of the fishery.

For its application to The Bahamas, the model was fit to national level data and literature values estimated in the 2012 stock assessment for Spiny Lobster in The Bahamas (Medley and Gittens 2012; note that the 2014 stock assessment is not yet publicly available) (see appendix C for additional details

and sources on these parameters). In the lobster production model, age 2 lobster move from nursery to adult habitat and are assumed to distribute evenly throughout contiguous shelf areas. Since recent survey-based estimates of lobster are not available, we validated the model based on widespread sampling from the Little and Great Bahama Banks (Smith and van Nierop 1986).

We applied this model in The Bahamas in order to quantify the contribution of nursery habitats (e.g., mangroves and seagrasses) within the MPA network to lobster recruits and annual harvest and export revenues. Protected areas contributed a significant amount of nursery habitat, which we defined as seagrass beds in shallow water within 1 km of shore, and mangrove forest within 250 m of shore. The amount of nursery seagrass and mangrove habitat was measured at two scales: (1) The total amount for each region—regions defined by shallow shelf areas divided by deep water and (2) The area of nursery habitat within each protected area (Figure 4). To understand the contribution of habitats within protected areas, we computed total harvest by region using the nursery habitat amounts from (1) and then we computed the harvest by region after discounting the regional habitat areas by the values from (2). The difference in harvest for a region is then attributable to the nursery habitats within the MPAs in that region. To estimate the export value of lobster catch, we used the estimated proportion of total lobster catch that reaches market (i.e. the tail) and the price per processed pound of lobster, \$10.86 (Department of Marine Resources).

There are a number of limitations to this approach. First, we know that *Laurencia* is an important factor for juvenile lobster, yet a lack of data on the spatial distribution of this alga to make it impossible to include in the economic valuation. Further, the early life-stage habitat we did include, mangrove and seagrass, are sourced from 2005 Landsat data, the best and most recent available, yet there may be gaps and inaccuracies or the data may be outdated. The model assumes that juvenile lobster respond to habitat quantity rather than quality and this is, in part, a function of data availability. The island-scale analyses that include a risk assessment seek to address this by relating risk to habitat functionality. Second, while we know coral reefs are valuable for other commercial fisheries (see section 3, Literature Review), they are less so for lobster (due to the abundance of casitas) and therefore the model does not include corals. Finally, the model does not account for areas with and without fishing, nor how MPAs effect spawning stocks (i.e. the ‘spillover’ effect), and assumes that harvest selectivity (and catchability) is invariant across the country. Thus we cannot account for the fact that protection from fishing (no-take or regulated) has costs and benefits too—a protected area may have both diminished value to fishers if that lobster is not available and greater value outside the park to fishers from spill-over. While these issues are drawbacks of the model, they are less problematic for quantifying the economic value of nursery habitat within the current MPA system as ECLSP is the only no-take area.

Results

Results show that nursery habitats within the MPA network are contributing 6.01 million lbs. and \$23.53 million in revenue each year (Figure 5). In some regions—Andros, Abaco, Cay Sal, San Salvador, and Western Little Bahama Bank—a large proportion of the regions’ nursery habitat for lobster are within MPAs, either because the MPAs themselves are large (e.g. Andros West Side NP, Marls of Abaco NP, and Cay Sal MMA), or because the MPAs are strategically located (e.g. Pigeon Creek and Snow Bay NP on San Salvador and Northshore/The Gap NP on Western Little Bahama Bank). In other regions—Acklins, Exuma, Inagua, Northern Bahamas Bank—little nursery habitat is within MPAs. Nursery habitat within protected areas also provides benefits to fisheries elsewhere. This spillover effect is particularly challenging to quantify, but is apparent in these results: for example, since there are no MPAs in

proximity to Long Island, harvest in the Long Island bank region is attributed, in part, to nursery habitat in protected areas on somewhat distant, but contiguous shallow shelves.

Bank region	MPA	Proportion of region's nursery mangrove within MPA	Proportion of region's nursery seagrass within MPA
Abaco	Marls of Abaco NP	0.54	0.21
	South Abaco Blue Holes NP	0.04	0.01
	Cross Harbour NP	0.02	0.01
	Pelican Cays Land And Sea Park	0.00	0.01
	East Abaco Creeks - Snake Cays	0.00	0.01
	East Abaco Creeks - The Bight	0.01	0.01
	East Abaco Creeks - Cherokee	0.01	0.00
Acklins	Southeast Bahamas MMA	0.00	0.09
	Bight of Acklins NP	0.01	0.06
	Hogsty Reef Protected Area	0.00	0.01
Andros	Westside NP	0.69	0.53
	Joulter Cays NP	0.02	0.04
	Southern MP	0.00	0.02
Caysal	Cay Sal MMA	NA	1.00
Exuma	Exuma Cays Land & Sea Park	0.05	0.18
	Jewfish Cay MR	0.09	0.04
	Moriah Harbour Cay NP	0.02	0.03
Inagua	Little Inagua NP	0.17	0.05
New Providence	Southwest New Providence MMA	0.00	0.10
	Green Cay MP	0.00	0.02
	Bonefish Pond NP	0.16	0.01
Northern Bahama Bank	South Berry Islands MR	0.16	0.15
San Salvador	Graham's Harbour	0.00	0.17
	West Coast Dive Site	0.05	0.15
	Conception Island NP	0.00	0.10
	Pigeon Creek & Snow Bay NP	0.73	0.09
	Greens Bay NP	0.00	0.02
Western Little Bahama Bank	Northshore / The Gap NP	0.47	0.44
	East Grand Bahama NP	0.17	0.10

Figure 4. Contribution of mangrove and seagrass within each MPA to the island-region's total lobster nursery habitat. For example, Marls of Abaco National Park protects 54% and 21% of Abaco's mangrove and seagrass nursery habitats, respectively. NP=National Park, MR = Marine Reserve, MMA = Marine Managed Area.

Bank region	Annual contribution of nursery habitat in MPAs to lobster catch (millions of pounds)	Annual contribution of nursery habitat in MPAs to lobster revenue (\$ millions)
Abaco	1.13	4.42
Acklins	0.10	0.37
Andros	0.58	2.28
Cay Sal	0.21	0.84
Eleuthera	0.22	0.87
Exuma	0.23	0.90
Inagua	0.03	0.10
Long Island	0.06	0.25
New Providence	0.22	0.86
Northern Bahama Bank	0.22	0.87
San Salvador	0.10	0.38
Southern Great Bahama Bank	0.96	3.77
Western Bahama Bank	0.43	1.68
Western Little Bahama Bank	1.52	5.93
<i>totals</i>	6.01	23.52

Figure 5. Annual contribution of nursery habitats within MPAs to total lobster harvest and revenue, by island-region. Regions are defined by contiguous shelf divided by areas of deep water.

Tourism and recreation

Approach

To quantify the value of tourism to sites within current marine protected areas, we first estimated annual visitation rates to each MPA in the current network. Information on visitation rates to remote, unmonitored areas is largely unavailable, so we relied on estimates derived from the density of geotagged photographs posted publicly to the website Flickr, which has over 300 million public geotagged photos (www.flickr.com) and includes metadata including unique photographer ID, latitude/longitude of photo, and date the photo was taken. Counts of geotagged photos have been shown to be a useful proxy for visitation rates to natural areas (Wood et al. 2013, Sessions et al. 2016, Arkema et al. 2015).

Since Flickr users are not necessarily representative of the entire visitor population to a place, and since not all Flickr users share photos every time they visit a place, it is necessary to evaluate the degree to which geotagged photographs correlate with surveyed visitation in The Bahamas or in similar sites in the region. We did this by comparing photo-based visitation rates to survey-based rates published by the Ministry of Tourism of The Bahamas and by the National Park Service (NPS) of the United States, which manages five park units in the Caribbean. The Ministry of Tourism reports total visitor-nights to each island, or island group, from the year 2005 to 2015, the latest data available (Ministry of Tourism 2015). The NPS reports monthly visitation rates to parks for all years in this same period. We found a significant

positive correlation between the survey-based and photograph-based measures of visitation (Figure 6). Both the island-scale comparison and the park-scale comparison show very similar slopes to their log-linear relationships. We tested the park units because they are more similar to the MPA scale of interest than entire islands. We used the statistical relationship from the islands of The Bahamas to translate photo-user-days to real visitor-days. The photo-user-day metric is the number of occurrences, over a period of time and within a geographic boundary, of a unique photographer on a unique day.

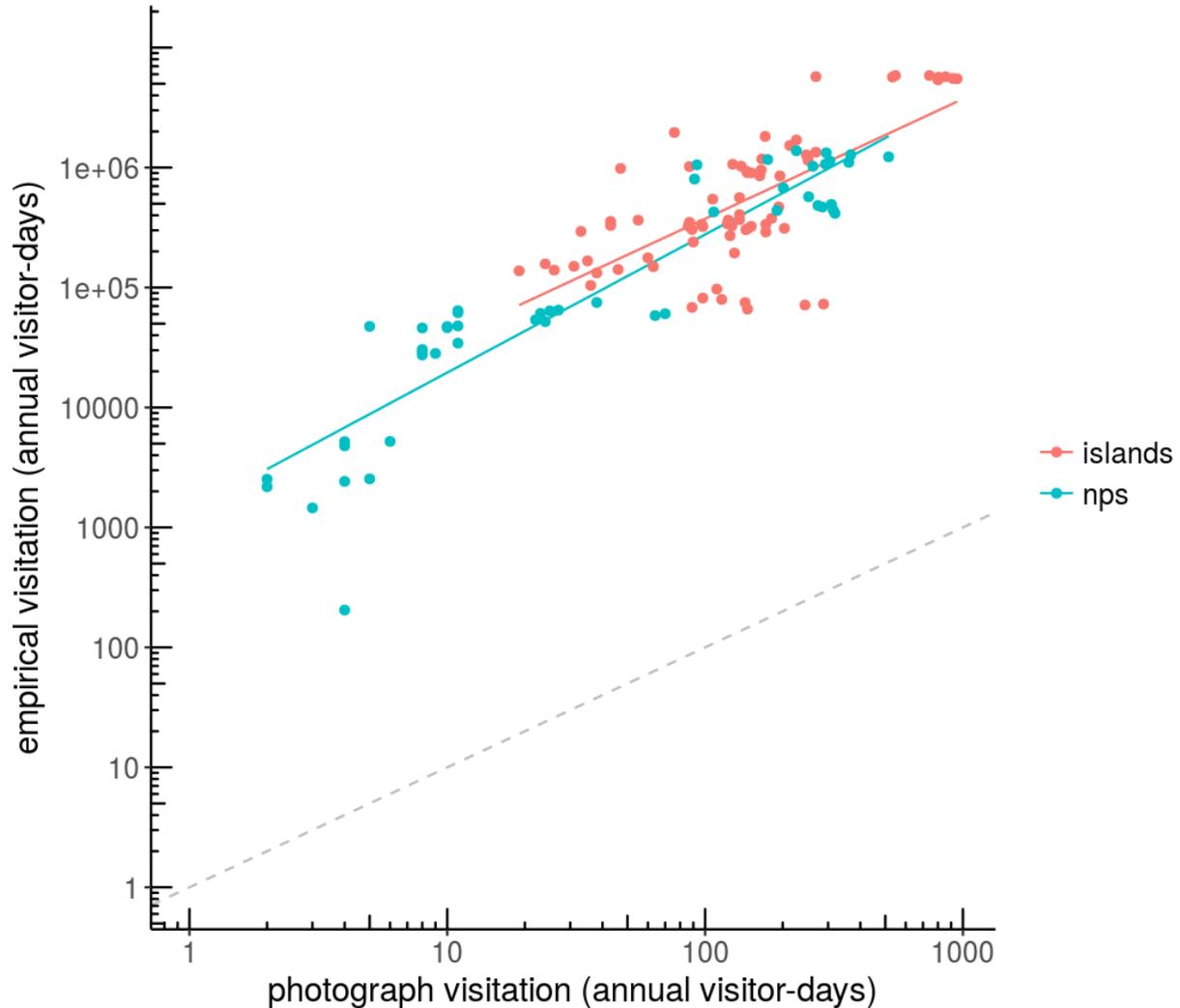


Figure 6. Comparisons show good agreement between photo-based estimates of visitation and empirical visitation data.

To estimate current visitation rates in each marine protected area, we used the InVEST Visitation model to count the annual average photo-user-days within each MPA, and then scaled those to real visitor-days using the relationship described above. To estimate tourist expenditures related to those visits, we relied on data describing the average daily expenditure for visitors to each island (Ministry of Tourism 2008). These island-wide estimates of daily expenditure may differ from daily expenditure to for MPA visitation because MPAs may be harder to reach or involve more expensive activities. For example, the average daily expenditure for Exuma is \$285 whereas Hargreaves-Allen (2011) have estimated average

daily expenditure for visitors to ECLSP closer to \$450. Average daily expenditures vary by island and also by whether a visitor is a stopover or cruise arrival. We determined that only three MPAs can reasonably be visited by cruise passengers during a day-trip excursion. Since the photo-based visitation estimates include stopover and cruise visitors, we estimate the proportion of visitors that may be cruise passengers using the Ministry of Tourism’s “arrival mode” dataset, which counts total arrivals to each port of entry in the country, and reports the number of cruise arrivals (<http://www.tourismtoday.com/services/statistics>). We associated the three MPAs with their nearest port of entry, and applied the cruise proportion for that port to the estimated visitation rate for each MPA. This approach of applying average tourist expenditures to the number of estimated visitors to a park captures the estimated total daily expenditure of visitors who visited a MPA; some of this expenditure may not be directly attributable to the visit itself. At the same time, our method also does not capture the total willingness to pay for a site-visit—which would be expected to be higher than actual measured expenditures—or the fact that many marine protected areas are remote and may require above-average expenses to visit sites within them.

Results

Across the entire MPA network, we estimate an annual average of 383,000 visitor-days, with \$67.6 million in tourist expenditures associated with visits to these areas. SWMMA is the most highly visited area in the current MPA network, due to its proximity to Nassau and easy access to its waters. ECLSP, in contrast, is the second most-visited area, despite it being much less accessible (Figure 7). Photo-based visitation estimates are dependent on the size of the place being measured, which is evident by the estimates for large MPAs such as Cay Sal and Southeast Bahamas Marine Managed Area. Scaling visitation rates by area reveals which places are most densely populated with visitors (Figure 8). Since average expenditure varies by island and by visitor type (stopover vs. cruise), the relative values among MPAs changes when measured by expenditures instead of overall visitor-days (Figure 9). For example, Crab Cays National Park and Green’s Bay National Park bring in a large of visitors relative to their size. Only seven percent of the total expenditures is attributable to cruise passengers, the vast majority of which is spent on diving or snorkeling in SWMMA.

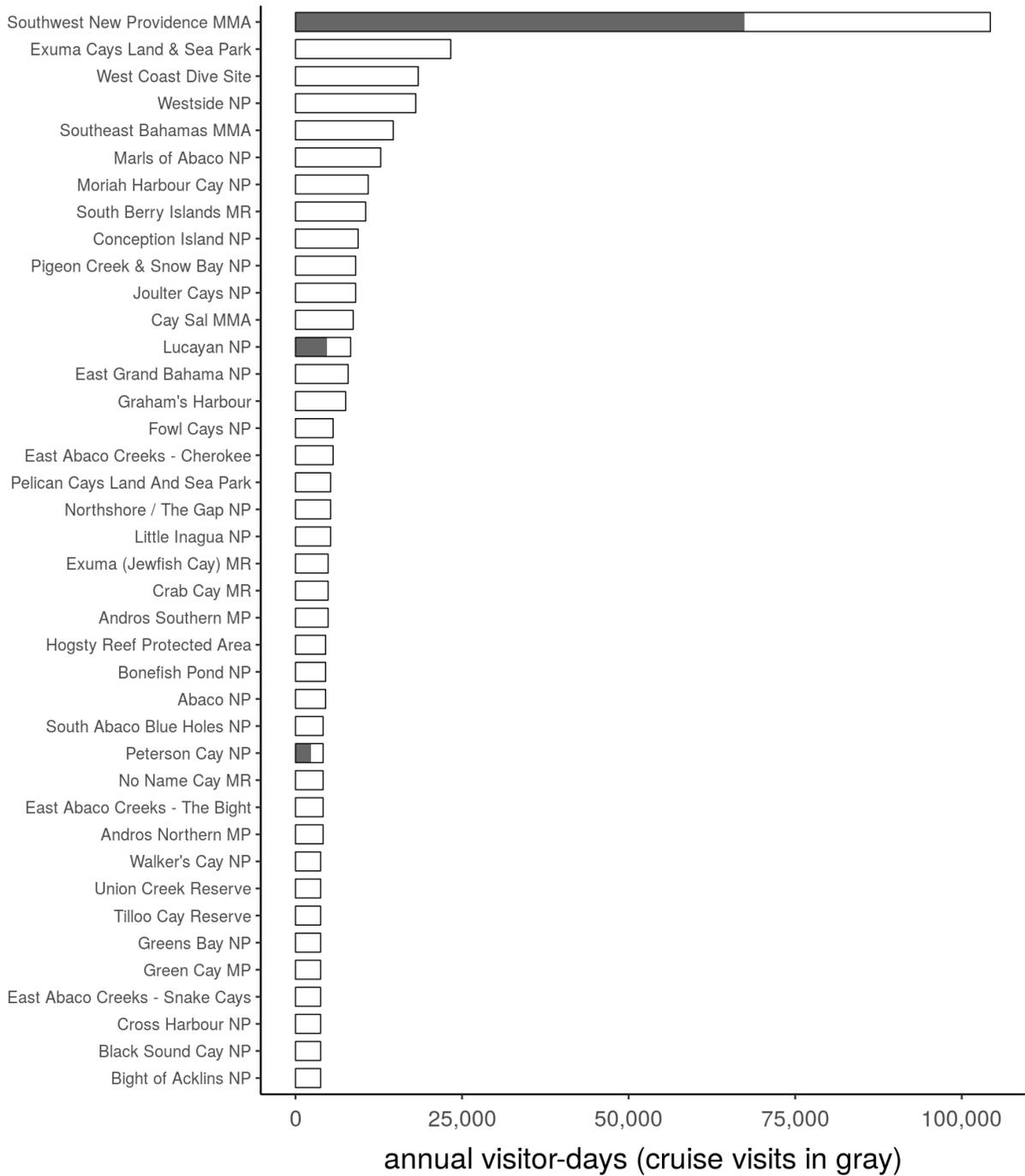


Figure 7. Estimated annual visitor-days for each marine protected area. Visitors are split into two pools, cruise arrivals (in gray) and stopover visitors (in white).

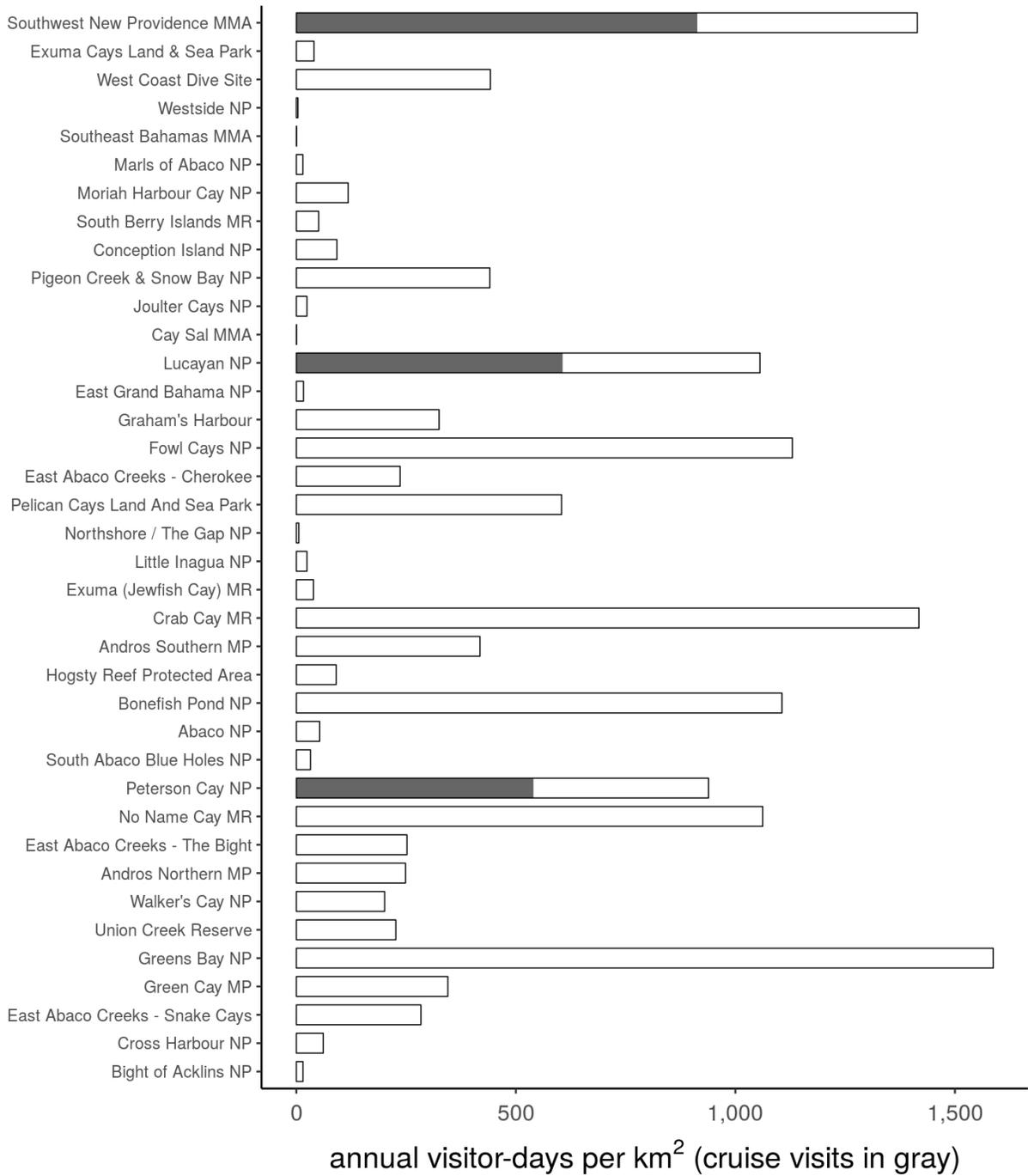


Figure 8. Density of visitors to each marine protected area.

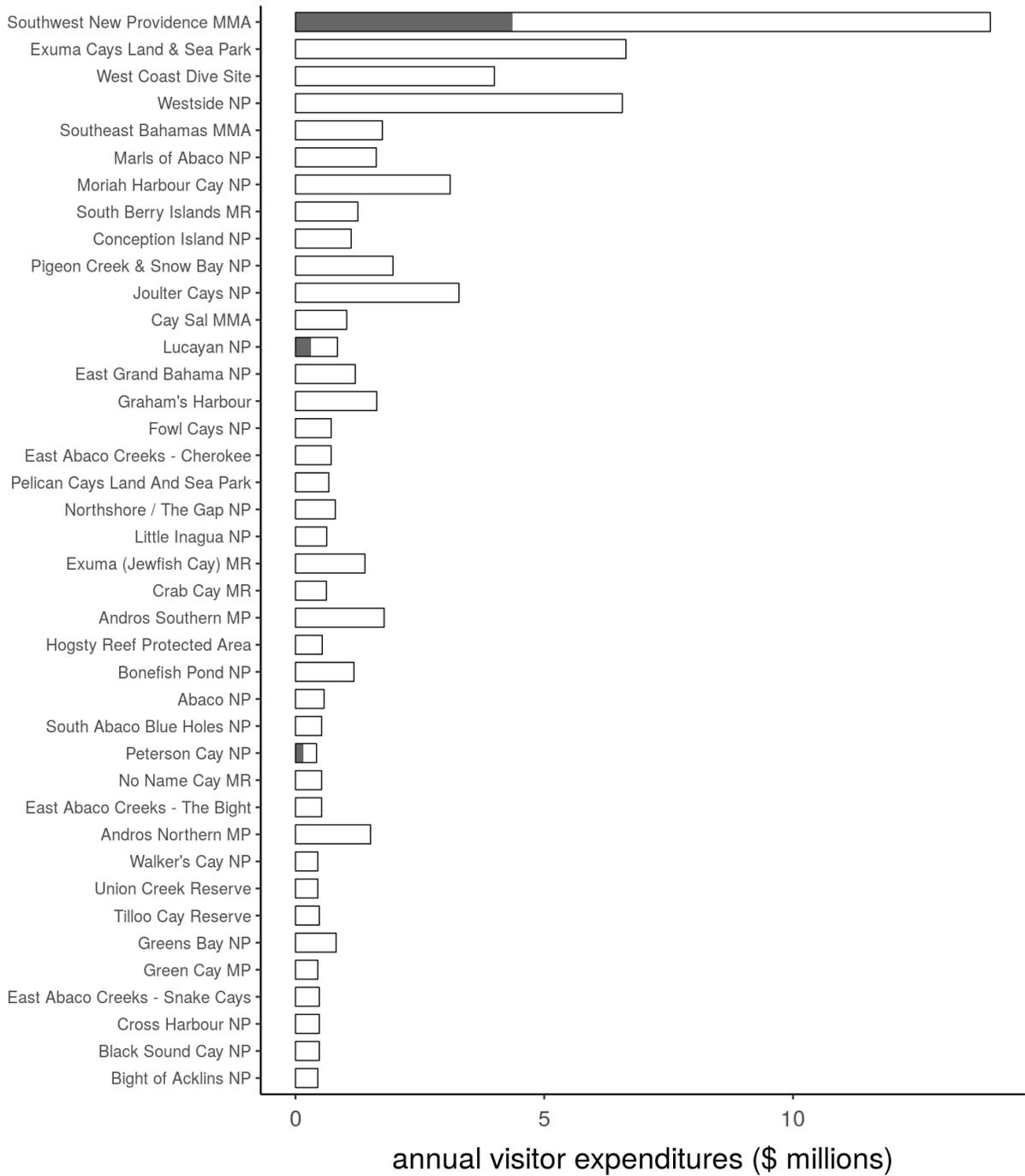


Figure 9. Annual expenditure from recreation and tourism to each marine protected area. Expenditures are split into two types, those from cruise arrivals (in gray) and those from stopover visitors (in white). Average daily expenditures vary by island and by visitor type.

Coastal protection provided by natural buffers

Approach

To assess where habitats in the MPA network, such as coral reefs, mangroves and coppice forest, and seagrasses provide the greatest reduction in the risk to coastal communities from erosion and flooding, we used an index-based approach, combined with maps of population data and annual income. The index-based approach computes the relative vulnerability of shoreline to coastal hazards based on spatially explicit characteristics of the coastline including presence of habitats, elevation and bathymetry, wind and wave direction and velocity, shoreline geomorphology, and surge potential (see appendix C for additional details about these spatial data sets) (Arkema et al. 2013, Langridge et al. 2014). The hazard index is typically coupled with social and economic data on people, property, and infrastructure (depending on data availability) to highlight where human settlements and critical infrastructure are most vulnerable to storm waves and surge.

We applied this index-based approach to measure and map the role of habitats, within the current marine protected area network, for protecting people from coastal hazards. First, the relative coastal exposure was mapped for the entire coastline of The Bahamas, at an interval of every 250 m along the coast, based on the geospatial data listed above. We then identified shoreline areas where coastal habitats—corals, coastal forests (mangroves, pine, or coppice), and seagrass beds—within MPAs reduced exposure along the shoreline, controlling for other geophysical variables in the hazard index. For each major island group, we used census data to quantify the number of people and annual income within 1.5 km of the shoreline currently protected by habitats within MPA boundaries. Annual income figures collected through the census provide a level of spatial detail in economic risk that was not available through the more conventionally reported metric of exposed property value. In the absence of adequate data on property value, researchers have used productivity based metrics like income and per capita GDP to estimate exposure in monetary units (Dasgupta et al., 2011; Hinkel et al., 2014). There has been limited research converting between exposure in terms of income to exposure in terms of durable asset value as this will likely vary as a function of many factors; however, Nicholls et al. (2008) demonstrate an empirical relationship where asset value in coastal cities is roughly 5 times greater than per capita income, indicating our monetary estimates are likely the lower bound.

Results

Habitats within the current MPA network serve to protect approximately 39,000 people and \$806 million in annual income of those people living near coastlines in The Bahamas (Table 1). The majority of this demand for coastal protection comes from New Providence, the most densely populated island, where 9% of the coastal population lives in areas partially protected by corals in the newly designated Southwest New Providence Marine Managed Area (SWMMA) or mangroves and coastal forests of Bonefish Pond National Park. Other less populated islands also receive important benefits of coastal protection, such as San Salvador and the Berry Islands, where fully one-half and one-third of their populations, respectively, benefit from the value of healthy, functional, coastal ecosystems within protected areas on those islands.

Table 1. Economic and social value of habitats within MPAs for providing protection from coastal hazards such as storms and sea-level rise. NP=National Park, MR= Marine Reserve, MMA=Marine Managed Areas

Island group	Current MPAs	Reduction in exposure (\$ millions annual income)	Reduction in exposure (# of people)
Abaco	Abaco NP – Black Sound Cay NP – No Name Cay MR – Fowl Cays NP – Tilloo Cay Reserve – Pelican Cays Land And Sea Park – Cross Harbour NP – Marls of Abaco NP – East Abaco Creeks (The Bight) – East Abaco Creeks (Snake Cays) – East Abaco Creeks (Cherokee) – South Abaco Blue Holes NP	\$32.32	3,630
Acklins/Crooked	Bight of Acklins NP	\$0.00	0
Andros	Northern Marine Park – Southern Marine Park – Westside NP – Joulter Cays NP	\$6.40	782
Berry Islands	South Berry Islands MR	\$1.92	238
Exuma	Exuma Cays Land & Sea Park – Exuma (Jewfish Cay) MR – Moriah Harbour Cay NP	\$15.89	1,482
Grand Bahama	Northshore/The Gap NP – East Grand Bahama NP – Peterson Cay NP – Lucayan NP	\$16.63	1,027
Inagua	Union Creek Reserve – Little Inagua NP	\$0.00	0
New Providence	Bonefish Pond NP – Southwest New Providence MMA	\$717.53	30,416
San Salvador	West Coast Dive Site – Greens Bay NP – Graham's Harbour – Pigeon Creek & Snow Bay NP	\$15.76	1,403
<i>totals</i>		\$806.45	38,978

Carbon storage

Approach

We measured the climate change mitigation value of carbon storage of ecosystems within MPAs using the InVEST Blue Carbon model (Sharp et al 2017). This model measures the total carbon stock of an area given the presence of carbon-storing plants (mangrove and seagrass in the case of The Bahamas) and the amount of carbon stored in aboveground, belowground (i.e. soils), and litter pools, for each habitat-type. Carbon pool values were collected by reviewing studies of empirical sampling and by applying a predictive model that estimates mangrove biomass variation using spatially explicit bioclimatic variables (Hutchinson et al. 2013).

Based on these carbon pool parameters, and geospatial data representing seagrass and mangrove distributions in The Bahamas, we quantified the total carbon stored in each of the current marine protected areas. We estimated aboveground mangrove biomass based on the global predictive model proposed by Hutchison et al. (2013), which accounts for quarterly extremes in temperatures, precipitation, and seasonality. Belowground mangrove biomass was estimated using the allometric relationship between aboveground and belowground biomass (Hutchison et al. 2013). National variation in climatic variations meant that estimated biomass varied from 167 - 200.9 tons per hectare (Mandoske 2017). These estimates are on the higher range of mean total carbon found by Baretto et al. (2015) across four sites on Eleuthera. In lieu of local data seagrass values were informed by the literature and were specific to the western tropical pacific (Fourqurean et al. 2012): aboveground

biomass was 0.84 t C per hectare and belowground biomass was 150 t per hectare; litter values were not available (Mandoske 2017). Additional local studies, such as Baretto et al. (2015), will help to refine mangrove and seagrass carbon values for The Bahamas.

We estimated the economic value of these protected habitats by applying a price of \$12.58/metric ton of carbon, based on the Interagency Working Group's 2015 social cost of greenhouse gases (IWG 2016). We use the social cost of carbon because market-based prices are set by supply and demand and carbon-markets are generally more relevant when considering return-on-investment. In addition, there are no carbon-markets within The Bahamas, making a market price for the country difficult to select. Further, public officials are tasked with considering social welfare and the carbon market often reflects prices lower than the social damage. Despite the choice to use the social cost of carbon, it has its own limitations, primarily that the social cost is considered too low and there is continual debate in the scientific and economic communities about factors that should be considered within the social cost of carbon.

Results

Within the entire MPA network, over 400 million metric tons of carbon are stored, at a value of over \$5 billion in avoided damages from emissions globally (Figure 10, Figure 11, Figure 12). The rich mangrove forests within Andros West Side National Park, which covers most of the western half of Andros island, store the vast majority of the carbon in the entire protected area network at the greatest social value (Figure 10, Figure 12). Because the total carbon storage is highly dependent on size of the MPA, we also scaled carbon storage by area. This revealed the per unit area value of relatively small protected areas, if they have dense mangrove and seagrass resources, such as Tilloo Cay Reserve, a very small protected area off the eastern coast of Abaco (Figure 11).

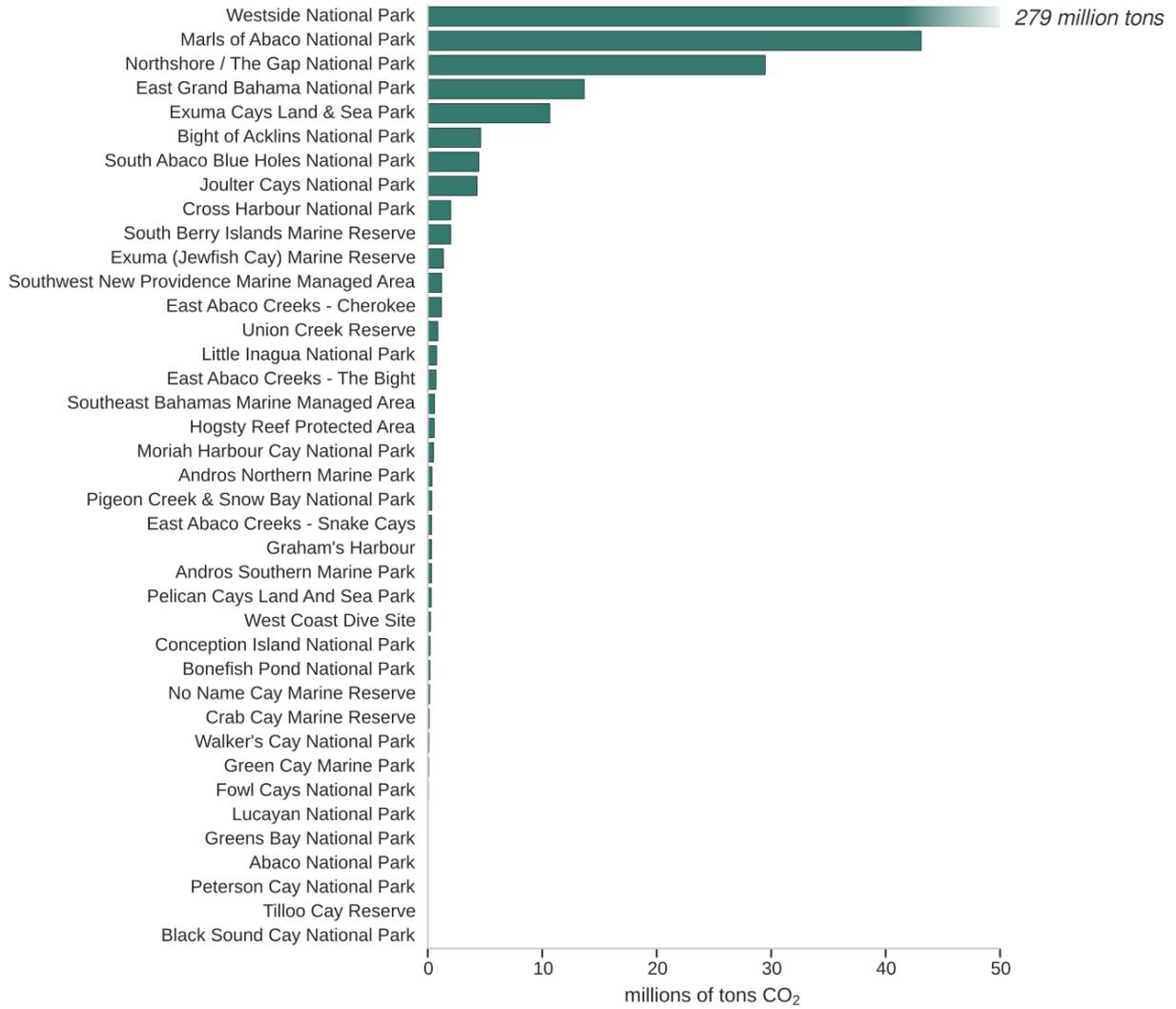


Figure 10. Total avoided carbon emissions stored by mangroves and seagrass within each marine protected area.

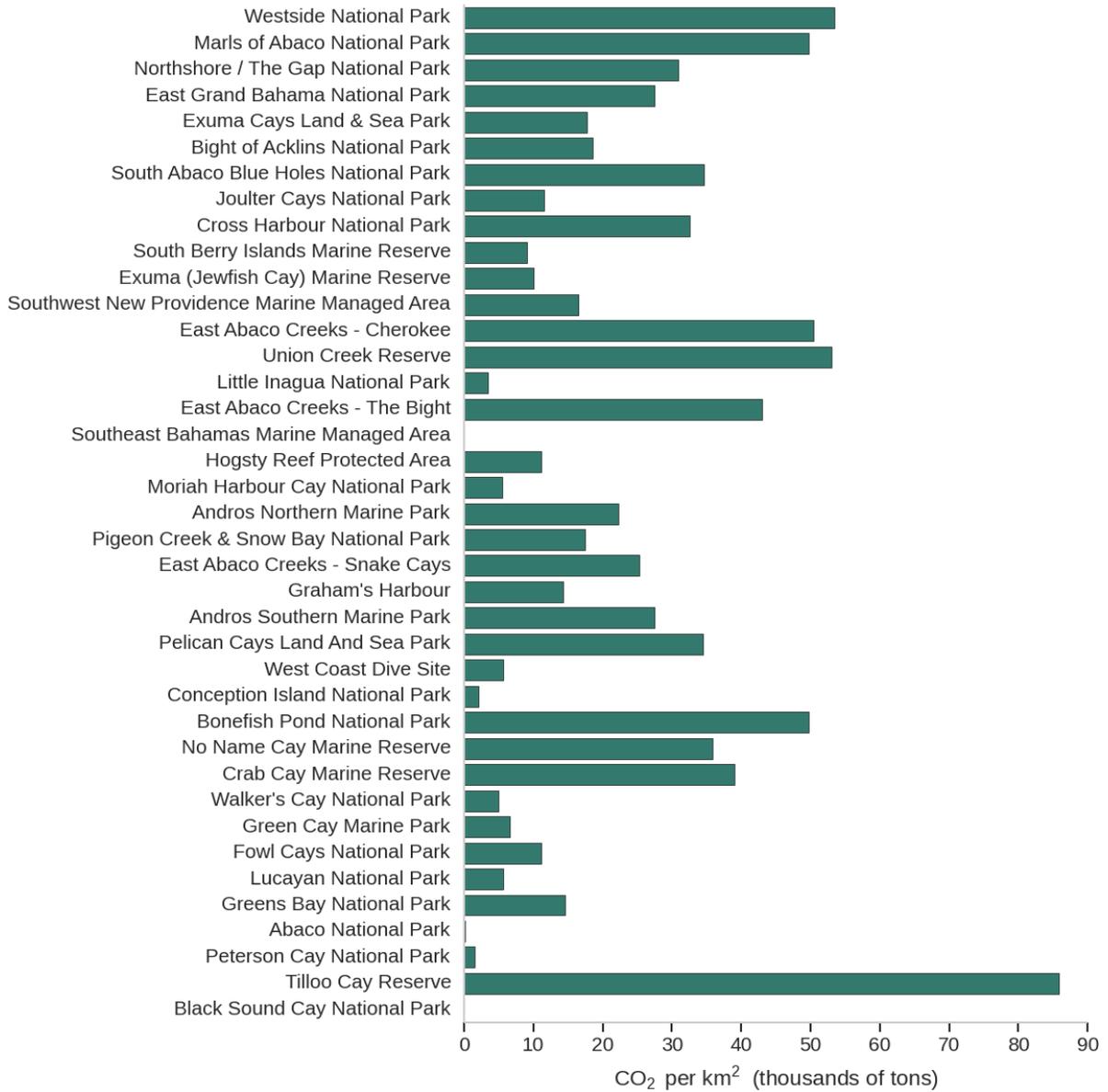


Figure 11. Carbon stock density (i.e. scaled by area) of mangroves and seagrass within each marine protected area.

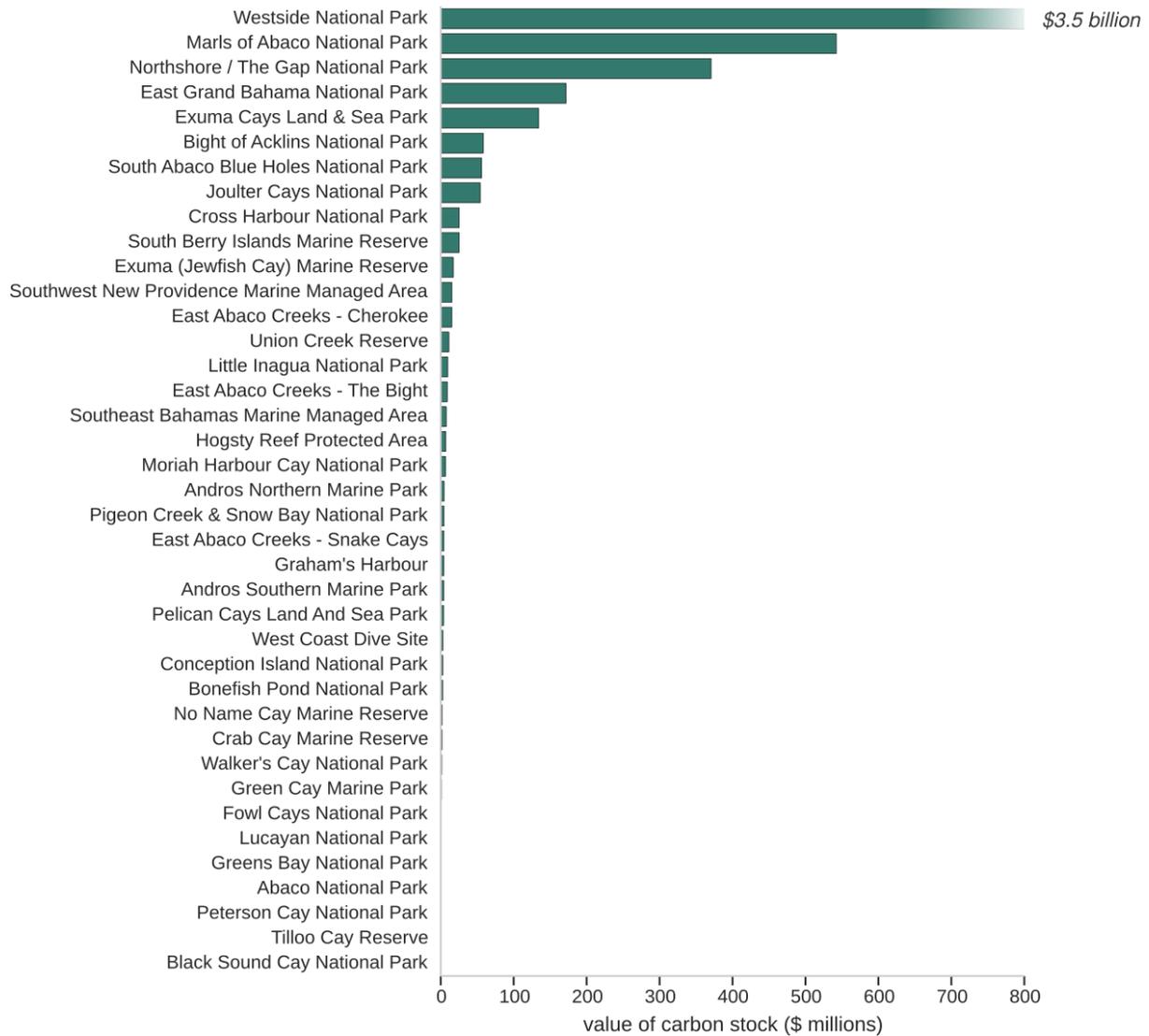


Figure 12. Avoided damages of carbon storage for climate mitigation attributable to habitats within each marine protected area.

5. Island-scale valuation of ecosystem services to inform future management

The MPAs in the current network differ in economic value of ecosystem services within them and their management status. Some MPAs have finalized management plans and others have plans in the development stage. Some islands are scoping the potential of MPAs to manage coastal and marine activities in the future. We explored the influence of current and future management of nearshore activities on economic values of ecosystem services for five different islands representing different stages of management. For some islands—i.e. Exuma, Bimini, and Eleuthera—we use the general approach outlined above and capture the gross value of the ecosystem services as compared to no service provision, rather than the net benefit of MPA designation. Our island-scale analyses around New

Providence and Andros include the current risk from human activities in these regions to habitats and services. These results provide some insight into the maximum potential gains if MPA designation were able to fully protect habitats. Our results for New Providence and Andros come closer to demonstrating the value of MPAs for ecosystem service provision. Coupled with information on costs, this information could be leveraged in a cost benefit analysis to estimate the net social welfare impact of MPAs in The Bahamas.

Exuma



Aerial view of Exuma Cays Land and Sea Park (photo from ExumaPark.org) and coral within the park (photo from The Nature Conservancy)

Introduction and overview of past work

Exuma Cays Land and Sea Park (ECLSP), established in 1958, is the oldest existing National Park in The Bahamas and the oldest no-take fishing area in the Caribbean region. It covers 450 km² at the north end of the Exuma Cays (Figure 13). The park's unique habitats and species (including the endangered Bahamian iguana), protected status, and mooring system draw visitors from around the world who come to enjoy the natural beauty, snorkel, dive, and otherwise explore this special area. Because of the area's history and attributes, it has been the subject of a number of ecological, social, and valuation studies. We briefly describe some of this past work before exploring the spatial variation in ecosystem services within the park.

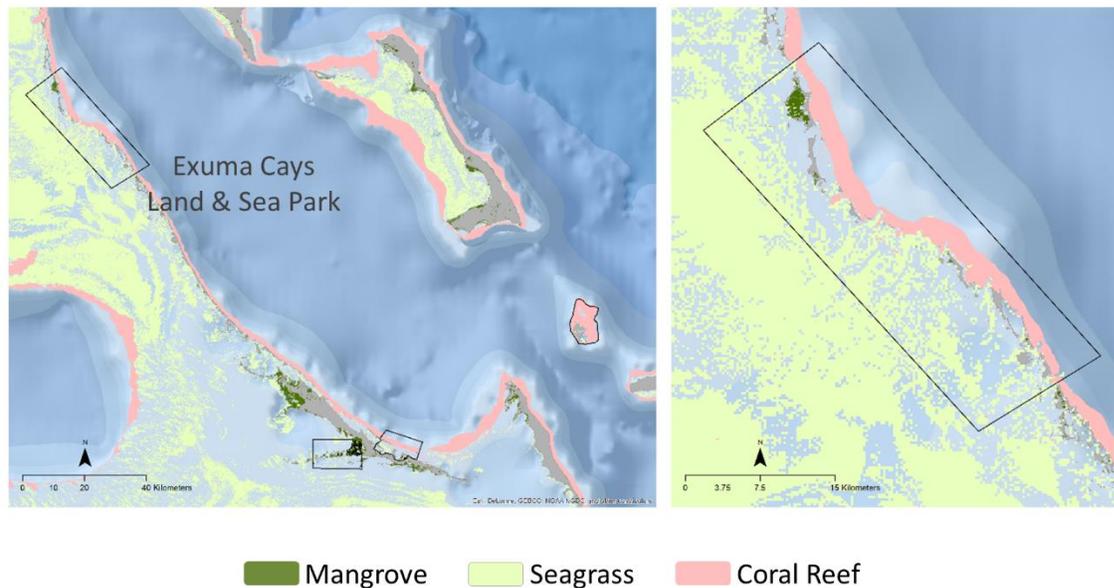


Figure 13. Exuma Cays Land and Sea Park.

Past studies demonstrate the ecological benefits of ECLSP for natural habitats and fisheries. Within ECLSP, corals recover from disturbance faster and conch, grouper, and lobster biomass and productivity are greater. Reduced fishing has promoted faster coral recovery following disturbance by enabling herbivorous fish (e.g. parrotfish) to naturally reduce macroalgal cover (Mumby and Harborne 2010). Adult queen conch biomass has been found to be as much as 15 times greater inside ECLSP than surrounding areas and this resulted in larval densities an order of magnitude greater within the park than outside it (Stoner and Ray 1996). Further, conch within the park require lower adult densities for mating than those outside the park, the result of phenotypic variation caused by fishing pressure (Stoner et al. 2012). Similarly, Nassau grouper biomass and size, as well as reproductive capacity, are greater within the park than outside it and this effect extends upwards of five kilometers beyond the park boundary (Sluka et al. 1997), highlighting an important spill-over effect in which the no-take MPA is benefiting fishing in surrounding areas. Though harder to document across fisheries, the success of ECLSP at increasing biomass and reproduction of key species may mean the area helps to support these populations outside the park. Finally, lobster biomass has also been shown to be higher within the park (Lipcuis et al. 1997). For a comprehensive review of the ecological benefits of the park, please refer to Sobel and Dahlgren 2004.

Management remains one of the key social issues around the park. Ervin’s 2009 study of all parks in The Bahamas identified ECLSP as one of the most vulnerable due to limited enforcement paired with threats from climate change and tourism (Hargreaves-Allen and Pendleton 2010). For a full discussion of these management challenges, including costs and benefits associated with alternative strategies, please see Hargreaves-Allen (2012).

Previous work has also suggested the extensive economic value of ECLSP for fisheries, second home owner development, and tourism, among others (Hargreaves-Allen and Pendleton 2010). It is estimated that ECLSP “generated \$9 million in direct and measurable economic impact in 2009” as well as supports 110 jobs (Hargreaves-Allen and Pendleton 2010). Spillover from the park of conch and grouper

contribute to subsistence and commercial fisheries outside the park. Second home owners within the park pay an estimated \$14 million in property tax. For tourism, there have been roughly 40,000 stop-over visitors to Exuma annually between 2005 and 2007. Visitors to Exuma include boaters, day-trippers, divers staying locally, and live-aboard divers and these tourists spent nearly \$2,500 per trip to Exuma in 2010 (Hargreaves-Allen and Pendleton 2010). In-depth studies specific to Exuma have explored avenues to promote and maintain sustainable tourism (Total Tourism Solutions 2014). For a full discussion of the economic benefits of ECLSP, please see Hargreaves-Allen and Pendleton (2010).

Spatial variation of ecosystem services within ECLSP

Spatially explicit valuation of tourism, lobster, coastal protection, and climate mitigation services further strengthen the understanding of ECLSP's importance. ECLSP receives an estimated 23,000 stop-over visitor-days, with an estimated expenditure of \$6.6 million annually. This is within the range estimated by Hargreaves-Allen and Pendleton (2010), who conservatively estimated that 18,346 tourists visit the park annually: 9,986 day-trip visitors from hotels (out of 15,914 nearby overnight stays), 2,360 diver days, and 6,000 boaters annually. Visitation across the island chain is concentrated in and around the park and at the southern extent, demonstrating the dual forces—natural resources and infrastructure—that draw in tourists (Figure 14).

With 1.4 km² of mangrove and 38.6 km² of seagrass in shallow, nearshore areas suitable for juvenile lobster (Figure 13), 240,341 lbs. of lobster annually, worth just under \$1 million in export value, are attributable to nursery habitat within the park. This nursery habitat area supports adult lobster beyond the no-take area of ECLSP, for example, on the Exuma Bank, as well as fisheries on adjacent banks connected by shallow shelves. Furthermore, the lobsters not caught within the reserve may also support future catches outside the reserve by contributing their spawn; however, to our knowledge the ecological, economic, and social data required for estimating spill-over of spiny lobster in economic terms for ECLSP does not currently exist.

While coral, seagrass, and mangrove protect much of the Exuma Cays coastline, the limited population and undisclosed property values means that we cannot effectively place a monetary value on this protective service (though the overall high value of property within the park suggests the protective role of habitats would be especially valuable there). However, these same ecosystems provide essential protection to people along the southern extent of the Cays (Figure 14). Finally, extensive seagrass and mangrove habitats throughout the park (Figure 13) store over 10.7 million tons of carbon, representative of avoided damages from emissions of over \$134.18 million globally (Figure 14). While mangrove store more carbon per unit area than seagrass, the abundance of seagrass within the park makes it a particularly important resource.

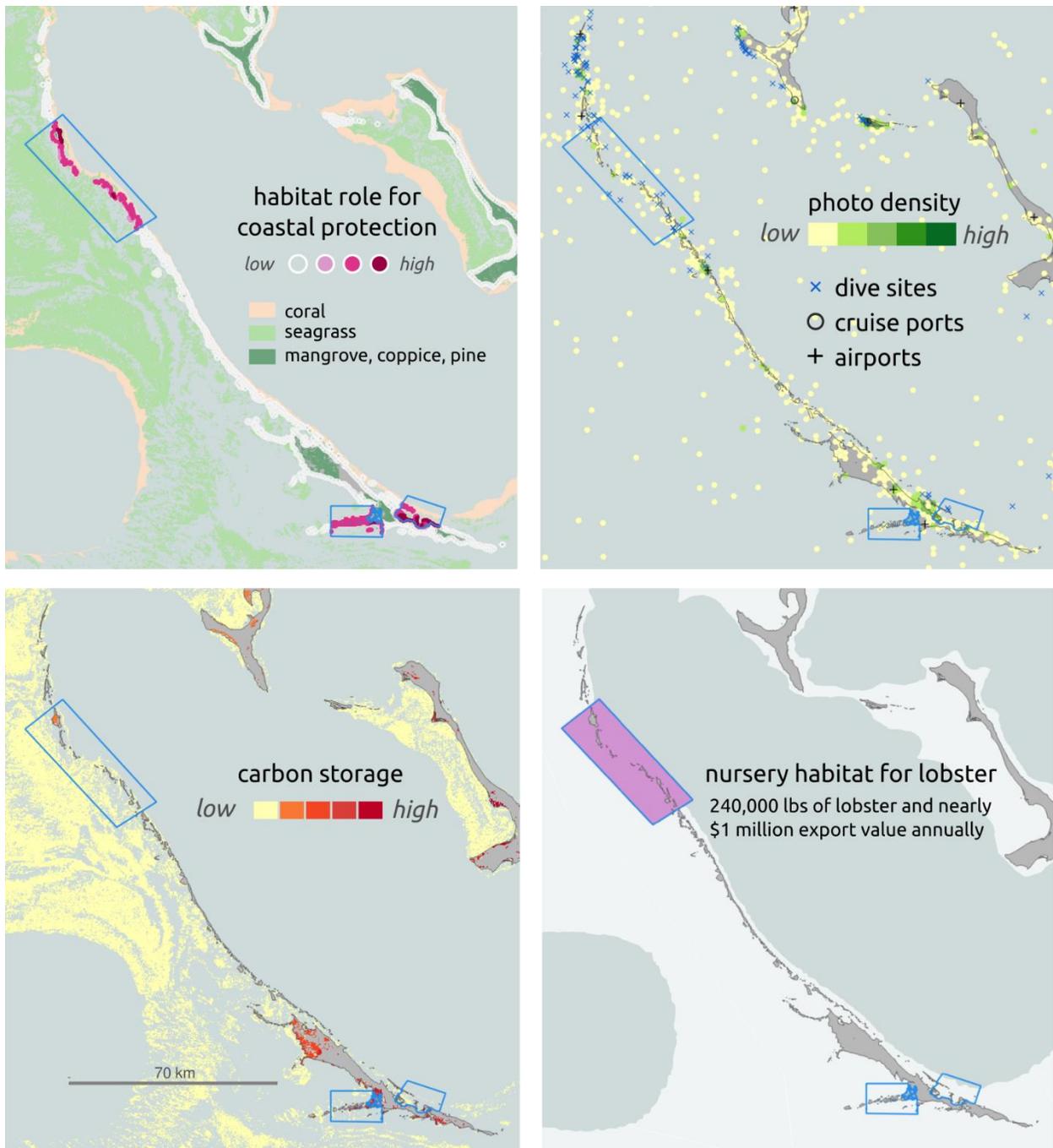


Figure 14. Ecosystem services in and around Exuma Cays Land and Sea Park: habitat role in protecting shorelines, visitor density, carbon stored by coastal habitats, and nursery habitat for lobster.

Exploring alternative development strategies for Andros and their influence on the island's MPAs



Beach and small boat on Andros (photo by Katherine Wyatt).

Introduction

The Island of Andros lies 65 km to the west of Nassau, the capitol of The Bahamas. Encompassing a land area of 6,000 km², an area greater than all other 700 Bahamian islands combined, Andros is largely undeveloped. Vast mangrove and coppice forests, the third largest barrier reef in the world, seagrass beds, sand flats, and a concentrated system of blue holes support the country's commercial and sport-fishing industries, nature-based tourism activities, agriculture, and freshwater resources. While valuing this wealth of natural resources, Androsians also seek investments in infrastructure, training, and educational opportunities to support themselves and ensure the wellbeing of generations to come. As part of the larger National Development Planning process, Vision 2040, Androsians outlined alternative visions for the future, "scenarios", within which different management strategies are defined for marine protected areas and national parks. Andros has four designated protected areas (i.e. Andros West Side National Park, Joulter Cays National Park, North Marine Park, South Marine Park) and one possible area benefiting from future protection (i.e. the barrier reef along the east coast of the island; Figure 15).



Figure 15. Existing protected areas around Andros. We also explored services within the area around the Andros barrier reef (outlines here).

The following are alternative Future Development Scenarios for Andros from the Andros Master Planning Process. Here we highlight components relevant to the Andros MPAs.

- **Business as Usual:** represents a future similar to the current situation with little investment in new infrastructure, educational opportunities, or development. Joulter Cays National Park is not fully adopted, no new marine protected area policies or management plans are implemented, and enforcement of existing policies remains limited.
- **Conservation:** gives priority to ecosystem health and protection of habitats and species rather than economic development. Coastal development is limited to the existing footprint. Joulter Cays and the Barrier Reef are adopted as National Parks. Policies limit detrimental activities within protected areas and resources are devoted to enforcement. North and South Marine Parks, Joulter Cays, and the original boundaries of Andros West Side National Park are enforced no-take areas.

- *Sustainable Prosperity*: blends human development and conservation goals by investing in critical infrastructure and education to achieve a nature-based economy that can be sustained over time. Examples of activities include daily ferries from Nassau, small and mid-sized Bahamian owned businesses (e.g., hotels, processing factories for local goods), community agriculture, and mangrove restoration (as both a natural means of shoreline protection from storms and as habitat for lobster). Joulter Cays and the Barrier Reef are fully adopted as national parks and managed to limit heavily detrimental activities like mining, dredging, and shipping. Fishing regulations including seasonal closures and size limits are enforced effectively.
- *Intensive Development*: gives priority to major economic development rather than ecosystem health and protection of habitats and species. Example activities include construction of a cruise ship port in North Andros, large, energy intensive resorts and luxury housing developments, expanded mining activities, and seawalls along the entire east coast of the island. No new parks are adopted and management remains limited, increasing destructive fishing practices.
- *Restoration*: mirrors the current scenario and additionally restores full coral biomass and functionality within the North and South Marine Parks. This scenario was not part of the original Andros project and was added during Bahamas Protected project.

Working with these stakeholder-designed scenarios, NatCap assessed how these actions and management strategies would affect the natural resources and ecosystem services people care about: habitat quality, spiny lobster catch, nature-based tourism, protection from storms and erosion, and climate mitigation through carbon storage. To understand spatial variation and future change in the distribution of benefits from ecosystems, we used a suite of models in the InVEST software package (Sharp et al. 2017). As described above (Section 3, page 12) the models produce biophysical, economic and social values for several services provided by coastal and marine ecosystems (Nelson et al. 2009, Goldstein et al. 2012, Guerry et al. 2012). InVEST also contains a risk assessment framework for identifying where human activities are most likely to pose a risk of habitat degradation under the current and several future scenarios, which we describe below.

Approach

For each scenario envisioned during the Vision 2040 National Development Planning process, we assessed the cumulative risk from ten categories of human activities to six habitats (after Arkema et al. 2014). Human activities were included based on stakeholder input, literature review of important stressors, and which activities are likely to change under alternative future development scenarios (Table 2, Figure 15). These categories were development and infrastructure, dredging and mining, nature-based tourism, transportation of goods and people by water, fishing, forestry, agriculture, protected areas, invasive species, and sea-level rise. The spatial extent of each activity was mapped for each future scenario (Figure 15). Further, the characteristics (e.g. intensity, temporal duration, management effectiveness) of each activity were also defined for each scenario. We selected habitats based on those most important to stakeholders and those which underpin valued ecosystem services. For example, seagrass and mangrove were included, in part, because they provide nursery habitat for lobster and their abundance affect harvestable adult lobster. We also assessed cumulative risk to beaches and coral reefs, in part, because of their importance for tourism and coastal protection.

We assessed where habitats are at the greatest risk of degradation from the cumulative effects of human activities. Risk is a function of the exposure of each habitat to each activity and the habitat-specific consequences of that exposure (Halpern et al. 2008, Teck et al. 2010, Patrick et al. 2010, Hobday

et al. 2011, Samhoury and Levin 2012, Arkema et al. 2014). Exposure depends on the extent of geographic overlap between habitats and human activities, the duration of time that the activity and habitat overlap, the intensity of the stressor, and the degree to which management strategies mitigate impact. Consequence is a function of the habitat-specific sensitivity of ecosystems to stressors associated with human activities (reflected in terms of potential changes in area and structure as a result of exposure to stressors) and resilience of habitats based on ecological life history characteristics (e.g., mortality, recruitment, connectivity). For each stressor-habitat combination, we used criteria scores for exposure and consequence that were informed by primary literature and vetted by local experts during the Sustainable Development Plan for Andros process. Cumulative risk is the spatially explicit sum of individual risk scores. We used maps of high, medium, and low risk to estimate the area of functional habitat capable of providing ecosystem services. In high and medium areas, we assumed that 0% and 50%, respectively, of the existing habitat was capable of providing services; in low-risk areas, we considered all habitat to be functional (following Arkema et al. 2015).

We used results of the cumulative risk assessment to model changes in ecosystem services in order to understand how alternative development scenarios and their implications for MPA management would influence nursery habitat for lobster and carbon storage and sequestration provided by seagrass and mangroves within the MPAs. We also quantified potential changes in tourism and coastal protection values to the subregions of Andros. The use of risk analysis for current and future scenarios of human use help to demonstrate the relative benefit of management. Combined with the cost of implementation and management, this information could be used in estimates of the net value of MPA designation.

Table 2: Human activities and drivers of change. Aerial imagery is from 2015, Andros Island Conservation Assessment was done in 2005, AIS data is from 2014.

Human Use	Source	Description
Development	Digitized aerial imagery (TNC), stakeholders	Private, residential, and commercial development including roads, lodges, airports, factories, airports and more
Dredging and mining	Digitized aerial imagery, stakeholders	On land and in the ocean for quarry, sand, aragonite and other minerals; in the ocean to maintain transportation pathways
Nature-based tourism	TNC, Andros Island Conservation Assessment, BNT	Areas identified during the stakeholder engagements, including areas for dive, bonefishing, bird watching, kayaking etc.
Transportation of goods and people by water	Marine Automatic Identification System (AIS), Stakeholders	Ferries, mail boats, and cargo ships. Personal transportation and fishing vessels are not included.
Fishing	Area of Interest	Fishing for lobster, conch, scalefish, and sponge.
Forestry	Department of Forestry	Includes conservation forests, forest reserves (for timber use), and protected forest (that can be converted for development).
Agriculture	Digitized Aerial Imagery (TNC), Department of Forestry	Large-scale (e.g. for BAMSI and otherwise zoned) and small-scale.
Invasive Species	Andros Island Conservation Assessment	Invasive species locations for <i>melaleuca</i> , <i>leucaena</i> , and <i>casuarina</i> buffered by 750m where density was reported as sparse or dense. Lionfish are represented across the coral reef..
Sea-level rise	Allen and Holding 2015	<i>Not included in the current scenario.</i> Represents 2m of sea-level rise. Digitized from Allen and Holding 2015.

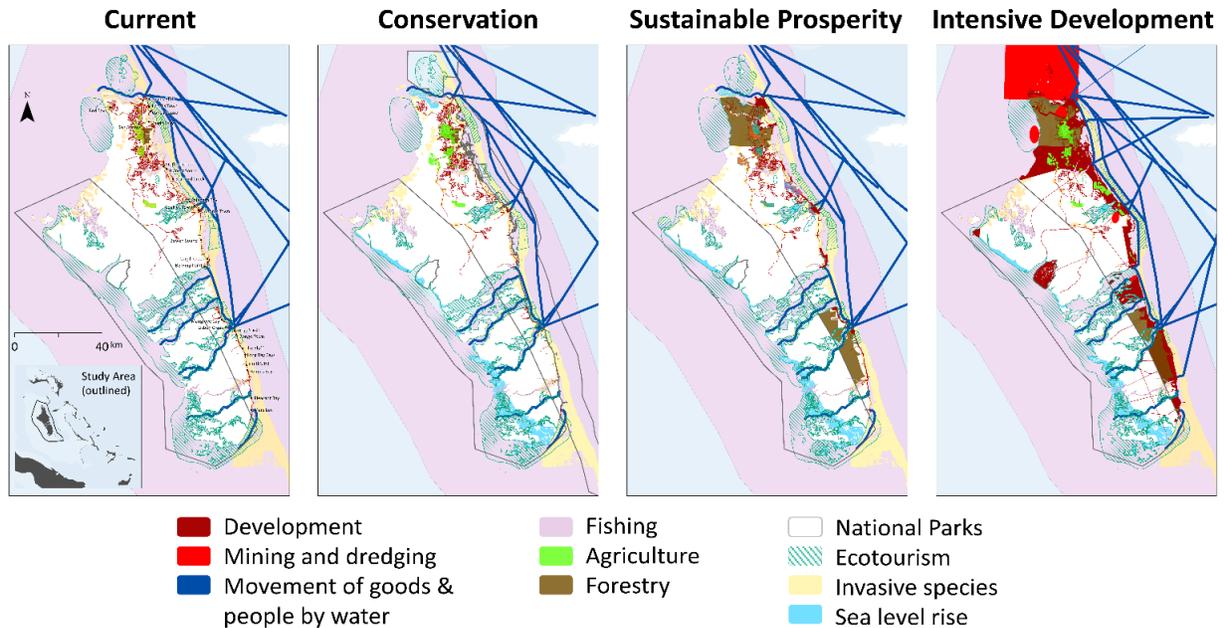


Figure 16. Human activities on and around Andros, now and under three future scenarios. The restoration and business as usual scenarios are not shown; they assume current activities endure, but under the restoration scenario, coral within Andros North and South Marine Park are fully restored.

Risk to habitats within protected areas

Within protected areas, relatively small areas of mangrove, beach, seagrass, and coral are presently at high risk of degradation. Within Andros West Side National Park and Joulter Cays National Park, less than 5% of seagrass and mangrove are at high risk. In North and South Marine Park, less than 1% of mangrove and seagrass are at high risk. In the South Marine Park nearly 8% of coral are at high risk. Around the barrier reef, 45% of mangroves, 5% of beaches, and 2.5% of coral is at high risk; over 98% of seagrass is at moderate risk (45% of mangroves and 95% of beaches are at moderate risk). Areas of higher risk to mangrove, beaches, seagrass, and coral are primarily driven by the overlap of

development (including roads), invasive species, and dredging. Currently, unregulated, fishing practices result in the moderate risk evident across much of the seagrass area (Figure 17).

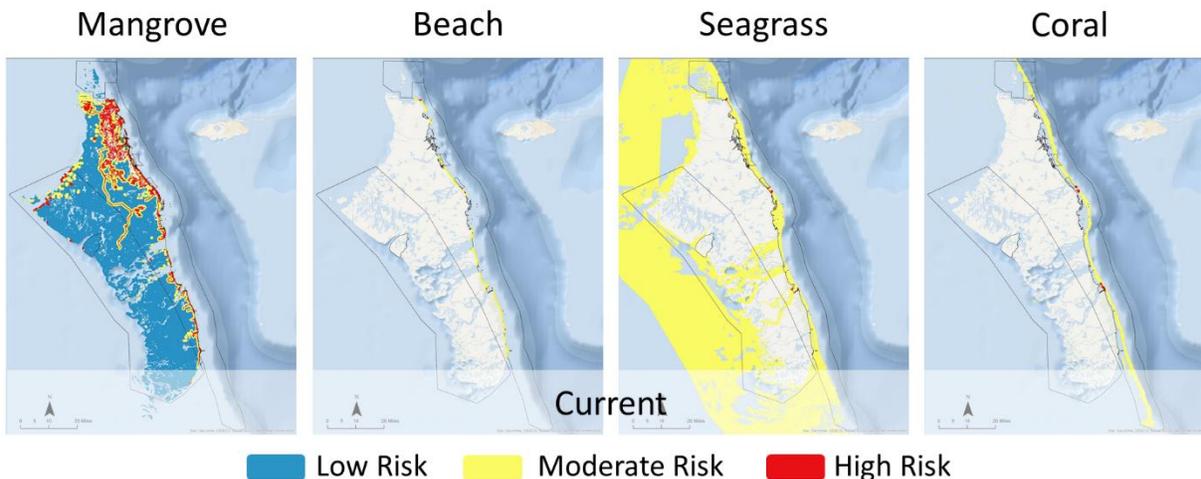


Figure 17. Cumulative habitat risk to mangrove, beaches, seagrass, and coral on and around Andros.

Risk to habitats differs between alternative management scenarios. Risk to mangroves in all protected areas remains comparable between scenarios except in the Intensive Development scenario, where an additional 185 km², 30 km² are at high risk in Andros West Side National Park and Joulter Cays National Park, respectively. No additional mangrove is at high risk in Andros North and South Marine Park, respectively (relative to Business as Usual), because there is little mangrove within these parks and it is at high risk under business as usual and at moderate risk in other scenarios. Risk to nearly all seagrass within the protected areas is reduced to low risk under Conservation and Sustainable Prosperity scenarios and increased to high risk under the Intensive Development scenario. For beaches, risk is comparable between scenarios, except in the Intensive Development scenario where all beaches are at high risk. Corals experience similar risk under Conservation and Sustainable Prosperity scenarios and a drastic increase (to nearly 100% high risk) in risk under the Intensive Development scenario. Conversely, corals in North and South Marine Park are at low risk in the Restoration scenario. In the Barrier Reef region, across most scenarios less than 5% of corals are at high risk in all scenarios except the Intensive Development Scenario in which the entire coral reef is at high risk. Across habitats, risk is consistently highest in the Intensive Development scenario and these impacts are especially pronounced in the North and South Marine Park, which border the developed coast (Figure 18, Figure 19).

These variations in risk across protected areas and between scenarios illustrate the effect of changes in the extent and management of human activities on habitats in MPAs. Increased risk to mangroves and beaches is almost entirely driven by the increased footprint of infrastructure and roads, which are intensive activities with large impacts on habitats. While small areas of seagrass along the eastern coast are similarly affected by development (and dredging), reductions in risk to seagrass in the Conservation and Sustainable Prosperity scenario reflect improved management of recreational and commercial fishing. Not surprisingly, areas of coral restoration result in the lowest risk to corals, though this scenario assumes that coral restoration is fully successful in restoring coral functionally (e.g. biomass, structure, diversity) and reducing the stress of human activities. Interestingly, the removal of fishing pressure to Andros' North and South Marine Park and West Side National Park in the Conservation

Scenario does not markedly reduce risk to coral, seagrass, or mangrove (i.e. the majority of coral is at moderate risk in each of these scenarios). This is likely because other human activities and stressors—e.g. invasive species, tourism, and marine transportation—continue to adversely affect these habitats. In effect, ensuring low risk to these habitats requires integrated management across sectors.

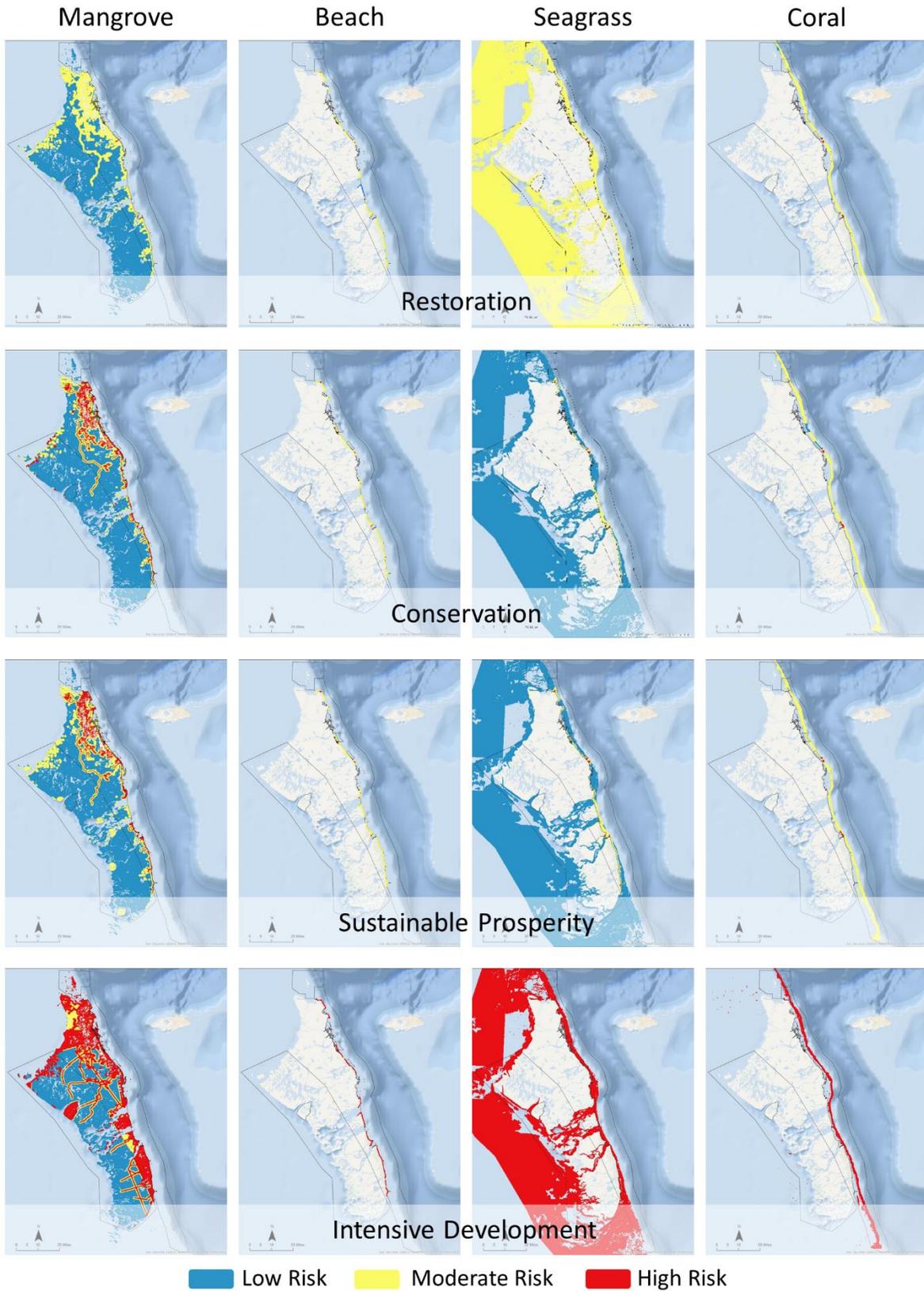


Figure 18. Risk to mangrove, beaches, seagrass, and coral on Andros under Conservation, Restoration, Sustainable Development, and Intensive Development scenarios.

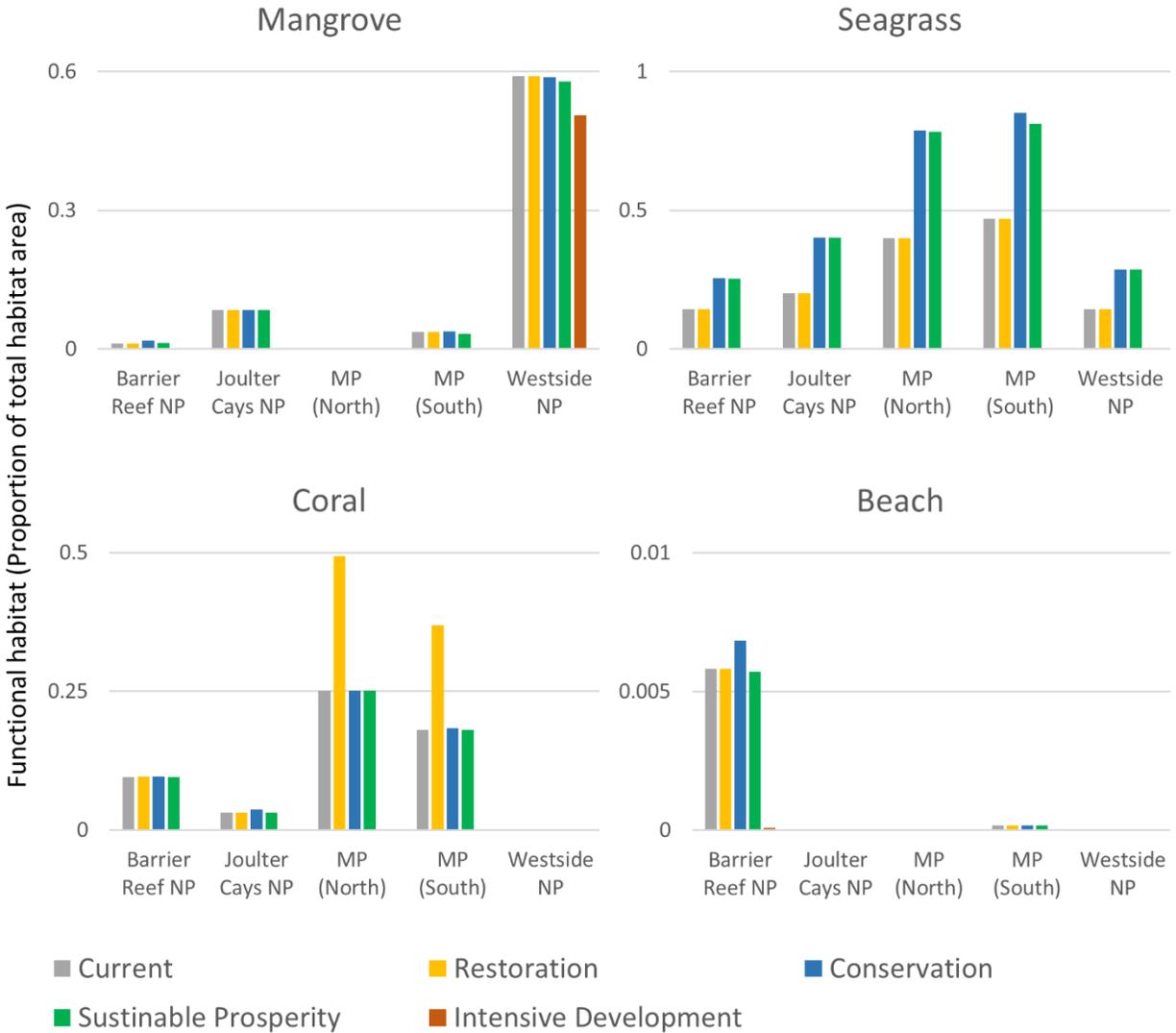


Figure 19. Density of functional habitat within each MPA across multiple scenarios.

Change in services

These future scenarios include a wide variation in habitat quality and function, which means the services flowing to people from these ecosystems is likely to vary across these scenarios as well.

Nursery habitats for spiny lobster fishery

Nursery habitat around Andros contributes 3.5 million lbs. to national lobster catch, amounting to nearly \$14.5 million in export value. Currently, nursery habitat in Andros West Side National Park provides the greatest contribution to catch (3.7 million lbs.) and export value, \$13.3 million annually, compared to other protected areas, largely due to its size and extensive mangrove and seagrass habitat. The Barrier Reef area contains nursery habitat contributing \$1.6 million towards export value annually. Nursery habitat within Joulter Cays National Park and Andros North and South Marine Parks contribute smaller amounts to lobster catch (less than \$200k for Joulter and less than \$35k for North and South Marine Parks). Under the Conservation and Sustainable Prosperity management scenarios, lobster catch attributable to nursery habitat within West Side National Park would increase to \$21 million annually,

the result of improved management of nursery habitat, especially improved fishing practices. Without resources and management, the unregulated coastal development and destructive fishing practices modeled in the Intensive Development scenario would plummet lobster catch to less than half of the value expected under other management scenarios, demonstrating the potential negative consequences of unchecked use annually and over the long-term.

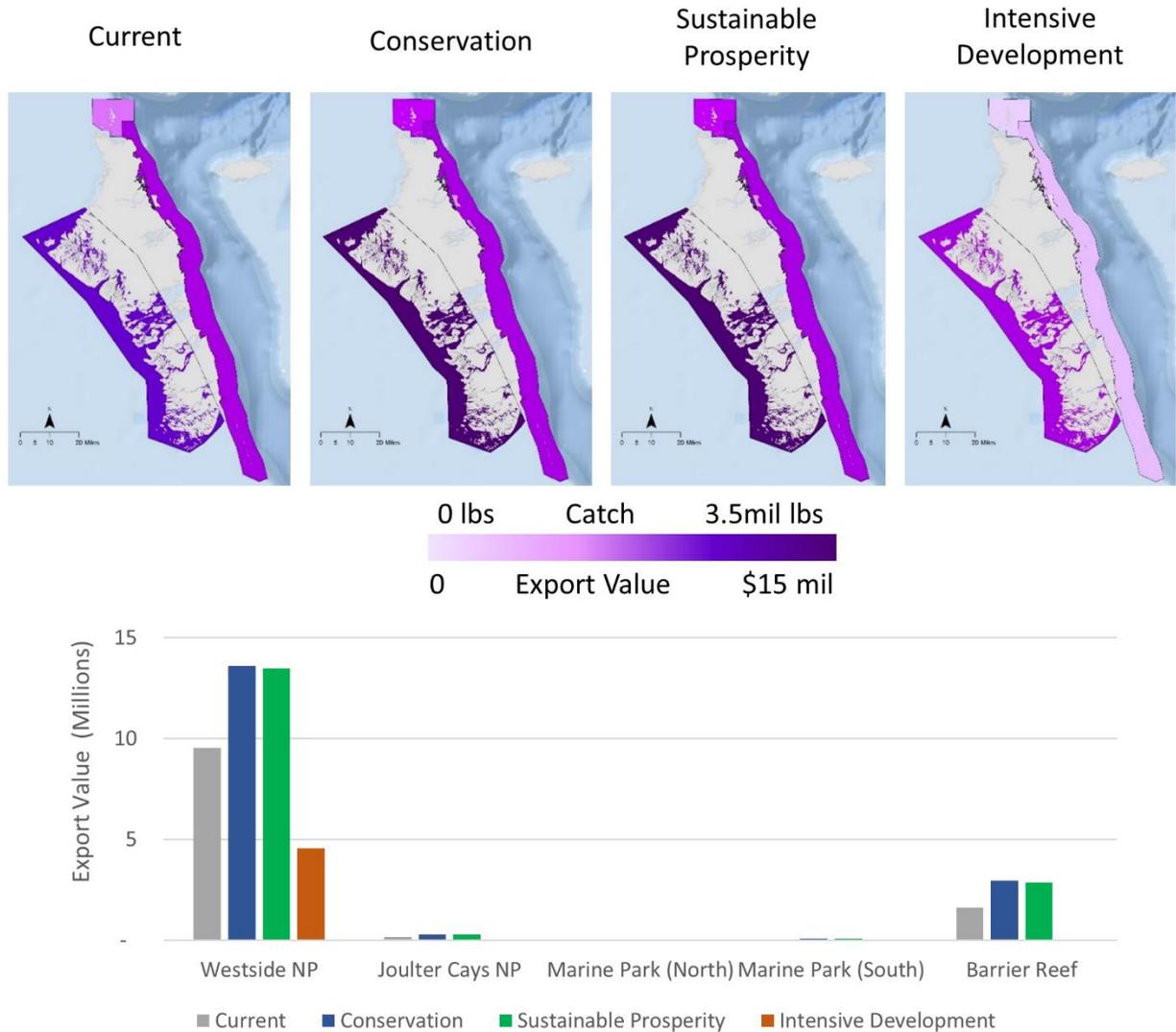


Figure 20. Lobster catch and export value attributable to nursery habitat within MPAs under alternative management strategies on Andros: current, conservation, sustainable prosperity, and intensive development.

Tourism and recreation

Variation in predicted rates of visitation and expenditures from tourism reflects the influence of habitat quality (including within the protected areas) accessibility, and infrastructure across the island, and how these factors change across scenarios. Relative to Business as Usual, the Sustainable Prosperity scenario offers an opportunity to enhance tourism throughout the island, but the differences vary considerably between districts. North Andros and Mangrove Cay would benefit the most, with an increase in visitation, expenditure, and jobs of 37%. In North Andros, this amounts to additional 44,740 visitor-

nights, US\$16.3 million, and 56 jobs relative to business as usual. In Mangrove Cay, increased tourism would mean an additional 7,400 visitor-nights, US\$2.5 million, and 35 jobs. Visitation to Central and South Andros would also increase by 19 and 9%, respectively, bringing additional gains in expenditure and jobs to both districts.

This Sustainable Prosperity scenario represents a strategic decision to develop transportation, infrastructure, and amenities that locals and tourists can use, while taking care to not deplete the natural resources that are the primary draw for tourists. Our habitat risk analyses showed the potential of designation and regulation of marine protected areas to preserving habitat quality, and our tourism projections show how that can translate into sustained benefits from ecotourism. For example, while the Conservation scenario prioritizes preservation of ecosystems within MPAs, it lacks targeted investment in infrastructure that tourists require. On the other hand, the Intensive Development scenario seeks to attract large numbers of tourists, for example with coastal development and a cruise port in North Andros, but does so at the expense of habitats within protected areas, for example with sand mining in the Joulter Cays. Our analysis shows that this development undermines tourism benefits because it degrades the natural resources that were the primary attractors of tourists in the first place.

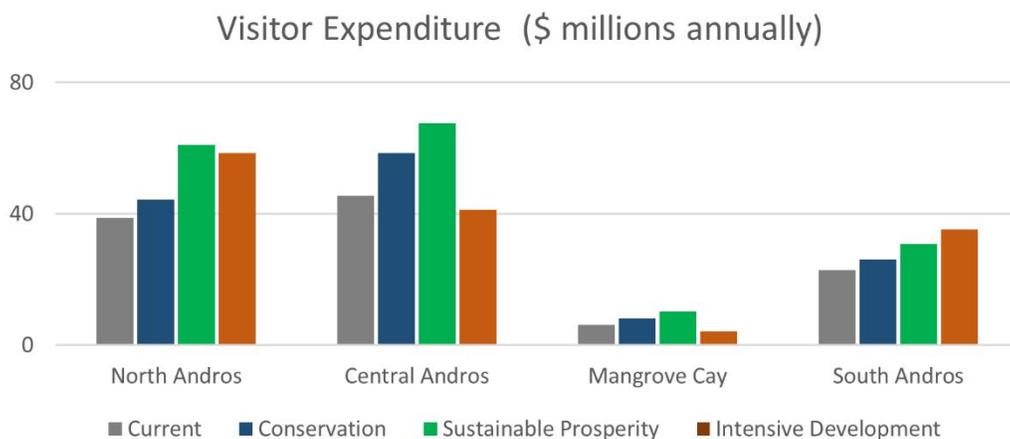
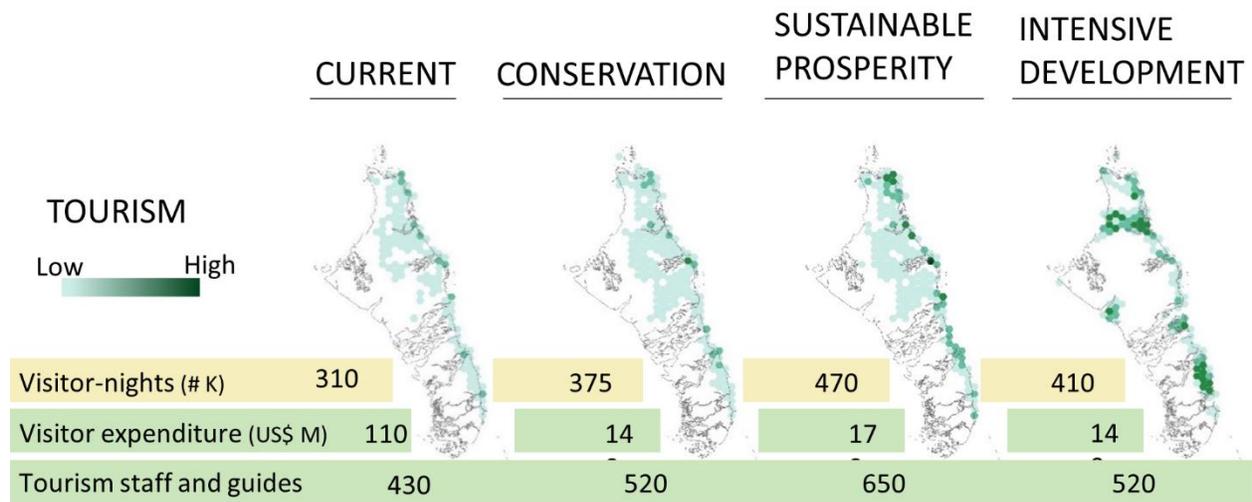


Figure 21. Visitor nights and expenditure under alternative management strategies for Andros.

Coastal protection provided by natural buffers

Our analysis for Andros revealed that nearly 70 km of the populated east coast of Andros is highly vulnerable to storms and sea-level rise, with coastal habitats such as mangrove and coppice forests, coral reefs and seagrass reducing the risk of almost 71% of the coastline, protecting roughly 50% of the islands' population and income. The location of nearly all Andros hotels along the coast suggest they also benefit from this protective service. The existing protected areas on Andros are not currently located to effectively protect coastal communities from storms, but this could change if the Barrier Reef region became a National Park, as habitats within it reduce the impact of coastal hazards along the east coast, where people live. The future scenarios show how variation in the quality of these habitats as a result of management practices translate into variation in length of shoreline, people, and income protected. While we were not able explicitly incorporate the effects of storms on sea-level rise on the freshwater lens on Andros, losses in functional habitat modeled under future scenarios may also adversely affect the freshwater lens. In the future, results from our models suggest that changes in the extent of functional habitat within marine protected areas under the Conservation and Sustainable Prosperity scenarios would result in the shortest length of shoreline at high risk to coastal hazards, due to the buffering capacity of intact habitats. Under these scenarios, the amount of coastline most vulnerable to coastal hazards would be reduced by roughly 6% compared to Business as Usual and would similarly protect roughly half the population and income. Because the coastal population is expected to increase more under the Sustainable Prosperity scenario than the Conservation scenario, coastal habitats protect 8% more people and \$250,000 more in income under the Sustainable Prosperity scenario than the Conservation scenario.

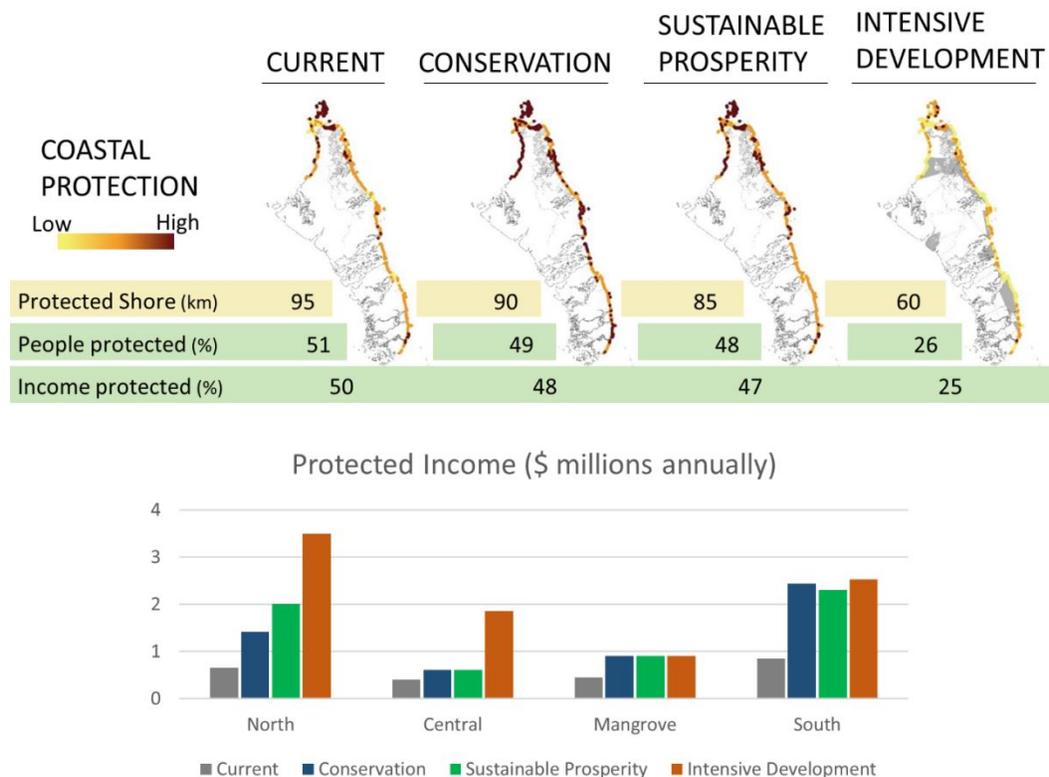


Figure 22. Shoreline, people, and income protected under alternative management scenarios on Andros.

Carbon storage

Habitats within Andros West Side National Park contribute the greatest amount of carbon storage, now and under all future management scenarios. Avoided damages attributable to mangroves and seagrass within West Side National Park amount to approximately \$6 billion globally. The density of carbon storage is also the greatest within West Side, 92,486 tons per km², reflecting the abundance of seagrass and mangrove throughout much of the park. Habitats within The Barrier Reef area store 19.12 million metric tons of carbon, worth \$240.5 million in avoided damages globally, and has substantially lower stock density (8,875 metric tons per km²) than West Side. Habitats within Joulter Cays National Park, Marine Park North, and Marine Park South are similarly dense in their carbon storage, each storing 22-30 metric tons per km². Across the 25-year horizon presented in the management scenarios, the Conservation and Sustainable Prosperity scenarios perform similarly, increasing carbon storage by 3% in Andros West Side National Park and 9-11% in Barrier Reef area. The loss of habitat under the Intensive Development scenario also means a loss of carbon storage, amounting to \$550 million in damages from the West Side National Park alone. While the consequences of carbon emissions are felt globally, the intensity of development and poor management in the Intensive Development scenario would not reflect the global leadership towards climate mitigation that The Bahamas and in the Caribbean countries have taken (Figure 23).

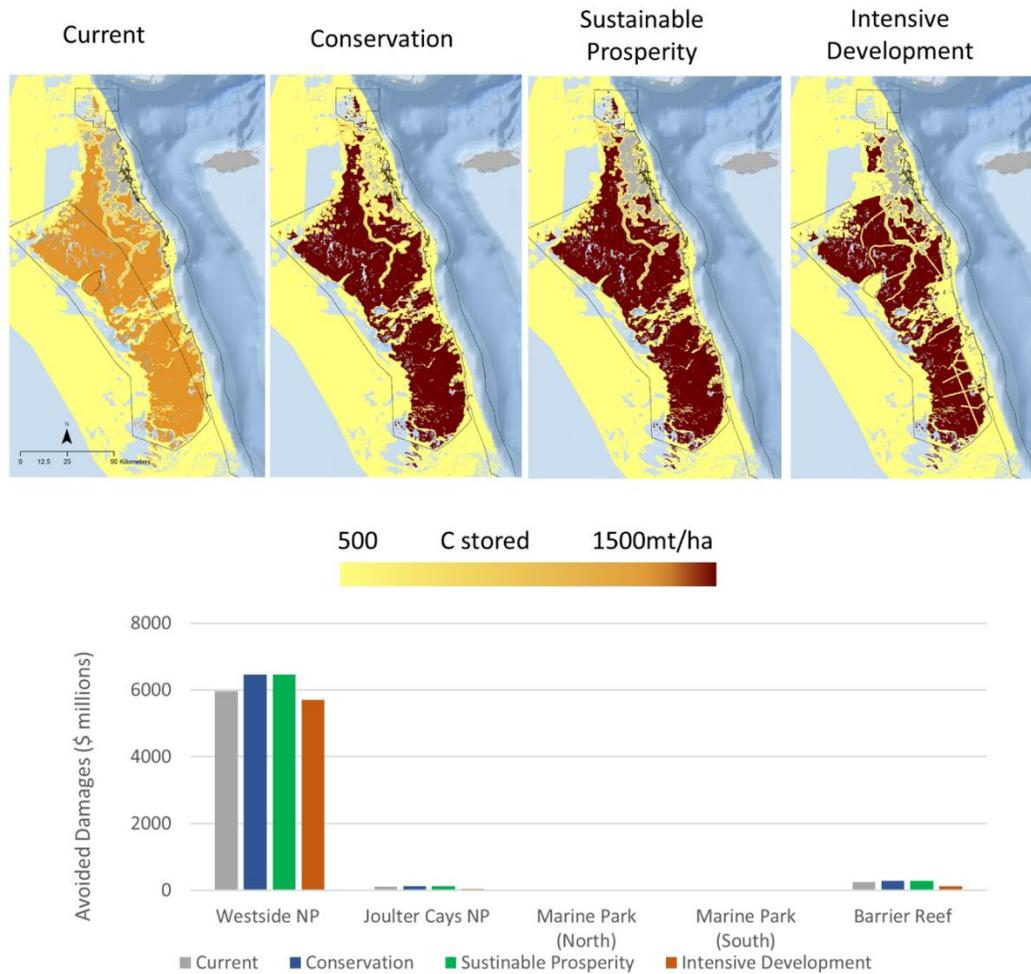


Figure 23. Avoided emissions and damages across alternative management strategies for Andros.

Opportunities for improved management around New Providence



Cable Beach on New Providence (photo from Caribya)

Introduction

New Providence is the most populated and developed island in The Bahamas, including over 70% of the Bahamian population, the capitol, Nassau, and much of critical governmental and commercial

infrastructure and activities of the country. In addition, its beaches and accessibility by cruise ship and airplane, draw well over 2.5 million tourists annually from around the world. The island’s coastal area is also home to the newly established Southwest New Providence Marine Managed Area (SWMMA) as well as older Bonefish Pond National Park (est. 2002) (Figure 24). SWMMA is the among the newest of Bahamas protected areas and, nestled along the north, west, and south coasts of New Providence, is also one of the most urban. The area where the marine managed area is sited currently hosts a multitude of uses: shipping and cruise visitors, tourists, coastal development, and local commercial and subsistence fishing, among others. In places where diverse activities overlap, it’s important to understand what’s occurring and where in order to reduce conflicts between users, reduce and manage impacts to natural systems, and ensure that the benefits the area has historically provided (e.g. clean, intact beaches and coral for recreation, and abundant fish stock for fisherman), continue into the future.

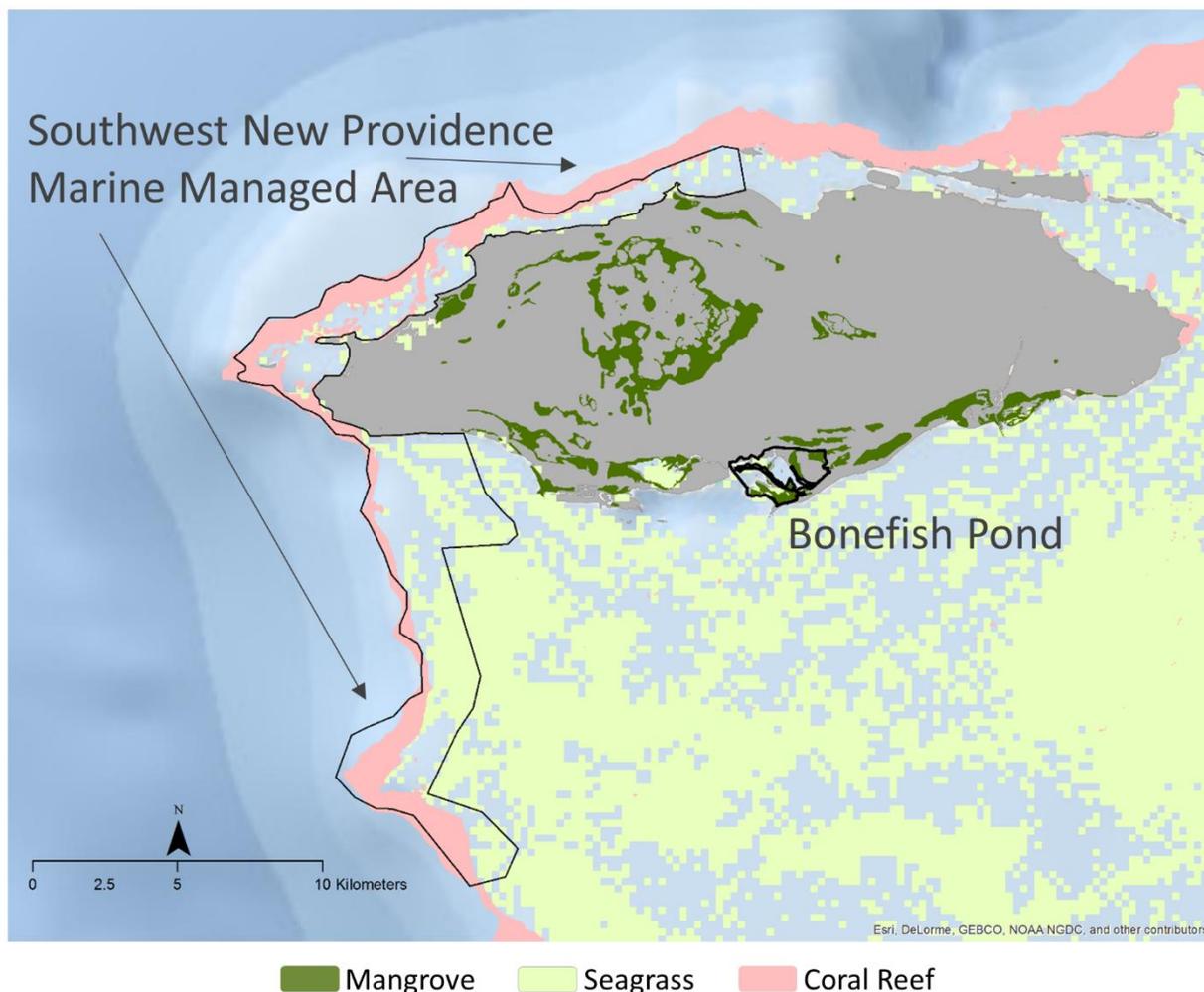


Figure 24. Southwest New Providence Managed Area (SWMMA) and Bonefish Pond.

To evaluate the overlap and effect of these human activities on protected areas in and around New Providence—and to illuminate trade-offs and potential management opportunities—we mapped and modeled the cumulative risk of human activities on habitats and the effect on tourism, nursery habitat for lobster, coastal protection, and climate mitigation. To quantify risk to habitats and the change in ecosystem services we used the suite of InVEST models as described in the previous section (Section 3,

page 12) and below. Briefly, we use the Habitat Risk Assessment model to assess the cumulative risk to habitats from a suite of human activities currently occurring within SWMMA. We compare this current-risk scenario to a scenario without risk, “current-no-risk”. In addition, we model a restoration scenario where, across roughly 10 km² identified by local expert Craig Dahlgren, coral reefs (60% of which are in SWMMA) are restored to fully intact and functional habitats (i.e. ideal levels of biodiversity, density, structure, area, etc.; Figure 27). Though this would be challenging to accomplish, we use this scenario to demonstrate the potential gains from restoration. Risks to habitats in each scenario—current-risk and restoration—are then used to model how changes in functional ability affect visitors, the lobster fishery, protection from storms and erosion, and carbon storage for climate mitigation. The use of risk analysis for current and future scenarios of human use help to demonstrate the relative benefit of management. Combined with the cost of implementation and management, this information could be used in estimates of the net value of MPA designation.

Risk assessment

We assessed the cumulative risk to habitats from seven human activities co-occurring within SWMMA using a risk assessment approach (Arkema et al. 2014). We assessed where habitats are at the greatest risk of degradation from the cumulative effects of human activities.

Risk is a function of the exposure of each habitat to each activity and the habitat-specific consequences of that exposure (Halpern et al. 2008, Teck et al. 2010, Patrick et al. 2010, Hobday et al. 2011, Samhoury and Levin 2012, Arkema et al. 2014). Exposure depends on the extent of geographic overlap between habitats and human activities, the duration of time that the activity and habitat overlap, the intensity of the stressor, and the degree to which management strategies mitigate impact. Consequence is a function of the habitat-specific sensitivity of ecosystems to stressors associated with human activities (reflected in terms of potential changes in area and structure as a result of exposure to stressors) and resilience of habitats based on ecological life history characteristics (e.g., mortality, recruitment, connectivity). For each stressor-habitat combination, we used criteria scores for exposure and consequence that were informed by primary literature and vetted by local experts during the Sustainable Development Plan for Andros process. Cumulative risk is the spatially explicit sum of individual risk scores.

Human activities

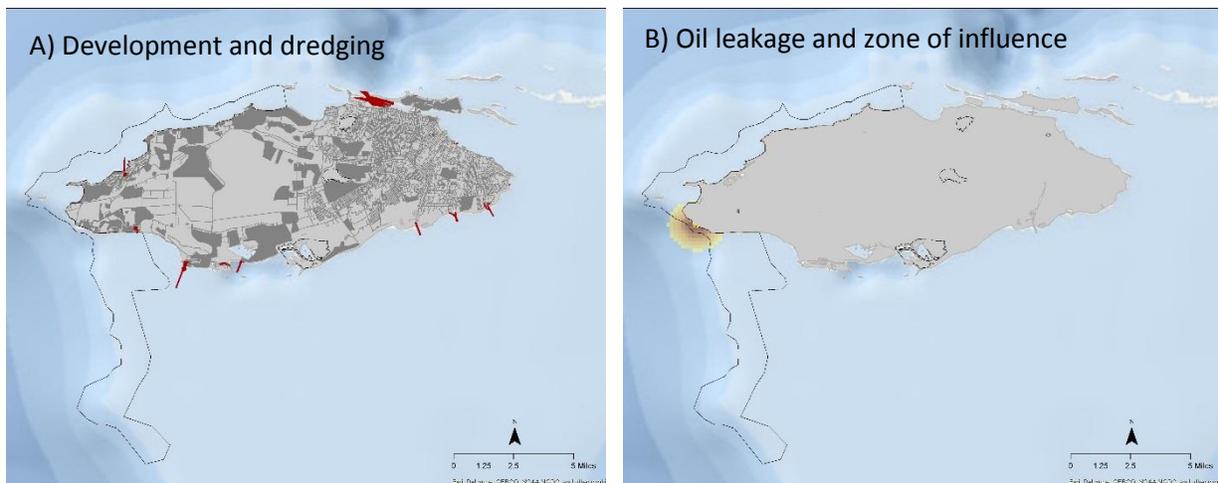
To understand the extent and effect of human activities on New Providence protected areas, we focused on seven categories of ongoing human activities: development, dredging, fishing, invasive species (i.e. lionfish and *Casuarina*), marine transportation, oil leakage around Clifton Pier, and tourism. We selected these categories of human activities based on data available and conversations with stakeholders and core partners. We attempted to capture those activities most important to Bahamians as well as those activities which may adversely affect the areas and habitats people care about.

Human activities originating on land included development, dredging, and the oil leakage around Clifton Pier. The spatial extent of development was digitized from aerial imagery and included roads, buildings, hardscaping, docks, and jetties (Figure 25a). We assumed that the impact of development (e.g. through sediment, pollution, land use change), or the ‘zone of influence’, extends an additional 1.5 km and that these impacts linearly decay within the zone of influence (Arkema et al. 2014). Dredging was also digitized from aerial imagery (Figure 25a); we assumed a 1 km zone of influence for dredging. Because it was important to represent the area impacted by leaking oil around Clifton Pier, yet no maps currently

exist, we approximated the extent. We identified the area immediately around the oil transfer dock as having relatively high concentrations of oil consistent through time; this aligned with the location of oil containment booms, publically available photos, and the area visibly darker on google imagery. Oil has also been regularly reported and documented at least as far away as the west point of Clifton Heritage Park so we applied a zone of influence of 1.5 km to capture this area. This linearly decaying zone of influence aligns with reports from BREEF documenting the presence of oil at the Coral Reef Sculpture Garden at 85% of sampled days⁵. There have also been reports of occasional oil on further west than Clifton Heritage Park and to the east on Goulding Cay, Albany Marina, Adelaide, and South Beach indicating our approximation is likely an underestimate (Figure 25b).

Tourism and invasive species occur in terrestrial and marine environment around the New Providence area. Tourists have the potential to degrade natural habitats through trampling and pollution; for example, highly visited corals suffer from additional breaks from direct impact and sediment from disturbed sand (see Arkema 2014 SI). To map the extent of tourism we used the documented locations of travelers by Flickr to 500m hexagonal grid-cells and assumed a zone of influence of 250m (Figure 25c). Lionfish, which compete with native grouper and are associated with increased coral macroalgal cover, are abundant throughout New Providence corals (Johnson et al. 2015) and we mapped their location as the full extent of corals as well as the adjacent 500m. To map the extent of *Casuarina*, which competes with native vegetation and whose shallow root system increases erosion, we used buffered point data (750m) created through The Nature Conservancy’s aerial survey work of invasive species (Figure 25d). We applied a 250m zone of influence for both lionfish and *Casuarina*.

Marine activities included fishing and marine transportation. We mapped fishing pressure as the area on and around (500m) coral reefs based on past studies (Harborne 2017) and consultation with local experts that suggested relatively high fishing intensity in and around the coral reefs around New Providence (Figure 25e). For marine transportation, we focused our efforts on larger vessels and used data from the vessel automatic identification system (AIS) to map the relative intensity of vessels within 1 km grid cells (the resolution of the data) (Figure 25f).



⁵ Based on the linearly decaying zone of influence, the Coral Reef Sculpture Garden is assumed to be exposed to 60-80% of the impacts of the oil.

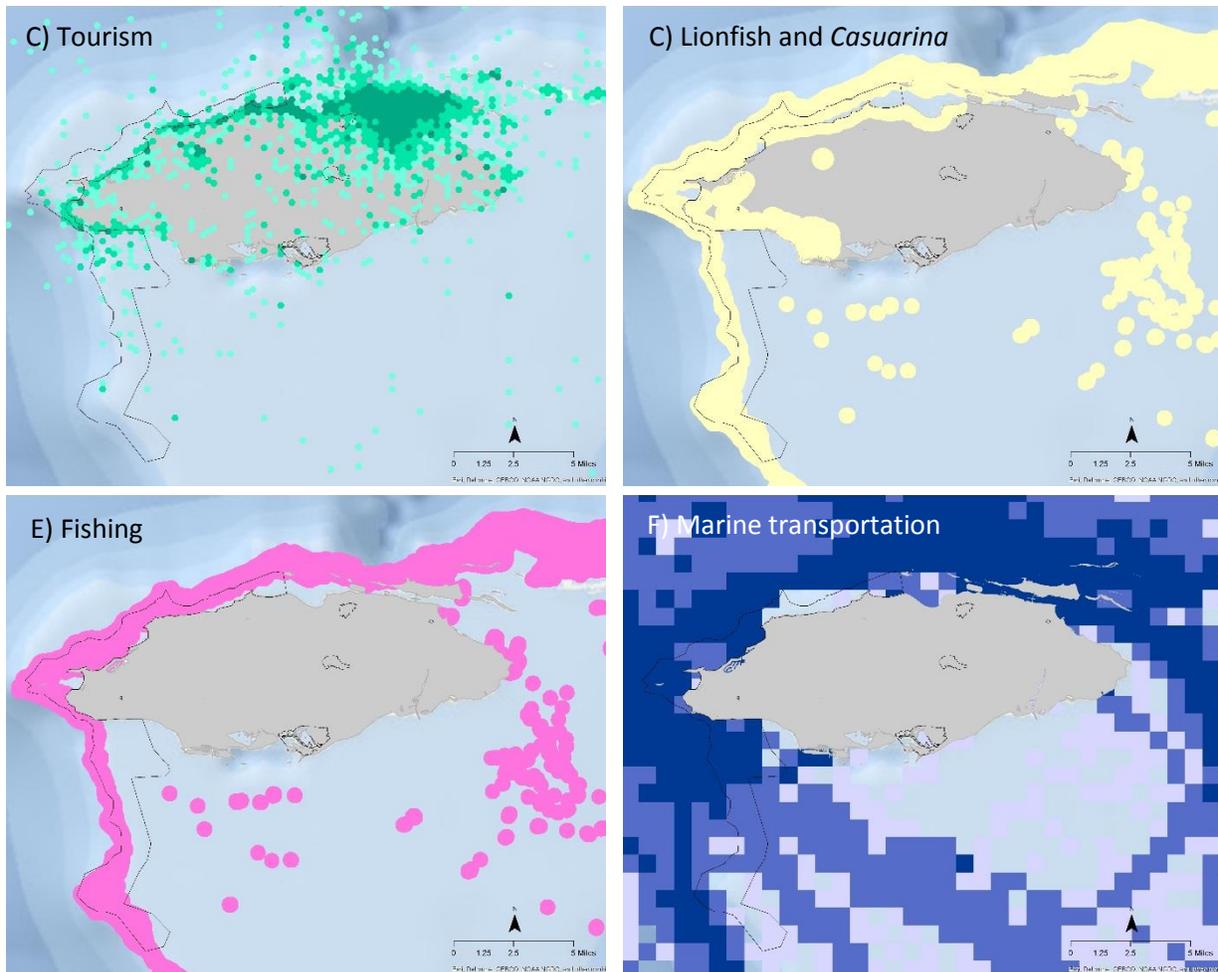


Figure 25. Human activities on and around New Providence. For tourism and marine transportation, darker colors represent greater intensity. Marine managed areas are outlined in black.

Risk to habitats

The extent and multitude of human activities on and around SWMMA puts much of the region at high risk of habitat degradation. All beaches are at moderate or high risk and this risk is driven by the overlap of development, tourism, invasive species, and, in the case of high risk areas, dredging (Figure 26a). Risk to seagrass is similarly driven by the overlap of moderately-impactful human activities; high risk occurs where high impact dredging and oil occur (Figure 26b). Corals are at high risk of degradation near development, the oil leak, and in areas where tourism occurs along the coastline shared with SWMMA. The restoration scenario adds 6.35 km² of low risk coral, 20% of the total coral within SWMMA (Figure 27). Pressure from fishing and lionfish threaten corals and result in moderate risk of degradation even where higher impact activities do not occur (Figure 26c). For terrestrial habitats—mangrove, coppice, and pine—risk corresponds to areas of development and, where applicable, invasive *Casuarina* (Figure 25d-f). Across habitats, areas of low risk are rare and occur only where human activities do not.

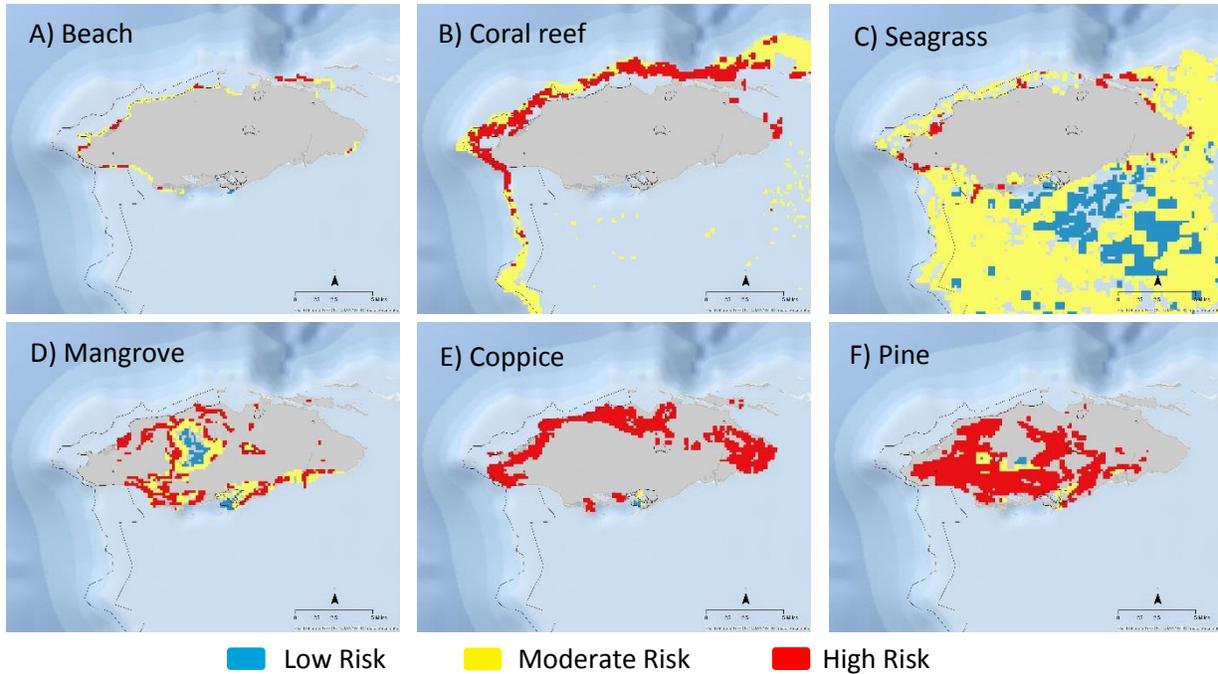


Figure 26. Cumulative risk to habitats on and around New Providence.

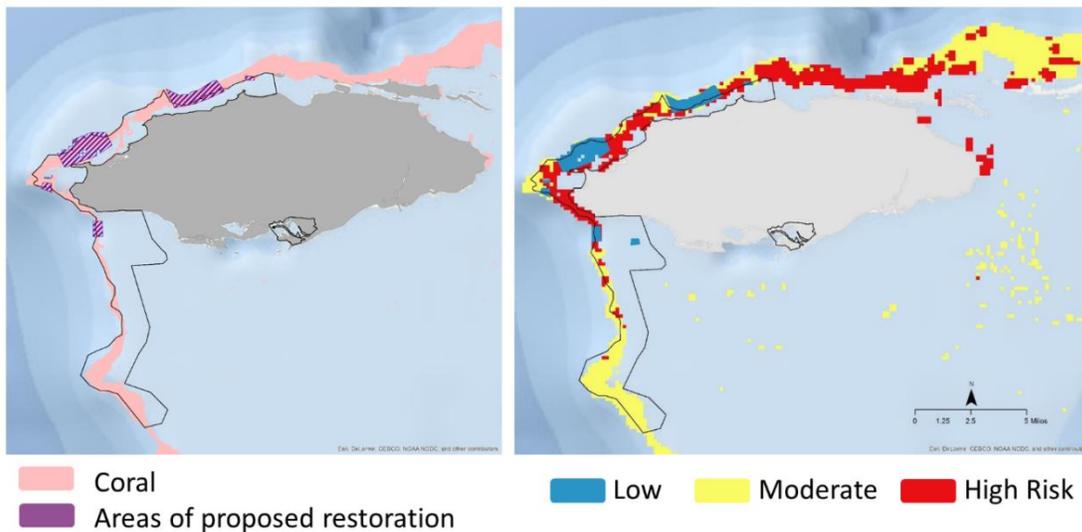


Figure 27. Areas of proposed coral restoration identified by local expert Craig Dahlgren (left). These areas are assumed to be fully functional, i.e. at low risk (right).

Change in services

Habitats at higher risk of degradation are less likely to be able to support the delivery of services to people. For example, degraded mangrove and seagrass will store less carbon and provide low quality nursery habitat to lobster. We used maps of high, medium, and low risk to estimate the area of functional habitat capable of providing ecosystem services. In high and medium areas, we assumed that 0% and 50%, respectively, of the existing habitat was capable of providing services; in low-risk areas, we considered all habitat to be functional (following Arkema et al. 2015).

The vast extent of moderate and high risk across all habitats heavily reduce the ability of the area on and around New Providence, and specifically within SWMMA, to provide critical lobster nursery habitat, support recreation and tourism, protect people from coastal hazards, and store carbon. Relative to if habitats face no risk, current human activities reduce the amount of catch and export value attributable to nursery habitat within SWMMA by nearly 50% relative (from \$260 thousand current-no-risk to \$132 thousand current-risk). The increased risk to beaches and corals, which draw visitors for recreation, reduce potential visitation by 14%, a loss of \$16 thousand annually. Further, 6% of New Providence's population, and 12% of its annual income is at greater risk from storms and erosion as a result of the risk to habitats from multiple human activities around the entire island—illustrating further why protection of habitats within the MPA, which would reduce the risk to mangroves, seagrass, and coral, is so critical. Finally, relative to if habitats faced no risk, coastal habitats within SWMMA store half as much carbon, a loss of 1.3 million metric tons with a social cost of \$16 million (Figure 28).

The restoration of coral along the northern coast and western tip of New Providence would increase visitor expenditure and the number of people and income protected from storms and erosion. Because lobster nursery habitat and carbon storage depend on mangrove and seagrass, they are not affected by coral restoration. Based on the statistical relationship within The Bahamas between healthy corals and visitation (and other factors e.g., access, infrastructure etc., Arkema et al. 2016), we estimate that restoring corals within SWMMA would result in an additional \$662 thousand in visitor expenditure annually (Figure 28) (from nearly 5,000 visitors). Coral restoration, through improving the protective of coral in these areas, would protect an additional estimated 18,800 people and \$521 million in annual income (Figure 28). Though the restoration scenario tackles a large area, a return to fully functional coral is challenging, and coral restoration would require years to achieve, the scenario nevertheless demonstrates the potential gains from investing in restoration. Combined with the cost of implementation and management, these values could be used to help estimate the net benefits of MPA designation and implementation.

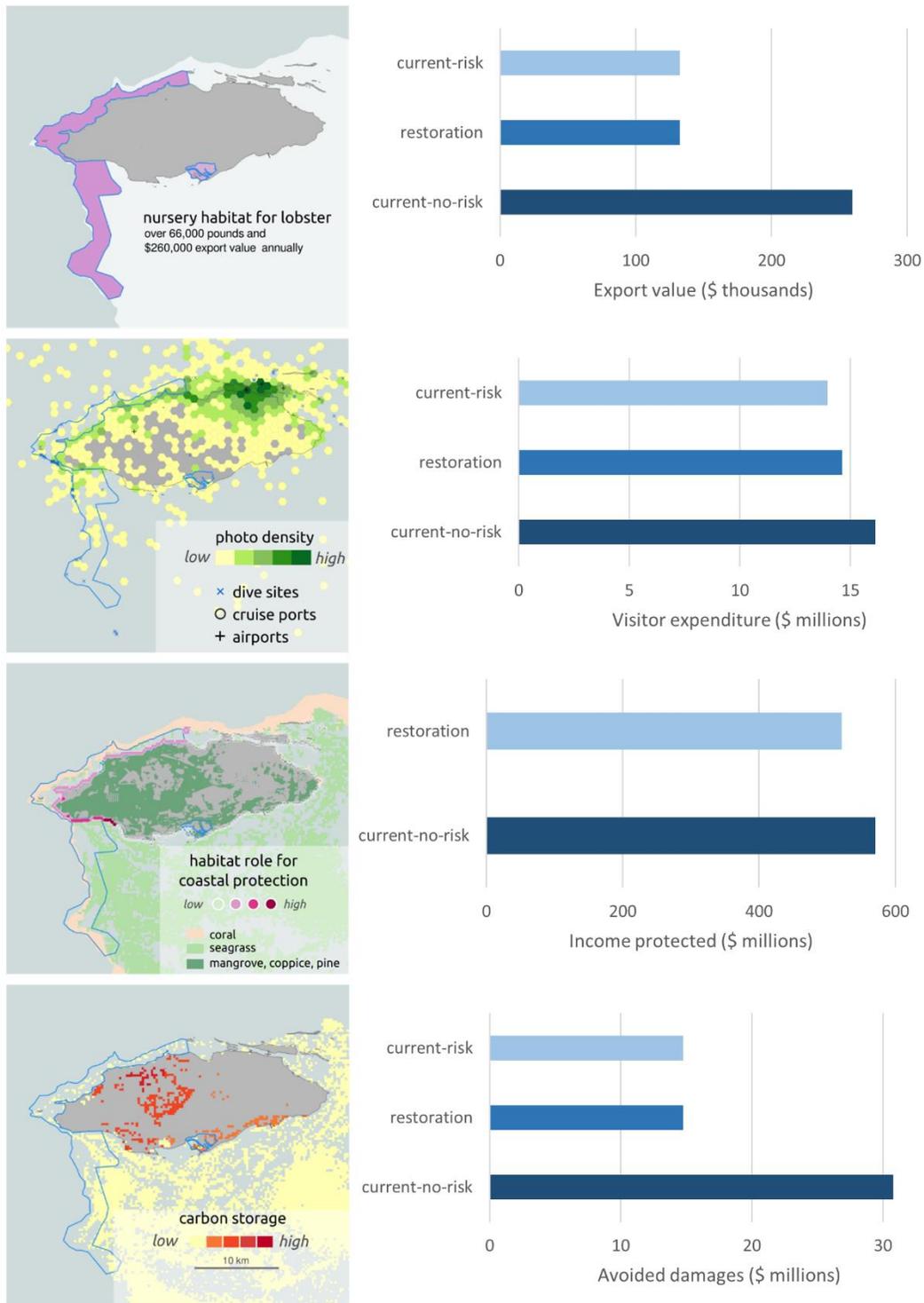


Figure 28. Benefits provided by habitats within Southwest New Providence Marine Managed Area. Lobster harvest and export value attributable to nursery habitat; photo (visitor) density and visitor-expenditure; habitat role for coastal protection and the

additional income protected relative to current-risk; carbon storage and avoided damages from emissions globally. All values are annual.

The suite of human activities cumulatively affects habitats, resulting in increased risk of degradation and reduced delivery of important benefits to people. Given SWMMAs new designation for protection, there's an opportunity to zone and manage human activities to increase these benefits. As an upper bound to the potential benefits of habitat protection, an additional \$128 thousand of annual lobster export value, \$16 thousand in visitor expenditure, \$4.7 billion in protected income, and \$16 million in avoided damages globally from climate change are possible. In just one example of potential management, restoration could bring in an additional \$600 thousand in visitor expenditure and protect over \$600 million in annual income. These potential gains across the four services could offset the cost of management. Because habitats are degraded from a multitude of human activities, effective management will require cross-sectoral coordination. The difference in economic value between the current scenario without accounting for risk from stressors like oil and the current scenario that accounts for risk gives us a sense of the return of management to safeguard ecosystems and the benefits they provide. Stakeholders and community members can assess whether the potential gains associated with improved habitat quality are worth the potential cost of limiting and managing human activities within SWMMA.

Bimini



Photo by Grant Johnson

Introduction

Located along the edge of the western Great Bahamas bank, the islands of Bimini are the most northwestern in The Bahamas (Figure 1). North Bimini provides the only significant population of mangroves along the edge of the bank, which are critical nursery habitat for shark, spiny lobster, bonefish, queen Conch and several other ecologically and economically important marine species. In addition to mangroves, extensive seagrass beds stretch into the shallow waters to the east of the island and the coral reef flanks its northern and western sides (Figure 29). While these ecosystems underlie the livelihoods and wellbeing of the residents of Alice Town and Bailey Town, by providing food from

local fisheries, tourism revenue, and protection from storms, the natural habitats are threatened from development of condos, resorts, marinas and other infrastructure.

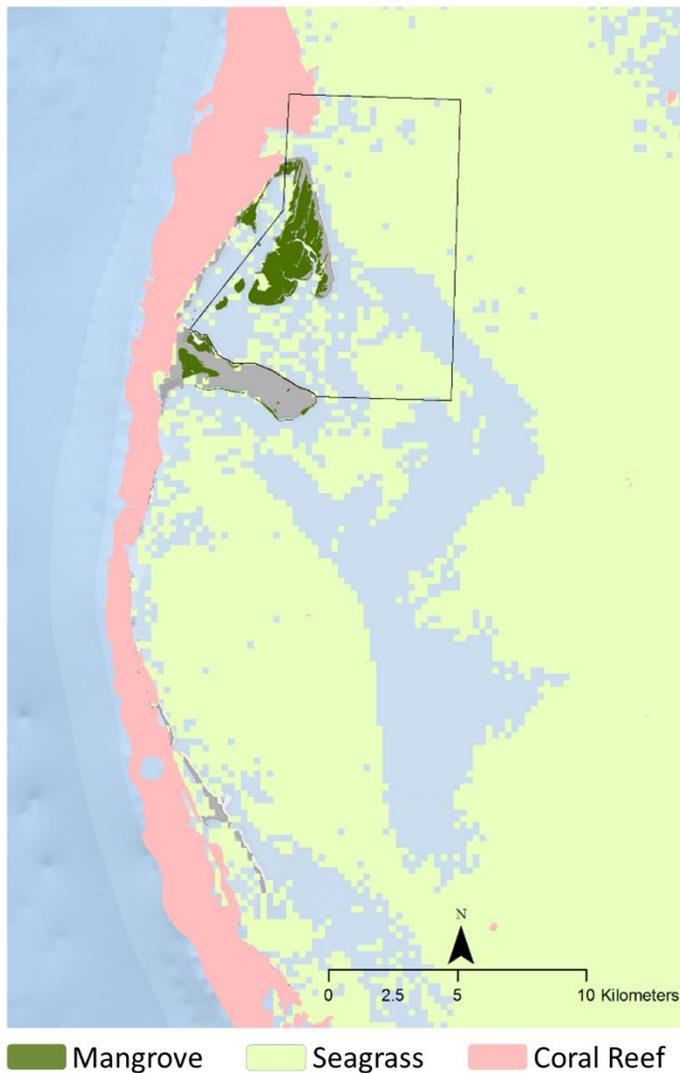


Figure 29. Proposed protected area around Bimini.

To protect the ecosystems of Bimini and the benefits mangroves, seagrasses, and corals provide to its residents now and in the future, the North Bimini Marine Reserve (NBMR) was declared in 2010. Several rounds of public meetings were conducted, and key stakeholders, the Department of Marine Resources, and several Bahamian NGOs hashed out the boundaries. The reserve was designated a no-take area where only catch and release bone-fishing and land crab harvest by local Biminities would be allowed. However, despite the fact that the reserve has been publicly announced, it has never been gazetted. Without protection, the benefits provided by Bimini's the natural ecosystems in the NBMR could be lost. To shine a light on the significance of these benefits, we quantified, mapped and valued coastal protection from storms, value of nursery habitat for lobster, visitation and expenditures from tourists, and the value of avoided carbon emissions provided by the coral reefs, mangroves, and seagrass beds within the reserve.

Delivery of Ecosystem Services

Nursery habitat and tourism

The North Bimini Marine Reserve (NBMR) contains nursery habitat for lobster and recreational opportunities for visitors. According to our ecosystem service models, which link nursery habitats within a protected area to catch from nearby fishing grounds, habitats in NBMR support 76,505 lbs. of lobster catch and \$299,104 of revenue annually (Figure 30). The NBMR includes 3.1 km² of mangroves and 9.6 km² of seagrass in shallow, nearshore areas suitable for juvenile lobster. These habitats support adult lobster on the Northern Bahama Bank, where the MPA is located, as well as fisheries on adjacent banks connected by shallow shelves. In addition to nursery habitat supporting the lobster fishery, the ecosystems within NBMR are essential for drawing anglers to the wider Bimini area and tourists interested in snorkeling and diving. The more than 19,500 visits (i.e., visitor days, see Appendix and Wood et al. 2013) to NBMR generate \$3.3 million in expenditures each year attributable to the reserve alone (Figure 30). All of these are stopover visitors, though there has been on and off cruise service to Bimini Bay over the years.

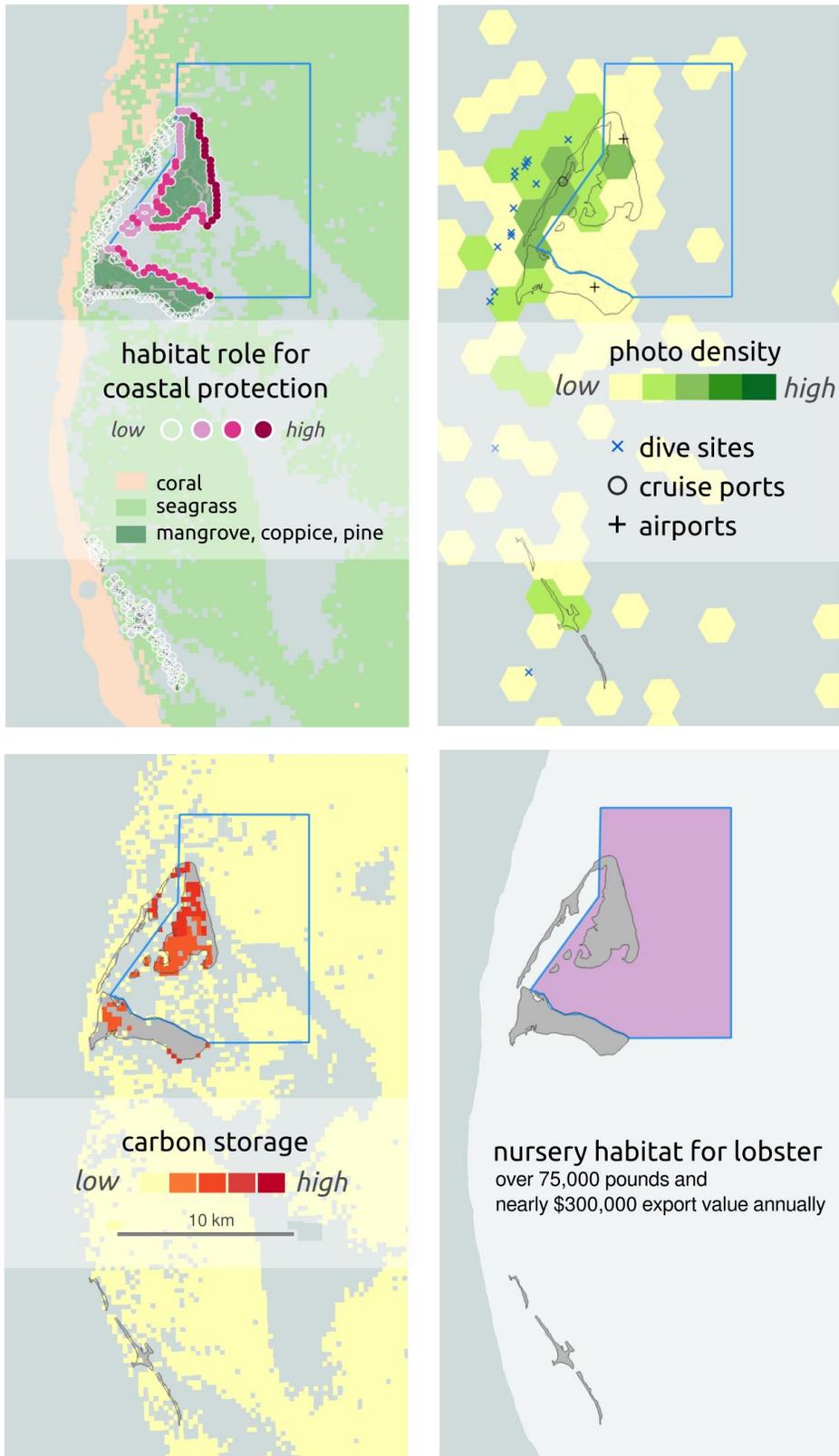


Figure 30. Ecosystem services around Bimini: the role of habitat in protecting shorelines, visitor density, carbon stored by coastal habitats, and nursery habitat for spiny lobster.

Coastal protection and carbon storage

The mangroves, seagrass, and even the little bit of coral within the reserve play a role in reducing impacts from coastal hazards such as erosion and flooding. Bimini has a population of approximately 7,700 Bahamians (according to the 2010 census), all of whom live in the coastal zone. Ecosystems within the reserve reduce the risk of nearly half of those people (3000 people). Only populations within close proximity of habitats to the reserve experience the corresponding risk reduction. We estimate reduced exposure to \$31.2 million in annual income, or 40% of the total annual income of Bimini residents. This is likely a conservative estimate of the value of NBMR ecosystems, as both population data and annual income are only reported for Bahamians, thus ignoring the coastal protection value to many non-Bahamians living or recreating on Bimini. In addition, the intensity and frequency of storm and hurricanes and associated damages could increase with climate change. The NBMR includes 59.7 km² of seagrass beds and 7.7 km² of mangrove forests that have the capacity to store and sequester carbon, thus helping to reduce climate change impacts. These ecosystems store over 3.5 million tons of carbon stock, worth \$46.2 million in avoided emissions globally (Figure 30).

As The Bahamas decides the future of the North Bimini Marine Reserve, these economic and social values of the ecosystems within the proposed protected area are important to consider. Management actions that reduce the risk of degradation to ecosystems have the potential to benefit not only the seagrass, mangroves, and coral and the species living within, but also the people of Bimini that rely on these ecosystems for their sustenance, livelihood, and safety.

Eleuthera



Photo compilation from "A Shared Vision for South Eleuthera" plan.

Introduction

Eleuthera, Cat Island and Long Island are important islands in the Bahamian archipelago and have been identified as priority areas for Marine Protected Areas. We decided to take an economic valuation approach to help guide the selection process, with the idea that some of the principles applied on the analysis of Eleuthera could also be applied on the other islands. Extending 180 km in length, yet in some places less than a mile in width, Eleuthera is a diverse island in both its human and ecological communities. The barrier reef to the east, and the extensive seagrass beds, sand flats, and Schooner Cays to the west, support a diversity of marine flora and fauna, including sharks, rays, seahorses, and turtles. These ecosystems also support the 11,000 people living on Eleuthera (2010 Census). Queen conch, grouper, spiny lobster, and other marine species are the basis of an active fishing community, providing both sustenance and livelihoods. From Harbour Island to Governor's Harbour to Rock Sound, the pink sand beaches, rocky bluffs, reefs, and caves draw almost 40,000 stopover visitors annually (Ministry of Tourism 2015). And the Heritage and Conservation Trail developed by the One Eleuthera Foundation and its collaborators fosters recognition of the island's cultural heritage for locals and travelers alike. Other efforts include the Island School, which leverages Eleuthera's unique ecosystems to create an ocean classroom for students worldwide, and the Centre for Training and Innovation (CTI), which provides Bahamians with the technical skills and education necessary to secure jobs while getting

hands on training within their business enterprises. These programs all exemplify the linked social-ecological system of Eleuthera.

Despite its unique ecological land- and seascape and innovative social programs, Eleuthera does face several challenges. Bahamians report that the upscale economy of Harbour Island makes it difficult for people that work on the island to live there. Locals have little access to the expenditures from cruise ship visitors limited to Princess Cay and yachts occupy several marinas in Southern Eleuthera yet contribute little to the local economy besides purchase of gas. In addition to tourism related challenges, the fishing industry is also at risk. Fishermen report increased fishing effort, especially for grouper and conch, and the prohibitive price for gas puts pressure on them to fill orders and thus in some cases leads to take of undersized and illegal individuals (Wise 2017). Many fishermen also speak of fishers coming from outside The Bahamas that disregard local rules and regulations. Other external factors, like climate change, and its associated storms and sea-level rise, also put the island at risk. The famous glass window bridge has been rebuilt many times. Risking seas and the potential for increasing intensity and frequency of storms mean further investment in infrastructure will continue into the future.

To address the stress posed to the marine environment of Eleuthera, especially related to over-fishing, BNT, TNC, BREEF, the Perry Institute, have been working with stakeholders to identify potential sites for a marine protected area. Unlike most regions in The Bahamas, Eleuthera, Long Island, and Cat Island do not have any marine protected areas currently in the network. The One Eleuthera Foundation was born out of a community effort to save Lighthouse Point, a popular beach and recreation area on the southeastern end of the island with archaeological and scientific significance. Several potential sites have also emerged out of recent stakeholder workshops, yet there is debate about the ecological significance of these sites. While there are reports of interest from locals in marine protected areas there is also skepticism and anger that tourists would have access to MPAs for scuba diving, boating and other recreational activities, but they would be prohibited from fishing. These tensions suggest the need for community-based fisheries programs and integrated, ecosystem-based management of multiple sectors and activities on Eleuthera.

Spatial valuation of ecosystem services

An ecosystem services approach can help to place fisheries related issues within the larger management context by incorporating multiple benefits provided by ecosystems that resonate with diverse stakeholders. Other islands, such as Andros, have extensive information on the value of ecosystem services, but Eleuthera does not. Thus, as a part of this project we quantified the economic value of four ecosystem services across Eleuthera: the catch and revenue of the lobster fishery attributable to nursery habitats; visitation and expenditure from tourism spatially throughout the island; coastal protection provided by coral reefs, mangroves, coppice forest, and seagrass; and carbon storage and sequestration provided by mangroves and seagrass. We created maps to look at spatial variation in the delivery of

ecosystem services to inform future spatial planning and summed results by the three regions—North, Central, and South Eleuthera (Figure 31).

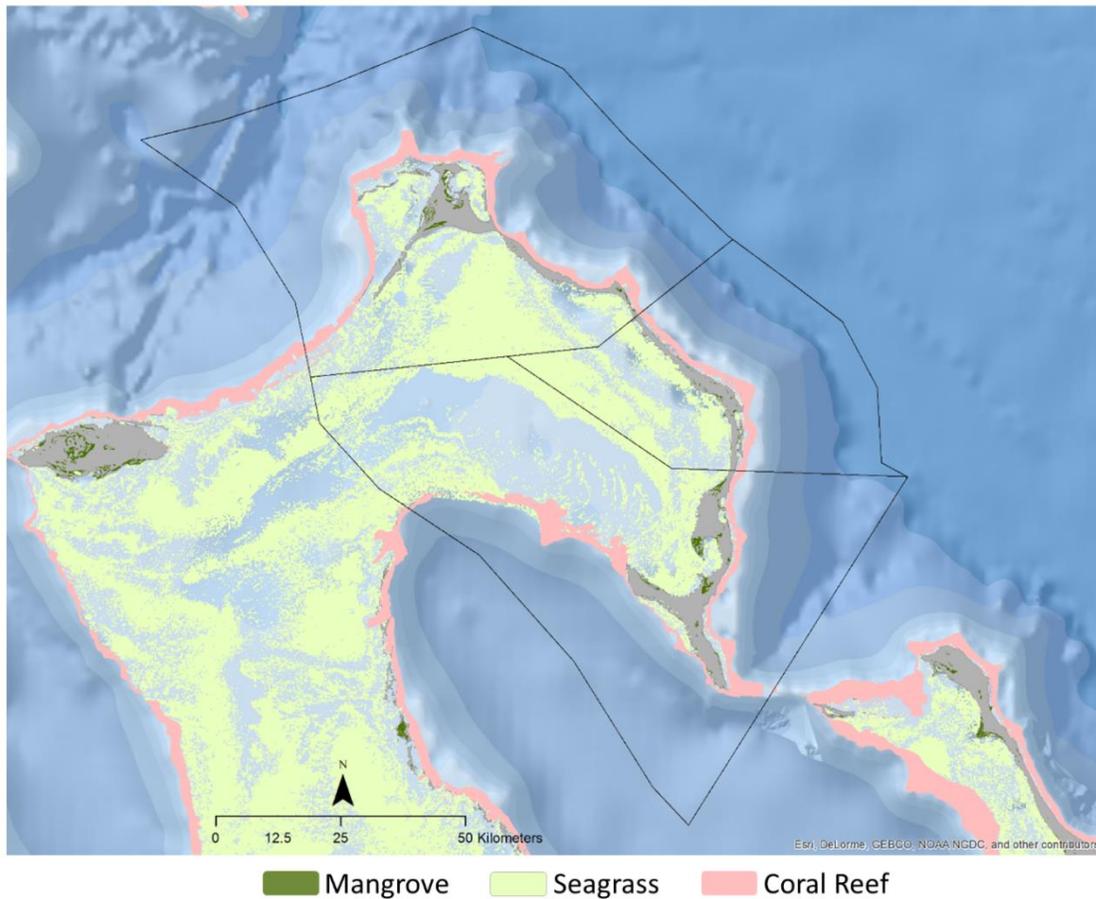


Figure 31. Eleuthera’s coastal and marine habitats with northern, central, and southern regions delineated.

Value of Eleuthera’s nursery habitats for spiny lobster

We quantified the catch and revenue of spiny lobster attributable to the nursery habitats surrounding Eleuthera. We used an age-structure matrix model parameterized with stock assessment information from the Department of Marine Fisheries, which links nursery habitat to the carrying capacity of juvenile lobster and adult populations on nearby banks (Sustainable Development for Andros 2016). Overall the nursery habitats in and around Eleuthera support nearly 1.5 million lbs. of spiny lobster catch and are valued at \$5.7 million. These habitats support 8.6% of the national catch. The value of nursery habitats varies spatially with the distribution and abundance of mangroves and seagrass. Habitats in North Eleuthera support \$2.6 million in spiny lobster export value (45% of Eleuthera shelf production). The nursery habitat of Central and South Eleuthera are worth approximately \$1.1 million and \$2.0 million in export value, respectively (Figure 32). We estimate value based on the export value reported in the fisheries stock assessments. This is likely an underestimate of the overall value of the nursery habitats on Eleuthera because much of the lobster caught around the island is not exported (Casuarina McKinney-Lambert *pers. communication*).

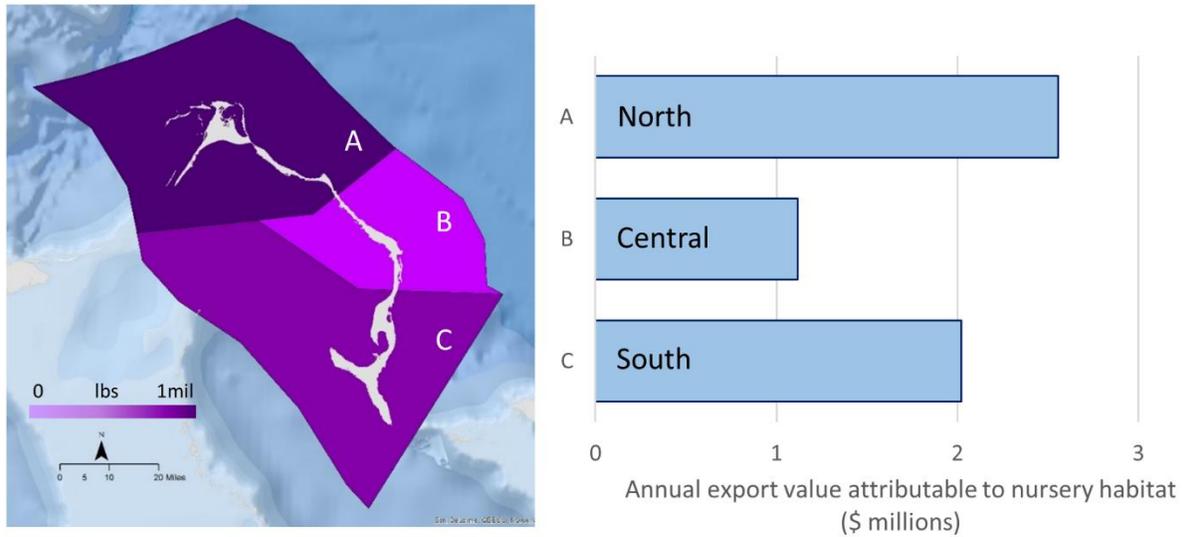


Figure 32. Catch and export value attributable to nursery habitat in northern, central, and southern regions of Eleuthera.

Tourism & Recreation

We mapped and quantified the spatial variation in visitation and expenditures from tourism to Eleuthera using Ministry of Tourism data and information on relative visitation extracted from geotagged photos posted to social media sites (Wood et al. 2013, Sustainable Development for Andros 2016). We found the highest visitation to Northern Eleuthera, followed by Central, and Southern (Figure 33). Our analyses estimate approximately \$30 million in expenditures generated in Northern Eleuthera, followed by \$17 million and \$11.5 million in Central and Southern Eleuthera respectively. Spatial variation in visitation and value are the result of the distribution of features that draw and support tourists (e.g.,

airports, roads, dive sites, cultural sites, and ecosystems), as well as the overall size of the area.

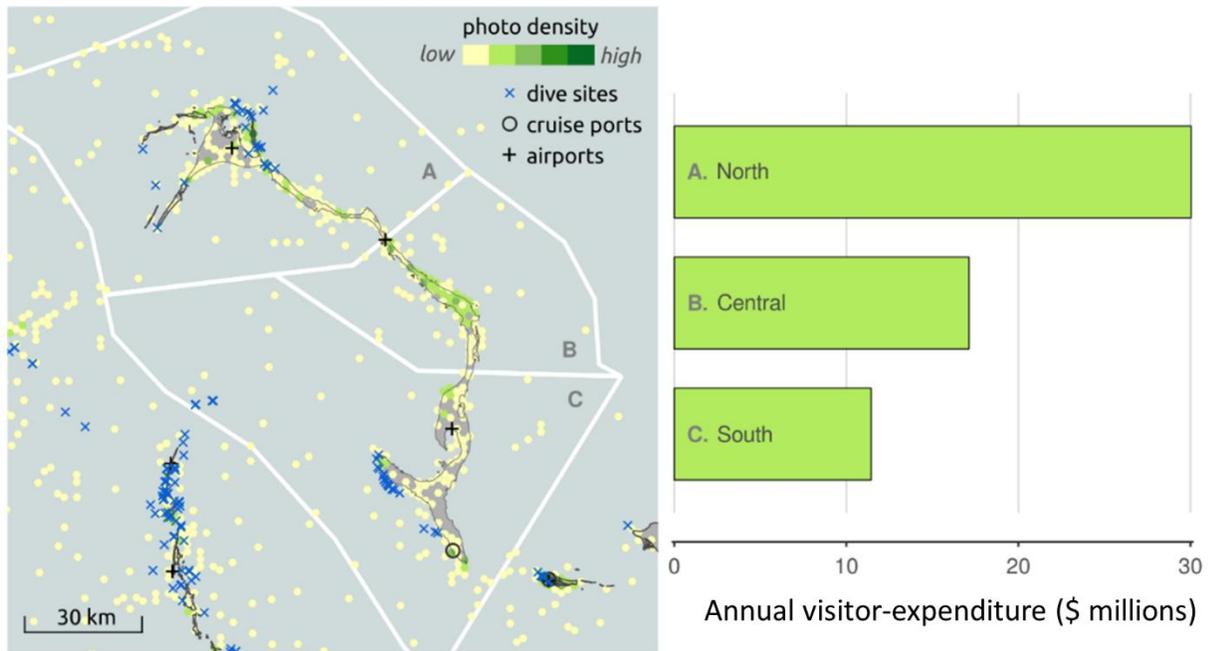


Figure 33. Relative visitation density and annual expenditure from visitors in northern, central, and south regions of Eleuthera.

Coastal protection provided by natural buffers

We also quantified the value of coastal ecosystems for their role in reducing the risk of coastal communities to flooding and erosion. Our approach uses an index-based coastal hazard model that incorporates spatial data on shoreline type, wave exposure, elevation, surge, and ecosystem buffer. We found that the coral reefs, mangrove and coppice forests, and seagrass beds surrounding Eleuthera provide some measure of protection for every section of coastline around the island, thus reducing the risk of coastal hazards to nearly all of the human population and protecting nearly \$130 million in annual income. This does not capture the value of second homes since they are not included in the census. Among the population, more than a thousand elderly people who may be less able to evacuate during a storm and thus more vulnerable. Our results suggest that the ecosystems in the North are the most highly valued for coastal protection; however, this is in part driven by the higher annual income in this part of the island. While all of Eleuthera is clearly benefiting from buffering by natural coastal habitats, some settlements such as Harbour Island and Current Island in the North, Deep Creek and Bannerman town in the South, and Windermere Island and Savannah Sound in the central region are all associated with the darkest purple areas in Figure 34 that indicate places where ecosystems matter a lot for protecting shorelines. Ecosystems off the coast of the purple areas should be protected in order to sustain their ability to reduce the risk of coastal hazards now and into the future.

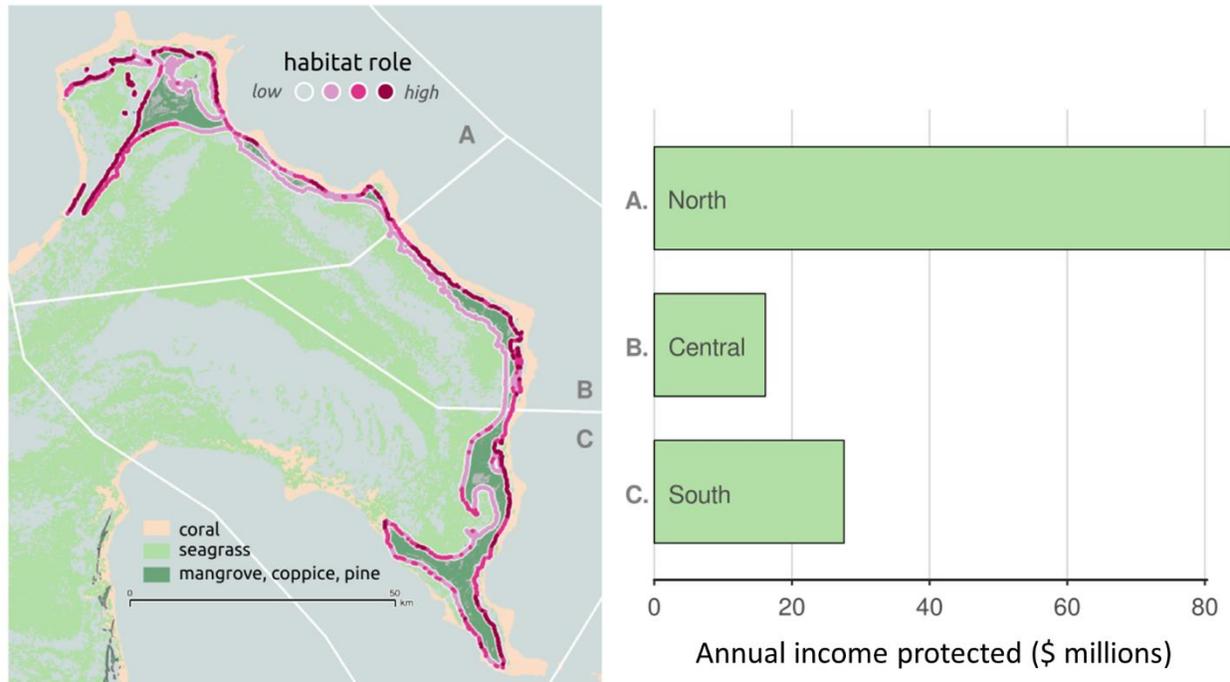


Figure 34. The relative role of habitat in protecting Eleuthera's coastline and annual income protected in northern, central, and southern regions.

Carbon storage

Lastly we quantified and valued the ecosystems around Eleuthera for their ability to store and thus provide climate mitigation benefits. Our analyses suggest that the mangroves and seagrass in and around Eleuthera store more than 120 million tons of carbon, worth over \$1.5 billion in avoided damages globally. The ecosystems of South Eleuthera were the most highly valued for carbon storage, with its dense pockets of mangrove forest and extensive seagrass beds. Northern Eleuthera has about half the area of mangrove as Southern Eleuthera, but because mangroves store the most carbon in their biomass and soils, the overall value of these ecosystems for avoided carbon emissions was nearly as high in North as South Eleuthera (Figure 35).

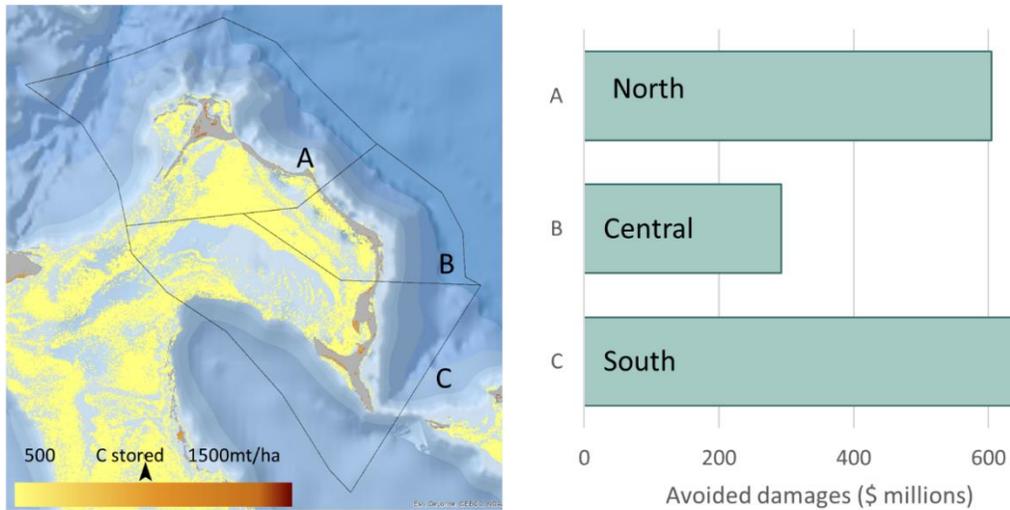


Figure 35. Carbon stored by coastal habitats and the social cost in northern, central, and southern regions of Eleuthera if stored carbon were emitted.

Our ecosystem service analyses reveal the value of diverse benefits provided by the natural features of Eleuthera to people. These results can be used to identify those places within Eleuthera, like the remaining spots of mangrove, that provide important carbon and nursery habitat benefits and thus should be protected. They can also be used to communicate about areas of the coral reef that should be protected to reduce risk of coastal hazards. Finally, tourism expenditures may also mean opportunities for jobs, such as the boat captains that shuttle people hourly to Harbour Island and the students at CTI learning the hospitality skills to manage ecotourism businesses on the island.

6. Discussion and synthesis

Conclusions

Marine Protected Areas in The Bahamas contain a wealth of ecosystems that provide a diversity of benefits to the Bahamian people and beyond. According to our analysis of the economic values of four key ecosystem services, half of the country's spiny lobster catch is supported by seagrass and mangrove nursery habitat within MPAs and is worth more than \$23.5 million in export value. We estimate approximately 400,000 visitor-days occur within the network MPAs annually, generating \$67.6 million in tourism expenditures. Mangroves and seagrasses within the network also store approximately 400 million tons of CO₂ equivalent, mitigating climate change through avoided damages from emissions worth more than \$5 billion globally. Coral reefs, seagrasses, mangroves and other types of coastal forest and wetlands within the MPA network reduce the risk of coastal hazards for nearly 40,000 people living within 1.5 km of the shore, valued in terms of reduced exposure to more than \$800 million in annual income (Table 3).

Table 3. Synthesis of four economic values provided by ecosystems within the MPA network.

Ecosystem Service	Values provided by ecosystems within the existing MPA network	Factors that influence spatial variation in ecosystem service value (not comprehensive)
Tourism	383,000 visitor-days and \$67.6 million in expenditures annually	Island differences in visitation, expenditure, habitat extent, access, infrastructure
Coastal protection	Reduced exposure to 39,000 people and \$806 million in income annually	Habitat type and quality, coastal elevation, shoreline type, surge potential, wave characteristics, sea-level rise, proximity of habitats in MPA to coastal population
Nursery habitat for spiny lobster	6 million lbs. and \$23.5 million in revenue from the lobster fishery is attributable to nursery habitat annually	Habitat type and extent, larval recruitment to nursery habitat, proximity of nursery habitat to shallow shelf habitat for adults
Carbon storage for climate mitigation	400 million tons of CO ₂ stored and \$5 billion in avoided damages from emissions globally	Relative abundance of mangroves and seagrass, carbon stored in soil and aboveground biomass (based on climate).

While these economic values are substantial, they underestimate the total value of ecosystems within MPAs to the economy of The Bahamas and the wellbeing of Bahamians. These estimates do not include all services provided by ecosystems within MPAs, such as their contribution to other commercial fisheries (beyond spiny lobster; see Clavelle and Jylkka 2013, Blackwell et al. 2013, Smith and Zeller 2015) and potential spillover effects of adult queen conch and other commercial fish species to outside the reserves. Nearshore ecosystems can enhance water quality through filtration services and MPAs provide job generation through protected area management and associated tourism activities, and cultural, educational, and mental health benefits that scientists are just beginning to have the tools to measure. Further, the values we present are the gross value of four ecosystem services, rather than the net benefit of MPA designation and implementation. By focusing on four of the most key ecosystem services, our analysis reveals that some MPAs generate more benefits than other sites, due to a variety of ecological, social, and economic factors, and that this has important implications for management. For example, Southwest New Providence Marine Managed Area (SWMMA) and Exuma Cays Land and Sea Park (ECLSP) receive the top two number of visits of any of the sites in the network and generate the most expenditures, at more than \$14 million and \$6 million, respectively. In contrast, several of the MPAs around Abaco (but not all) and Acklins/Crooked Islands receive the fewest (Figure 7). ECLSP and SWMMA also highlight different drivers of tourism. Well-managed healthy ecosystems, such as those within the ECLSP, draw boaters, yachters, snorkelers and divers, despite the challenge of travel and cost to the remote park. In addition, access and infrastructure can also drive visitation, which is likely the case for SWMMA, situated in New Providence, the most populated island in The Bahamas and serviced by several snorkeling and diving outfitters.

We also find spatial variation in the other three services. Coastal protection depends on where people are most at risk from factors such as waves and storm surge and where MPAs are close enough to shore for the habitats within them to buffer the shoreline, such as around New Providence, in some areas along the coast of Andros, and in Abaco, Exuma, and Grand Bahama (Table 1). Carbon storage depends

on the relative abundance of seagrass and mangroves, which store different amounts of carbon, and other factors such as mangrove biomass, which varies with abiotic factors like precipitation. Habitats within the Andros West Side National Park store the most carbon, valued at more than \$3.5 billion, both because of its overall size and because of the extent of mangroves, which store more per unit area than seagrass, within its boundaries, whereas some of the small MPAs store the least (Figure 12). The value of nursery habitats within MPAs for spiny lobster depends in part on the distribution of nursery habitats relative to the shallow water shelves where adults congregate. This is why the MPAs around Abaco, Andros, and Grand Bahama (Northshore/The Gap) contain nursery habitat that is particularly valuable for (Figures 4 and 5). These spatial differences in the value of ecosystem services among sites within the existing network can be used to help prioritize management across a diffuse network for a suite of economic values.

Our analysis of New Providence and Andros also highlights the fact that human activities can lead not only to degradation of ecosystems within MPAs (Figures 18, 26), but also to the loss of benefits these ecosystems provide to Bahamians and people living outside The Bahamas, who also benefit from climate mitigation and improved tourism. On Andros, our analysis suggests that ad hoc management, over-fishing, and extensive development even within MPAs under the Intensive Development scenario would not only decimate corals, seagrass, mangroves, and coppice (Figure 18), but also reduce coastal protection, carbon storage and sequestration, and tourism benefits (Figures 20-23). Our analysis of habitat risk due to multiple activities within the SWMMA shows that the majority of coral reefs, seagrass, beaches and other habitats are a high risk currently from the cumulative effects of coastal development, marine transportation, dredging, continuous oil leakage, and tourism (Figure 26). This risk of habitat degradation stunts the economic value of ecosystem services within the MPA, compared to if risks of human activities were minimized substantially within the protected area (Figure 28). By including an assessment of risk from current human activities in these regions, our analyses provide some insight into the potential gains if MPA designation and implementation were able to fully protect habitats. Clearly, some amount of these activities will need to occur in and around an area as large as SWMMA and as close to the capitol of The Bahamas to continue to provide recreational and fishing opportunities; however, a multiple use area like SWMMA can be managed to protect ecosystems and the benefits these ecosystems provide to people (natural buffers from hurricanes, fisheries catch and revenue, tourism opportunities etc.). Our work on Andros (especially the Sustainable Prosperity scenario) highlights how investments in infrastructure and coastal development can be targeted to avoid loss of habitats that are critical for both nature and people.

Implications of findings for MPA Policy

The economic value of ecosystems within the MPA network and societal benefits they provide to Bahamians indicate that MPAs are central to the national economy and should be considered within the context of more comprehensive planning processes, such as the Vision 2040 National Development Plan and the Integrated Coastal Zone Management planning process. In The Bahamas, like many countries around the Caribbean (Arkema et al. 2015), coastal and marine ecosystems are fundamental to the economic development of a country and therefore cannot solely be the focus of fisheries departments and NGOs, but must be part of integrated management (Arkema and Ruckelshaus 2017). Well-managed and protected coastal and marine ecosystems also have the potential to help The Bahamas meet its international commitments, such as those under the Convention of Biological Diversity. In addition, The Bahamas is engaged in planning towards the United Nations Sustainable Development Goals (SDGs).

Several SDGs are related to ecosystem services and economic values of marine protected areas. These include Goal 14 to conserve and manage ocean ecosystems, and the goals related to poverty alleviation (Goal 1), hunger (Goal 2), health (Goal 3), climate action (Goal 13), and sustainable cities and communities (Goal 11).

A recent high profile global analysis of MPAs suggests that effective management of MPAs requires sufficient financial and human capital (Gill et al. 2017). Only four out of the 40 MPAs in the current network have management plans with 15 more drafted (Fig. 1). The coral reefs, mangroves, seagrasses, beaches and other ecosystems within the current network support fisheries and tourism related livelihoods, subsistence food sources, security from storms and sea-level rise, climate mitigation, water quality, educational, mental health benefits, and other economic and human wellbeing benefits. Without proper management, these ecosystems and ecosystem services they provide are at risk from degradation from the cumulative impacts of human activities in the coastal zone. Our economic analysis suggests a need to invest in the management of the Bahamian MPA network to sustain the ecosystems and benefits they provide to people now and into the future. This also includes continuing to invest in the collection of data to inform management. For example, continuing to collect spending information from visitors and more comprehensive collection of visitation rates to MPAs would be informative for understanding the return on investment in MPA management.

Finally, our analysis highlights the importance of siting new MPAs. We quantified the economic values of services provided by coastal and marine ecosystems in northern Bimini, around all of Eleuthera, and by the barrier reef east of Andros. The coral reefs, mangroves, seagrasses, and other ecosystems around Eleuthera and in the northern Bimini reserve provide significant coastal protection, fisheries, carbon storage and sequestration, and tourism related benefits. For these benefits to be sustained into the future they need to be well-managed and protected. Our analysis points to several opportunities for new protected areas. Andros has an extensive network of MPAs in place, but only a very small portion of the barrier reef, perhaps the most vulnerable ecosystem, is included in this network. Eleuthera does not currently have any marine protected areas in the network, nor does nearby Long Island and Cat Island. Yet our analysis of the ecosystem services provided by coastal and marine ecosystems in and around Eleuthera indicates the suite of important benefits provided to people of the island that need to be managed and protected over the long-term. And the North Bimini Marine Reserve has been approved and is waiting to be gazetted.

[Next steps and recommendations for declaring new MPAs](#)

This report focuses on the economic valuation of the ecosystems within the current network of Bahamian MPAs and management implications for the network going forward. However, the Caribbean Challenge Initiative also includes the 20-20 goal of 20% coverage of coastal and marine environments by the year 2020. Bahamas Protected is pursuing several streams of work to scope new areas in which to expand the network. The effort includes a stakeholder engagement process to elicit and review sites proposed by community members, several scientific analyses that generate areas of interest for conserving habitats for key species and habitat diversity within the network. Bahamas Protected is also developing various communication materials to engage relevant stakeholders and policy makers. These streams of work offer several opportunities to leverage an ecosystem services approach and the analysis of economic valuation presented here in the next steps of this project.

First, the results of the economic valuation of ecosystem services suggest several take home messages that could inform the design and future management of the Bahamian MPAs. For the nursery habitat contribution to the spiny lobster fishery, there appear to be some shallow shelf regions with MPAs containing a large percentage of nursery habitat (e.g., Abaco, Andros); whereas other shelf regions have little protection of nursery habitat (e.g., New Providence). Placement and management of future MPAs might consider siting areas to protect nursery habitat on shelf regions currently without protection. Our results for the economic value of tourism within MPAs highlight the dual draws for tourists— infrastructure and access to support tourism, like the roads, outfitters, and lodging opportunities found around SWMMA, and remote nature as found on ECLSP. This is not to say that the quality of habitats around SWMMA does not matter. When development becomes so extreme that it wipes out ecosystems entirely, that can have negative impacts on the tourism industry (Stuart Cover pers. communication, Arkema et al. 2015). Rather our results suggest that considering investments in access and infrastructure to draw tourists, coupled with management of human activities to reduce risk to fragile ecosystems is likely to lead to the best economic returns. For coastal protection, our results show how coastal habitats within MPAs reduce the exposure of populations on some islands (e.g. New Providence, San Salvador, Berry Islands etc.). Future MPAs could be targeted in areas where habitats are in close proximity to population centers or remote islands where emergency services before and after a storm may be limited. Lastly, for avoided carbon emissions and climate change, MPA size is the largest factor, but where new large MPAs around mangroves are not possible, protected smaller areas of dense mangroves or large areas of seagrass meadows would be worthwhile for climate mitigation. The gross economic values for each ecosystem service can be further weighed against the threat of habitat degradation, the cost of MPA designation and implementation, and the needs of local communities to determine the marginal value of current and future MPAs.

Second, the ecosystem services approach we used to quantify the economic values of ecosystems within the current MPA can also be applied to alternative options for future MPA locations. Because production and delivery of ecosystem services varies spatially, it is not appropriate to simply assume an additional 10% of coverage would lead to double the current values. In the same way that we quantified four services across the existing 40 sites, for the Bimini reserve, and in and around Eleuthera, quantitative models can also be used to estimate values for nursery habitat, carbon storage and sequestration, coastal protection, and tourism for additional areas of interest. In the absence of proposed sites, an alternative option for selecting the additional 10% could be to optimize the ecosystem service models. This would allow Bahamas Protected, stakeholders, and policy-makers to identify which benefits they cared about most and the models would generate maps of locations where conservation would enhance multiple economic and societal benefits and who would benefit.

Lastly, in our work around the world, we have found that fostering an iterative process between economic valuation of ecosystem services and stakeholder engagement is effective for harnessing the benefits of participatory processes and the best available science (Ruckelshaus et al. 2015, Arkema et al. 2015, Arkema and Ruckelshaus 2017). Processes that incorporate active participation, information exchange, transparency, fair decision-making, and positive participant interactions are more likely to be supported by stakeholders, meet management objectives, and fulfill economic, societal and conservation goals (Cash et al. 2003, Posner 2016). Focusing on community values can help generate social support and ensure ecosystems are well managed to meet shared human needs, rather than focusing on impacts to the environment, which can alienate some sectors. Furthermore, ecological,

economic, and social data and modeling are essential for avoiding unintended consequences, understanding assumptions, and making predictions about how management decisions made today will affect future outcomes. The Bahamas Protected project has the opportunity to continue to integrate its scientific analyses within the community engagement process so that stakeholders can help to explore alternative options for siting future MPAs and understand how these options would influence the sustainability of ecosystems and benefits they provide to people into the future.

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Appendices

Appendix A. Bahamas Valuation Database

<https://drive.google.com/open?id=0B7WlweBPtLutQWVST2dFWHQwejA>

Appendix B. Bahamas Valuation Abstracts

Barreto, C.R., Daneshgar, R.R., Tiedemann, J.A. 2015. Carbon sequestration of dwarf red mangrove in The Bahamas. *American Fisheries Society Symposium* 83:000-000

Mangrove ecosystems are being lost globally at an alarming rate due to deforestation, reclamation, and urbanization. Not only is the loss of these ecosystems detrimental to the commercially and ecologically important marine species they support, there is also a reduction in the ecosystem services they provide, namely mitigating rising carbon dioxide levels by serving as carbon sinks. These ecosystems, labeled as “blue carbon” sinks, potentially sequester more than 10 times the carbon that tropical and temperate ecosystems do. Thus, conservation and restoration of these blue carbon sinks is imperative. We explored how much carbon is currently stored in dwarf red mangrove *Rhizophora* mangrove biomass in tidal creeks of Eleuthera, Bahamas. In October of 2012, four sites were selected near Cape Eleuthera, maximizing site variability. All sampling was done from six plots established at each site. The quantity of carbon stored in mangroves was determined from plant biomass, which was extrapolated from plant volumes. Mangrove volumes were determined from growth parameters of individuals. It was observed that there were large differences from site to site in number of individuals, sediment depth, biomass accumulation, and carbon allocation of mangroves, but the total amount of carbon stored from site to site in mangroves did not differ. The site with the greatest biomass and carbon storage also had the greatest sediment depth, suggesting a correlation between the two. Regardless of the site to site variability, mangroves proved to be good stores for carbon. Future work should search for the factors that explain site to site variability.

Blackwell, B.D., Brumbaugh, D.R., Dahlgren, C.P. 2013. Economic benefits of the South Berry Islands marine reserve. Report submitted to the Nature Conservancy Northern Caribbean Program, Nassau, Bahamas, 62 pp. and appendices.

Because of interest in assisting the implementation of active management in the South Berry Islands Marine Reserve (SBIMR), we conducted a review of the sustainable finance literature for protected areas to highlight general guidelines and options for sustainable financing of the reserve. We then focused in on sustainable finance mechanisms that are of particular relevance to marine protected areas and the Caribbean region, and evaluated which of these offer the most potential for application in The Bahamas and especially The SBIMR. According to estimates derived from the Draft Management Plan for The SBIMR, active management of the reserve will require \$1.8 Million per year. Many potential options or mechanisms meeting this funding requirement are discussed in this report. In this summary, we focus on key options and mechanisms analyzed in the final section of this report.

Blue Earth Consultants, LLC. 2016. Stakeholder analysis report: The Bahamas conch fisheries management and sustainability program. Rep. The Nature Conservancy.

Queen Conch, a mollusk that is harvested throughout the Caribbean, holds strong economic and cultural significance in The Bahamas. This Stakeholder Analysis Report describes information on the cultural and economic values and local and export markets for conch in The Bahamas. To gather data and information for this Stakeholder Analysis Report, Blue Earth Consultants, LLC (Blue Earth) performed web-based and literature research to find existing information relating to conch markets in The Bahamas, and then worked with The Nature Conservancy to develop and administer interviews and questionnaires to individuals throughout The Bahamas. We traveled to four islands and conducted interviews with more than 30 experts (e.g., non-governmental organization and agency staff, scientists, and fishers) to gain targeted insight on particular aspects of the fishery. We also conducted more than 90 shorter questionnaires with key stakeholders (e.g., restaurateurs, fishers, vendors, processors, and buyers) and more than 170 with members of the public. While the questionnaire sample sizes are

not necessarily statistically representative, they do shed light on public and stakeholder perceptions related to The Bahamas conch fishery and provide information for building future studies. Blue Earth compiled all interview and questionnaire responses and analyzed to calculate averages and ranges of responses and draw out trends in qualitative information.

Buchan, K.C. 2000. The Bahamas. *Marine Pollution Bulletin* (41); 94 - 111.

The archipelago of The Bahamas contains the largest tropical shallow water area in the Western Atlantic. Located on the northern and eastern margins of two large submerged banks and a number of smaller more isolated banks, the Bahama Islands, of which there are over 700, are low-lying and composed of limestone. A sub-tropical climate and a geographic position between two major warm ocean currents affect the region with seasonal variability, which influences the biological communities inhabiting the ocean and coastal areas. The Bahama Banks are separated from the North American continent by the Florida Straits and from each other by deep channels, some in excess of 2000 m. Two deep water channels cut into the larger Great Bahama Bank. Most of the marine area is shallow (<<20 m), resulting in an extremely important marine resource with both ecological and economic value. The Bahama Islands are dependent on their seas to maintain a GDP of US\$ 2.7 billion through tourism and harvest of marine resources. To date, the fishing industry has benefited from the relatively high ecological productivity of the shallow banks and their related habitats. Commercially important fisheries include Spiny Lobster, conch and Nassau grouper which, together, make up the bulk of fisheries income. Clear warm waters and white sand beaches, along with its close proximity to the USA, make The Bahamas a prime tourist destination. Tourism is the mainstay of the Bahamian economy, accounting for 60% of the gross domestic product. Agricultural and forestry operations are limited and impacts in the coastal zone from these are negligible. However, land reclamation and construction for tourism development, along with sand mining, dredging, overfishing, poor fishing practices and their respective impacts of habitat loss, beach erosion and over-exploitation of target and non-target marine resources are becoming increasingly apparent as developmental pressures grow. Environmental regulations are in place through a number of parliamentary acts. Management of established marine and coastal protected areas has been undertaken by The Bahamas National Trust (BNT), which along with other organisations, carry out environmental education programs to increase awareness and reduce impact on the marine and coastal areas of the archipelago.

Caribbean Coastal Services LTD (CCS) and SEV Consulting. 2016. Consulting services to prepare a national Integrated Coastal Zone Management policy framework for The Bahamas and phase 1 dissemination. RFP No. BEST-ICZM-1, Nassau, The Bahamas.

We outline the economic issues and challenges related to the ICZM in The Bahamas and how ecosystem service values can help to address these. Next we provide some basic background information on studies to date. We then describe our theoretical approach. Next we report the methods used to generate the ES values, followed by the results of the valuation, by habitat and then for the whole country. We conclude with an analysis of the limitations to this approach, a discussion of the values generated and identification of future research needs. The second section describes the main ways in which ES values can be used to inform ICZM policy and decision making related to coastal resources in The Bahamas, for example for raising revenues from ecosystem services and using scenario analysis to inform land use decisions. It also identifies sustainable livelihood opportunities.

Clavelle, T., Jylkka, Z. 2013. Ecosystem service valuation of proposed protected areas in Abaco, The Bahamas. Sustainable Fisheries Group, University of California, Santa Barbara.

Preserving The Bahamas' wealth of natural resources is crucial to maintaining the country's cultural identity and supporting local and national economies. The two areas above were selected for their importance in closing ecological gaps in The Bahamas' protected area network. In the face of development pressure, assessing the economic value of these areas' resources helps provide an argument for their conservation.

With this in mind, this project examined how the inhabitants and visitors of Abaco depend on the ecosystem services of mangroves, wetlands, seagrass, and coral reef habitats. To accomplish these goals, we collected site-specific information on the economic activities occurring in the proposed areas, taking into consideration fishery

harvests, recreational fishing, diving, and eco-tours. To produce valuation estimates for Cross Harbour and East Abaco Creeks, ecosystem service values derived from studies of similar context were incorporated into a benefit transfer framework in order to approximate the overall economic value of the areas.

Cline, W. 2008. Shark diving overview for the islands of The Bahamas. Nassau, Report of The Bahamas Ministry of Tourism. Nassau, Bahamas: Cline Marketing Group.

Recreation diving with sharks estimated to generate US\$78 million in revenue in 2007 and roughly US\$800 million in gross revenue to The Bahamas economy since 1987.” (note that the original report has not been found. This summary was found through other reports including from <http://clmeims.gcfi.org/valuation-bibliography/cline-w-2008-shark-diving-overview-islands-bahamas-nassau-report-bahamas>

Food and Agriculture Organization of the United Nations (FAO). 2009 National fishery sector overview: The Commonwealth of The Bahamas

Covers overall fisheries data, the catch profile, landing sites, fishing production means, main resources, and management applies to fisheries. It also overviews fishing communities, post-harvest use, fishery sector performance, sector development, and sector institutions.

Fedler, T. 2010. The economic impact of flats fishing in The Bahamas. Report prepared for The Bahamian Flats Fishing Alliance. 20 pp.

Project Objectives

1. To quantify the number of active and inactive guides in The Bahamas.
 2. To estimate the number of guided and non-guided flats anglers and the duration of their stays.
 3. To estimate the direct expenditure impacts made by flats anglers in island economies.
 4. To estimate the value added impacts of flats angler direct expenditures.
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Gittens, L.G., Braynen, M.T. ND. Bahamas national report – CFMC/OSPESCA/WECAFC/CRFM working group on queen conch. Department of Marine Resources, Ministry of Agriculture. Nassau, Bahamas.

Includes brief overview of the fishing industry, policy and legislation, development activities, fisheries management and conservation activities, consumption and trade, and data collection systems on queen conch.

Haas, A.R., Fedler, T. and Brooks, E.J. 2017. The contemporary economic value of elasmobranchs in The Bahamas: reaping the rewards of 25 years of stewardship and conservation. *Biological Conservation* 207 (March): 55–63

Elasmobranch populations in The Bahamas offer a unique juxtaposition to the widespread decline of many species around the world, largely due to management and conservation initiatives implemented over the last 25 years. Several industries have been built around the diverse and abundant elasmobranch assemblages found in The Bahamas, however a comprehensive assessment of the non-consumptive economic value of this resource has yet to be undertaken. In this study, we identified various sectors that benefit from elasmobranch populations in The Bahamas, which included tourism, film and television and research. We incorporated data from operator and participant surveys, government sources and information available on the Internet to calculate the economic value and location of these various sectors. This study establishes The Bahamas dive industry as the largest in the world, contributing approximately \$113.8 million USD annually to the Bahamian economy in direct and value added expenditures. Elasmobranch tourism generated 99% of the total revenue, and the balance generated by film and television and research. The relative economic importance of shark diving was greater in economically disadvantaged out-islands where specific charismatic species are sought. This was also in locations where a large proportion of the revenue generated by those activities does not enter the Bahamian economy. The sustained national stewardship demonstrated by the Bahamian government will ensure that this important

economic resource continues to be productive, but also highlights the need for regional Caribbean-wide commitment to the management of highly migratory species that are important to many economically depressed areas of The Bahamas.

Harborne, A.R. Mumby, P.J., Kappel, C.V., Dahlgren, C.P., Micheli, F. Holmes, K.E., Brumbaugh, D.R. 2008. Tropical coastal habitats as surrogates of fish community structure, grazing, and fisheries value. *Ecological Applications* 18(7): 1689-1701

Habitat maps are frequently invoked as surrogates of biodiversity to aid the design of networks of marine reserves. Maps are used to maximize habitat heterogeneity in reserves because this is likely to maximize the number of species protected. However, the technique's efficacy is limited by intra-habitat variability in the species present and their abundances. Although communities are expected to vary among patches of the same habitat, this variability is poorly documented and rarely incorporated into reserve planning. To examine intra-habitat variability in coral-reef fishes, we generated a data set from eight tropical coastal habitats and six islands in the Bahamian archipelago using underwater visual censuses. Firstly, we provide further support for habitat heterogeneity as a surrogate of biodiversity as each predefined habitat type supported a distinct assemblage of fishes. Intra habitat variability in fish community structure at scales of hundreds of kilometers (among islands) was significant in at least 75% of the habitats studied, depending on whether presence/absence, density, or biomass data were used. Intra-habitat variability was positively correlated with the mean number of species in that habitat when density and biomass data were used. Such relationships provide a proxy for the assessment of intra-habitat variability when detailed quantitative data are scarce. Intra-habitat variability was examined in more detail for one habitat (fore reefs visually dominated by *Montastraea* corals). Variability in community structure among islands was driven by small, demersal families (e.g., territorial pomacentrid and labrid fishes). Finally, we examined the ecological and economic significance of intra-habitat variability in fish assemblages on *Montastraea* reefs by identifying how this variability affects the composition and abundances of fishes in different functional groups, the key ecosystem process of parrotfish grazing, and the ecosystem service of value of commercially important finfish. There were significant differences in a range of functional groups and grazing, but not fisheries value. Variability at the scale of tens of kilometers (among reefs around an island) was less than that among islands. Caribbean marine reserves should be replicated at scales of hundreds of kilometers, particularly for species-rich habitats, to capture important intra-habitat variability in community structure, function, and an ecosystem process.

Hargreaves-Allen, V. 2010. The economic valuation of the natural resources of Andros. Conservation Strategy Fund.

To estimate economic values, the area of each habitat type was multiplied by the average values, drawn from current academic literature, of ecosystem services from each habitat. Those habitats which tend to generate large values per area are beaches, wetlands and to a lesser extent forests and mangroves. On Andros, the most extensive habitats are forests and wetlands, followed by estuaries and seagrass beds. The value of ecosystem services provided by these habitats is approximately \$260 million, although estimating such values is complicated by issues of additionality and marginality, as well as inadequate data. Of this, 59% comes from forests, 23% from wetlands and 7% from coral reefs. Furthermore, 25% comes from carbon storage, 19% from extraction of raw materials and 11% from biodiversity values. In addition, water resources generate a net value of \$3.5 million.

Contribution of Natural Resources to the Economy.

In addition to net ecosystem values, we estimated the impact of ecosystems on the Bahamian economy, measured in terms of gross revenues from activities that depend on natural resources. This concept of impact is different from value in that it does not separate out all the non-natural inputs to production but simply aims to assess how much activity and employment is related to the areas natural ecosystems. In order to account for the indirect and induced effect of natural resource related revenues, an economic multiplier of 25% was used. Overall, 67% of these revenues are generated by extractive activities and 33% by non-extractive ones. Commercial fishing (including crabbing and sponging) generates a huge \$70 million in revenues, which is shared among a huge number of people and households. If all tourism related activities are added together, they constitute \$43.6 million in revenues each year. Much of this tourism is related to recreational fishing, for which guided trips alone

generate over \$10 million each year. Farming, research /education programs and sponging generate relatively fewer revenues.

Andros natural resources generate \$142 million in direct revenues each year and employ over 80% of the population either full or part-time. Overall, \$70 million stems from commercial fishing and \$44 million from nature-based tourism. If we consider secondary impacts (related to spending not included here, such as fisheries equipment, construction and inter-island transport), we estimate that the total impact is \$177 million each year. It should be noted that these are gross revenue estimates and that direct, indirect and opportunity costs can be significant.

Hargreaves-Allen, V. 2011. The economic value of ecosystem services in the Exumas Cays; threats and opportunities for conservation. Conservation Strategy Fund

The report is structured as follows. In chapter 1, I present background information on The Bahamas and the Exumas and an introduction to the theoretical background of ecosystem service valuation. In chapter 2, I present a spatial habitat analysis of the area for each major ecosystem in the Exumas, which was specially commissioned for this report. This is used to generate estimates of the economic value of these ecosystem services each year from the coral reefs, mangrove, estuaries, scrublands and beaches found there. In chapter 3, I present the results of an extensive tourist survey that was carried out for this report, in order to measure tourist values and preferences for conservation in the Exumas. I also outline the results of an analysis of the economic impact of the Exuma Park. In chapter 4, I identify the main threats of concern in the Exumas and the likely impact on the ecosystem service values. In addition, I determine a suite of potential conservation actions, such as a turtle hatchery, coral restoration to world heritage status. Further research is also outlined, which is highly recommended to further this work and the final section draws key conclusions as to the value of this area and its conservation.

Hargreaves-Allen, V. 2012. Costs, benefits and feasibility of conservation measures to preserve the biodiversity, ecosystem services and scenic beauty of the Exuma Cays. Nassau, Bahamas.

Here, I conduct an analysis, to compare the costs, benefits, equity and feasibility of potential conservation interventions to preserve the Exuma Cays. In the first section, I develop scenarios for the most promising potential interventions. In the second I conduct the multi-criteria analysis to generate recommendations as to which interventions should be pursued based on a number of pertinent criteria and provide suggestions for where further research is needed.

Hargreaves-Allen, V., Pendleton, L. 2010. Economic valuation of protected areas in The Bahamas. Conservation Strategy Fund.

In this report, we provide a conceptual model using a diagram, to demonstrate exactly how two protected areas in The Bahamas contribute to local economic value and also to economic activity for Bahamian businesses. Our focus here is on two protected areas that are part of the larger system of National Parks in The Bahamas: The Exuma Cays Land and Sea Park (ECLSP) and the Retreat Gardens. These Parks are very different. The Retreat Gardens is a terrestrial and frequently visited Park within an urban area of the island of New Providence (Nassau, Bahamas). The ECLSP is a marine park found in a relatively inaccessible part of The Bahamas. However, the general lessons learned from these two protected areas can be applied generally to other protected areas in The Bahamas, with lessons from the ECLSP being applicable to other marine parks and lessons from the Retreat Gardens being applicable to cultural and terrestrial parks. We begin with a description of values and impacts of both National Parks. We then quantify the main economic impacts where data is available and describe those where it is not. Next, we consider who receives these benefits and what the implications for this are. Finally, we also consider the future impact of threats and more sustainable management on the values identified.

This analysis will serve to highlight the economic contribution of these two protected areas, in a way which can be compared to other investments in The Bahamas in the future. Protected areas are costly to establish and maintain and can incur direct, indirect and opportunity costs. Furthermore, the benefits of protection sometimes are not as obvious as the costs and may not be seen immediately. As a result, it is important to quantify the benefits of protected areas in order to understand the benefits of conservation investments. We consider economic impacts and value in terms of current benefits, which may or may not be represented in markets and in terms of future

benefits, especially in the context of habitat loss, biodiversity declines and other threats in this region and globally, which will only increase the value of areas which have maintained high environmental quality. Demonstrating economic benefits may also stimulate investment in Bahamian Parks, increase support for conservation measures and led to increased funding. This sort of an analysis can also be a useful way of collecting baseline information, which can be used to show management improvements over time or to identify areas which need better attention.

Johnston, M.W., Purkis, S.J., Dodge, R.E. 2015. Measuring Bahamian lionfish impacts to marine ecological services using habitat equivalency analysis. *Mar boil* 162: 2501-2512

Marine ecological services provide goods, amenities, food resources, and economic benefits to millions of people globally. The loss of these services, attributed to the infiltration of marine invasive species such as the Indo-Pacific lionfish (*Pterois volitans*), is measurable. The highly successful lionfish now flourishes in great densities in the US Gulf of Mexico and Atlantic waters and the entire Caribbean, yet the loss of ecological services attributed to the invader has not yet been assessed. In this study, we employ a derivative of a well-utilized method of ecosystem valuation known as habitat equivalency analysis to measure the time-value-adjusted loss of biomass- and recruitment-related ecosystem services brought by lionfish to Bahamian reefs. Drawing upon the literature examples of tangible lionfish damages in The Bahamas, we (1) quantitatively evaluate the loss of ecosystem services instigated by lionfish by measuring the total service-year losses partitioned over yearly time steps, (2) provide a metric by which ocean managers may value the remunerations of Bahamian lionfish controls when weighed against removal costs, and (3) deliver a tool to quantify changes in ecosystem services as a consequence of invasive species impacts and control.

We found that the invader imposed losses of 26.67 and 21.67 years to recruitment and biomass services per km² of Bahamian reef if left uncontrolled. In the same accord, the most conservative Bahamian lionfish removal regime modeled, i.e., which produced a 50 % recovery of pre-lionfish ecosystem function over 10 years, provided service gains of 9.57 and 4.78 years per km². These data deliver a platform upon which to quantify present and future fiscal costs of the lionfish invasion and also to value lionfish control efforts.

Micheletti, T., Jost, F., Berger, U. 2016. Partitioning stakeholders for economic value of ecosystem services: examples of a mangrove system. *Natural Resources Research*. Vol. 25, No 3.

Although the importance of ecosystem services provided by natural forests, especially mangroves, is well known, the destruction of these environments is still ubiquitous and therefore protection measures are urgently needed. The present study compares the current approach of economic valuation of ecosystem services to a proposed one, using a study case of a mangrove system as an example. We suggest that a cost-benefit analysis for economically valuing environmental services should be performed with three additional modifications consisting of (i) a categorization of local stakeholders as demanders of particular ecosystem services, (ii) acknowledgement of the government as one of these demander groups, and (iii) the inclusion of opportunity costs in the valuation. The application of this approach to the mangrove area in the east portion of Great Abaco Island, The Bahamas, reveals that not only the ecosystem services received differ between demander groups, but the monetary benefits and costs are also specific to each of these groups. We show that the economic valuation of the ecosystem should be differentiated for each category, instead of being calculated as a net _societal value_ as it is currently. Applying this categorization of demanders enables a better understanding of the cost and benefit structure of the protection of a natural area. The present paper aims to facilitate discussions regarding benefit and cost sharing related to the protection of natural areas.

Total Reported Landings CY 2015

These data from the Department of Marine Resources documents pounds and export value, summarized by species and by island.

Smith, N.S. and Zeller, D. 2016. Unreported catch and tourist demand on local fisheries of small island states: the case of the Bahamas, 1950-2010. *Fish. Bull.* 114:117–131

Tourism is vital to the economy of small island states like The Bahamas and is closely linked to fisheries. Fish is a protein source for tourists and residents, and both groups expect to catch and eat local fish. To adequately manage these dual demands, we need to know total removals of fish, as well as patterns of demand by tourists and residents in the past and present. Using a reconstruction approach, we performed a comprehensive accounting of fisheries catches in The Bahamas from commercial and noncommercial sectors for 1950–2010 and estimated the demand from tourism over the same period. Our results distinctly contrast with national data supplied to the Food and Agriculture Organization of the United Nations (FAO), which presents only commercial landings. Reconstructed total catches (i.e., reported catches and estimates of unreported catches) were 2.6 times the landings presented by the FAO for The Bahamas. This discrepancy was primarily due to unreported catches from the recreational and subsistence fisheries in the FAO data. We found that recreational fishing accounted for 55% of reconstructed total catches. Furthermore, 75% of reconstructed total catches were attributable to tourist demand on fisheries. Incomplete accounting for catches attributed to the tourist industry, therefore, makes it difficult to track potentially unsustainable pressures on fisheries resources.

Sullivan Sealey, K. 2011. Final Report: assessment of illegal, unreported and unregulated fishing in the Bahamian Spiny Lobster Fishery. University of Miami

This report is not exhaustive, but aims to highlight the most important areas of IUU fishing in the Bahamian lobster fishery that require attention to move the MSC certification process forward. The goal was to provide an assessment particularly for illegal and unreported spiny lobster fishing in national waters. The “benchmark” used in this assessment was the known export of 5.2 million pounds of lobster tails (this translates into 12.5 million individual lobsters). These 5.2 million pounds of exported lobster is based on a four-year average from 2005-2008, provided by the Department of Marine Resource Management, Government of The Bahamas¹. The value of the Bahamian lobster fishery can be estimated at near \$100 million dollars in terms of export, employment and in-country tourism². Table 1 provides a summary of the current exports of lobsters and estimated IUU fishing from in-country recreational fishers, commercial fishers, and foreign fishing vessels operating in The Bahamas to determine the total biomass of lobsters taken from Bahamian waters.

Illegal and unreported catches are the current uncertainties in the Bahamian lobster fishery. To date, little or no information is available on the scale and intensity of illegal fishing or for legal, non-commercial fishing. “Illegal” fishing is the taking of lobster by any means that is in violation of the existing laws and regulations. “Unreported” fishing includes fishers whose activity and information is not available to the relevant national authority or regional organization. The organization of this report focuses on three stakeholder groups: 1) restaurants, resorts and resident consumers of lobsters, 2) recreational lobster fishers (residents and visitors), and 3) commercial fishers primarily selling lobsters to licensed processors. The surveys of restaurants and resorts revealed that largest restaurants serve legal sized lobster from known wholesalers, and overall, the potential risk for undersized lobster to be consumed in the restaurant industry is only 5% of the current export quantities.

The Nature Conservancy (TNC). 2015. Knowledge, Attitude and Practices (KAP) Research Queen Conch Report.

The goal of the KAP study was to provide information to the *Conchervation Campaign* that can help in 1) communicating to government decision-makers the level of support in the Bahamian population for conch conservation and specific management strategies, and 2) developing strategies that foster a social and behavioral change that supports conch conservation.

The overall consensus is that Bahamians do support government actions to improve management of the conch fishery and are willing to change their own behavior to conserve conch, despite limited knowledge of conch management and regulations, because Queen Conch is a species that is intrinsically woven into the Bahamian culture.

Thomas, C., Auscavitch, S., Brooks, A., Stoner A. 2014. Assessing essential queen conch (*Strombus gigas*) habitat in Eleuthera, The Bahamas: population declines suggest the urgent need for changes in management. *Proceedings of the 67ths Gulf and Caribbean Fisheries Institute*. Christ Church, Barbados

Queen conch (*Strombus gigas*) are economically and culturally important throughout the greater Caribbean region. However, recent surveys have shown declines throughout their range. In The Bahamas, there exists one of the last viable conch fisheries, but overfishing and illegal juvenile harvest is observed throughout the family islands. In Eleuthera, many local residents rely on marine resources, particularly conch, for subsistence. Population declines may have devastating effects on an already impoverished part of the country. A marine protected area has been suggested for South Eleuthera, but without current information on conch populations and identification of essential habitat, ideal placement and effectiveness cannot be assessed. To determine the health of the local conch population, we performed surveys in two crucial habitats: shallow water habitat and deep water breeding grounds. Utilizing towed snorkel surveys, we obtained necessary baseline data in nearshore habitat with moderate fishing pressure; preliminary results show low numbers of conch, with a mean density of 18 conch/ha. The deep water surveys (performed on SCUBA) were compared to surveys from the 1990s, to determine if local waters are still used by conch for reproduction. Although mating and egg masses were identified in the deep water, the mean density of 11 adults/ha is significantly lower than previous population estimates, and below the threshold identified for a healthy breeding population. Coupled with midden surveys that show only 14% of locally harvested conch are adult, the data suggest a drastic decrease in the South Eleutheran conch population, a potential early sign of population collapse.

Appendix C. Model parameters

Table C-1: Key inputs to Fisheries Production model for spiny lobster

Input	Value	Source
Species life history		
Growth parameters	$L_{\infty}=185$, $K=0.204$	Leocádio and Cruz 2008
Maturation parameters	$L_{50} = 93\text{mm}$	Arce and de Leon 2001
Mortality rate	$M = 0.36$	2012 Stock Assessment
Recruitment parameters		
Steepness	0.8	2012 Stock Assessment
R_0	64,524,000	Estimated in model
SPR (Spawners per Recruit)	2.64	Calculated from life history
Harvest parameters		
Vulnerability by age	$v_{0-2} = 0$, $v_{3-7} = 1$	Minimum legal size
Harvest rate	0.183	2012 Stock Assessment
Price per lb. (tail meat)	\$10.86	Average export price (1997-2014) from DMR
Habitat distribution		
Seagrass	Within 1km of coastline	Landsat
Mangroves	Within 250 of coastline	Landsat
200m Bank area		Landsat

Table C-2. Input parameters for coastal vulnerability model.

Model Input	Description	Year	Extent	Source
Area of Interest	(Vector) This defines the Area of Interest (AOI) for the model run.	2015	National	Created by Natural Capital Project.
Land Polygon	(Vector) This input provides the model with a geographic shape of the coastal area of interest, and instructs it as to the boundaries of the land and seascape.	2015	National	Created based on 0 m contour from BathyTopo model (see below)
Bathymetry and Topography	(Raster) This is used to calculate to relief in the <i>Coastal Vulnerability</i> tool	2015	National	BathyTopo (30m) created by Steve Schill of TNC Caribbean from (1) digitized

	and to generate cross-shore profiles in the <i>Nearshore Wave and Erosion</i> model			nautical charts, (2) WRI bathymetry data, and (3) SRTM topography.
Natural Habitats	(Vector) Maps the type and extent of habitat.	Varies	Bahamas	<i>Landsat, NCRI, Rapideye, Land Survey</i>
Shoreline Geomorphology	(Vector) Geomorphology is the shoreline type (sandy beach, rocky beach, low cliff, muddy shoreline, etc.).	2015	National	Caribbean-wide maps created by TNC digitizing beaches and rocky shores were edited and expanded to include other shoreline types (e.g. muddy shorelines) by NatCap staff.
Wave and Wind Field	(Vector) These inputs are used by the model to calculate wind and wave exposure.	2005-2010	Global	Globally available NOAA WaveWatch III data is available as default data with the model and is considered adequate. Wave and wind exposure are calculated based on six years of data.
Continental Shelf	(Vector) This input is used by the <i>Coastal Vulnerability</i> tool to calculate storm surge rank.		Global	A globally available dataset of the continental margins was prepared by the Continental Margins Ecosystem (COMARGE) effort in conjunction with the Census of Marine Life, and is available as default data with the model.
Sea Level Rise	(Vector) This input is used by the <i>Coastal Vulnerability</i> tool to calculate the sea level rise rank.	2012	Global	Estimates of Global Mean SLR projections from Parris et al. (2012) were used to develop SLR ranks for the CV model. A rank of 1 was applied to the Current scenario, and a rank of 2 for all future scenarios. This was based on the estimated rise expected by 2040 (planning horizon for current scenarios) as compared to the rise anticipated by 2100 (which was assigned a rank of 5).