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BAHAMAS
NATIONAL TRUST

STATE OF THE ENVIRONMENT: **POST HURRICANE DORIAN REPORT**

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Hurricane Dorian challenged the people and environments of The Bahamas, exacting a grave toll on the communities of Abaco and Grand Bahama. The pine forests, mangroves and coral reefs that support life on the islands sustained significant damage in many areas. A confluence of anthropogenic factors challenge the recovery of Abaco and Grand Bahama including 1) increasing storm frequency and intensity due to global climate change, 2) infrastructure development, dredging, mining, and agricultural activities that destroy or degrade natural habitats 3) coral diseases like Stony Coral Tissue Loss Disease (SCTLD) 4) invasive and introduced species that outcompete native plants and compromise shorelines, and 5) the impact of pollutants like the petroleum released during the Equinor Oil Spill. In the context of a future with higher storm frequency, this situation is dire and demands swift and effective restorative actions to prepare for the next storm. The Bahamas' vulnerability is even greater considering the threat of oil exploration and other high-risk infrastructure and development projects proposed in the country. Healthier ecosystems are more resilient and more likely to rebound following a disturbance, like a hurricane, and sustainably deliver the ecosystem services upon which a society depends.

Following Hurricane Dorian, The Bonefish and Tarpon Trust (BTT) reported damage to 40 percent of mangrove habitat on Abaco and 73 percent of mangrove habitat on Grand Bahama. The Bahamas' Ministry of Environment & Housing's Forestry Unit reported that 24 percent of forests on Abaco were damaged and 77 percent of forests on Grand Bahama were damaged. In those forests, the Bahamas National Trust (BNT) has documented a significant decline in bird populations in storm-affected areas of Grand Bahama and Abaco with the complete loss of Bahama Warblers from the pine forests of Grand Bahama. The Bahamas Marine Mammal Research Organisation (BMMRO) recorded the death of two whales and, in collaboration with Louisiana Universities Marine Consortium (LUMCON) and Florida International University (FIU), noted changes in community composition in seagrass beds within the path of the hurricane. And finally, even after efforts to remediate the impacts of the oil spill, Waterkeepers Bahamas (WKB) has recorded petroleum concentrations of up to 1,910 mg/kg in the soil and 9.3 mg/L in standing water on Grand Bahama near the Equinor oil storage facility damaged by the storm, which has likely resulted in negative physical and toxicological impacts on the organisms in those habitats.

Four primary recommendations characterize the suggestions put forward by the organizations that contributed to this report:

1. Restoration and monitoring will be pivotal in protecting coral reefs and other ecosystems from threats including: hurricanes, coral bleaching, Stony Coral Tissue Loss Disease, and pollution such as oil spills
2. The pine forests and mangroves of Abaco and Grand Bahama require rehabilitation, restoration and monitoring efforts to return to a functional state as habitats, protective structures, and community and tourism resources.
3. It is important to recognize the value of ongoing long-term studies as these studies have provided a critical baseline from which the extent of damage from Dorian can be more thoroughly documented.
4. The Petroleum related policies of The Bahamas should include taxation or other revenue streams related to the petrochemical industry (including fuel transport, etc.) to provide for national risk management investments and regulations to ensure adequate prevention, preparedness and response capability to disasters that reflect the value of ecosystems and the communities that rely on them.

INTRODUCTION

Climate change is fast becoming one of the greatest threats to global biodiversity (Markham, 1996). This is especially true for low-lying countries like The Bahamas, where sea level rise and increased frequency and intensity of storms has the potential to rapidly reduce or shift habitat availability and quality. On September 1, 2019, Hurricane Dorian made landfall in The Bahamas as a category-five storm with sustained winds up to 185 mph, taking almost four days to travel over the islands of Abaco and Grand Bahama (Alvila et al., 2020). Since its passing, scientists have collaborated to document the environmental damage exacted by the catastrophic storm in order to inform restoration efforts and monitor recovery. Through direct observations and inferences from satellite imagery, researchers have assessed the impact on terrestrial and marine habitats that were in Dorian's path. The results demonstrate clearly that severe storms can significantly alter or destroy entire ecosystems in a single event.

Below, we take a comprehensive look at this research that followed Hurricane Dorian to highlight lessons learned and make recommendations for the way forward. In addition, this report can be used as a resource for the Oil Spill Contingency Plan Committee (OSCP) as they begin to implement and monitor Phase IV of their Response Plan, which according to the Plan, "includes those actions taken to restore the environment to its pre-spill condition (where possible) including assessing damages incurred, taking appropriate corrective actions, caring for affected wildlife, and studying post-spill environment impacts."

IMPACT ASSESSMENTS

Several Non-Governmental and Governmental agencies partnered to assess the impact of Hurricane Dorian on the various habitat types, species groups, and ecosystems affected by the storm. Contributing institutions are listed in Table 1. The work represented includes water quality analysis, avian and forest surveys, and marine surveys.

This work was made possible by funding from generous donors including, but not limited to the Moore Bahamas Foundation.

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Table 1. Collaborators who contributed to Post Hurricane Dorian Impact Assessments and their organizational affiliation.

IMPACT AND REMEDIATION OF EQUINOR OIL SPILL

CONTRIBUTING ORGANIZATION: WATERKEEPERS BAHAMAS

BACKGROUND

Waterkeepers Bahamas is a non-profit organization focused on protecting the natural environments of The Bahamas through proactive policy change, legal action, advocacy, and education. The group has taken the lead in observations of the oil spill and advocating for an adequate remediation process. The 185 mile-per-hour winds of Hurricane Dorian tore away the tops of crude oil storage tanks and subsequently spread oil from two full tanks over an area encompassing more than 21 square miles (Fanchiotti, 2019) of habitat surrounding the Equinor oil storage facility on Grand Bahama. Nearly 5-million gallons of oil were released from the facility which was spread over wetlands, pine forests, and a quarry by winds blowing to the northeast.

Crude oil contains complex mixtures of hydrocarbons that are insoluble in water and have complex interactions with biological systems.

"Spilled oil can be rapidly lethal to fish, birds, mammals and shoreline organisms due to the readily dissolved components of oil and the physical effects of smothering and destruction of the thermal insulation and buoyancy provided by fur and feathers.

Chronic and sublethal effects are associated with the less soluble components of oil such as the polycyclic aromatic hydrocarbons (PAHs), and some effects may be expressed long after brief exposures. Biomagnification of hydrocarbons in food webs is not an issue because fish, birds and mammals can quickly metabolize and excrete petroleum hydrocarbons, although metabolism of PAHs often creates metabolites more toxic than the parent compound", (Boufadel et al., n.d.). Crude oil exposure has been shown to reduce the growth rates of plants along shorelines and in riparian zones (Lee et al., 2003). In marine systems, fish and invertebrate embryo development is hampered by crude oil exposure (Camus & Olsen, 2008). Aquatic birds are susceptible to mortality following oil exposure as oil on feathers compromises their ability to fly, the water resistance of their feathers and therefore, their ability to regulate their temperature (Lee et al., 2015). An estimated 800,000 birds died as a result of the 2010 Deepwater Horizon Oil Spill, according to exposure probability models (Haney & Geiger, 2014).
In addition, just 0.5 mg of oil on the surface of an egg has been proven to be lethal in mallard ducks (Finch et al., 2011) and the same is likely true for birds nesting near the Equinor spill site. This oil is deposited as oil-exposed birds return to the nest to incubate eggs, coating the egg with oil, impeding gas exchange between the egg and outside environment.

METHODS

Waterkeepers Bahamas analyzed soil samples collected from the Equinor spill site on the 4th of March 2021, eighteen months after the storm. Surface water samples were taken on the same day.

RESULTS

Figure 1 and Table 2 show the results f soil sample analyses and table 3 shows the results of surface water analyses. The highest concentrations of total petroleum hydrocarbons (TPH) (up to 151,000 mg/kg) were measured in soil samples in areas 2 and 3, the areas that received the most wind-blown oil. As the samples were collected, Dr. Ancilleno Davis and Waterkeepers Bahamas staff noticed visible oil sheens on the water surface as they walked along, displacing oil from the subsurface. This observation confirms the presence of oil in the subsurface, in spite of remediation efforts.

SAMPLE	TOTAL PETROLEUM HYDROCARBON CONCENTRATION (MG/KG)
AREA 3 SOIL 1	173 MG/KG
AREA 3 SOIL 2	1,910 MG/KG
AREA 3 SOIL 3	187 MG/KG
AREA 4 SOIL 4	151,000 MG/KG
AREA 2 SOIL 5	9.27 MG/KG
AREA 2 SOIL 6	126 MG/KG
AREA 2 SOIL 7	15.3 MG/KG
AREA 3 SOIL 8	38.2 MG/KG
AREA 1 SOIL 9	48.2 MG/KG
AREA 1 SOIL 10	126 MG/KG

Table 2. March 4, 2021, Total Petroleum Hydrocarbon soil sample results.

Approximately 31 acres of terrestrial habitat has been removed from the oil spill site and will require revegetation. In the quarry to the north of the spill site, there remains oil residue on the surface and this site also requires remediation. "Throughout the impact area and beyond the boundaries of the published oil spill impact area, oil was detected on rocks, trees and in soil, including a film of oil in the areas of the wetlands that were partly exposed", says Dr. Ancilleno Davis, a member of the Waterkeeper survey team. He reports observing just ten species of birds on the site with none of them being wetland species and only one being a resident forest species.

WATER SAMPLE ID	CONCENTRATION OF HYDROCARBONS (MG/L)
STAT 6	0.43 MG/L
STAT 7	1.7 MG/L
STAT 8	9.3 MG/L

Table 3. March 4, 2021 Water samples for diesel-range hydrocarbons (C-10-28).

Figure 1: Equinor site with sampling locations.

CONCLUSIONS

Concentrations of oil found in the oil spill site were still high enough to negatively impact birds and other organisms that may be exposed, even after 18-months of weathering and remediation work. In addition, significant remediation remains needed at the quarry site, north of the main area cleared by Equinor. Following a thorough investigation of the Equinor oil spill and comparison to similar environmental spills, Waterkeeper Alliance and Waterkeepers Bahamas issue the following opinions of the disaster at Equinor:

1. The Equinor oil release impact zone has not been fully delineated and requires further delineation and mitigation of both habitat and wildlife impacts.
2. Equinor oil residues in soil and surface water are at levels that have and will impact the local wildlife and habitat.
3. The Equinor storage facility has not been hurricane hardened to withstand the expected wind or tidal forces expected in Grand Bahama.
4. Crude oil releases that occur on land, or reach land, compound the difficulty in remediation and the impacts can persist for decades after a spill. Crude oil residues, if not remediated, will have a long-term impact on bird nesting success as well as impacts to the overall ecosystem.
5. Strategic remediation of the Equinor crude oil residues should be undertaken using methods that reduce the impact to the areas' ecological services. Long-term monitoring should be conducted to verify ecosystem recovery.
6. Based on the delayed Equinor response tothe hurricane Dorian release, it is obvious that response assets are not available within a timely manner to address the potential catastrophic releases in the future. This issue must be addressed. Preparation and planning for expected events is needed similar to U.S. Oil Protection Act (OPA) requirements for spill planning, preparedness, response and funding. A detailed offensive interventions spill response plan must be developed to replace the typical defensive wait-and-see and then clean up the beaches plan. An offensive plan must include specific strategies to protect sensitive ecological resources and specifically endangered, threatened and vulnerable species and their habitats.

7. The Bahamas should consider expansion of surface water protection legislation and regulations requiring "spill prevention, countermeasure and contingency (SPCC) planning" similar to the U.S Clean Water Act requirements for large above ground storage facilities. This plan would require adequate response capabilities. Adequate, on-island capabilities should be established including oil boom containment and oil spill isolation capabilities as well as the training and equipment to deploy those capabilities. This planning should be consistent with and included in, the "Caribbean Island Oil Pollution Response and Cooperation Plan" and the "Bahamian National Oil Spill Contingency Plan (NOSCP)". Facility specific table-top and field exercises should be undertaken according to established plans to increase preparedness in a disaster.
8. There is a need for an effective Incident Command in the event a response is needed, with a clear process for initial command and then hand-offs in the event of a large spill. An Incident command structure should be formalized that includes oversight by experienced experts in the field that are accountable to public institutions.
9. In addition to prevention preparedness and response, a Natural Resource Damage Assessment should occur after every major spill to understand the required remediation steps and costs as well as any financial liability of the responsible party to pay for restoration and loss of services or livelihoods. Such an assessment should be codified in legislation to better protect the long-term interests of The Bahamas and its citizens. Such an assessment would take the following into account:

a. Tourism is predominantly from cruise ships and overnight visitation. The Bahamian economy is dependent on clean beaches and marine-based opportunities offered by the islands.

b. The Bahamas and surrounding areas are home to 10 critically endangered, 15 endangered and 42 vulnerable species according to the International Union for the Conservation of Nature ("IUCN Red List of Threatened Species," 2005). A major release of crude oil would have long-lasting, and in some cases, irreversible consequences on endangered and vulnerable species.

c. Effective spill containment and response is critical and a Grand Bahamas reserve account or trust fund should be established by the oil storage and handling facilities as part of the SPCC process.

d. Marine mammals and sea turtles could be affected by oil spills through various pathways: surface contact, inhalation, ingestion, and baleen fouling. As air-breathing animals, health impacts from oil spills can be fatal or result in long-term health decline.

IMPACTS ON BIRDS AND FORESTS

CONTRIBUTING ORGANIZATION: BAHAMAS NATIONAL TRUST

BACKGROUND

The Bahamas National Trust (BNT) was established by an Act of Parliament in 1959 as a non-governmental, autonomous, statutory body, mandated with the development and management of the National Park System in The Bahamas. In its efforts to conserve biodiversity across The Bahamas, the organization deployed teams to survey both within and outside national parks on Grand Bahama and Abaco after Hurricane Dorian. This information will inform conservation, advocacy, education and policy recommendations to support biodiversity on Abaco and Grand Bahama and the lives of the people who depend on these ecosystems.

Grand Bahama and Abaco are two of the four islands in The Bahamas that support Pine Forest ecosystems.

A significant portion of the Pine Forests on both islands were catastrophically damaged during the hurricane, with implications for bird species that depend on these habitats.

Species of particular concern are the critically endangered Bahama Nuthatch which is only found in the Pine Forests of Grand Bahama and has not been seen since 2018. The Bahama Parrot (a subspecies of the Cuban Amazon Parrot) whose largest breeding population is contained within the Pine Forests of Abaco. The Bahama Warbler, another endemic, is found exclusively in Pine Forests on Grand Bahama and Abaco. In addition to the resident and endemic birds found in these pine forests, numerous migratory birds rely on these habitats for up to six months of the year. The Abaco Boa *(Chilabothrus Exsul)*, an endemic snake, is also reliant on terrestrial habitats on Abaco although they mainly utilize coppice habitats.

METHODS

Assessments were conducted from January 20th to 30th, 2020 on Abaco and February 17th to 28th, 2020 on Grand Bahama. The methodology followed (Franklin & Steadman, 2013) which involved conducting 13-minute point counts to determine avian species richness and abundance as well as vegetation plots (veg plots) where plant diversity, canopy and understory height, and number of stems at breast height (1.3m) in 100 square meter plots were recorded near point counts. The American Bird Conservancy (ABC) - BNT team visited most of the points covered by Franklin and Steadman at least once to complete a 13- minute point count survey (Figure 2).

Figure 2. Avian Survey site locations visited across Abaco and Grand Bahama.

RESULTS
ABACO

A total of 102-point counts and 43 vegetation plots were conducted in both hurricane-damaged and undamaged pine and coppice where sites were considered damaged if there was visible breakage of tree trunks in the area. Forty-one species (15 migrants, 27 residents) were seen during point counts (Table 4), and

preliminary observations show bird diversity was higher in undisturbed pine sites with low (<3m) understory and poorer in profoundly disturbed pine sites.

All four endemic species, as well as Bahama Parrots and West-Indian Woodpeckers, were observed during the point count period. Bahama Warblers, an endemic and pineland species, was observed more frequently in undisturbed pineland than damaged pineland and were not seen in the coppice. Differences between bird species composition in disturbed and undisturbed coppice forests were less than those in pine forests.

Bird abundance in damaged coppice and pine sites was reduced compared to undamaged sites based on the results of a Wilcoxon test of average bird abundances at each site where p values less than 0.05 are considered significant (coppice, $p = 0.006$; pine, $p < 0.001$) (figure 1). We compared average bird diversity between damaged and undamaged pine sites using a Wilcoxon test of the Shannon-Weiner Diversity Index (H) calculated for each point count. We note that bird diversity is not significantly different between damaged and undamaged coppice sites, but there was significantly lower bird diversity in damaged pine sites compared to damaged coppice sites (Figure. 2)

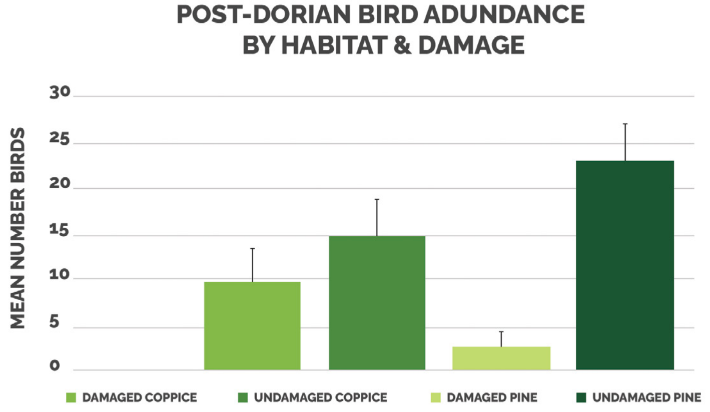


Figure. 3 Comparison of bird abundance between damaged and undamaged coppice and pine habitats in Abaco in December 2020. Error bars indicate standard error, and stars indicate significant differences where α=0.05.

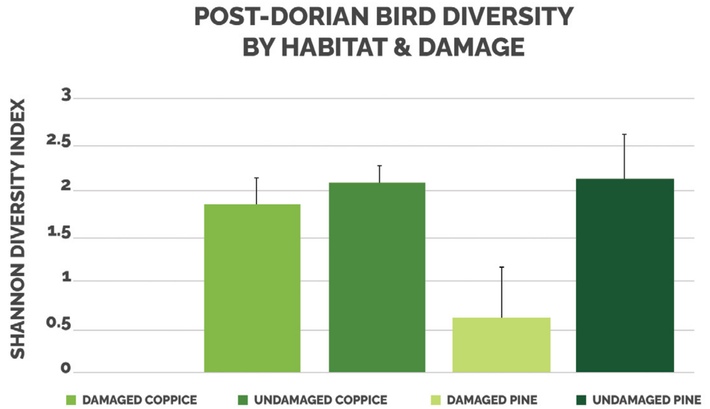


Figure. 4 Comparison of bird diversity using the Shannon-Wiener Index (H) between damaged and undamaged coppice and pine habitats in Abaco in December 2020. Error bars indicate standard error, and stars indicate significant differences where α=0.05.

RESULTS
GRAND BAHAMA

A total of 74 avian point counts and 34 vegetation plots were done throughout Grand Bahama. A total of 19 species (six migrants, 13 residents) of birds were observed during the assessment period (Table 4), including one endemic species (Bahama Yellowthroat), although most were in remarkably low numbers, with just two birds at most point counts. No other endemic species were seen during or outside our point count period or during our vegetation plots, even in suitable, diverse habitat

COMMON NAMES	SCIENTIFIC NAMES	MIGRANT/RESIDENT	ABACO	GRAND BAHAMA
AMERICAN KESTREL	*FALCO SPARVERIUS SPARVERIOIDES*	RESIDENT	X	X
AMERICAN REDSTART	*SETOPHAGA RUTICILLA*	MIGRANT	X	X
BAHAMA NUTHATCH*	*SITTA INSULARIS*	RESIDENT		
BAHAMA PARROT	*AMAZONA LEUCOCEPHALA BAHAMENSIS*	RESIDENT	X	
BAHAMA SWALLOW*	*TACHYCINETA CYANEOVIRDIS*	RESIDENT	X	
BAHAMA WARBLER*	*SETOPHACA FLAVESCENS*	RESIDENT	X	
BAHAMA WOODSTAR	*NESOPHLOX EVELYNAE*	RESIDENT	X	
BAHAMA YELLOWTHROAT*	*GEOTHLYPIS ROSTRATA ROSTRATA*	RESIDENT	X	X
BANANAQUIT	*COERBA FLAVEOLA BAHAMENSIS*	RESIDENT	X	
BLACK AND WHITE WARBLER	*MNIOTILTA VARIA*	MIGRANT	X	
BLACK-FACED GRASSQUIT	*MELANOPSIZA BICOLOR BICOLOR*	RESIDENT	X	
BLACK-THROATED BLUE WARBLER	*SETOPHAGA CAERULESCENS*	MIGRANT	X	
BLUE-GREY GNATCATCHER	*POLIOPTILA CAERULEA CAESIOGASTER*	RESIDENT	X	
CAPE-MAY WARBLER	*SETOPHAGA TIGRINA*	MIGRANT	X	
COMMON YELLOWTHROAT	*GEOTHLYPIS TRICHAS*	MIGRANT	X	X
CUBAN EMERALD	*CHLOROSTILBON RICORDII*	RESIDENT	X	X
GREATER-ANTILLEAN BULLFINCH	*MELOPYRRHA VIOLACEA VIOLACEA*	RESIDENT	X	
GREY CATBIRD	*DUMETELLA CAROLINENSIS*	MIGRANT	X	X
HAIRY WOODPECKER	*LEUCONOTOPICUS VILLOSUS*	RESIDENT	X	X
HOODED WARBLER	*WILSONIA CITRINA*	MIGRANT	X	
LA-SAGRAS FLYCATCHER	*MYIARCHUS SAGRAE LUCAYANENSIS*	RESIDENT	X	X
LOGGERHEAD KINGBIRD	*TYRANNUS CAUDIFASCIATUS BAHAMENSIS*	RESIDENT	X	X
MERLIN	*FALCO COLUMBARIUS COLUMBARIUS*	MIGRANT	X	
NORTHERN MOCKINGBIRD	*MIMUS POLYGLOTTUS ORPHEUS*	RESIDENT	X	X
NORTHERN PARULA	*SETOPHAGA AMERICANA*	MIGRANT	X	
NORTHERN WATERTHRUSH	*PARKESIA NOVBORACENSIS*	RESIDENT	X	
OLIVE-CAPPED WARBLER	*SETOPHAGA PITYOPHILA*	RESIDENT	X	
OVENBIRD	*SERIUS AUROCAPILLA*	MIGRANT	X	X
PALM WARBLER	*SETOPHAGA PALARUM PALARUM*	MIGRANT	X	X
PINE WARBLER	*SETOPHAGA PINUS PINUS*	RESIDENT	X	X
PRAIRIE WARBLER	*SETOPHAGA DISCOLOR*	MIGRANT	X	X
RED-LEGGED THRUSH	*TURDUS PLUMBEUS PLUMBEUS*	RESIDENT	X	X
RED-TAILED HAWK	*BUTEO JAMAICENSIS SOLITUDINIS*	RESIDENT	X	
RED-WINGED BLACKBIRD	*AGELAIUS PHOENICEUS BRYANTI*	RESIDENT	X	X
SMOOTH-BILLED ANI	*CROTOPHAGA ANI*	RESIDENT		X
THICK-BILLED VIREO	*VIREO CRASSIROSTRIS CRASSIROSTRIS*	RESIDENT	X	
WEST INDIAN WOODPECKER	*MELANERPES SUPERCILLIARIS BLAKEI*	RESIDENT	X	X
WESTERN SPINDALIS	*SPINDALIS ZENA TOWNSENDI*	RESIDENT	X	
WHITE-CROWNED PIGEON	*PATAGIOENAS LEUCOCEPHALA*	RESIDENT	X	X
YELLOW-RUMPED WARBLER	*SETOPHAGA CORONOTA*	MIGRANT	X	
YELLOW-THROATED VIREO	*VIREO FLAVIFRONS*	MIGRANT	X	
ZENAIDA DOVE	*ZENAIDA AURITA ZENAIDA*	RESIDENT	X	
CUBAN PEWEE	*CONTOPUS CARIBEUS BAHAMENSIS*	RESIDENT	X	

Table 4. Birds observed on Abaco and Grand Bahama during field assessments. Asterisks (*) indicate endemic species.

CONCLUSIONS

Hurricane Dorian's impact has drastically reduced the amount of pine forest habitat on Grand Bahama, jeopardizing the future of the Bahama Warbler and many other pineland bird species on the island (Table 5.)

In contrast, Abaco still has substantial remaining pine forest, especially in the south of the island. The damage wreaked by Hurricane Dorian makes these habitats even more valuable as reservoirs for biodiversity and refuges where hunting and tourism activities can persist after the storm. The disappearance of the Bahama Warbler from the pine forests of Grand Bahama reduced the population of this bird to the level of an endangered species as assessed by the IUCN Redlist in 2020 on the recommendation of the participants in this survey of bird diversity. This is the first step in restoring the pine habitats of our two northernmost islands and protecting the bird populations that rely on them. The BNT is also working to encourage locals to capitalize on the value of their forests through sustainable tourism as a means to support the economies of these islands in the wake of Hurricane Dorian. Through our basic "Eco-guide" training course we have introduced over 15 individuals to the potential of eco-tour activities in the pine forests of Abaco and Grand Bahama.

SEED COLLECTION AND DISPERSION

Due to the high mortality of the pineland ecosystem, tree planting methods need to be incorporated into any restoration plans for both islands. Although The Bahamas currently does not have the facilities needed to tackle such an enormous task, an alternative can be through pine seed collection and dispersion. Areas on Grand Bahama and Abaco that received minimal damage can be used as seed collection sites. This task can be incorporated into a school activity that can educate students about the importance of the pineland ecosystem and foster environmental stewardship on Abaco and Grand Bahama (once schools and other needs on both islands are remedied).

ISLAND	EXTENT OF FOREST (KM^2)			BALE & BERGH, 2019			POPULATION ESTIMATES
	INTERACTIVE WORLD FOREST MAP & TREE COVER CHANGE DATA | GFW, N.D	BALE & BERGH, 2019	SANCHEZ ET AL., 2014	FOREST IMPACTED (%)	FOREST CATASTROPHICALLY IMPACTED (%)	POTENTIAL HABITAT REMAINING (KM^2)[A]	NUMBER OF INDIVIDUAL
ABACO	300	602	543	86	22.5	227-455	817-1638
GRAND BAHAMA	100	286	456	100	100	5-23	18-83

Table 5. Estimated Terrestrial Vegetation loss after Hurricane Dorian

MONITORING

Follow-up monitoring on both islands is required to ascertain the population behaviour of birds accurately. The Bahamas National Trust is planning future surveys to assess populations post-Dorian. Evaluation of current listings (or lack thereof) of endemic and range-restricted birds under the International Union for Conservation of Nature (IUCN) criteria are underway to inform any necessary changes to designations in light of population and habitat changes post-Hurricane Dorian. Appropriate listings under the IUCN help to prioritize and focus resources on species that need conservation intervention the most.

IMPACT ON REEF HABITATS

CONTRIBUTING ORGANIZATION: PERRY INSTITUTE FOR MARINE SCIENCE

BACKGROUND

The Perry Institute for Marine Science (PIMS) studies marine ecosystems across The Bahamas and the Caribbean, working alongside governments, international NGOs and local organizations. PIMS executed surveys of Bahamian reef ecosystems across Abaco and Grand Bahama prior to hurricane Dorian (November 2018-August 2019), generating a remarkably precise baseline for analyzing the damage inflicted by Hurricane Dorian. After the storm, scientists from PIMS surveyed reefs surrounding Abaco and Grand Bahama in November 2019 and April 2021, cataloguing the immediate and medium-term impacts of hurricane Dorian on coral reef ecosystems.

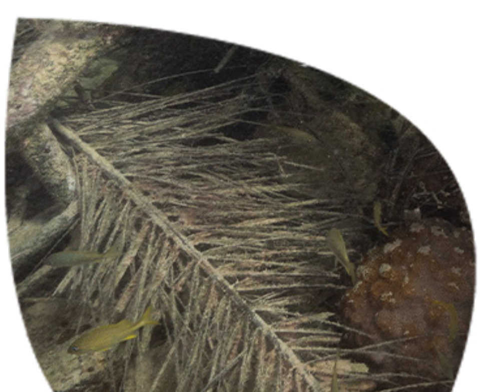
SCORE	DAMAGE	DEBRIS	SEDIMENT	BLEACHING
0	NO DISLODGED/ BROKEN CORALS	NO DIBRIS VISIBLE	NO SEDIMENT MOVEMENT OR SCOUR VISIBLE	NO PALE/ BLEACHED CORALS
1	SMALL CORALS DISLODGED/ BROKEN	SMALL AMOUNTS OF TERRESTRIAL DIBRIS: LEAVES, SMALL PEICES TRASH	SOME EVIDENCE OF MINOR SAND SCOUR	SOME PALE/PARTIAL BLEACHED CORALS
2	LARGER CORALS DISLODGED/ BROKEN	BRANCHES/ PLASTICS/ LIGHT METAL	LIGHT SILTATION; SEDIMENT MOVED TO/FROM BASE OF REEF	MANY PALE/PARTIAL BLEACHED CORALS
3	MAJOR STRUCTUAL DAMAGE TO REEF	LARGE TREES/TRASH	HEAVY SILTATION/LARGE SILT & MUD DEPOSITS	WISEDPREAD BLEACHING (MAY NOT BE ALL SPECIES)

Table 6. Scoring for component metrics of the HDI score.

METHODS

Scientists from the Perry Institute for Marine Science surveyed reef ecosystems across the little Bahama bank in the year prior to Dorian, within the two months after the storm, and in April of 2021. Reef health was characterized using the Atlantic Gulf Rapid Reef Assessment (AGRRA) methodology and a Hurricane Damage Index (HDI) developed specifically for assessing damage from Hurricane Dorian (Table. 6). In total 29 sites were surveyed before and after Hurricane Dorian. Having baseline data from before the storm allows the researchers to evaluate Dorian's impact with unprecedented precision. The AGRRA data was compared before and after the storm, generating a detailed, quantitative analysis of how the storm impacted reefs, specifically: 1) Structural damage to coral reefs, 2) Broken or dislodged coral colonies, 3) The amount of live coral on reefs 4)The condition of coral colonies on reefs, 5) The amount of harmful seaweeds that compete with corals and can prevent coral growth and survival, 6) Fish biomass on reefs. Comparisons of environmental factors (eg. proximity to the coast or the path of the storm) to the HDI revealed patterns in: (1) physical destruction of reefs, (2) sediment movement/ burial, (3) debris, and (4) coral health/bleaching.

Although less precise than quantitative data, HDI scores are more sensitive to hurricane damage and might pick up on the signals of hurricane damage on reefs more quickly than comparisons of AGRRA surveys (Figure 5.).



RESULTS

HDI scores show the relative extent of damage to reefs across Abaco and Grand Bahama (Figure 5). While HDI scores tended to be greater at inshore areas close to the path of Dorian, several sites close to Dorian's track received relatively minor damage and some farther away received greater damage. An analysis coupling the ecological effects of the reef with physical factors during the storm (e.g., wave height, storm surge, currents, etc.) is underway and may explain the observed spatial patterns better.

Using data collected with AGRRA survey methods, two reefs lost statistically significant amounts of structural complexity due to Hurricane Dorian. Specifically, Mermaid Reef and Moraine Cay Reef had less structural complexity after the storm passed than they did before it passed. For Mermaid reef, 3D models constructed using photogrammetry before Dorian compared to After Dorian verified the degree of physical damage to reefs with up to 20% of coral colonies moved or altered by the storm. In addition to structural damage, damage to coral colonies from anthropogenic debris and uprooted casuarina trees caused loss of coral on some reefs, as did the mass transport of sediment from inshore areas to reefs that either completely buried or smothered coral colonies. The increase in sediment loads in the water column also is suspected to be the driver of widespread bleaching on some reefs.

In April 2021, many of these bleached colonies had recovered but some saw significant amounts of colony mortality. In general, however, reef health did not continue to decline in areas affected by Dorian from October 2019-April 2021 on Abaco, but an outbreak of Stony Coral Tissue Loss Disease off Grand Bahama that was not present at sites surveyed in October 2019 was widespread in April 2021 and had caused significant coral loss on many reefs of Grand Bahama, particularly for brain corals and other highly susceptible species.

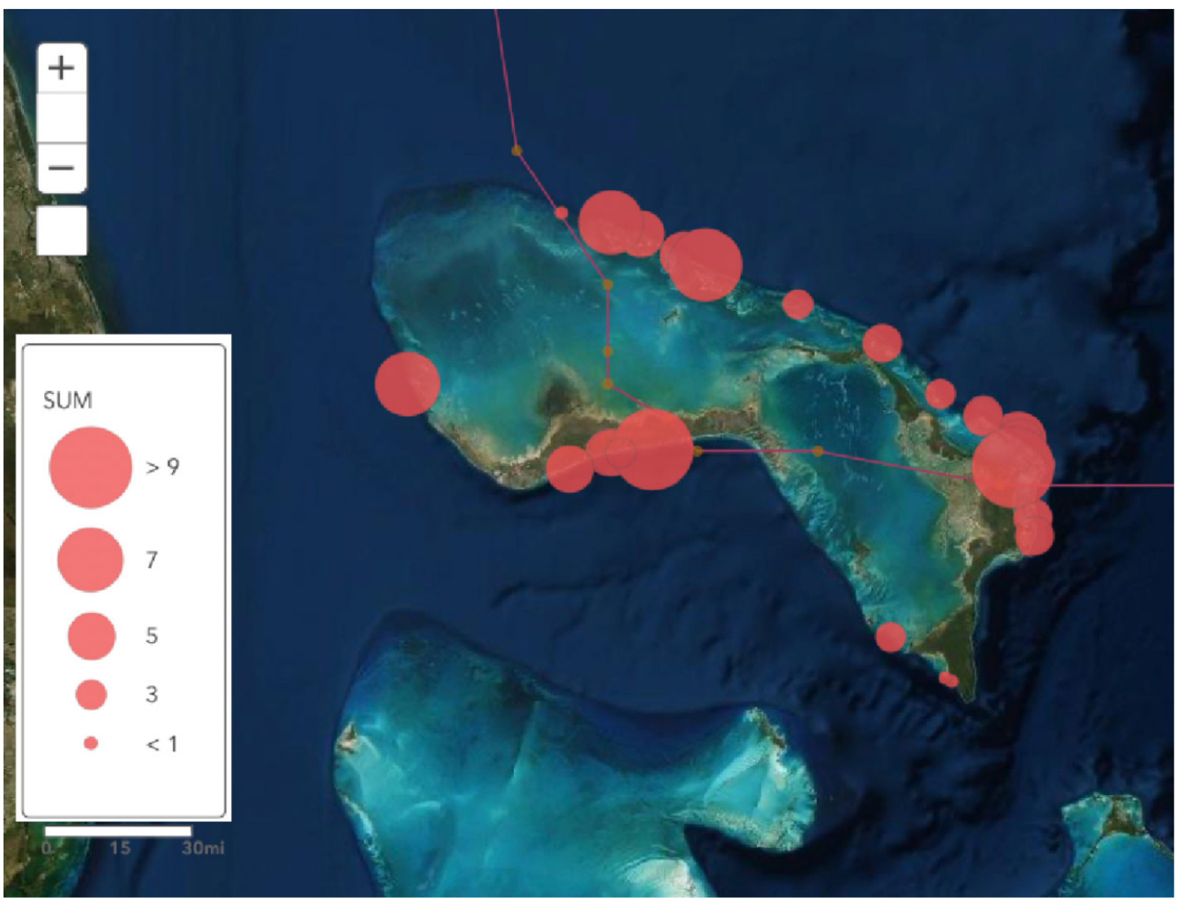


Figure 5. Hurricane Damage Index (HDI) for each reef surveyed. The size of circles indicates sum of individual damage scores at each site, higher index scores indicate greater damage. Red line indicates the path of Hurricane Dorian.

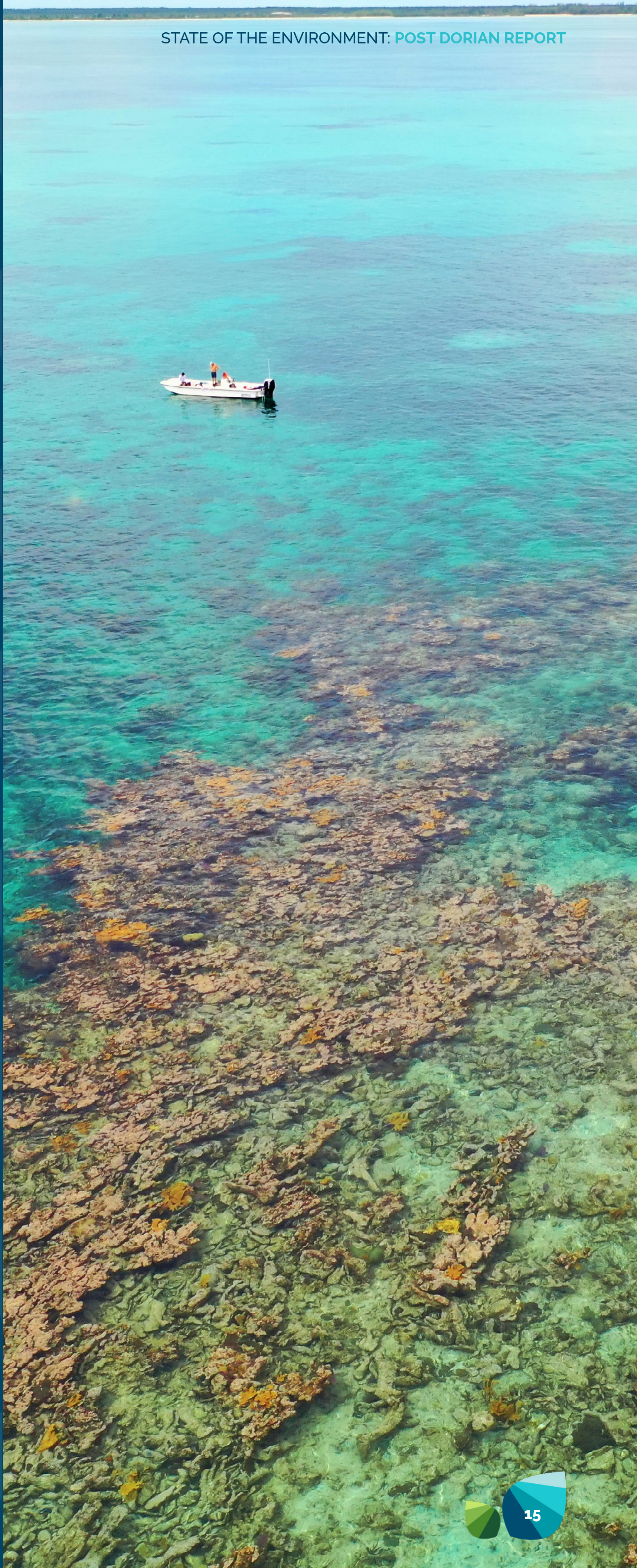
CONCLUSIONS

The HDI and AGRRA data indicate that the type and severity of damage experienced by reefs varied considerably. Neither damage on land nor the intensity of and proximity to the storm were closely correlated. Spatial patterns of damage likely depend on complex interactions between a variety of factors, including depth, proximity to land, type of adjacent marine and coastal habitats, and reef structure. Additionally, the track of Hurricane Dorian relative to reefs, landmasses that shelter the reef, the extent of the storm's impact, and strength of waves and storm surge all influence reef condition after the storm. Some reefs sustained damage to corals, impact from debris, silt inundation, coral bleaching, and reduction in fish biomass, yet other reefs saw little damage and even benefitted from the storm removing seaweed that competes with corals.

Reefs closest to shore were subject to damage from debris, especially the impact of invasive Casuarina trees uprooted by the storm and driven into reef structures by tides and storm surge.

Removing these casuarinas could have reduced the damage incurred by valuable near-shore reefs considerably while protection the shoreline from erosion in the process.

Between the October 2019 surveys and the most recent April 2021 surveys, some reefs have remained the same while some coral that was heavily bleached in 2019 suffered partial mortalities by April 2021. In contrast, reefs dominated by elkhorn coral (Acropora palmata) have shown more resilience and seem to be growing back in some instances. Reefs off the southern coast of Grand Bahama have shown declines in coral species known to be susceptible to Stony Coral Tissue Loss Disease. For reefs affected by Dorian and those subsequently affected by SCTLD, restoration may be the best option for helping populations of several critically endangered and endangered coral species recover.



IMPACT ON MANGROVE HABITATS

CONTRIBUTING ORGANIZATION: BONEFISH AND TARPON TRUST

BACKGROUND

The Bonefish and Tarpon Trust (BTT) is a non-profit organization with a mission to conserve and restore bonefish, tarpon and permit fisheries and habitats through research, stewardship, education and advocacy. Bonefishing is a key industry in The Bahamas and provides local fishing guides with a sustainable option for employment that supports their lifestyles while respecting their culture. The mangrove habitats that support bonefish populations also took the brunt of the damage from Hurricane Dorian, protecting inland areas from the direct force of winds and storm surges. As a result, many mangrove systems were compromised during the storm and will require restoration for them to deliver the ecosystem services that local populations rely on.

METHODS

Scientists from the BTT, the University of Alabama, and the Bahamas National Trust catalogued the status of mangrove stands surrounding Grand Bahama in February 2020. The field team visited 208 ground verification points on the island. Observations characterized 1) land cover type (mangrove, pine, water, etc.), 2) post-hurricane status (damaged or destroyed, not damaged or destroyed), and 3) geographic coordinates at each point. Then, University of Alabama collaborators generated a composite image of cloud-free high resolution (10-meter), atmospherically corrected Sentinel-2 imagery captured between January 1 and May 1, 2019. The reflectance values associated with each pixel are median values for the time period. Pixels representing water were excluded from analysis based on the Normalized Difference Water Index (McFeeters 1996).

Researchers identified mangrove and non-mangrove areas on the composite image based on field observations, generating a training dataset for the supervised classification process. Researchers then used a supervised classification process supported by the Google Earth Engine to estimate which pixels of the composite image represent mangroves based on the training data. The result of this process is a classified, thematic map depicting mangrove and non-mangrove land cover classes prior to the storm. Then, the researchers used median Normalized Difference Vegetation Index (NDVI) values from Sentinel-2 imagery from January 1 – May 1, 2019, and January – May 1, 2020, to evaluate mangrove health before and after the storm, respectively.

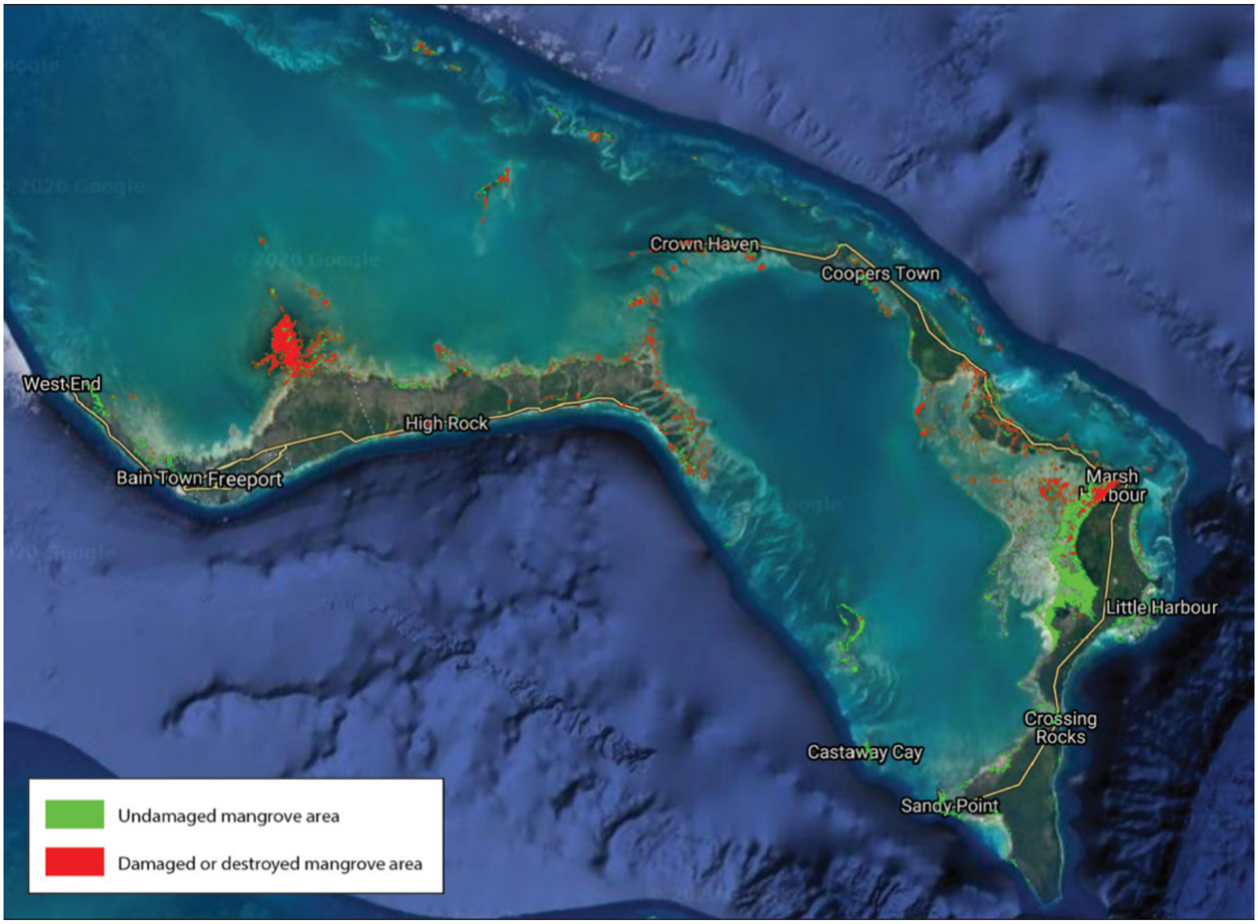


Figure 6. Map of hurricane damage to mangroves on Grand Bahama and Abaco. Note that the scale of this map gives the impression that there are more undamaged (green) areas than there are, especially about the Marls of Abaco – at a higher resolution and larger scale one would see gaps where this image shows solid groups of green pixels.

RESULTS

More than 73% (22,528 acres) of Grand Bahama's mangrove cover and 40% (21,678 acres) of Abaco's mangrove cover was damaged during Hurricane Dorian (Figure 6.).

The north coast and east end of Grand Bahama, and the Marls and west coast of Great Abaco Island suffered the most severe damage to mangroves. From direct observation, red mangroves suffered the most significant damage which may have implications for restoration approaches.

CONCLUSIONS

The results presented above describe a coarse survey of satellite imagery, supported by ground-truthed datapoints. This preliminary analysis has motivated further work to determine where the damage to mangroves was worst and how further monitoring and future restoration should occur. The BNT, BTT, and their partners are working to develop stocks of mangroves for replanting on Grand Bahama and Abaco.

IMPACT ON MARINE MAMMALS

CONTRIBUTING ORGANIZATION: BAHAMAS MARINE MAMMAL RESEARCH ORGANISATION

BACKGROUND

Based in Abaco, the Bahamas Marine Mammal Research Organisation (BMMRO) has been conducting research on marine mammals in The Bahamas since 1991, to document and monitor the health of local populations and promote the conservation of marine mammals in The Bahamas. As some of the largest marine fauna and top predators in Abaco's nearshore ecosystems, bottlenose dolphins (Tursiops truncatus) are expected to be impacted both directly and indirectly by hurricane Dorian. Bottlenose dolphins in the Sea of Abaco comprise a small, resident population with individuals exhibiting high site fidelity (Claridge, 1994; Durban et al., 2000) and limited ranging patterns resulting in low gene flow across Little Bahama Bank(Parsons et al., 2006). This local population has experienced a 50% decline since the late 1990s (Fearnbach et al., 2012) likely due to the cumulative effects of increasing human activities, including coastal development, over-fishing, marine pollution, increased boat traffic and associated noise, and climate change causing more intense and frequent tropical cyclones. Notably, (Fearnbach et al., 2012) found a significant increase in apparent mortality in 1999 when two hurricanes (Dennis, category 2 and Floyd, category 4) passed over the study area. Intense hurricanes like Dorian can have direct impacts on marine animals like dolphins and whales that need to surface to breathe and injury from debris can be fatal. Of further concern is that indirect effects due to habitat loss can be strong even when direct effects are minimal (Nowicki et al., 2019).

METHODS

To search for live and dead stranded marine mammals following the passage of Dorian, two aerial surveys were conducted on 17 September and 27 September 2019 covering almost 600 km of the Abaco and eastern Grand Bahama coastline. The survey team consisted of 2 marine mammal observers and the pilot and flights were made in a Cessna 172 and Piper Aztec. Sightings data were collected for all megafauna and birds seen during the surveys.

Dedicated boat-based visual surveys for bottlenose dolphins were conducted in the inshore waters of the Sea of Abaco during November and February as well as additional opportunistic surveys. When a group of dolphins were sighted, photo-identification pictures were taken, group size and composition were noted (e.g., presence of calves). Individual dolphins were identified from the photographs using the unique pattern of natural markings (nicks) in the dorsal fin which have been shown to be long-lasting. Each individual dolphin was then compared to BMMRO's existing catalogue of bottlenose dolphins to build on individual sighting histories and document demographic parameters (e.g., reproductive rates). These photographic data are being used to estimate annual abundance of bottlenose dolphins in the Sea of Abaco and trends in abundance will be assessed. Photographs were also taken to document each dolphin's body condition (nutritional status), recent shark bites or any other injuries as indicators of individual health. Loggerhead static acoustic recorders were deployed underwater in the Sea of Abaco to monitor the change in ambient noise and dolphin presence/absence in a once noisy environment that suddenly became virtually silent, as the rebuild and recovery efforts commenced for Abaco. The devices were programmed to record on a schedule of either 2 or 5 minutes every 10 minutes at sampling rates between 36 kHz – 50 kHz to detect dolphin vocalizations. This schedule allowed the devices to record for approximately 25 days before needing to be retrieved and the sd data cards and batteries changed. Retrieval and redeployment were carried out on the same day in each case.

RESULTS

No stranded animals were found during the aerial surveys, but carcasses would have been difficult to find amongst large amounts of debris along the shoreline and beaches. However, BMMRO received reports of two stranded whales immediately following the passage of the storm. On 6 September 2019, a decomposing carcass of a dwarf sperm whale (Kogia sima) was discovered in the shoreline debris on the west side of Elbow Cay (Figure 7). The skeletal remains were examined by BMMRO scientists on 7 October 2019 and a late-term foetus was found in its uterus. A second whale was reported dead on the beach on the east side of Man O'War Cay immediately following the storm, but this carcass washed back out to sea and there are no photographs available to identify the species.

Figure 7. Stranded dwarf sperm whale (Kogia sima) on Elbow Cay reported 6th September 2019 (photo courtesy of Mari Matthews).

Twenty-five boat-based visual surveys for coastal bottlenose dolphins were conducted in the Sea of Abaco between November 2019 and July 2020, covering a total of 2018 km. Sixteen groups of dolphins were sighted in groups ranging in size from 1 – 12 dolphins (median 2), totalling 43 dolphins. Dolphins were found in the same areas in the Sea of Abaco that have been used historically (Figure 8). The photo-identification analysis found 28 different individuals, including an adult female observed on February 24th with a neonate calf estimated to be less than 6-weeks old based on its size and presence of fetal folds. Of the total number of individuals found after the storm, sixteen dolphins (43%) were matched to BMMRO's pre-Dorian ID catalogue, including an old adult male first photographed as an adult in the Sea of Abaco in 1992.

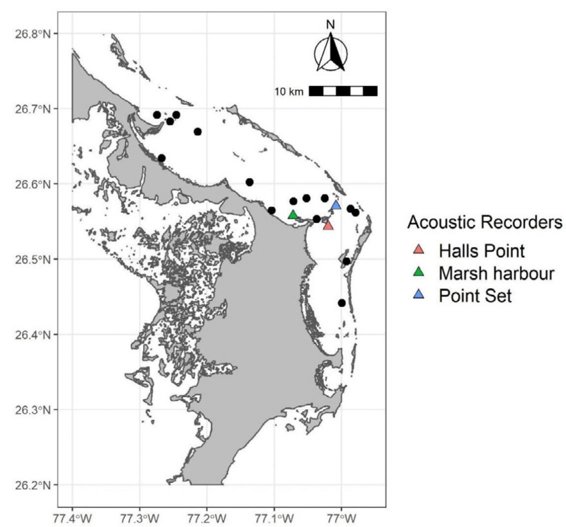


Figure 8: Locations of sightings of coastal bottlenose dolphins (Tursiops truncatus) since hurricane Dorian (black circles) and the deployment sites for three Loggerhead acoustic recorders (triangles).

Between October 2019 to date, acoustic recorders have been repeatedly deployed at three sites in the Sea of Abaco seven (Marsh Harbour) and eight times (Point Set and Halls Point) (Figure 8; Table 7). Over 60,000 files of acoustic data have been collected and these data have been analyzed as part of a Master's thesis at the University of St Andrews, Scotland.

DEPLOYMENT SITE	NUMBER DEPLOYMENTS	FIRST RECORDING DATE	TOTAL # DAYS RECORDED	LAST RECORDING DATE (ESTIMATED)
MARSH HARBOUR	7	12-NOV-2019	137	5-AUG-2020
POINT SET	8	11-OCT-2019	113	5-AUG-2020
HALLS POINT	8	11-OCT-2019	186	5-AUG-2020

Table 7: The number of times acoustic recorders were deployed at each location. Devices recorded for ~ 25 days per deployment and were retrieved and redeployed as close to the estimated last recording date as possible.

CONCLUSIONS

Although the number of dolphin mortalities from hurricane Dorian remains unknown, preliminary visual field data suggests that Dorian may not have catastrophic direct impacts on the bottlenose dolphin population in the Sea of Abaco. Post-Dorian, all age classes were observed including those that would be most vulnerable to direct impacts from an extreme weather event; we found older adults, a dependent calf that survived Dorian and two calves that have been born since Dorian, one of which was a neonate in February. However, the longer-term indirect effects on this small population are likely to be more significant (Nowicki et al. 2019), such as changes in the rate of shark attacks following hurricanes (Fearnbach et al., 2011). It is important that annual assessments continue in the future to capture the longer-term effects and monitor trends of this declining population. While human uses of the Sea of Abaco remain limited due to Dorian (and now COVID19), there is a window of opportunity to examine the status of marine life and provide policymakers with a recovery plan for this top predator to be implemented as Abaco rebuilds, e.g., areas where vessel traffic may need to be restricted.

IMPACT ON SEAGRASS COMMUNITIES

CONTRIBUTING ORGANIZATIONS: LOUISIANA UNIVERSITIES MARINE CONSORTIUM, FLORIDA INTERNATIONAL UNIVERSITY AND BAHAMAS MARINE MAMMAL RESEARCH ORGANISATION

BACKGROUND

Scientists from Louisiana Universities Marine Consortium and Florida International University had been conducting longitudinal studies of seagrass communities in Abaco between 2012-2018 which provided valuable baseline data to assess the impacts of Hurricane Dorian in Abaco. Following the storm, a field team from the Bahamas Marine Mammal Research Organisation return to these historic study sites and repeated surveys to compare seagrass densities and community composition before and after the storm. In addition, they deployed oysters as a bio-assay for water-born pollutants in sites across the island; in heavily and less damaged areas of Abaco.

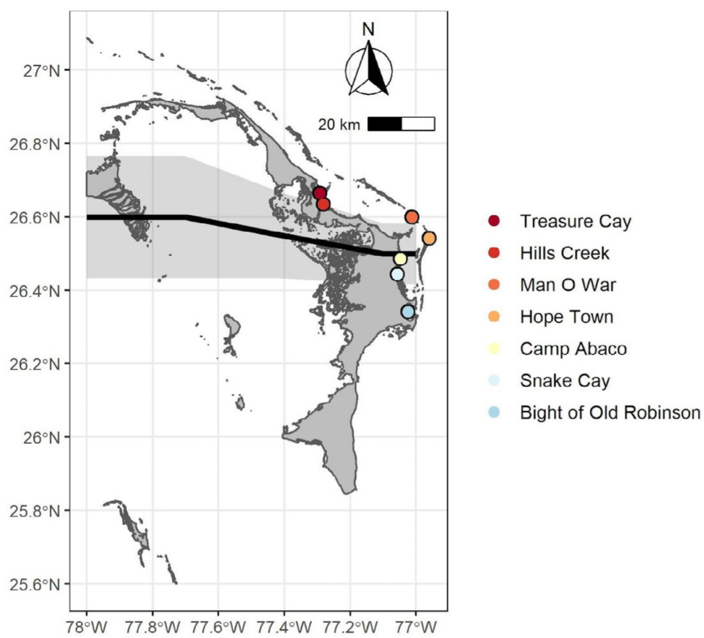


Figure 9: The location of seagrass surveys conducted three months after the passage of Hurricane Dorian. Surveys were repeated 9 months post-storm at Hills Creek, Camp Abaco, and Snake Cay. Pre-storm seagrass data exists for all sites other than Hope Town. The solid black line shows the track of Hurricane Dorian and the shaded area shows the range of maximum sustained winds. Hurricane Dorian track data was obtained from https://coast.noaa.gov/digitalcoast/tools/hurricanes.html accessed on May 1, 2020.

METHODS

The team assessed the abundance of the seagrass Thalassia testudinum by recording shoot density within a 0.10 x 0.10 cm quadrat. In addition, observers ranked the density of seagrass in 50 x 50-centimetre plots on a scale from 1 (absent) to 5 (abundant) to generate a measure of the abundance of the three seagrass species, Thalassia testudinum, Halodule wrightii, and Syringodium filiforme. Surveys were conducted at seven sites between 14-22 November 2019, within three months of Hurricane Dorian and at three sites between 18-29 May 2020, nine months after the storm (Figure 9).

The team was also interested in the impacts of storm runoff on the levels of chemical pollutants in the waters surrounding Abaco so they deployed oysters as a bio-assay for pollutants. Researchers collected oysters from unimpacted areas in southern Abaco, assorted them into groups with similar compositions by size and redistributed those groups in harbours affected by Dorian and control harbours that were less affected. Oysters were left at sites for 40-50 days, collected, shucked, and stored at -80° C *Thalassia* shoots were also collected during seagrass surveys for contribution to the contaminant study. Analysis for contaminants in oysters and seagrass is currently underway.

RESULTS

Prior to the storm, seagrass communities were dominated by T. testudium and had similar compositions and all sites had similar amounts of T. testudium. After Dorian, there was significantly less T. testudium in sites near the path of the storm up to nine months after the storm (Figure 10). In sites where T. testudium cover decreased, the abundance of H. wrightii and S. filiforme increased. Sites that were not impacted by Dorian, like those in south Abaco, maintained a high abundance of T. testudium.

Between October 2019 and May 2020, 529 oysters were deployed at 13 sites around Abaco (Table 8). In addition to oyster deployments, 250 oysters were collected from the sites and stored for contaminant load analysis to serve as a baseline. Analysis for contaminants is currently underway.

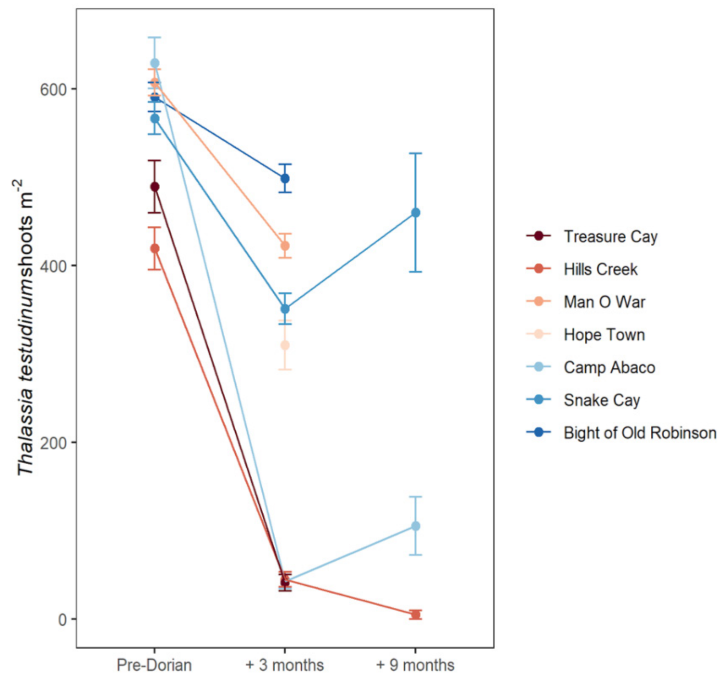


Figure 10: Thalassia testudinum shoot densities prior to Hurricane Dorian (2012-2018) and 3- and 9-months post-Dorian.

CONCLUSIONS

Seagrass beds are an important coastal ecosystem; they attenuate wave energy, stabilize sediments, store large amounts of carbon and provide nursery habitat for commercially important fish. The post-Dorian seagrass study demonstrates the devastating impacts of Dorian on seagrass beds in the direct path of the storm, but more widespread surveys over a longer time period are needed to identify long-term drivers of change in Abaco's seagrass beds. Decreasing other anthropogenic pressures, such as dredging, will improve seagrass resilience to storms. Analyzing the oyster and seagrass contamination levels from the samples collected in the surveys described above will provide vital information about health risks to the people of Abaco and their fisheries – informing future remediation and policy activities and suggestions.

DEPLOYMENT SITE	OCTOBER 2019	NOVEMBER 2019	MAY 2019
TREASURE CAY	0	31	15
HILLS CREEK	0	30	15
MARSH HARBOUR 1	12	20	15
MARSH HARBOUR 2	0	30	15
MARSH HARBOUR 3	0	12	0
MARSH HARBOUR 4	12	21	15
MARSH HARBOUR 5	12	18	15
MARSH HARBOUR 6	0	0	15
MAN O WAR	0	30	15
HOPE TOWN	0	30	15
CAMP ABACO	0	30	15
SNAKE CAY	0	30	15
LITTLE HARBOUR	0	31	15

Table 8: The number of oysters deployed at each location. Oysters were deployed in cages for 20-50 days. Upon retrieval oysters were measured, shucked, and frozen until funds are acquired to analyze the tissues for contaminants.

RECOMMENDATIONS FOR RESTORING NATURAL ECOSYSTEMS

It has been two years since Hurricane Dorian, and the response to the storm's impact has been varied. In some cases, like the restoration of mangroves, we have swiftly deployed resources towards restoring these ecosystems. However, a unified strategy with goals for informing and measuring long term success for these and other ecosystems remains outstanding. The following is a list of recommendations for responding to the impact of Hurricane Dorian and provide a template for The Bahamas to build resilience and improve response to storms:

1. Develop a national-level conservation horticulture program that develops and manages ex-situ collections of native plants that are genetically diverse and representative of wild populations to be used for restoration and reforestation.

2. Remove debris from reefs, coastal areas, forests, and other sensitive systems to reduce the impact physical destruction these can cause during future storms and serve as fuel for uncontrolled wildfires through already compromised forests. If large scale debris removal is not feasible, create fire breaks to reduce fire impacts on recovering forests.

3. Establish additional marine and terrestrial protected areas to build resilience. Marine and terrestrial organisms may relocate to safer areas during storms and return to recolonize damaged areas afterwards. In addition, the more healthy reefs or forests there are, the more reserves there are to repopulate non-motile populations like corals or trees.

4. Remove invasive Casuarina and other invasive plants from coastal and inland areas to improve coastal resilience. Casuarina trees blow over easily during storms, removing material from the coastline and becoming projectiles that damage reef structures once they enter the water. Inland, casuarinas replace native vegetation rapidly, reducing the chances that storm or fire damaged systems will return to their natural state.

5. Restore corals and mangroves in priority areas to help "jump-start" the recovery process, including the use of nurseries and other propagation methods where appropriate and cost-effective, while adhering to best practices to mitigate against unintended negative impacts such as the introduction of pests or diseases. Rehabilitating and restoring severely damaged coral and mangrove habitats has the potential to increase their rate of recovery and the chance that these areas persist in the face of future storm events and other stressors.

6. Develop a rapid response protocol for responding to disasters in The Bahamas to conduct assessments of damage to marine and terrestrial systems and rapidly implement strategies to improve ecosystem recovery. Include a database of current or previous studies to identify where pre-storm baseline data exist and facilitate collaborations to assess storm impacts. An organized emergency plan will facilitate comprehensive, timely responses that maximize the available resources and facilitate the most successful interventions possible.

7. Begin prescribed burning in pine forest areas as soon as possible to protect vital surviving mature pines and priority coppice from severe dry season wildfire, and to protect critical infrastructure and residences from wildfire flames and hazardous smoke.

8. Identify and approach priority communities for outreach and education regarding restoration and ecosystem management. Collaboration with local stakeholders will improve the efficacy of restoration activities by incorporating local knowledge and addressing local concerns such that the community voluntarily facilitates interventions.

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BONEFISH & TARPON TRUST
SCIENCE AND PERSPECTIVE
WATERKEEPERS BAHAMAS
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