

# INNOVATIVE 3D IMAGING TOOLS FOR ASSESSING DAMAGES TO CORAL REEF HABITATS CAUSED BY GROUNDING EVENTS



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**Cover Photo:**

Recovery of the stranded buoy at Lisianski. Photo:  
Swatland



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## Abstract

On November 6, 2015, a National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC) weather buoy was reported to be stranded on Neva Shoal, southeast of Kapou (Lisianski) Island in the Northwestern Hawaiian Islands (NWHI). The buoy mooring consisted of 13.72 m of 2.54 cm chain, 365.76 m of 2.54 cm wire, and nearly 2,438.40 m of 2.54 cm nylon mooring line. The buoy broke free from its assigned station 394.29 km northeast of Honolulu on March 10, 2013. The buoy continued to transmit information and drifted northeast before reversing course and drifting into Papahānaumokuākea Marine National Monument (PMNM) where it ran aground on the Neva Shoal in about 12.19 m of water in an area of high coral cover. Following the initial stranding in November 2015, the buoy moved more than 1.93 km in a southwesterly direction, most likely caused by larger swell events. The intermittent movement was due to a portion of the mooring being still attached to the buoy and dragging along the benthic substrate. The total damage caused by the dragging chain was significant and spread over a large spatial area. The buoy was recovered by the F/V *Lady Alice* on May 26, 2016. Researchers on the NOAA Rapid Assessment and Monitoring Program expedition surveyed the reef locations where the buoy was stranded after the removal of the buoy. Researchers were able to visit the last two recorded locations at which the buoy was stranded on May 7 and 8, 2016. Overlapping imagery was collected from the areas exhibiting damage from the buoy mooring. The images were processed using Structure-from-Motion photogrammetry to create 3D reconstructions of the affected coral reef habitats. The resulting 3D models and orthophotomosaics were analyzed with geospatial software to accurately quantify the impacts from the buoy stranding at these two locations. Utilizing this innovative methodology provides a useful visual and quantitative method for assessing the impacts and damage associated with grounding damage on coral reef habitats.

## Key Words

Weather buoy, grounding, coral reef, reef damage, damage assessment, 3D reconstruction, structure-from-motion, 3D mapping, Northwestern Hawaiian Islands, Papahānaumokuākea Marine National Monument, Hawai‘i

## Introduction

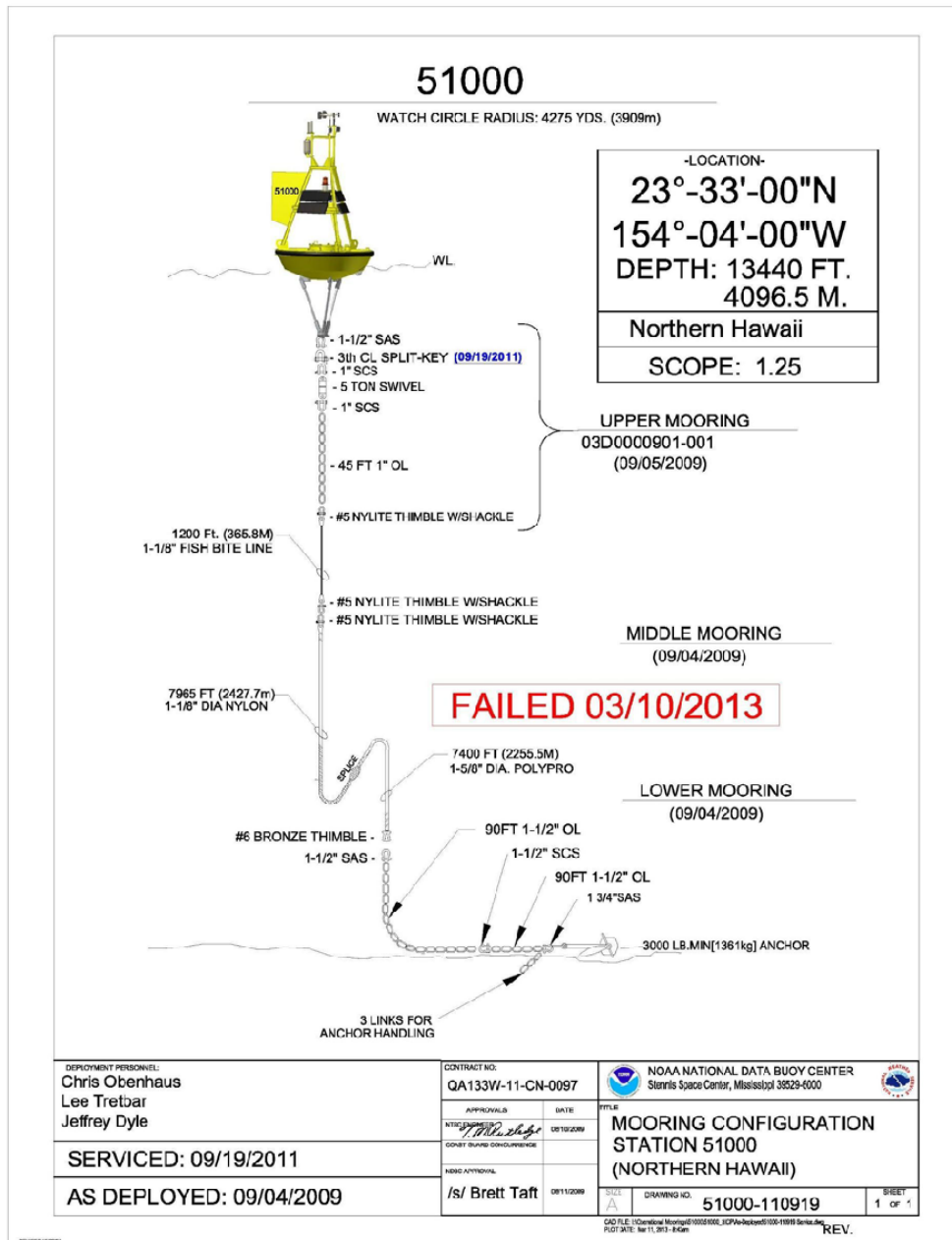
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On November 6, 2015, the National Data Buoy Center (NDBC) in Mississippi notified the NOAA Office of National Marine Sanctuaries (ONMS) for Papahānaumokuākea Marine National Monument (PMNM) in Honolulu, Hawai‘i that one of its weather buoys appeared to be stranded on Neva Shoal, southeast of Lisianski Island in the Northwestern Hawaiian Islands (NWHI). NDBC is part of the National Weather Service (NWS) and is responsible for the deployment, operation, tracking, and recovery of NOAA weather buoys.

The buoy is 3.05 m wide, extends 2.44 m below and 5.49 m above the waterline, weighs 1360.777 kg, and is made of closed cell foam. The buoy mooring consisted of 13.72 m of 2.54 cm chain, 365.76 m of 2.54 cm wire, and nearly 2,438.40 m of 2.54 cm nylon mooring line (Figure 1). The buoy went adrift from its assigned station 394.29 km northeast of Honolulu on March 10, 2013. The buoy continued broadcasting position and weather info from the time it broke loose until it was retrieved. According to NDBC plots, the buoy drifted northeast towards the west coast of North America, then reversed course and drifted into the monument where it eventually became stranded on Neva Shoal in about 12.19 m of water on coral-dominated reef habitat.

PMNM immediately began looking at options to retrieve the buoy. NOAA did not have a ship available until May, and the United States Coast Guard was unable to retrieve the buoy until September 2016. Winter weather in the NWHI produces sea and wind conditions that are not conducive to having a large ship work near a shallow reef with divers in the water, and the buoy grounding occurred at the start of the winter season. NDBC elected to contract a vessel and divers to conduct a retrieval operation, with a target date of mid to late April. During January and February, PMNM staff worked closely with NDBC to provide information for, and review of, the Statement of Work, and then to review and provide feedback on the proposals. In March, after NDBC selected a contractor, monument staff completed the National Environmental Policy Act (NEPA) and Endangered Species Act (ESA) documentation for the buoy recovery operation. In accordance with the 2006 Presidential Proclamation, activities in the monument must be issued a multi-agency permit. The buoy retrieval operation was permitted under the annual Co-Trustee’s Conservation & Management permit, which allows the seven co-managing agencies or their representatives to conduct activities that further the conservation and management goals of the monument. Despite having a contract completion date of April 30, the contractor delayed the recovery vessel’s departure and negotiated a revised contract completion date of June 5. The F/V *Lady Alice* recovered the buoy on May 26, 2016.

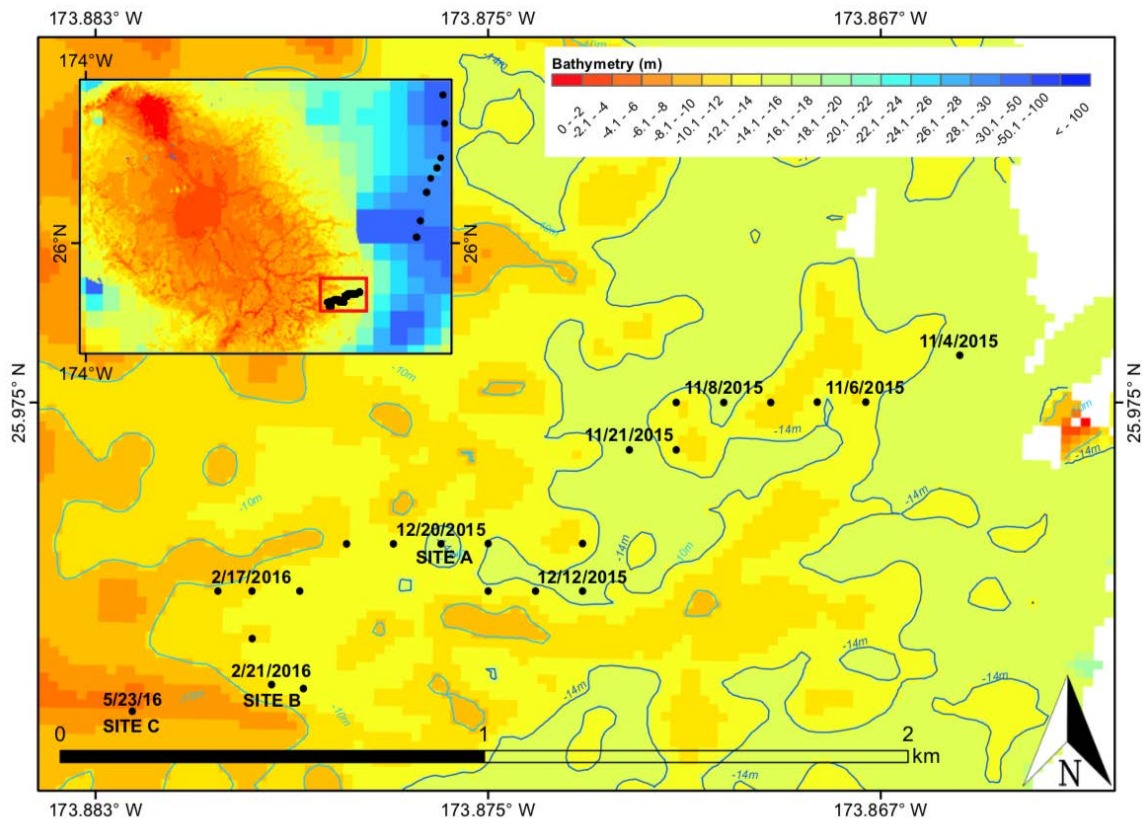
Since the initial stranding in November 2015, the buoy moved more than 1.931 km in a southwesterly direction, which was most likely driven by the frequent large swell events. The movement of the buoy after the initial stranding was intermittent, indicating that a majority of the attached mooring was dragging along the bottom causing the buoy to remain stationary until wave energy moved it into a new location.



**Figure 1.** Schematic diagram of the stranded buoy. The diagram provides technical information for all components of the mooring as well as its deployed location and date of mooring failure. (Image: NOAA)

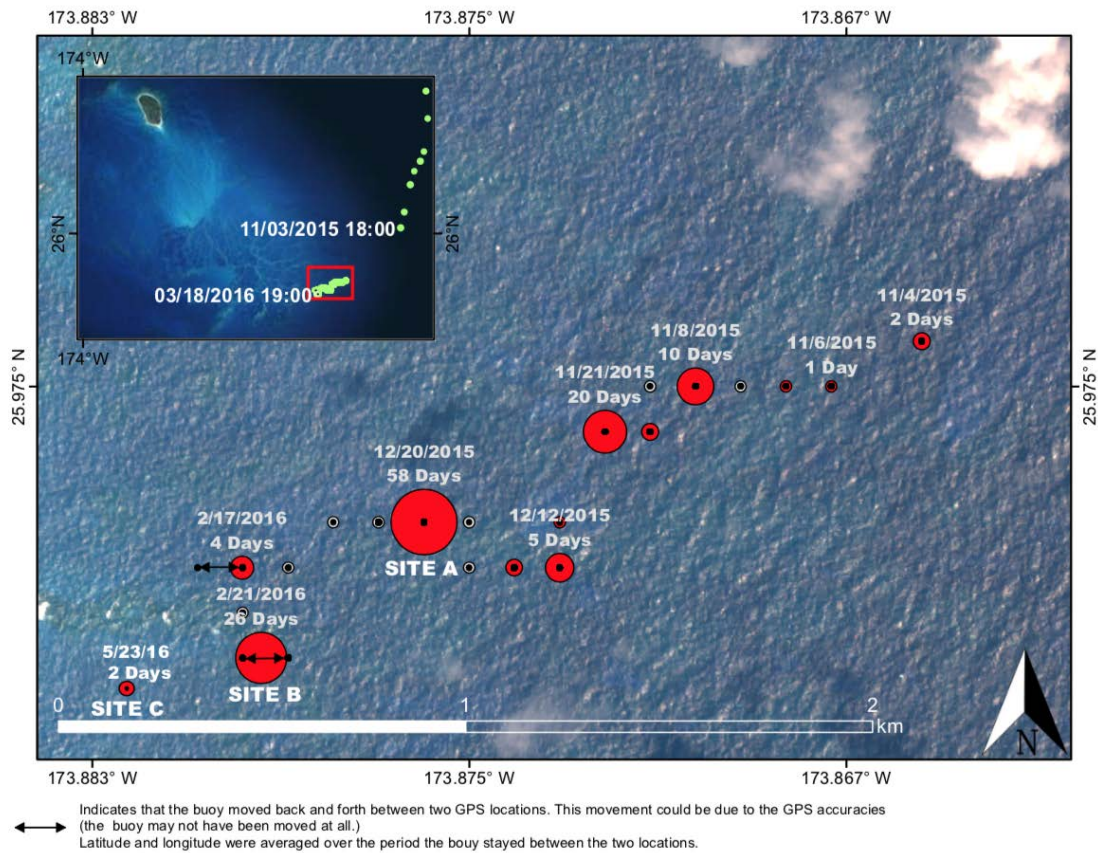


PMNM research cruise that departed in May reallocated ship days to conduct surveys of the buoy stranding sites. The buoy was stranded at several locations for multiple days, and moved west from one location to another until it was retrieved (figures 2 and 3). The last three sites the buoy was stranded at for over 10 days are called Site A and Site B, and the site from which the buoy was retrieved is called Site C (figures 2 and 3). Due to time limitations, the benthic research team was only able to survey Site B and Site C to assess for damage from the stranding.



**Figure 2.** Map showing the buoy stranding locations from November 2015 to May 2016. The buoy was stranded a substantial amount of time at Site A Site B, and was recovered from Site C. Divers were able to conduct damage assessment surveys at Site B and Site C after the buoy was retrieved. (Image: NOAA)

The benthic researchers had previously used 3D Structure-from-Motion photogrammetry techniques to survey coral health at long-term monitoring sites throughout PMNM. The same 3D reconstruction techniques were used to map the observed reef damage at both sites in order to provide a quantitative assessment of the buoy grounding impact on the coral reef habitat.




**Figure 3.** Map showing the number of days the buoy was stranded at each location from November 2015 to May 2016. (Image: NOAA)

## Methods and Results

Divers visually surveyed the coral reef habitat at the coordinates for Site B and Site C (figures 2 and 3). Once damage was visually confirmed at the coordinates, the divers surveyed as much surrounding reef areas as possible for damages caused by the buoy mooring. Damage was classified in three categories: abrasion, breakage, and death. Abrasion was identified as scarring to the live coral tissue caused by the mooring chain dragging along the benthic substrate. Breakage was identified as any pieces of coral broken and scattered on the benthos caused by dragging of the mooring chain. Death was any pieces or area of coral tissue that exhibited complete tissue mortality. Since the buoy and chain had been removed prior to the surveys, the divers were unable to collect any photos of the active damage occurring from the mooring chain.

Images of the survey area were collected from planar and oblique angles with 70 to 80 percent overlap using methods developed for 3D reconstruction of underwater habitats (Burns et al. 2015, Burns et al. 2016). Ground control points (GCPs) were placed throughout the surveyed

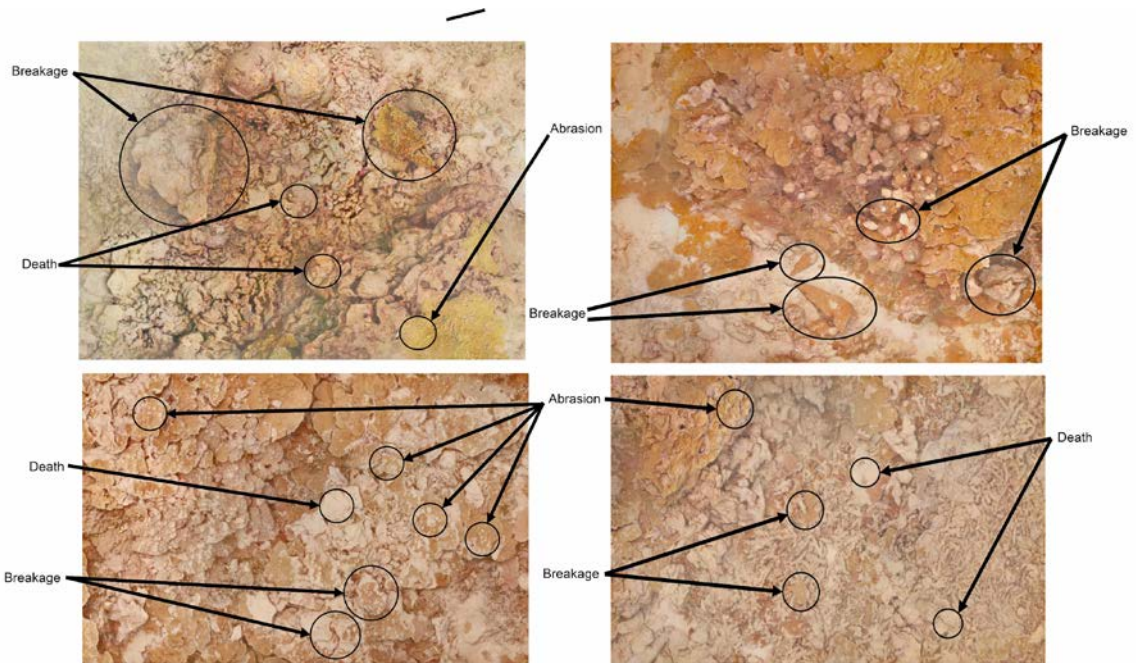


plots to enable accurate geo-referencing and spatial scaling. All photos were taken with a Canon 5D Mark III digital SLR camera with a 24 to 70 mm lens in an Ikelite housing with a 20.32 cm hemispheric dome port.

Three-dimensional reconstructions and orthophotomosaics of the coral reef plots were rendered using Agisoft PhotoScan modeling software (Agisoft LLC., St. Petersburg, Russia). Images were uploaded into the PhotoScan software and camera calibration was performed internally using Brown's distortion model. The overlapping images were aligned using scale-invariant feature transform algorithms to detect key points and match the overlapping image sequences. The invariant features were then used to create geometrical projective matrices and determine the exact position and orientation of the camera for each sequential image (Verhoeven et al., 2012; Westoby et al., 2012). 3D geometry was constructed on the 2D image plane using extrinsic parameters to link the pixel coordinates of an image point with the corresponding coordinates in the camera reference frame (Stal et al., 2012). Iterative bundle adjustments enable refinement of 3D coordinates and reduced reprojection error in order to create a sparse 3D point cloud that accurately represents the structure of the photographed coral reef plots. Markers were digitally annotated onto each of the GCPs and the reference x,y,z values of the GCPs were used to optimize the alignment of the photos and to create spatially accurate 3D point clouds. After the initial point cloud was optimized, a dense point cloud was generated and used to construct a continuous mesh surface that was then triangulated and rendered with the sequential images to create textured 3D digital surface models.

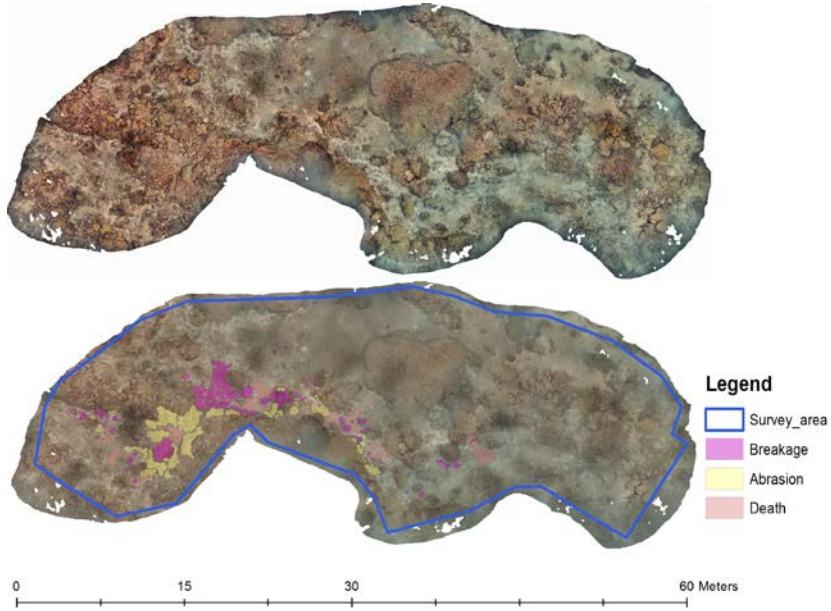
Digital elevation models (DEM) and orthophotomosaics from each reef plot were created in Agisoft and exported to ArcMap geospatial software. 3D topographic features of the coral plots are quantified from the DEM by calculating the surface properties of cells in three by three windows (Burns et al. 2016, Couch et al. 2017). The DEM resolution was set to one centimeter and polygons were annotated onto the data layers using the ArcMap editor tools. Annotations for the damage included "abrasion," "breakage," and "death" (Figure 4). Polygons were manually annotated over all areas of the survey plots exhibiting any of the three conditions of coral damage. Annotating the data layers allowed for extracting 2D and 3D habitat data for the various types of observed coral damage. The data associated with each annotation were used to quantify the precise surface area of each type of damage (abrasion, breakage, and death) caused by the buoy stranding in both surveyed reef plots (figures 5 and 6).



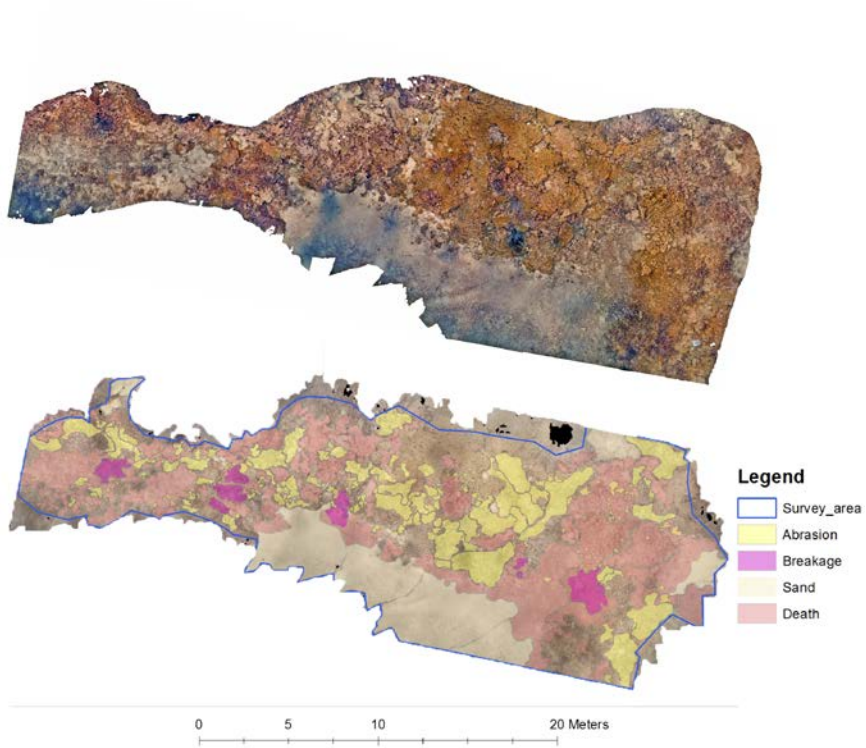


**Figure 4.** Images showing the three forms of recorded damage abrasion, breakage, and death. All forms of damage are evident in each image, and the arrows highlight specific examples. (Images:John Burns/NOAA)

The Site B survey area was 878.80 m<sup>2</sup> and the Site C survey area was 356.90 m<sup>2</sup>. The surface area for each observed type of coral damage as well as proportional values of the total surveyed areas for Site B and Site C is presented in Table 1. At Site B, 24.31 m<sup>2</sup> of the surveyed coral reef showed signs of abrasion, 23.53 m<sup>2</sup> of the surveyed coral reef had experienced breakage from the buoy mooring, and 15.56 m<sup>2</sup> of the surveyed coral suffered mortality from the buoy damage (Figure 5). At Site C, 69.64 m<sup>2</sup> of the surveyed coral reef showed signs of abrasion, 10.14 m<sup>2</sup> of the surveyed coral reef had experienced breakage from the buoy mooring, and 120.83 m<sup>2</sup> of the surveyed coral suffered mortality from the buoy damage (Figure 6).



**Figure 5.** Site B orthophotomosaic (top) and annotated orthophotomosaic (bottom). The annotated image and legend show the total area analyzed and each observed type of damage. (Images: John Burns/NOAA)



**Figure 6.** Site C orthophotomosaic (top) and annotated orthophotomosaic (bottom). The annotated image and legend show the total area analyzed and each observed type of damage. (Images: John Burns/NOAA)

**Table 1.** Total spatial area of each observed form of coral damage caused by the buoy stranding at both sites.

| Site name and survey area (m <sup>2</sup> ) | Coral Abrasion         |                                 | Coral Breakage         |                                 | Coral Death            |                                 |
|---|------------------------|---------------------------------|------------------------|---------------------------------|------------------------|---------------------------------|
|   | Area (m <sup>2</sup> ) | Percentage of total survey area | Area (m <sup>2</sup> ) | Percentage of total survey area | Area (m <sup>2</sup> ) | Percentage of total survey area |
| Site B<br>878.8                             | 24.31                  | 2.77%                           | 23.53                  | 2.68%                           | 15.56                  | 1.77%                           |
| Site C<br>356.9                             | 69.64                  | 19.51%                          | 10.14                  | 2.84%                           | 120.83                 | 33.85%                          |


## Conclusion

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Due to the short time-frame (two days) for investigating the damage, only two survey plots (Site B and Site C) could be completed to assess impacts caused by the stranded buoy. Visually identifying areas that were affected was initially difficult because of high turbidity and current at both sites. However, once the areas affected by damage were identified, the impacts were evident at both locations. Coral abrasion, breakage, and mortality were distinctly evident along paths where the mooring chain had been dragged across the benthos.

Site C exhibited an overall larger spatial area of coral abrasion, coral breakage, and coral mortality, with a combined total of 200.6 m<sup>2</sup>. Site B had an overall spatial area of 63.4 m<sup>2</sup> that was affected by buoy damage. These numbers only reflect the damage that was digitally annotated within the imagery collected during the two completed surveys. Considering the expansive area over which the buoy drifted while stranded at Neva Shoal, the actual overall damage to coral reef habitats at this atoll is likely to be substantially larger than reported here for these two specific locations.

Mapping the spatial scope of the buoy-grounding damage is an important step toward assessing potential ecological impacts to the affected coral reef communities. The damages to these coral communities can have serious implications for the management and conservation of coral reefs in PMNM. Coral mortality is often associated with invasion of the dead coral skeletons by algae (Done 1992). Mortality occurring at a large spatial scale can result in algal overgrowth (Couch et al. 2017) and possible phase-shifts to an algal dominated reef system (Done 1992).



Physical injury to corals can also cause substantial increases in disease susceptibility. Previous research has found corals with physical injury to be four times more susceptible to tissue loss diseases (Lamb et al. 2014). Physical injuries, such as abrasion and breakage, can reduce immune function associated with regeneration of coral tissue, which results in an increase in susceptibility to disease (Mydlarz et al. 2006).

The observed buoy damage is concerning because it caused both coral mortality as well as physical damage in the form of abrasion and breakage to live coral tissue. These impacts should be monitored and tracked over time to determine if the affected corals become susceptible to algal overgrowth or disease. It is important to monitor and observe the impacts of this disturbance event as loss of live coral can result in degradation of 3D habitat complexity (Burns et al. 2016, Couch et al. 2017). Loss of habitat complexity provided by live corals can reduce the diversity and abundance of associated reef organisms because complex habitat provides more refuge space, decreases the encounter rate between competitors, and promotes niche specialization (Komyakova et al., 2013). This buoy-stranding event provides a unique opportunity to monitor the reef habitat post-disturbance and quantify potential long-term ecological impacts associated with the physical damage to coral communities.

The 3D mapping analysis indicates that both locations exhibited several forms of physical damage caused by the buoy stranding. Considering the large-spatial areas affected at each site 63.4 m<sup>2</sup> at Site B and 200.60 m<sup>2</sup> at Site C this stranding event warrants further monitoring to assess the long-term ecological implications. Monitoring the fate of the affected coral communities can provide useful information for managers to predict potential impacts from future groundings occurring on coral reef ecosystems. Developing a better understanding of how stranding events can affect coral health and ecosystem function may lead to improved tracking technology and rapid response plans to retrieve buoys that have detached from their mooring systems. The 3D methods described in this study provide a powerful tool for precisely quantifying the impacts of disturbance to coral reef habitat. Future assessments of groundings and physical disturbances to reef habitats could use a similar approach to ensure a visual baseline and thorough quantification of damage is conducted.

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AMERICA'S UNDERWATER TREASURES