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Bonaire National Marine Park

Hurricane Matthew – Reef Damage Assessment

On the evening of the 29th September 2016 Hurricane Matthew passed north of Bonaire by approximately 240km, with maximum sustained wind speeds over 120km/h. After passing Aruba as a category 2 hurricane, the path of Matthew slowed its forward progress and turned north-northeast. Heavy storm surge generated by Matthew continued to strike the coastline and on the 4th-5th of October, a resurgence of waves ranging from 1.4-1.7 m height pounded the northern and western (leeward) shores of Bonaire and Klein Bonaire. After the waves subsided, STINAPA immediately sent survey forms to dive operators requesting information on reef conditions and offered assistance in removing large debris. Bonaire National Marine Park rangers took photos of damage to piers, docks, ladders, etc. and began removing large debris from the reef (Appendix II: Image 7). On the 6th to 7th of October 2016, STINAPA staff, interns and volunteers surveyed sites along the leeward shore of Bonaire to assess the initial impact of Hurricane Matthew.

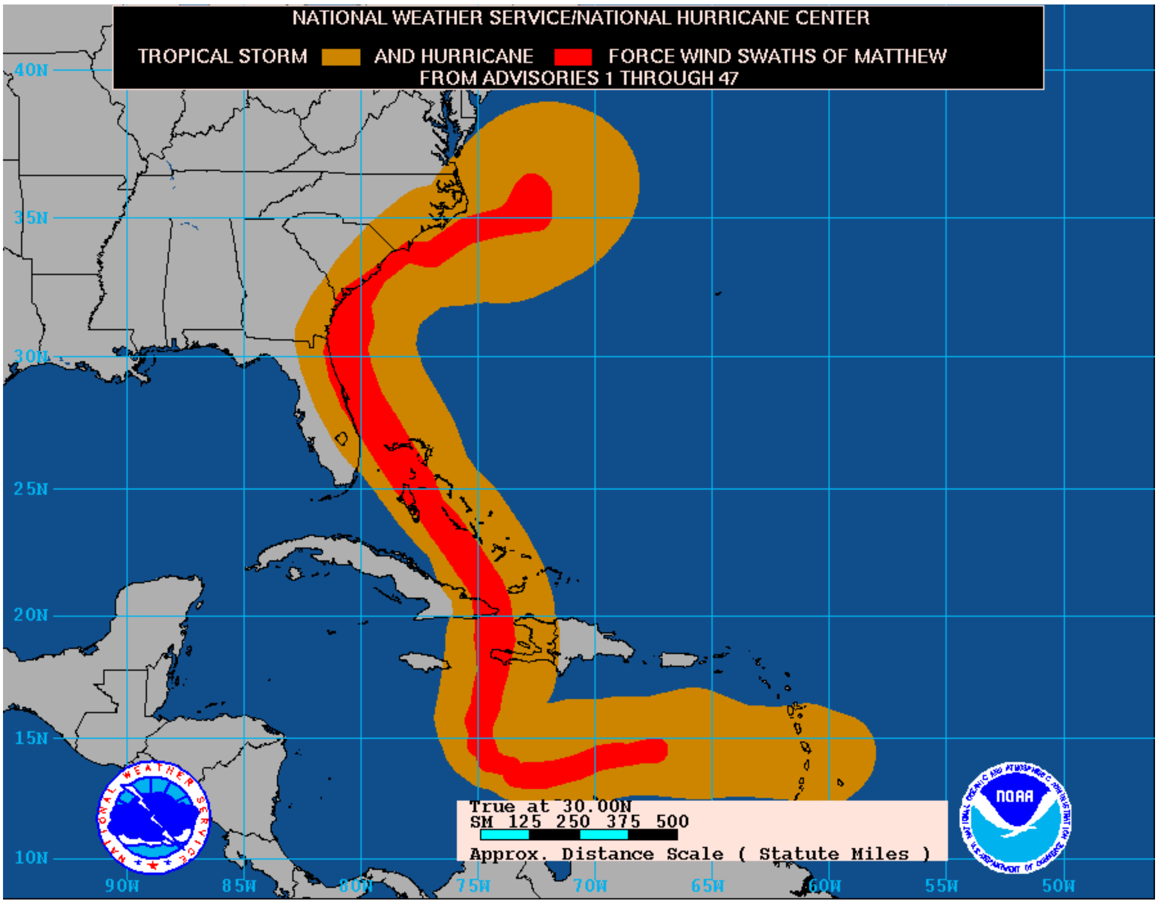

Fig 1. Path of Hurricane Matthew. Image from NOAA's National Hurricane Center: Matthew Graphics Archive.

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STINAPA Bonaire is a member of the Dutch Caribbean Nature Alliance

DCNA'S activities are funded through the support of the Dutch Postcode Lottery and the Dutch Ministry of the Interior (BZK).

Methods

Surveyors assessed a total of 18 sites via SCUBA in buddy teams on 6-7 Oct. 2016. Sites were chosen along the entire leeward coastline from North to South, including sites with expected damage (because of height and direction of waves) and sites with little or no expected damage (Appendix I: Fig II). Divers conducted a preliminary survey at sites believed to have sustained the heaviest wave action; they observed no damage at 30m depths, so no surveys were conducted deeper than 20m. At each site, surveyors assessed a 20*2m transect area at three depths (<10m, 10m and 20m). In each transect, surveyors recorded the total number of coral colonies within the given area, recording the size class of each colony (>10 and <30 cm, 30 cm – 100 cm, and >100 cm in diameter) and whether or not it suffered damage (e.g. whether or not it was fragmented, broken or overturned). Surveyors also recorded the total number of damaged versus undamaged sponges within each transect. In addition, surveyors estimated the percent of sand/silt covering living coral tissue and made general observations at depths of <10m, 10m, 20m and 30m. Finally, divers helped fan silt/sand from sponges and corals, and righted toppled corals when possible (Appendix II: Image 1 & 4) to help mitigate some of the damage to the reef.

Results

Corals at depths of 10m and deeper were relatively undamaged compared to those in the shallows (Fig 2; Appendix I: Fig 2). In the shallows (<10m depth), an average of 25% of the coral colonies were damaged (Fig 4). Most of the corals damaged by Matthew were fire corals (*Millepora complanata* and *M. alcicornis;* Appendix II: Image 1, 3 & 5). Surveyors also reported that several stands of branching corals (*Acropora cervicornis* and *A. palmata*) were damaged. Smaller colonies (10-30 cm in diameter) were damaged more than larger colonies (Fig 5) and this supports written observations that many larger boulder/mound corals were undamaged in the shallows.

Although eight sites had no sponge damage within the survey areas, the average sponge damage across all sites and depths was 12% with little difference by depth (Fig 3, Fig 4, Appendix I: Fig 2).

From general observations and photo documentation (Appendix II), there were many sites where the sand in the shallows had been scoured away (Appendix II: Image 2) and redistributed on other areas of the reef. Two days after the heaviest wave action, most of the corals had cleaned themselves of the sand cover. There was an average of less than five percent sand/silt covering corals at all depths. Unless corals are overly smothered/covered, they are often able to clean themselves of sand/silt using their cilia. See Appendix II: Image 4 for photo documentation of sand cover on coral and sponges.

Coral Damage

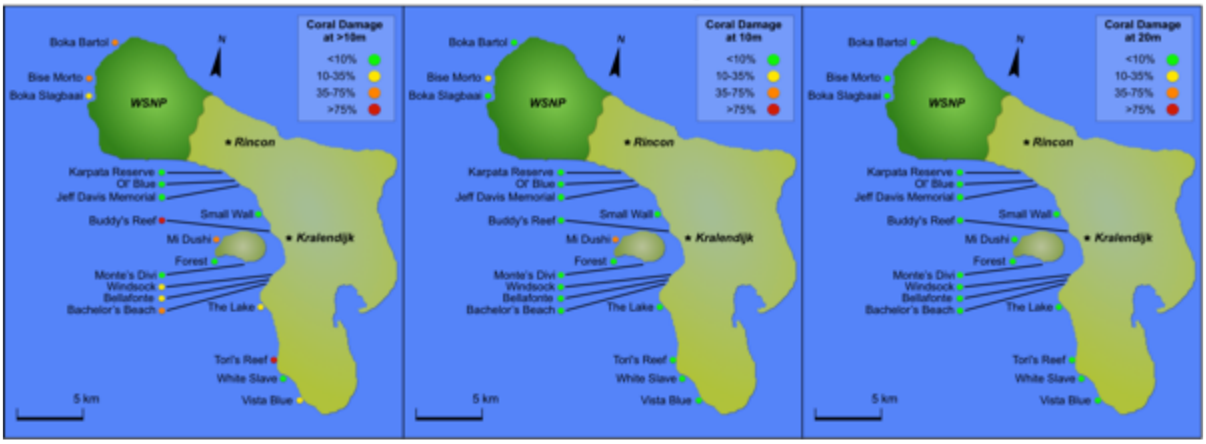

Fig 2. Coral Damage by depth (<10m, 10m, 20m) following Hurricane Matthew. STINAPA researchers and volunteers conducted damage assessment surveys at 18 sites on 7-8th October, 2016. Coral damage was qualified as the amount of fragmented, broken or overturned coral colonies relative to undamaged colonies in a 2*20m transect. Surveyors conducted one transect per depth at each site.

Sponge Damage

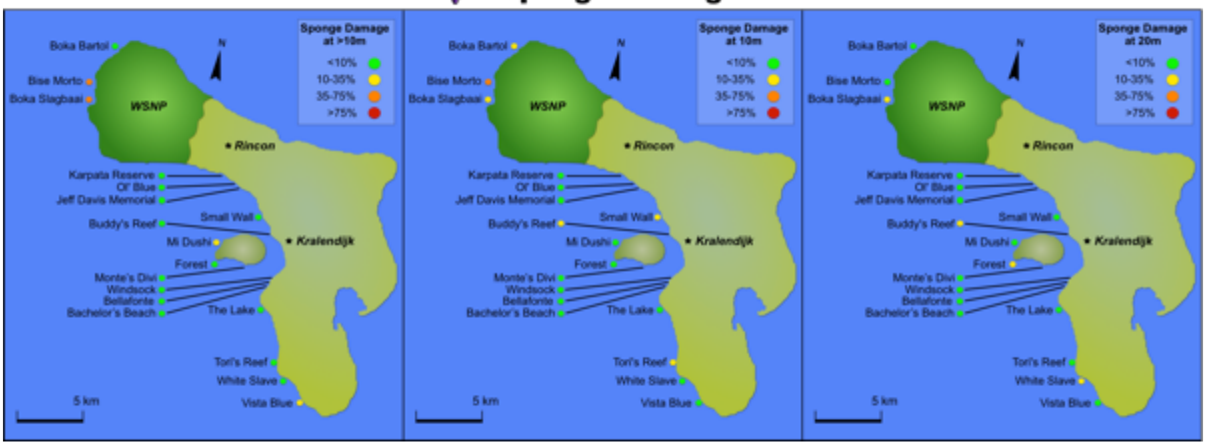

Fig 3. Sponge Damage by depth (<10m, 10m, 20m) following Hurricane Matthew. STINAPA researchers and volunteers conducted damage assessment surveys at 18 sites on 7-8th October, 2016. Sponge damage was qualified as the amount of broken or toppled sponges relative to undamaged individual in a 2*20m transect. Surveyors conducted one transect per depth at each site.

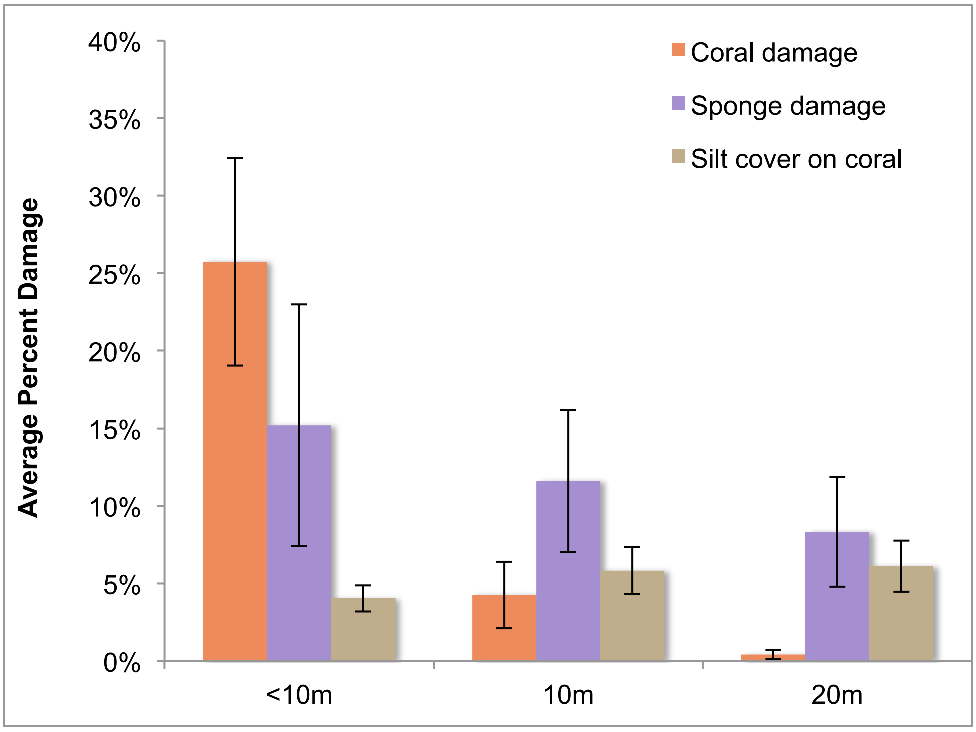

Fig 4. Average percent damage (to corals, to sponges, and silt cover on corals) by depth (<10m, 10m, 20m) following Hurricane Matthew. Error bars show ±1 Standard Error, (n=18 sites).

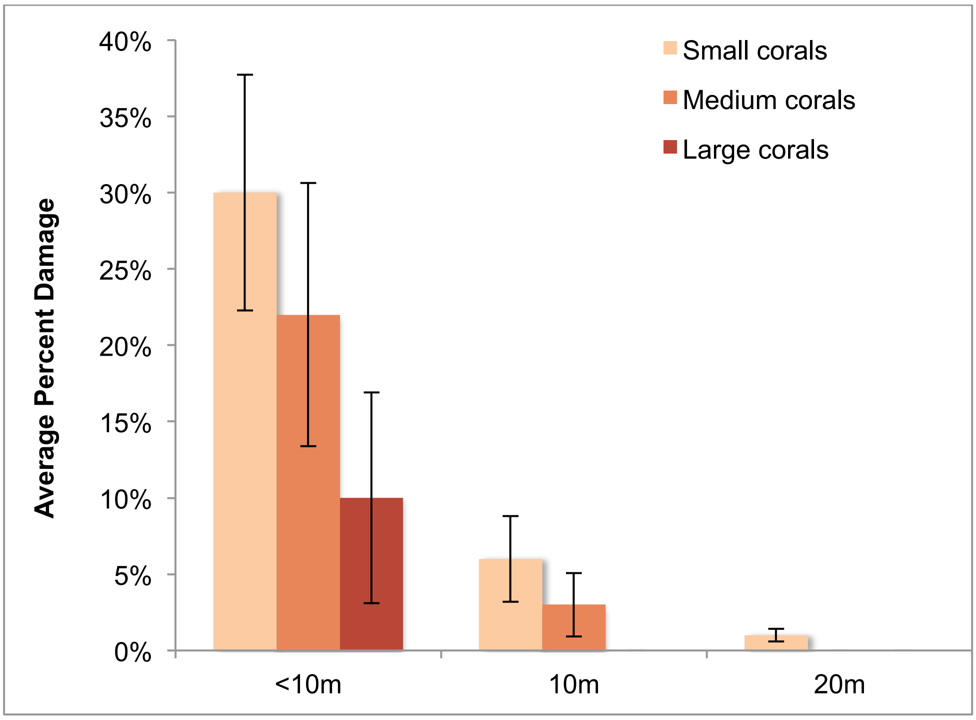

Fig 5. Average percent damage to coral colonies of varying size classes by depth (<10m, 10m, 20m) following Hurricane Matthew. Surveyors categorized coral colony size as small (>10cm & <30cm), medium (30cm-100cm) and large (>100cm). Error bars show ±1 Standard Error, (n=18 sites).

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Background

Tropical cyclones are an acute natural disturbance to coral reefs causing direct damage when storm surge topples, fragments and overturns corals, and damage to coral colonies and tissue from silt/sand abrasion and smothering (Bries et al. 2004). Cyclones also cause indirect damage from excess nutrients being released from the sediment/sand into the water column by wave action and by increased runoff of sediment and pollutants from high levels of rainfall (Gardner et al 2005).

In the Caribbean, Hurricane damage causes an average 17% reduction in coral cover for one-year immediately following impact, and reefs can take at minimum a decade to recover from heavy storm damage. However, a cyclone's impact on the reef both in the short and long term is highly variable and greatly depends on the characteristics of both the reef and the cyclone itself (Gardner et al 2005).

In recent years, a series of tropical cyclones have impacted the leeward reefs of Bonaire, including Hurricane Lenny (1999), Hurricane Ivan (2004) and Tropical Storm Omar (2008). In 1999, waves from Hurricane Lenny completely destroyed many of the shallow coral reefs of Bonaire, causing particular damage to branching corals (*Acropora* spp.). Some sites that had high coral cover prior to Lenny were completely bare down to a depth of 15m after the hurricane struck, changing the underwater landscape of the island. In 2004, Hurricane Ivan also caused heavy damage to branching corals (*Acropora* spp.) in the shallows while brain/boulder at similar depths were relatively unharmed by wave action (Scheffers & Scheffers 2006). In 2008, waves from Omar struck the leeward coast, causing extensive damage to depths of 10m or greater at some sites and also heavily damaging branching corals. Researchers conducting a study 2-3 months following Omar still observed toppled and fragmented corals, redistribution of sand on the reef and algae blooms on exposed coral rubble (Sommer et al. 2011). However, Omar had sustained 34 knots winds with gusts of 50 knots and over 4cm rainfall (Beven & Landsea 2009). These wind speeds were far greater than those of Matthew (Appendix I: Fig 1).

Conclusion

The results of the damage assessment following Hurricane Matthew show that, although the waves from Matthew damaged an average of 25% of shallow corals (<10m depth) and 10% of sponges on the leeward coast of the island and Klein Bonaire, Bonaire's corals were relatively undamaged compared to recent tropical cyclones (Appendix II: Images 8-9). The two surveyed sites with the highest percent damage in the shallows (Buddy's Reef and Tori's Reef) were branching coral restoration sites (Appendix I: Fig 2). At these two sites, surveyors conducted transects within the shallow coral restoration areas and the results reflect the susceptibility of these newly outplanted branching corals (*Acropora spp.*) to strong wave action. Similar to Ivan, boulder/brain corals at similar depths to these branching corals remained comparatively undamaged.

Following Matthew, the sites that showed the most damage in the shallows were some of the same sites that had been damaged by these previous storms and many of the broken corals were (fast growing) fire corals (*Millepora complanata* and *M. alcicornis*). The predisposition of these sites to heavy storm impact may be attributed to reef contour, shallow coral composition, as well as the typical wind and wave direction from such disturbances.

Although most of Bonaire's corals were spared from breakage and toppling (Appendix II: Images 8-9), coral recovery at the shallows of some of the sites most heavily hit by Lenny, Ivan and Omar was reset and must begin anew. While many sponges were also damaged by the storms, if toppled sponges are not moved about too much by wave action, they can reattach to the substrate and continue growing.

There may also be indirect effects from hurricane damage such as nutrients being released from the sediment/sand into the water column by wave action, death of small corals or coral recruits from abrasion of sand and/or rubble (small corals less than 10cm in diameter were not included in this initial assessment), and a decrease in immunity of corals due to stress, possibly resulting in these corals being more susceptible to disease.

This report provides a baseline of the immediate effects of Hurricane Matthew on reefs along Bonaire's leeward coast. Future studies should investigate the long-term progress of reef recovery following such disturbances, which provides insight into the reliance of our reefs and their ability to recover following future natural disasters.

The resilience of a reef, (i.e. it's ability to recover following a disturbance), is greatly dependent on the levels of other stressors to the reef such as overfishing, coastal development, pollution, unsustainable levels of tourism and rising sea temperatures as well as the severity of the disturbance. Bonaire's fringing reef is among the healthiest in the Caribbean, with high levels of coral cover, and average medium to high levels of resilience (IUCN 2011, Jackson et al. 2014). The sites on Bonaire with the lower levels of resilience are in areas with the greatest impact from coastal development, such as Chachacha (IUCN 2011).

While tropical storms and hurricanes often have dramatic and severe short-term impacts to reefs on the scale of months to years, researchers Bak and Niewland found that patterns in decadal declines in coral cover and colony density on Bonaire and Curaçao were not greatly altered by the aftermath of Hurricane Joan in 1988, instead they attributed local patterns of decline to coastal development, sewage, eutrophication and increased bacteria levels in the water (Bak & Niewland 1995).

Worldwide, coral reefs are in decline, and in the Caribbean, coral cover had declined more than 80% since the 1970s in association with increased prevalence of coral disease and decreased levels of herbivores on the reef (Gardener et al. 2003, Schutte et al. 2010). Climate change is predicted to result in more frequent high-intensity storms and more coral bleaching events due to rising in sea surface temperature. Fringing coral reefs have a role in protecting an island against wave damage and erosion. Since Bonaire's economy is based on (dive) tourism, and tourists are attracted mainly by the easily accessible fringing reef. The vitality of Bonaire's reefs is essential to the islands economy. The ability of our coral reefs to recover from inevitable events such as tropical storms depends on the amount of additional stress factors they are exposed to on a daily basis that we can manage and influence on a local scale.

21st of October, 2016
Report prepared by Caren Eckrich, Hannah Rempel and Wijnand de Wolf
STINAPA Bonaire

Acknowledgements

STINAPA would like to extend gratitude to our volunteer base and employees for their dedication and commitment to helping protect the Bonaire National Marine Park. Special thanks go out to volunteers Francesca Virdis, Augusto Montbrun, Bridget Hickey, Charlotte Hesterman, Emmanuelle Buchmuller, Ramon de Leon, Elsmarie Beukenboom, Susan Porter, Jessika Schilder and Jeffrey Gerrits for their participation in the survey. We would also like to thank local dive shops for donating tanks and helping support this research.

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Appendix I. Additional Figures

GFS 27 km	Wind speed (knots)								Wind direction								Rain (mm/3h)							
	02h	05h	08h	11h	14h	17h	20h	23h	02h	05h	08h	11h	14h	17h	20h	23h	02h	05h	08h	11h	14h	17h	20h	23h
28.09.2016	18	17	16	13	11	11	12	12	←	←	←	←	←	↙	↙	↙				0.3				0.7
29.09.2016	9	3	4	5	8	8	6	11	↙				↘	↘		↑	5	4.7	6.8	1.1	1.2	6.7		2.6
30.09.2016	16	18	23	22	22	25	24	23	↖	↖	↖	↖	↖	↖	←	←	6.4	12.2	8.4	5.9	2.7		1	0.5
01.10.2016	22	23	22	21	19	15	18	20	↖	↖	↖	↖	↖	←	←	↖						0.3		1.5
02.10.2016	20	19	17	18	13	18	19	18	↖	↖	↖	↖	↖	←	↖	↖	4.6		3.1					0.5
03.10.2016	19	18	19	16	19	18	15	15	↖	↖	↖	↖	↖	↖	↖	↖								
04.10.2016	17	16	15	10	10	14	16	20	↖	↖	↖	↖	←	←	←	↖								
05.10.2016	19	17	17	17	17	16	18	20	↖	↖	↖	↖	↖	←	←	←								

GFS 27 km	Wave (m)								Wave direction								Wave period (s)							
	02h	05h	08h	11h	14h	17h	20h	23h	02h	05h	08h	11h	14h	17h	20h	23h	02h	05h	08h	11h	14h	17h	20h	23h
28.09.2016	1.1	1.1	1.1	1	0.9	0.8	0.8	0.8	←	←	↙	↙	↙	↙	↙	↙	5	5	5	5	5	5	5	5
29.09.2016	0.9	1	1.2	1.6	2.2	2.8	3.1	2.9	↙	↙	↙	↙	↙	↙	↙	↙	5	6	7	8	11	12	12	12
30.09.2016	2.7	2.5	2.4	2.4	2.4	2.3	2.1	1.9	↙	↙	↙	↙	↙	↙	↙	↙	11	10	10	9	9	8	8	7
01.10.2016	2	2	1.9	1.8	1.8	1.6	1.5	1.6	↙	↙	←	↙	←	↙	←	←	7	7	7	7	7	7	7	6
02.10.2016	1.6	1.6	1.5	1.4	1.3	1.3	1.3	1.3	←	←	←	←	↙	↙	↙	←	6	6	6	6	6	6	6	6
03.10.2016	1.4	1.4	1.4	1.3	1.4	1.3	1.3	1.3	↖	←	↖	↖	↑	↑	↗	↗	6	6	6	6	6	6	7	7
04.10.2016	1.4	1.3	1.3	1.2	1.2	1.3	1.4	1.6	↘	↘	↘	↘	↘	↘	↘	↘	8	9	9	9	9	10	9	9
05.10.2016	1.7	1.6	1.5	1.4	1.3	1.3	1.3	1.3	↓	↙	↙	↓	↓	↓	↙	↙	8	8	7	8	8	8	7	6

Appendix Fig 1. Archived data from Windguru on Bonaire's wind speed (knots), wind direction and rainfall (mm/3hr; above) and wave height (m), wave direction and wave period (s; below) shown in 3-hour increments from 28th Sept. to 5th Oct, 2016. Data accessed 13th Oct. 2016.

	Percent Coral Damage			Percent Sponge Damage		
	<10m	10m	20m	<10m	10m	20m
*Bachelor's Beach**	43.33%	1.59%	0.00%	0.00%	0.00%	0.00%
*Bellafonte**	20.00%	0.00%	0.00%	0.00%	0.00%	0.00%
*Bise Morto**	60.00%	14.06%	3.13%	50.00%	50.00%	0.00%
Boka Bartol	38.30%	4.88%	0.00%	0.00%	16.67%	0.00%
*Boka Slagbaai**	17.86%	8.57%	4.17%	40.00%	26.32%	33.33%
*Buddy's Reef**	86.05%	2.13%	0.00%	1.00%	62.50%	21.43%
*Forest, Klein**	0.00%	0.00%	0.00%	0.00%	0.00%	21.43%
Jeff Davis	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Karpata Reserve	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
*Mi Dushi, Klein**	51.28%	37.50%	0.00%	33.33%	0.00%	0.00%
Monte's Divi	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ol' Blue	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
*The Lake**	25.93%	1.32%	0.00%	0.00%	0.00%	0.00%
Small Wall	0.00%	0.00%	0.00%	0.00%	20.00%	0.00%
*Tori's Reef**	79.17%	5.13%	0.00%	1.00%	33.33%	0.00%
Vista Blue	13.33%	0.00%	0.00%	13.33%	0.00%	0.00%
White Slave	0.00%	0.00%	0.00%	0.00%	0.00%	23.53%
*Windsock**	27.91%	1.45%	0.00%	0.00%	0.00%	0.00%

Appendix Fig 2. Table of percent coral and sponge damage by depth at each of the 18 survey sites. Sites with astrix were selected prior to surveys because they were believed to have sustained damage (10 of the 18 total sites).

Appendix II. Photo Archive

Image 1. Volunteer Emmanuelle Buchmuller righting a toppled fire coral (*Millepora complanata*) on Klein Bonaire. Photos taken 7th Oct, 2016 by volunteer Charlotte Hesterman.

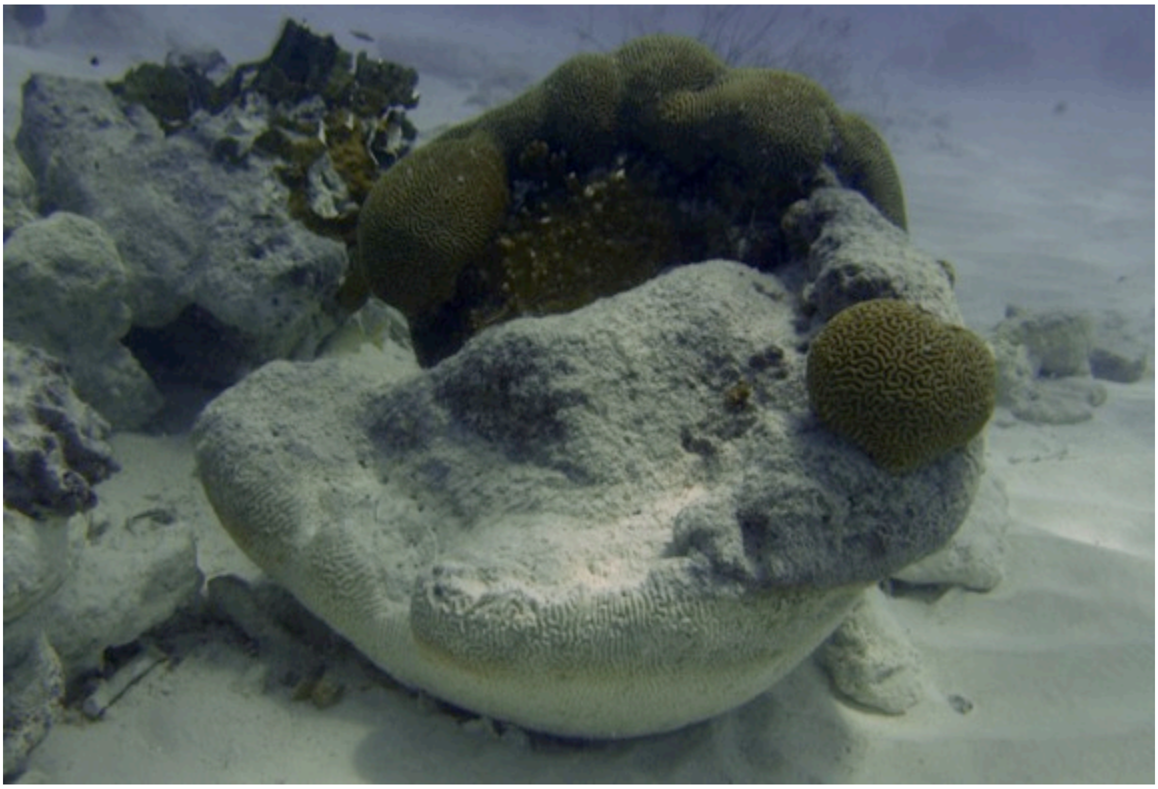

Image 2. Base of old coral exposed when wave action redistributed sand on the reef. Photos taken 7th Oct, 2016 by volunteer Charlotte Hesterman.

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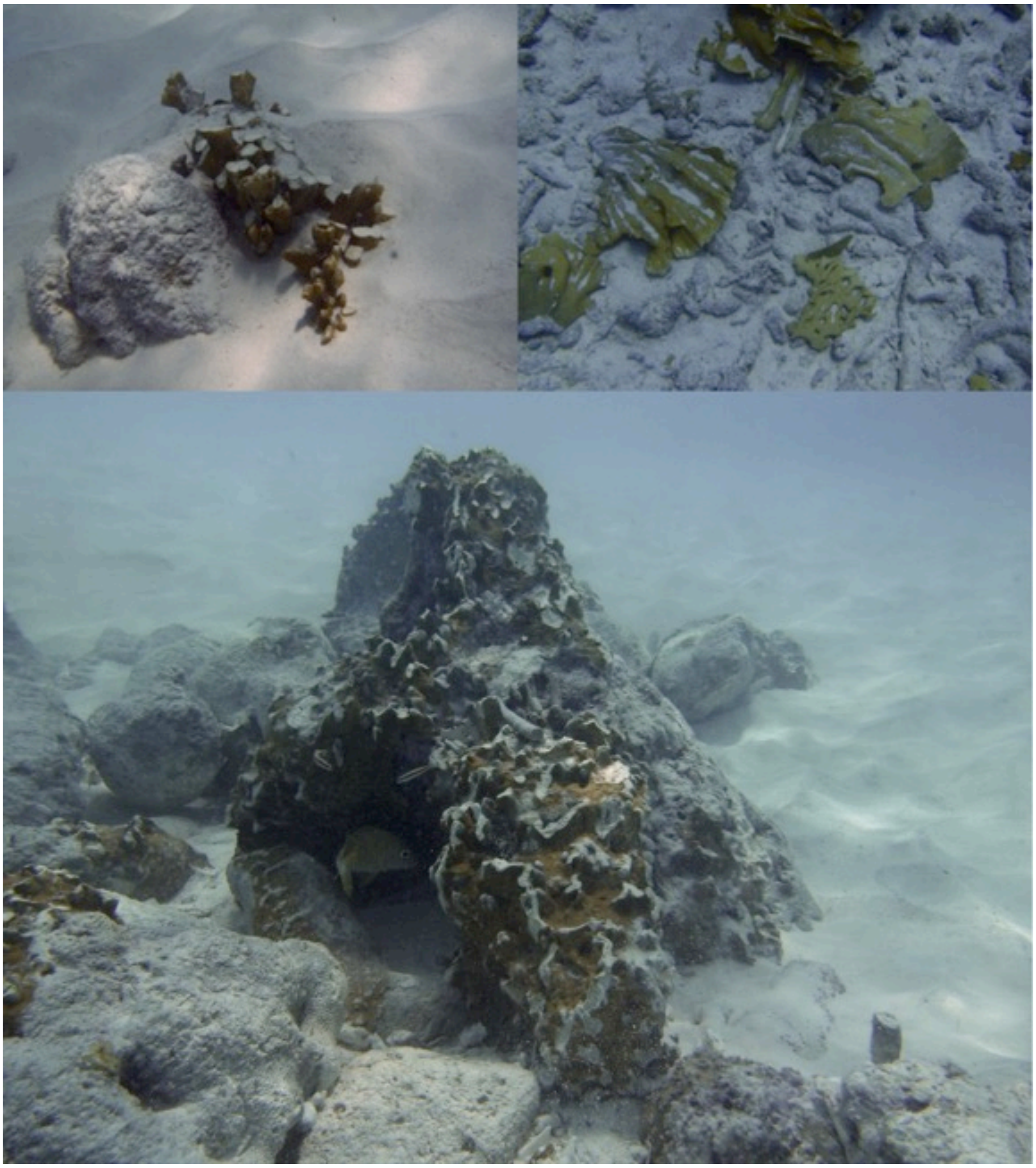

Image 3. Broken and fragmented fire corals (*Millepora complanata* and *M. alcicornis*). Photos taken 7th Oct, 2016 by volunteer Charlotte Hesterman.

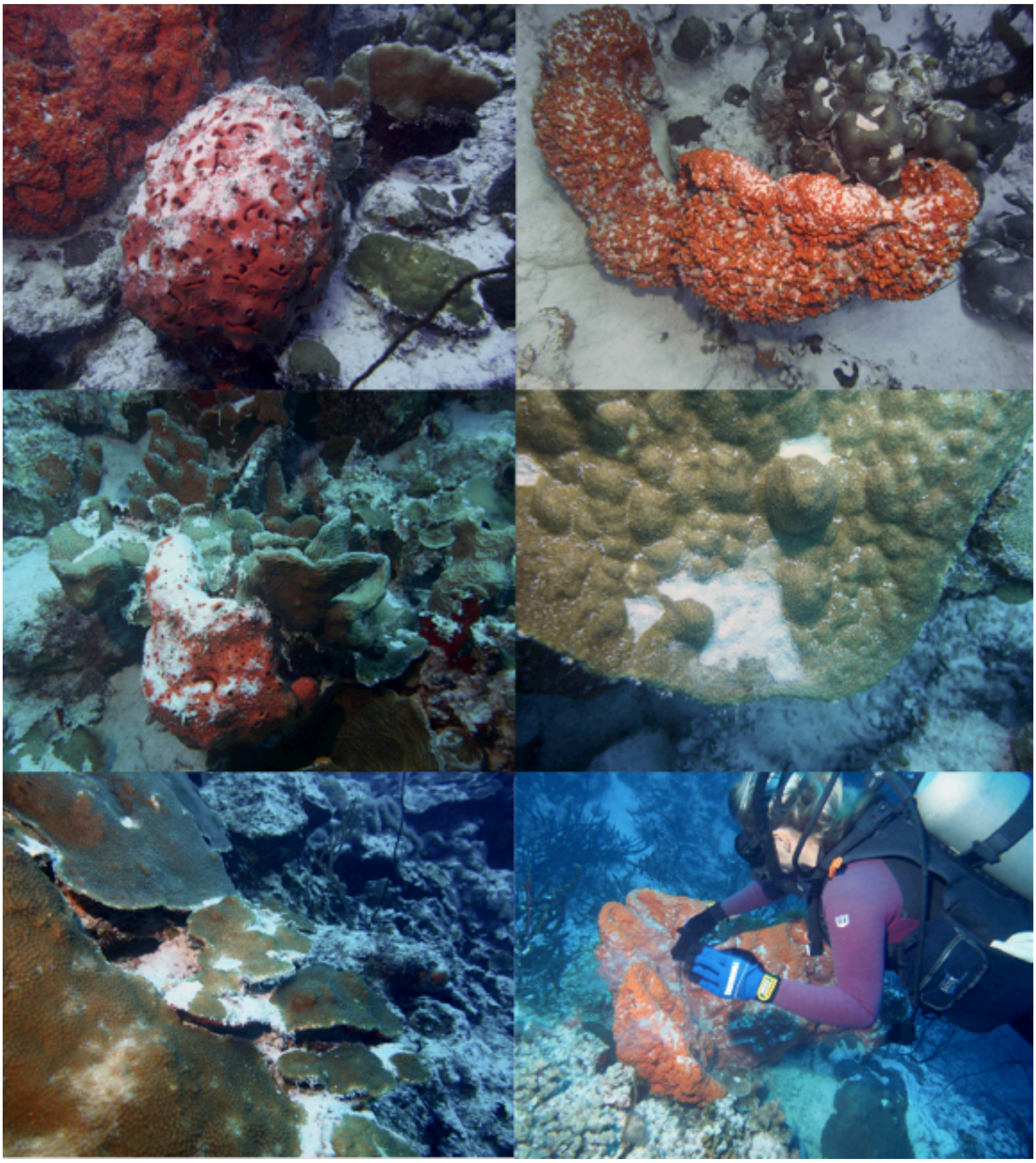

Image 4. Silt/ sand covering sponges and corals (photos 1-5, top to bottom, left to right), volunteer Emmanuelle Buchmuller waving sand of a sponge (photo 6, lower right). Photos taken 7th Oct, 2016 by volunteer Charlotte Hesterman.

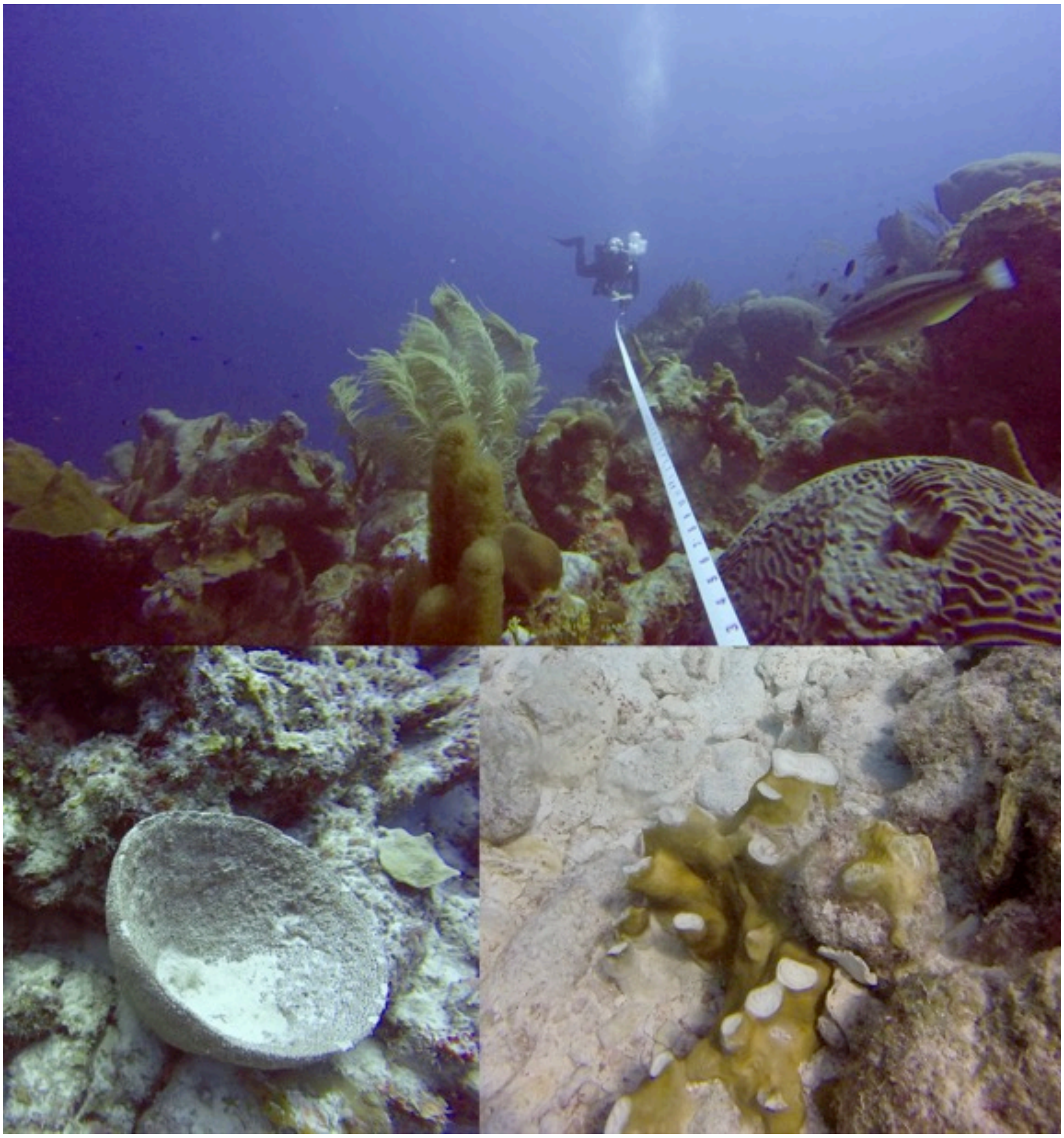

Image 5. Compilation of images from Washington-Slagbaai National Park: STINAPA WSNP Manager Paulo Bertulo conducting damage survey in WSNP (top), Silt on sponge (lower left), broken fire coral (*Millepora sp.,* lower right). Photos taken 7th Oct, 2016 by BNMP Manager Wijnand de Wolf.

Image 6. Soft coral that was toppled over on the southwest coast at 10m depth. Photo taken 7th Oct, 2016 by STINAPA Assistant Biologist Hannah Rempel**.**

Image 7. STINAPA Ranger Karel Rosaria views dock damaged by wave action along southern coastline. Photo taken 7th Oct, 2016 by Biologist Sabine Engel**.**

Image 8. Undamaged sponges and corals (*Agaricia, Millepora, Porites* and *Orbicella* species) at Mi Dushi and Forest, Klein Bonaire. Photos taken 7th Oct, 2016 by volunteer Charlotte Hesterman.

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Image 9. Undamaged soft coral and hard corals (*Acropora cervicornis, Diploria strigosa, Millepora complanata, Porites astreoides*) at <10m depth on southwestern coast. Photo taken 7th Oct, 2016 by STINAPA Assistant Biologist Hannah Rempel.