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Summary of the Vulnerable Marine Ecosystem Indicators Observed in the NAFO Closed Areas on the *Okeanos Explorer* Expedition "2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts"

by

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Abstract

From June 30 through July 29, 2021, the NOAA Ocean Exploration and partners conducted the "2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts" expedition, a telepresence-enabled ocean exploration expedition aboard the NOAA Ship *Okeanos Explorer*. The mission objectives were to collect critical baseline information about unknown and poorly understood deep-water areas off the eastern U.S. coast and high seas through mapping and remotely operated vehicle (ROV) operations. Thirteen of these ROV dives occurred in the NAFO areas closed to protect vulnerable marine ecosystems (VMEs) on seamounts, including in areas that will be closed effective January 1, 2022. Deep-sea coral and sponge communities were observed on every expedition dive targeting benthos. Here we describe the VMEs observed within these closures in support of the protection of the seamounts within the NAFO Convention Area from the harmful effects of bottom-contact fishing gears.

Introduction

From June 30 through July 29, 2021, NOAA Ocean Exploration and partners conducted the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts expedition, a telepresence-enabled ocean exploration expedition on the NOAA Ship *Okeanos Explorer*. The mission objectives were to collect critical baseline information about unknown and poorly understood deepwater areas off the eastern U.S. coast and high seas through mapping and remotely operated vehicle (ROV) operations. The expedition completed 20 ROV dives (Figure 1) ranging in depth from 300 to 4,2187 m. Fourteen of the 20 dives were "map and dive" where higher-resolution mapping data needed to successfully execute the dive was collected just hours before the dive took place, because previously there was no or poor data at each dive site.

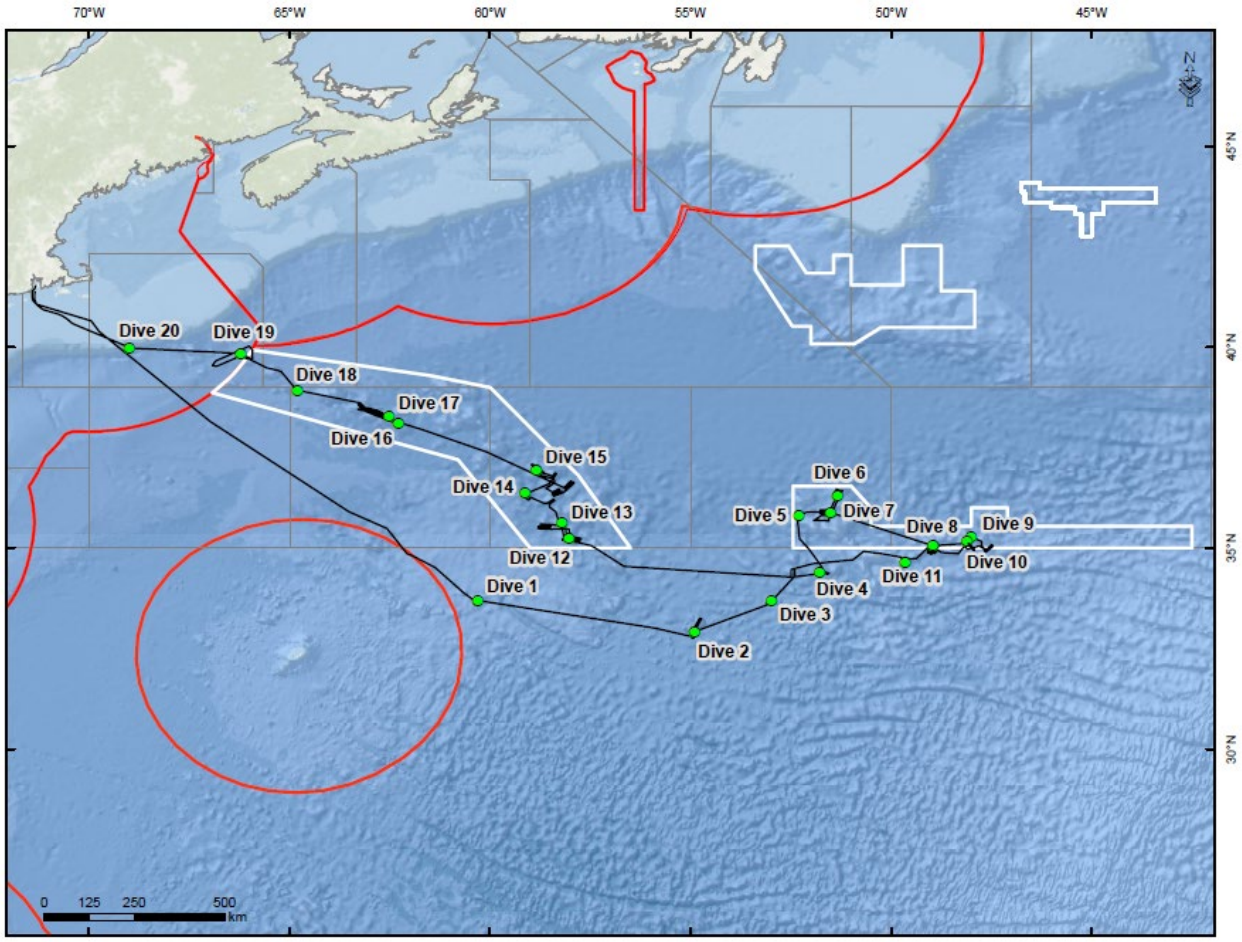

Figure 1. 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition map with dive sites. White lines: areas currently closed or closed effective January 1, 2022 by NAFO to protect VMEs; red lines: Exclusive Economic Zones of Canada, USA, Bermuda and France with respect to St. Pierre and Miquelon; black lines: cruise track. NAFO Divisions are outlined in grey.

Deep-sea coral and sponge communities were observed on every expedition dive in the NAFO closed areas (depth range 939-4187 m). Dive numbers 7, 8, 10, 12-18 occurred in areas that are currently closed, and dives 5, 6, and 9 are in areas that will close January 1, 2022, to bottom contact fishing by NAFO to protect vulnerable marine ecosystems (VMEs) on seamounts in the New England and Corner Rise Seamount chains (Figure 1, Table 1).

Table 1. Summary of 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts expedition remotely operated vehicle dives on seamounts within the NAFO Closed Areas with a list of VME Indicator taxa observed. *Dives located in the new Corner Rise Seamount Protection Area that goes into effect January 1, 2022.

Dive	Date	Latitude	Longitude	Shallowest Depth (m)	Deepest Depth (m)	VME indicators observed
Corner Rise Seamount Chain NAFO area						
Dive 05: Rockaway Seamount*	July 8, 2021	35.819207°	-52.305386°	4,096	4,187	Deep-sea sponges, Stalked crinoids, Large gorgonian corals, Cerianthid anenomes
Dive 06: Castle Rock Seamount*	July 9, 2021	36.300876°	-51.347289°	2,082	2,331	Deep-sea sponges, Stalked crinoids, Small gorgonian corals, Black coral
Dive 07: "Corner Rise 1" Seamount	July 10, 2021	35.890163°	-51.523687°	2,422	2,594	Small and Large gorgonian corals, Black coral, Deep-sea sponges
Dive 08: MacGregor Seamount	July 11, 2021	35.051091°	-48.969953°	939	1,272	Small and Large gorgonian corals, Black coral, Deep-sea sponge grounds
Dive 09: Yakutat Seamount – Shallow*	July 12, 2021	35.177792°	-48.116706°	1,192	1,366	Small and Large gorgonian corals, Black coral, Deep-sea sponges
Dive 10: Yakutat Seamount - Deep	July 13, 2021	35.265366°	-48.002336°	1,697	1,983	Stony corals, Small and Large gorgonian corals, Black coral, Deep-sea sponges
New England Seamount Chain NAFO area						
Dive 12: "Y" Seamount	July 17, 2021	35.222450°	-58.032272°	2,580	2,807	Large gorgonian corals, Black corals, Deep-sea sponges
Dive 13: "Near Hodgsen" Seamount	July 18, 2021	35.611445°	-58.206409°	2,359	2,531	Small and Large gorgonian corals, Black coral, Deep-sea sponges, Xenophyophores
Dive 14: "Seven" Seamount	July 19, 2021	36.348062°	-59.118589°	1,993	2,144	Small and Large gorgonian corals, Black coral, Deep-sea sponges
Dive 15: Allegheny Seamount	July 20, 2021	36.930406°	-58.858593°	3,336	3,447	Cerianthid anenomes, Small and Large gorgonian corals, Black coral, Deep-sea sponges

Dive 16: Gosnold Seamount	July 23, 2021	38.134593°	-62.304282°	3,177	3,238	Small and Large gorgonian corals, Deep-sea sponges
Dive 17: Gosnold Seamount (Shallow)	July 24, 2021	38.293979°	-62.533148°	1,714	1,783	Small and Large gorgonian corals, Black corals, Stony corals, Deep-sea sponges, Stalked crinoids
Dive 18: Asterina Seamount	July 25, 2021	38.926941°	-64.820437°	3,784	3,792	Small and Large gorgonian corals, Sea pens, Black corals, Stony corals, Deep-sea sponges

Summary of *Okeanos Explorer* ROV Dives in NAFO Closed Areas

Corner Rise Seamount Chain

Dive 05: Rockaway Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive05/welcome.html

https://www.youtube.com/watch?v=WRgV9vyDpHw

Dive 05 of the 2021 North Atlantic Stepping Stones expedition took place on the western flank of previously unexplored Rockaway Seamount, which is one of the northern- and western-most of the Corner Rise Seamounts. With a starting depth of nearly 4,200 meters, this was one of the deepest dives ever conducted in this part of the Atlantic (Figure 2).

Given the depth, it was not a surprise to scientists that the overall diversity and density of benthic fauna throughout this dive was lower than what has been seen at shallower depths on other seamounts during the expedition. Nevertheless a greater diversity of life was observed on the dive than was expected, with observations made of numerous sponges, corals, urchins, and squat lobsters as well as a number of swimming invertebrates (but no fish). VME indicator species included bamboo corals, cerianthid anenomes, stalked crinoids and deep-sea sponges (Figure 3). A diverse range of seafloor substrate types and bottom morphologies were encountered during the dive, including high-relief rock outcrops with scattered sediment and rock debris, extensive sediment plains with ferromanganese-coated rocks scattered across the sediment surface, and rock outcrops with complex volcanic flow morphologies (Figure 4).

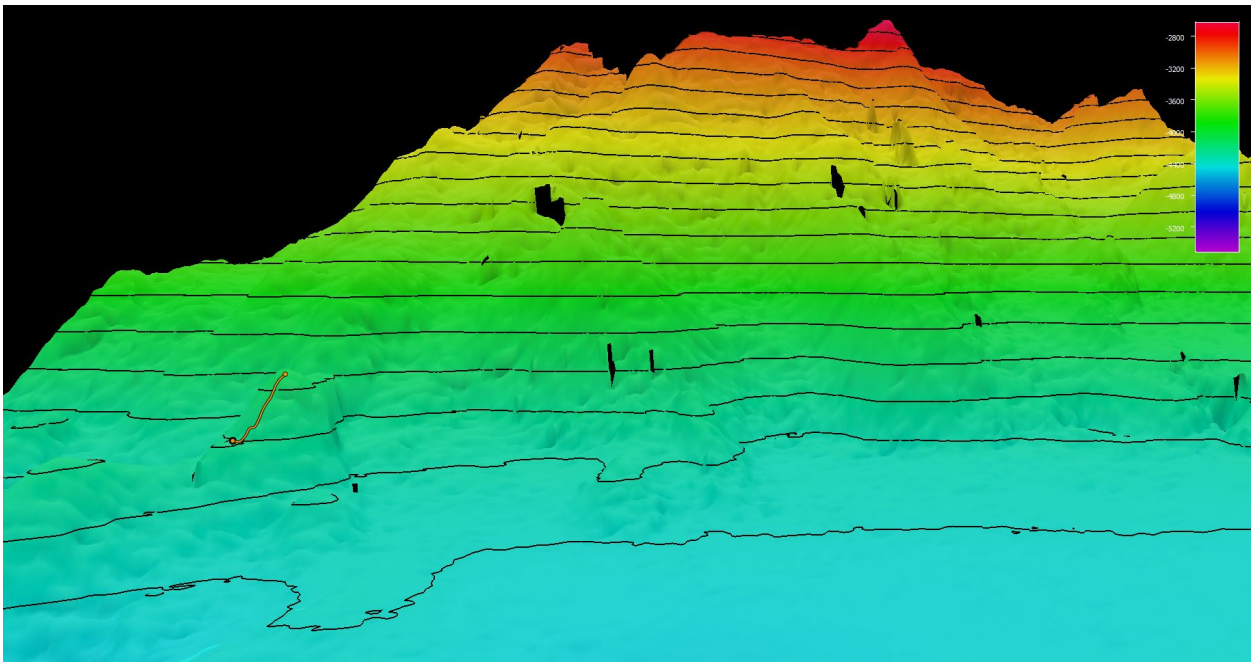

Figure 2. Image showing the dive track of Dive 05 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

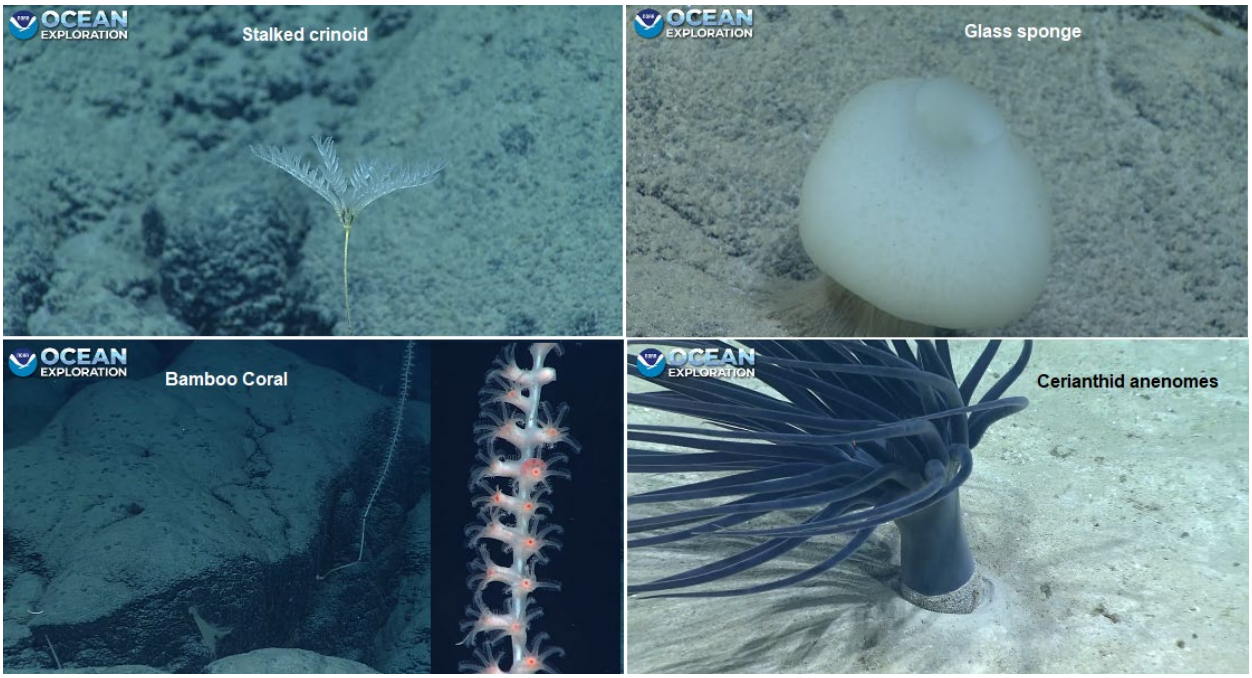

Figure 3. Examples of vulnerable marine ecosystem indicators observed on Dive 05 on Rockaway Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

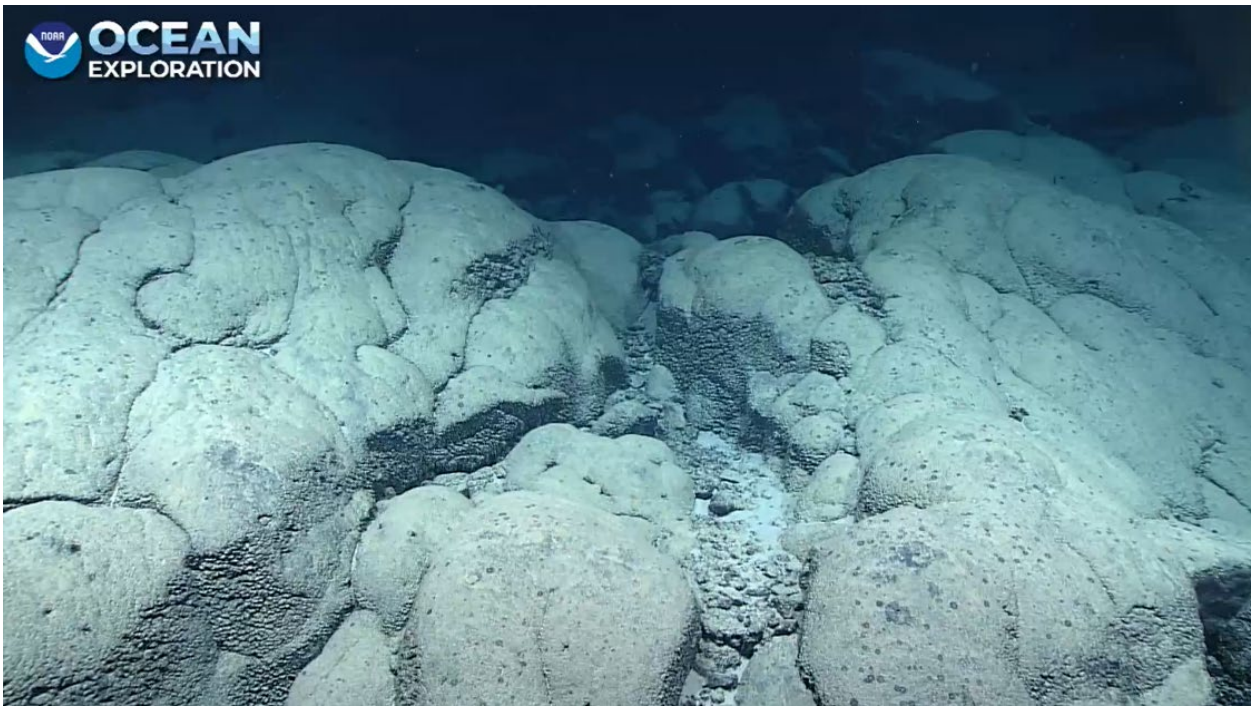

Figure 4. 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition Dive 05: Rockaway Seamount illustrating rock outcrops with complex volcanic flow morphologies.

Corner Rise Seamount Chain

Dive 06: Castle Rock Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive06/welcome.html

https://www.youtube.com/watch?v=5TxeXdH8NKk

Castle Rock Seamount is believed to be the northernmost seamount of the Corner Rise Seamount Chain. A wide range of seafloor environments were encountered during the dive (Figure 5), beginning with a mixed rock outcrop and sediment slope, which transitioned into a steep section of exposed lava flow morphologies, and finally a series of alternating, low-relief rock and sedimented areas. At the end of the dive, we observed a region of thicker and more extensive sediment cover and rocks with a distinctly different texture that may have been sedimentary (carbonate) rather than volcanic in origin.

General biological diversity was higher during this dive than the previous five dives of the expedition, though instances of marine life were spread across the entire dive transect in lower-density patches. Echinoderms dominated the dive, with observations made of crinoids, sea stars (including brisingids), brittle stars, and sea cucumbers. Several species of coral that had not yet been seen during the previous dives of the expedition were observed and while sponges were present throughout the dive, they were in lower abundance than seen on Dive 05. VME Indicator taxa observed include Small Gorgonian Corals (e.g., *Acanella arbuscula* and *Metallogorgia melanotrichos*), stalked crinoids, deep-sea sponges (e.g., *Polymastia* sp.) (Figure 6) and black coral (Figure 7).

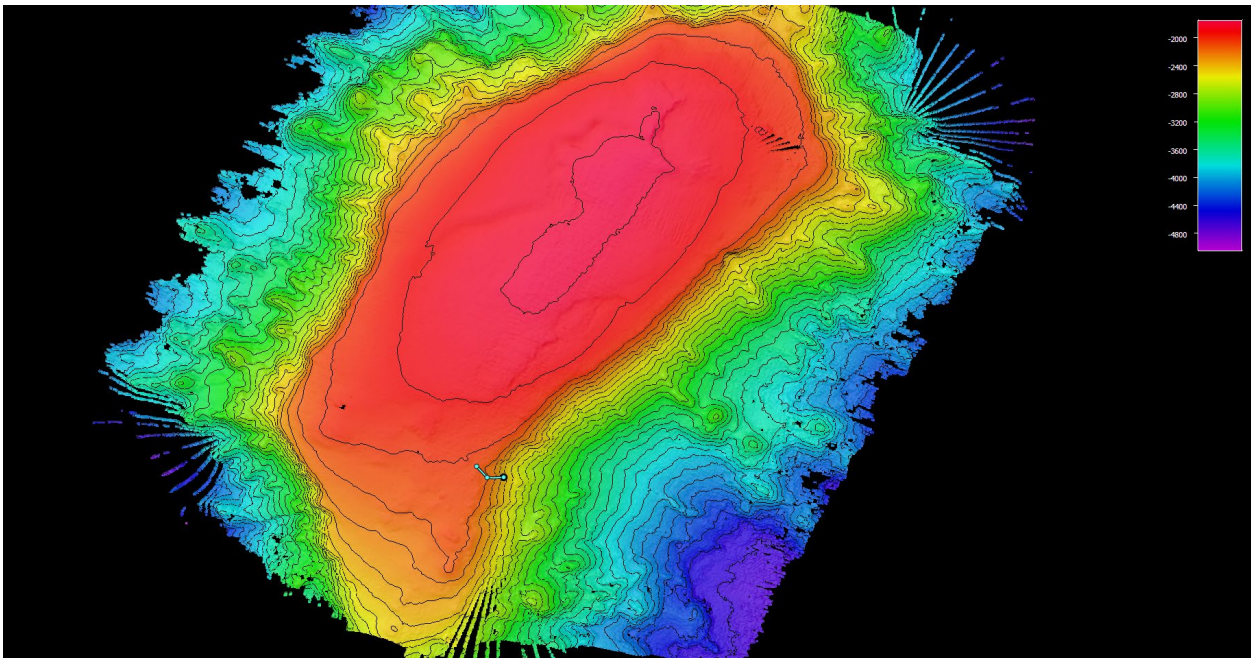

Figure 5. Image showing the dive track of Dive 06 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

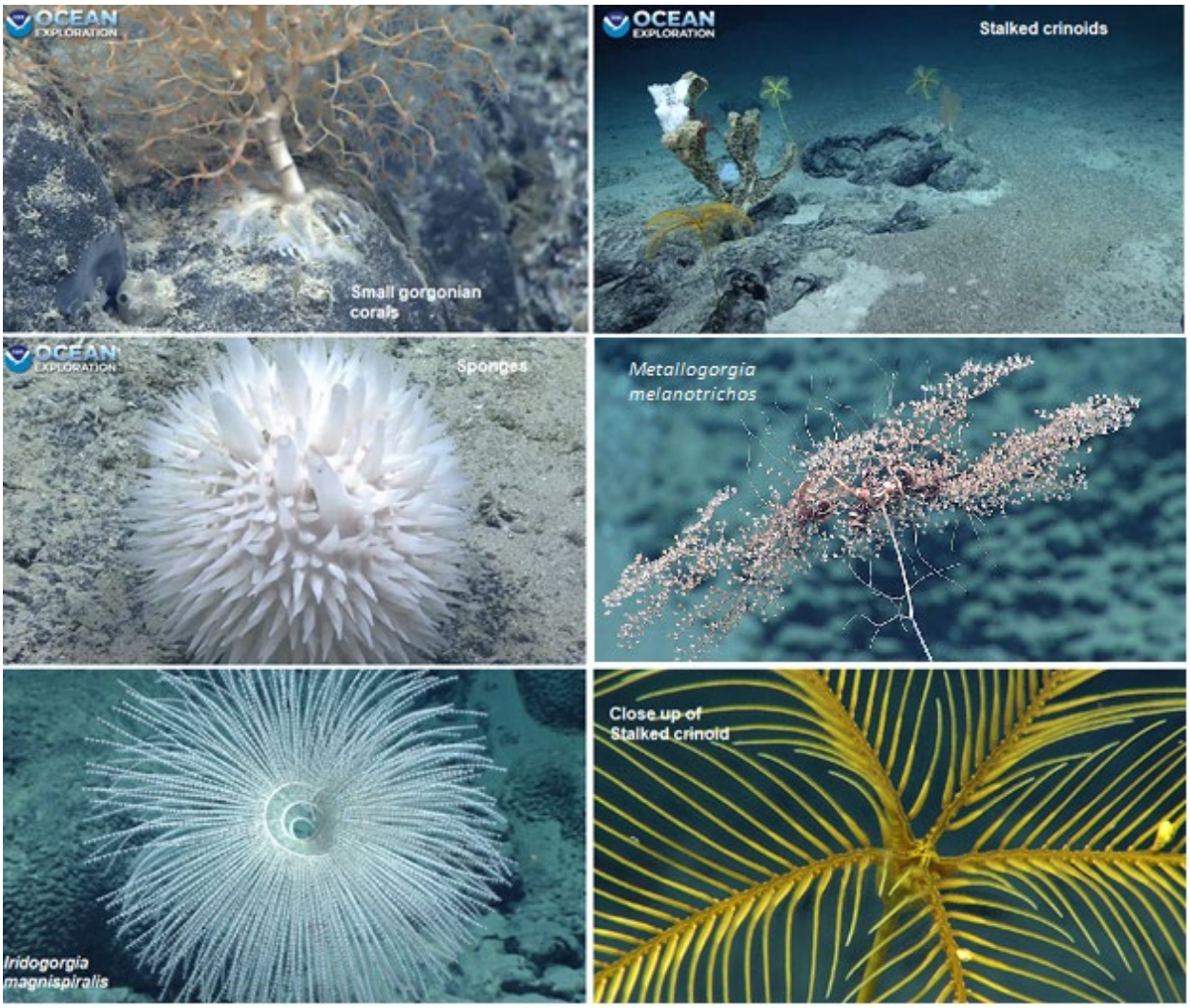

Figure 6. Examples of vulnerable marine ecosystem indicators observed on Dive 06 on Castle Rock Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

Figure 7. Image of a black coral observed on Dive 06 on Castle Rock Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

Corner Rise Seamount Chain

Dive 07: "Corner Rise 1" Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive07/welcome.html

https://www.youtube.com/watch?v=tq2WGUM5V-o

Mapping of "Corner Rise 1" Seamount revealed a kidney bean-shaped guyot with steep flanks (Figure 8). Dive 07 explored the southeast end of this seamount.

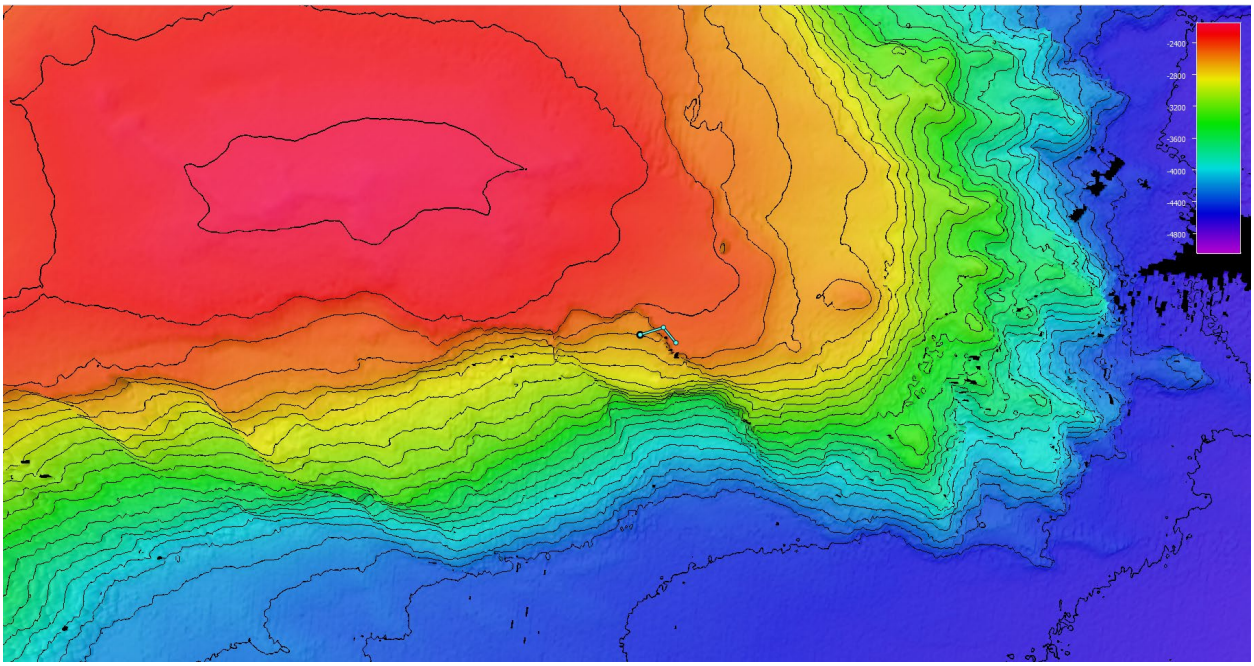

Figure 8. Image showing the dive track of Dive 07 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

The ROV *Deep Discoverer* landed on a smooth, sediment-free rock pavement interrupted in places by higher-relief outcrops of what appeared to be volcanic flow materials. Further upslope, an extremely steep rock wall that was approximately 100 meters tall was encountered. This wall was covered with abundant sponges and corals; fossilized cup corals (*Desmophilum dianthus*) covered many of the exposed surfaces. Other biological observations were sparse and spread out for most of the dive, with a low overall abundance. Sponges were relatively well represented. VME Indicator taxa observed included deep sea sponges, black corals, large and small gorgonian corals (Figures 9, 10). Densities of large gorgonian corals were quite high in some areas (Figure 10).

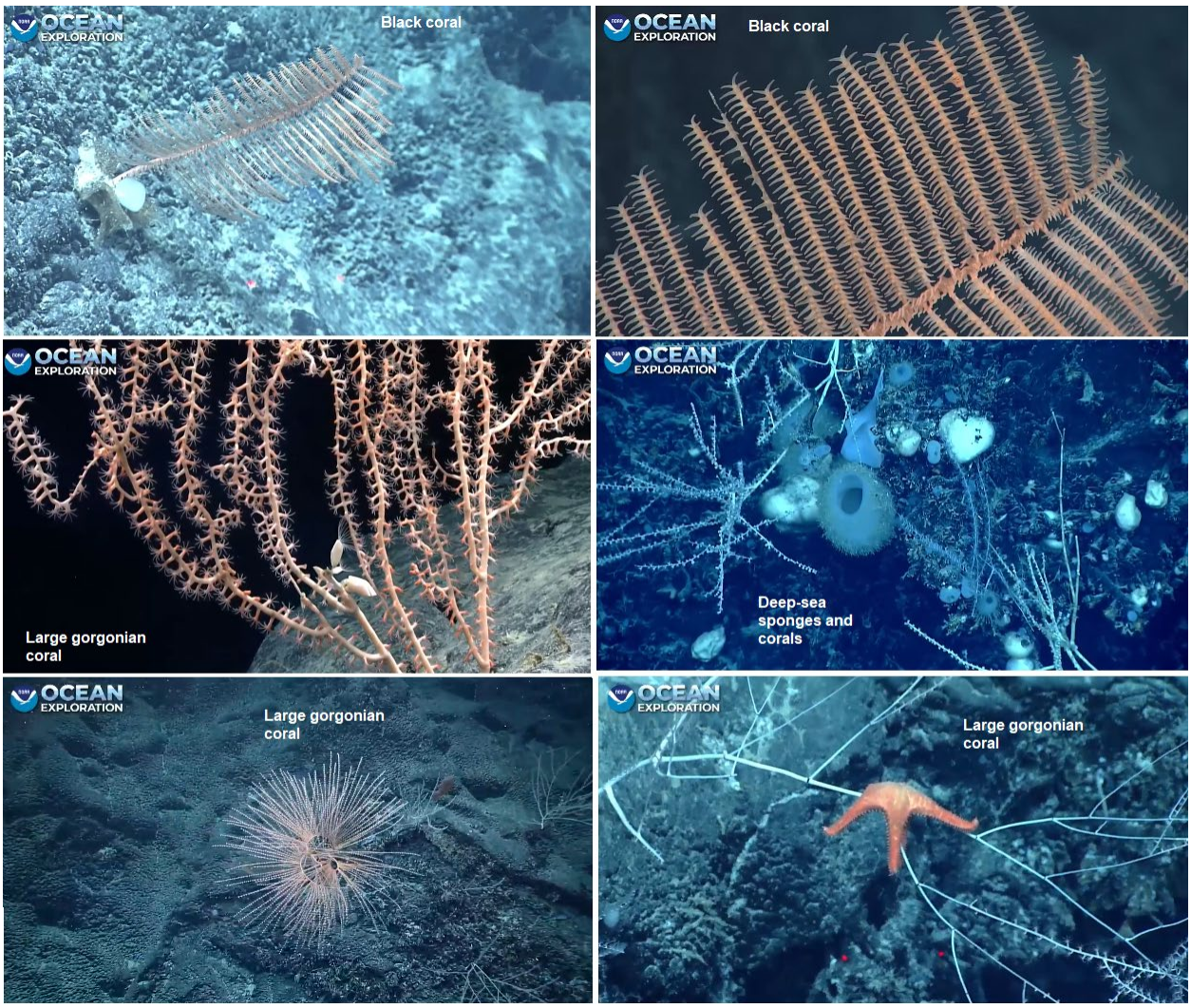

Figure 9. Examples of vulnerable marine ecosystem indicators observed on Dive 07 on Corner Rise Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

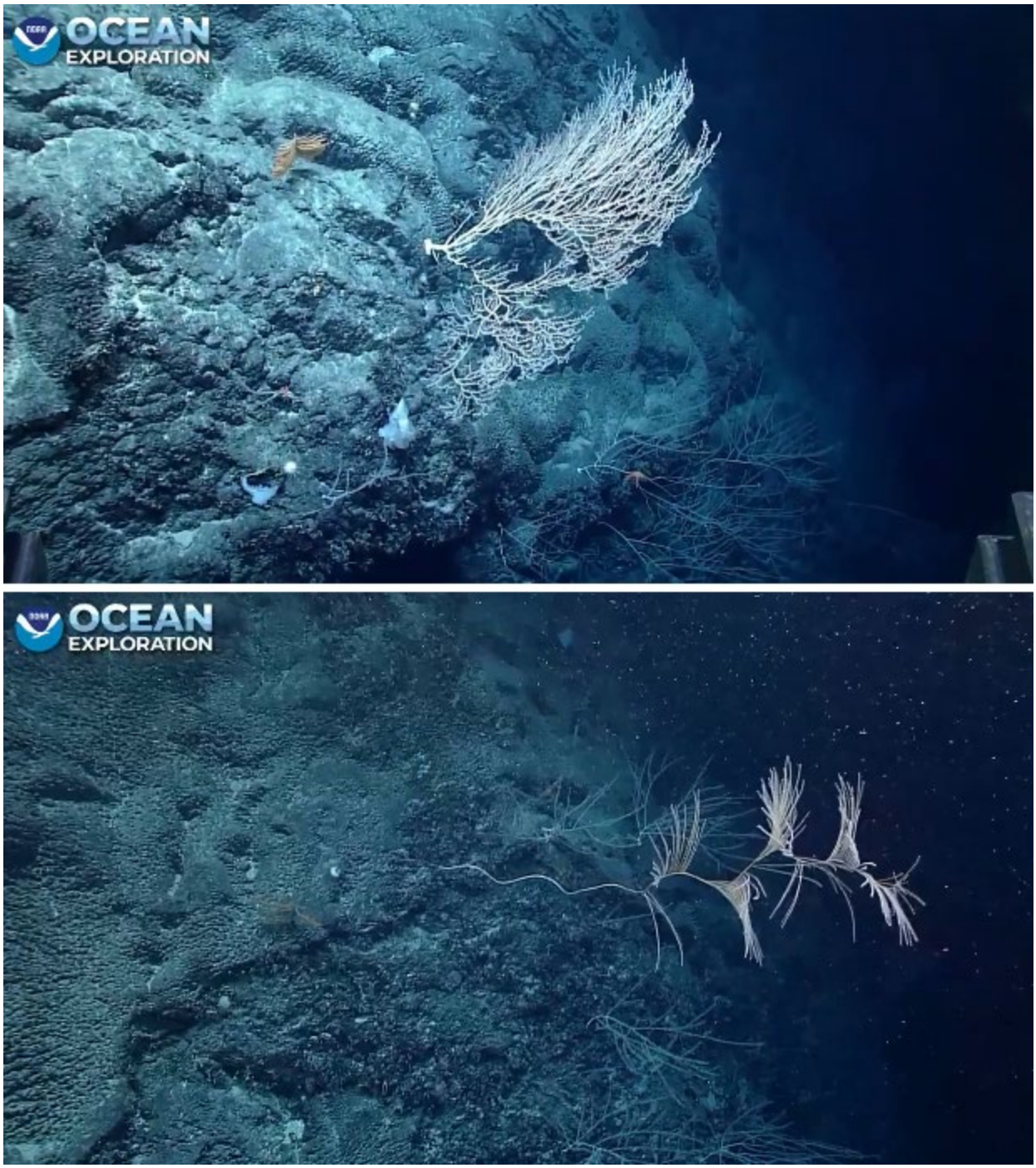

Figure 10. Examples of vulnerable marine ecosystem large gorgonian coral indicators observed on Dive 07 on Corner Rise Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

Corner Rise Seamount Chain

Dive 08: MacGregor Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive08/welcome.html

https://www.youtube.com/watch?v=POWkQitQIUU

The ROV dive on MacGregor Seamount explored along the face of a near-vertical wall that may have been the remnants of an old volcanic cone that has since been eroded away (Figure 11). Given that the Corner Rise Seamounts were formed by hotspot volcanism around 75 million years ago, this could be a very old feature. In addition to being impressive from a geological perspective, the wall was also home to a diversity of corals, with dense patches of soft corals in the genus *Chyrsogorgia* and exceptionally large colonies of octocorals in the genus *Thourella* dotting the wall, with interspersed *Iridiogorgia* sp. corals as well (Figure 12).

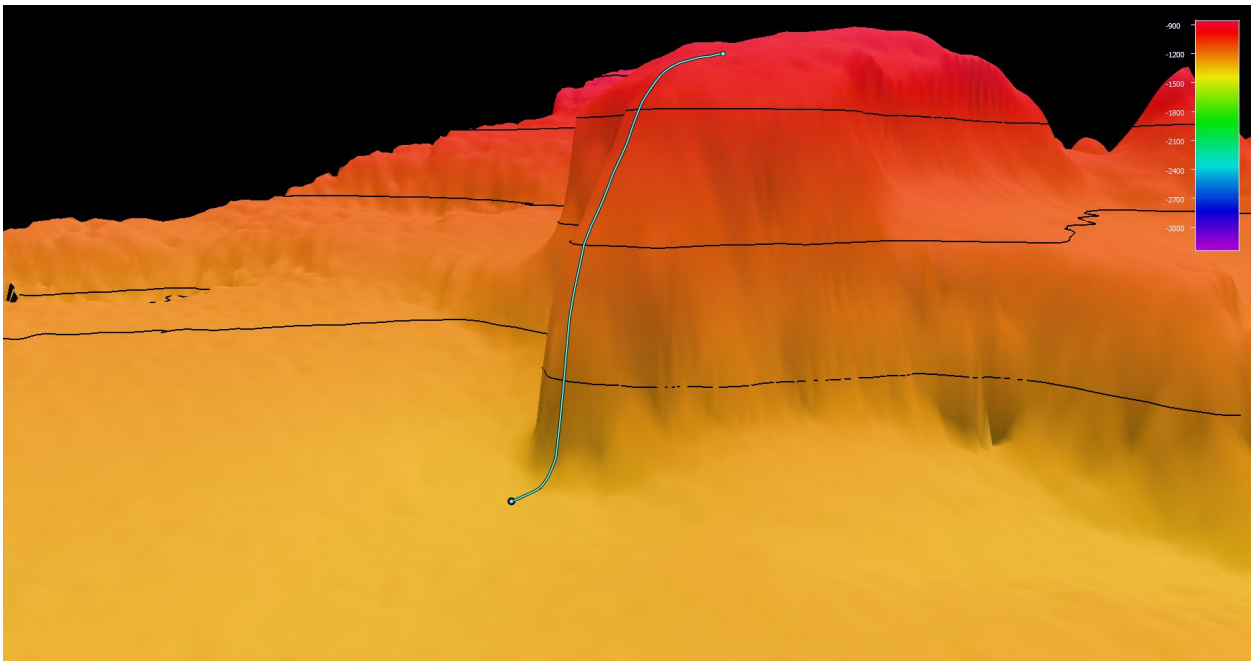

Figure 11. Image showing the dive track of Dive 08 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

Biological communities were diverse in different areas of the dive. The diversity of deep-sea coral vulnerable marine ecosystem indicators was greatest along the carbonate wall were a number of large gorgonian and black coral species were observed (Figure 12). Large and extensive sponge grounds were discovered at the top of a carbonate reef platform, alongside reef-building hard corals and associated fauna (Figure 13). These can be considered VMEs based on their spatial extent and the density of the sponges.

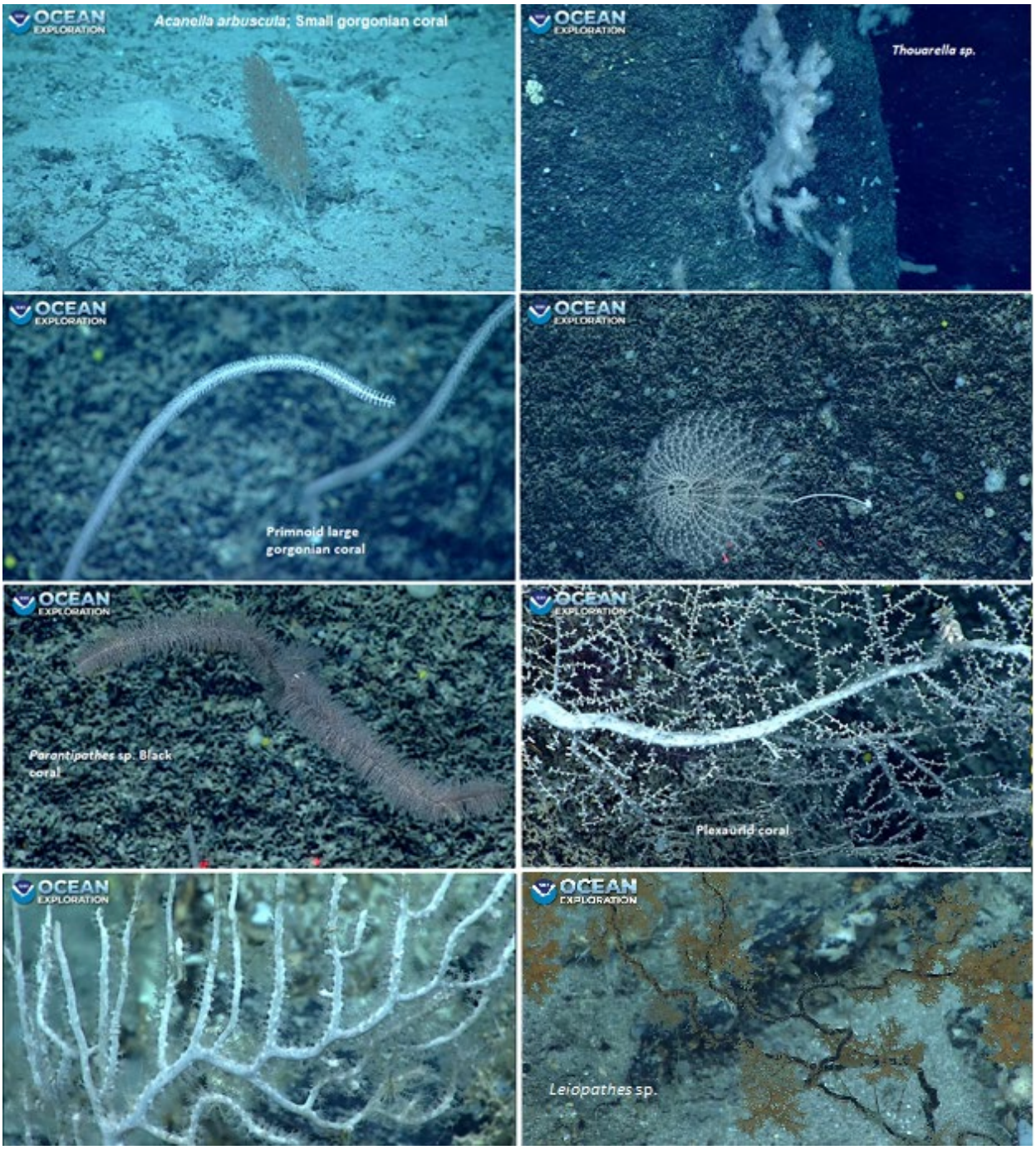

Figure 12. Examples of coral vulnerable marine ecosystem indicators observed on Dive 08 on MacGregor Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

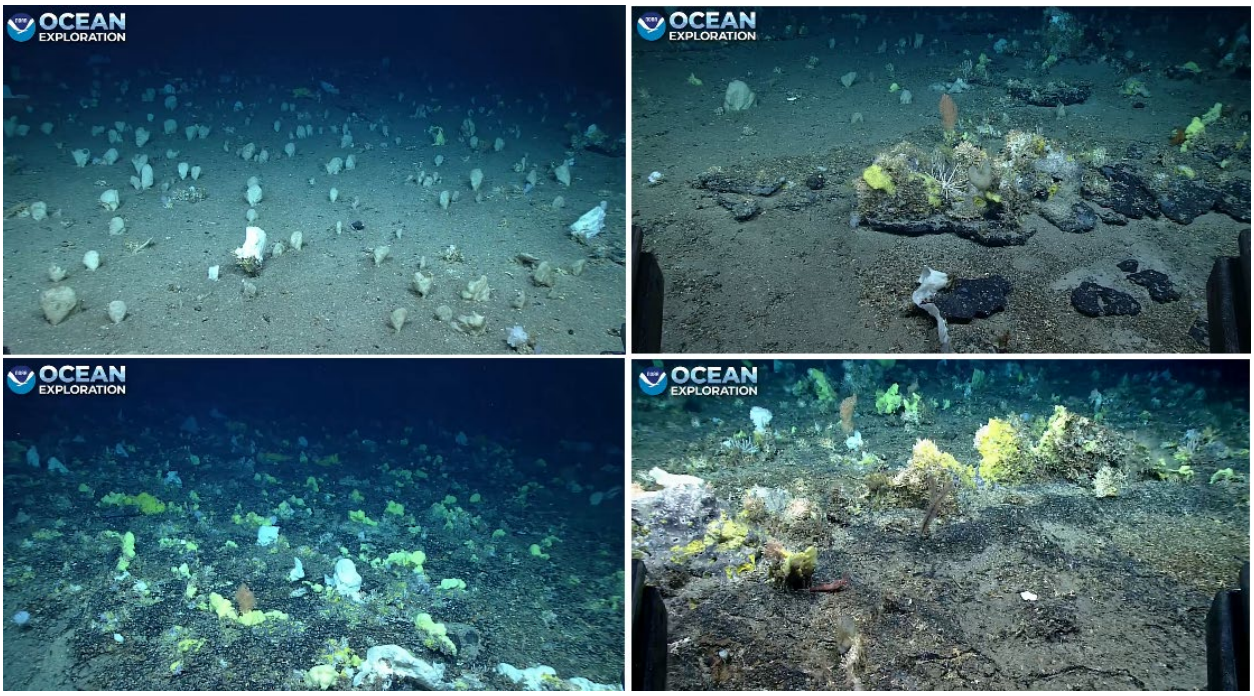

Figure 13. Examples of deep-sea sponge ground vulnerable marine ecosystems observed on Dive 08 on MacGregor Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

Corner Rise Seamount Chain

Dive 09: Yakutat Seamount - Shallow

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive09/welcome.html

https://www.youtube.com/watch?v=FmatgwPowVI

Dive 09 of the 2021 North Atlantic Stepping Stones expedition was the first of two expedition dives on Yakutat Seamount, this one being the shallower of the two. The remotely operated vehicle landed on coarse sediments near the base of a near-vertical face of an elongated carbonate platform feature at the summit of the southwestern arm of the seamount (Figure 14). At the base of the wall as well as at its summit, ancient coral rubble, undercut carbonate outcrops, and erratic dropstones were observed. The steep wall of the platform was largely continuous and smooth with some wavy texture, which may be the result of a paleo reef that experienced wave action that took place when this seamount was in shallower water.

A range of corals and sponges as well as urchins, sea stars, a few anemones and polychaete worms, and a larger number of fish than seen on previous dives were observed. An unusual purple octocoral in the family Plexauridae was observed at a depth of 1,368 meters (Figure 15) during Dive 09 of the 2021 North Atlantic Stepping Stones expedition. During the dive, at least five species of black corals, a bamboo coral in the genus *Acanella*, and two other species of octocoral were observed. Throughout the dive an unknown "finger sponge" in high-density patches was observed (Figure 15). The white sponge was often covered in a yellow encrusting sponge.

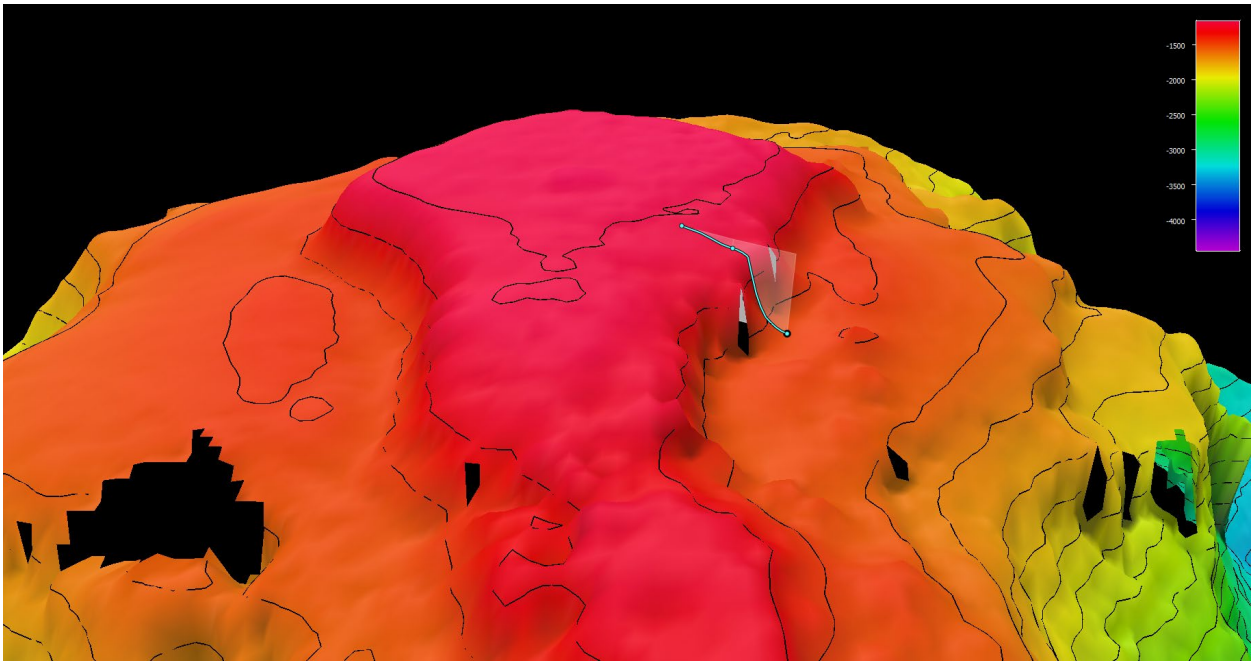

Figure 14. Image showing the dive track of Dive 09 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

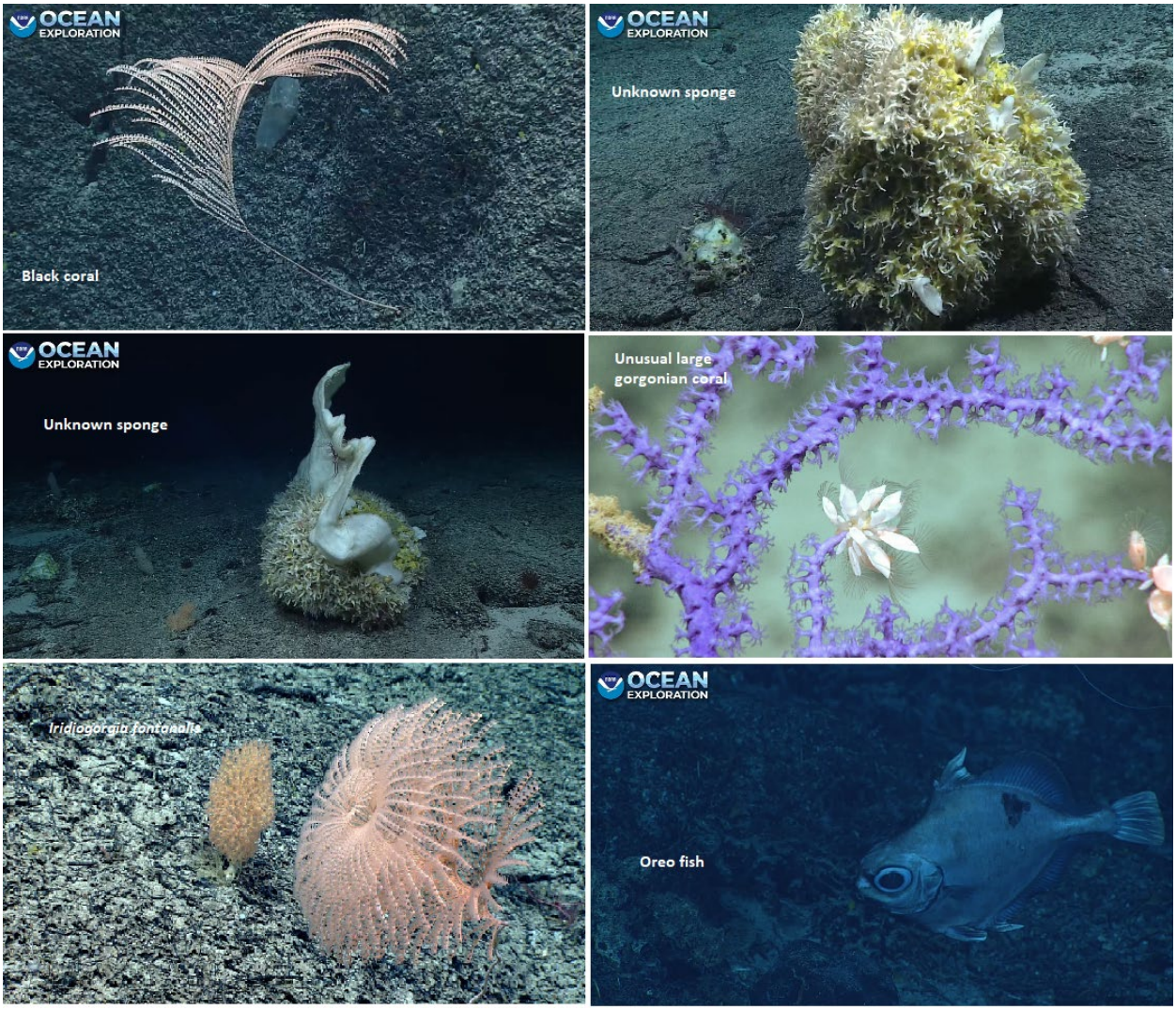

Figure 15. Examples of vulnerable marine ecosystem indicators and of an Oreo fish observed on Dive 09 on Yakutat Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

Corner Rise Seamount Chain

Dive 10: Yakutat Seamount - Deep

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive10/welcome.html

https://www.youtube.com/watch?v=LTE72z3w9B4

Dive 10 was the second 2021 North Atlantic Stepping Stones expedition dive on Yakutat Seamount, part of the Corner Rise Seamount Chain. This dive was deeper than dive 09 on Yakutat, with a starting depth of approximately 1,980 meters. The dive explored a saddle feature between two bathymetric highs located on the central ridge of the seamount (Figure 16).

The dive started on a smooth pavement of rock that appeared to be igneous sheet flows with patches of coarse sediments of biological origin and loose ancient coral rubble. Large corals and sponges were notably absent there, possibly due to the loose rubble not being conducive to larval settling. As the dive progressed, large igneous outcrops were observed, including large collapsed pillows of basalt that provided habitat for numerous

organisms, including corals and sponges. A steeper wall feature was then traversed that appeared to be a large block of carbonate rock that was weathered and eroded in places and supported a low diversity of life, with sparse sponge colonies and virtually no corals. At the top of the ridge, more smooth pavement surfaces were observed, with a considerably different landscape in terms of marine life, with several large sponge colonies, healthy corals (Figure 17), and more abundant anemones, sea stars, and brittle stars.

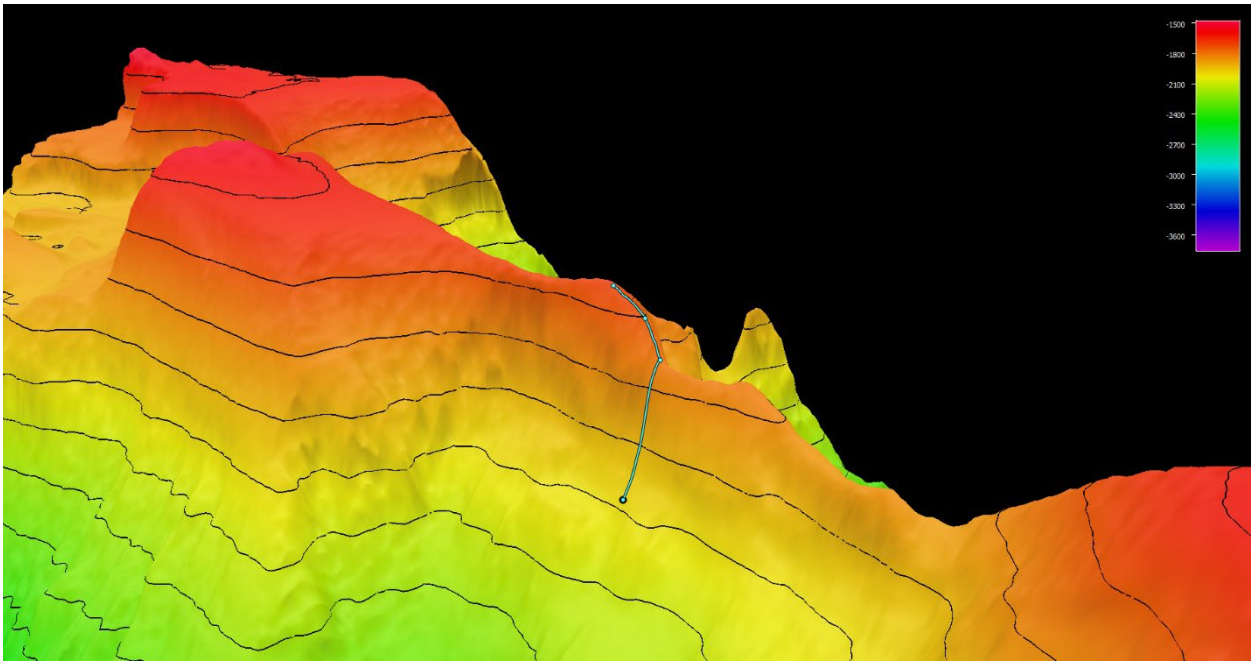

Figure 16. Image showing the dive track of Dive 10 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

The coral *Enallopsammia rostrata* were observed (Figure 17) forming small habitats. At the base of the wall black corals in the genera *Bathypathes* and *Stauropathes*, *Acanella* bamboo corals, *Chrysogorgia*, and *Anthomastus* soft corals were observed.

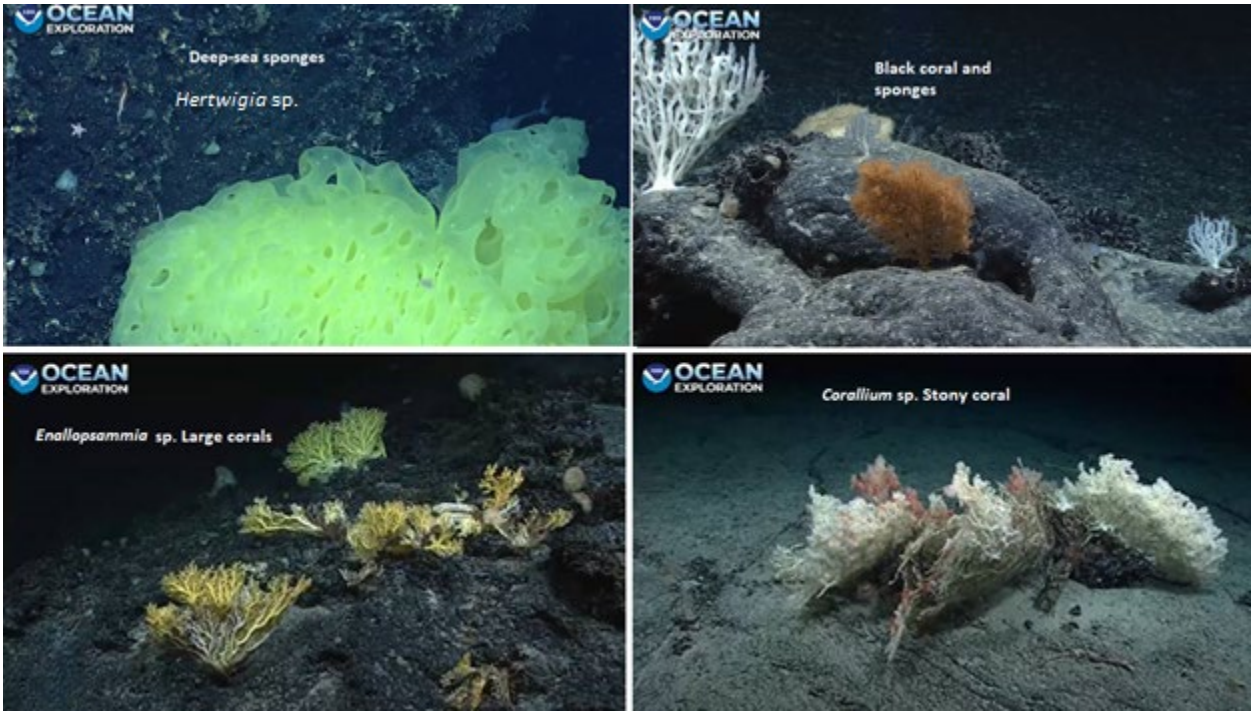

Figure 17. Examples of vulnerable marine ecosystem indicators observed on Dive 10 on Yakutat Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

New England Seamount Chain

Dive 12: "Y" Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive12/welcome.html

https://www.youtube.com/watch?v=5lQbn3gB0pQ

Dive 12 of the 2021 North Atlantic Stepping Stones expedition was the first dive of the expedition to take place within the New England Seamount Chain. This previously unmapped and unexplored seamount was the easternmost of the New England Seamounts that was explored during the expedition (Figure 18).

During the dive, the ROV observed a range of geological features — from small-scale ripples on a sedimented seafloor with thin crusts of igneous rock cropping out of the sediment to a mass-wasting deposit of igneous boulders and cobbles, intact lobate flow structures of igneous rock coated with ferromanganese crust, and a large vertical pillar that appeared to be a volcanic parasite cone.

Biological observations were sparse at the beginning of the dive, during the deepest part of the transect. As the ROV reached the upper areas of the dive, the density and diversity of organisms appeared to increase, and several large bamboo and primnoid coral colonies as well as several species of glass sponges and demosponges, brisingid sea stars, sea cucumbers, anemones, and a few fish were observed. Primnoid colonies, many that were more than 1.5 meters tall, were observed during the upper areas of the dive (Figure 19). Black corals were also seen on the rippled sediment at the start of the dive.

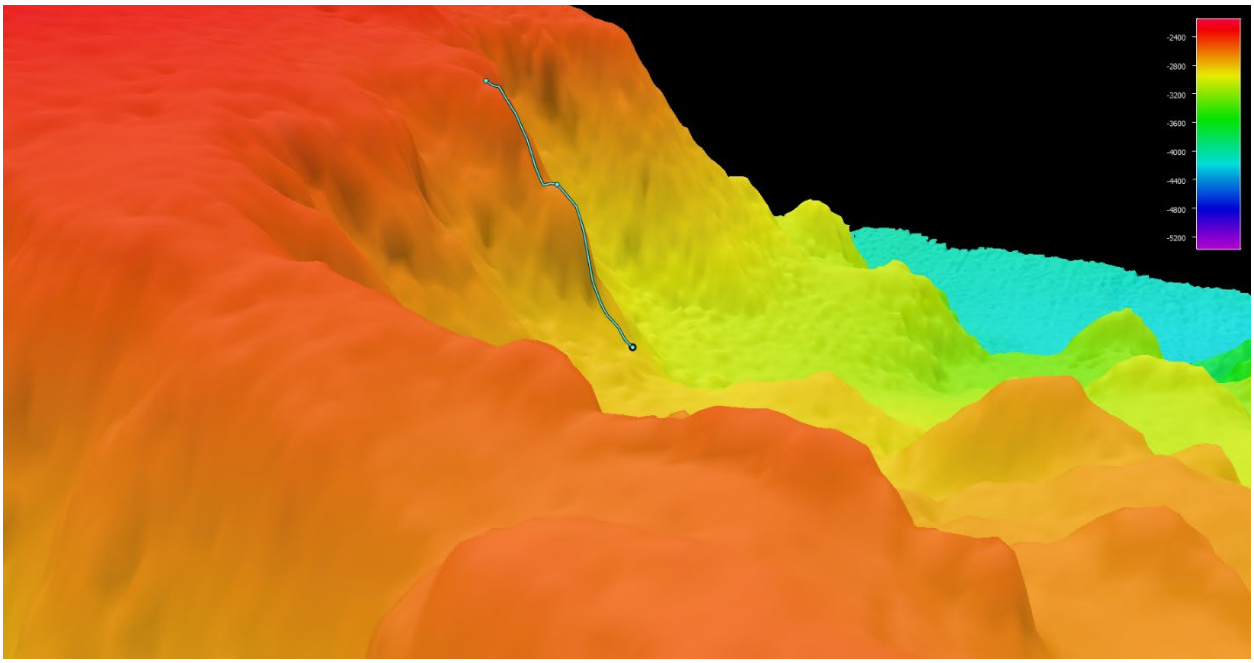

Figure 18. Image showing the dive track of Dive 12 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

Figure 19. Examples of coral vulnerable marine ecosystem indicators observed on Dive 12 on "Y" Seamount during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration. The large primnoid colonies (upper) were over 1.5 m. Bamboo corals were also observed (lower).

New England Seamount Chain

Dive 13: "Near Hodgsen" Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive13/welcome.html

https://www.youtube.com/watch?v=Z6uBdTo7XwU

https://www.youtube.com/watch?v=KzWissBMqYo

During Dive 13 of the 2021 North Atlantic Stepping Stones expedition, the ROV explored the southern face of an unnamed seamount dubbed "Near Hodgsen" Seamount. The dive targeted a square-shaped platform at the top of the seamount that was revealed in the multibeam bathymetry data collected the night before the dive (Figure 20).

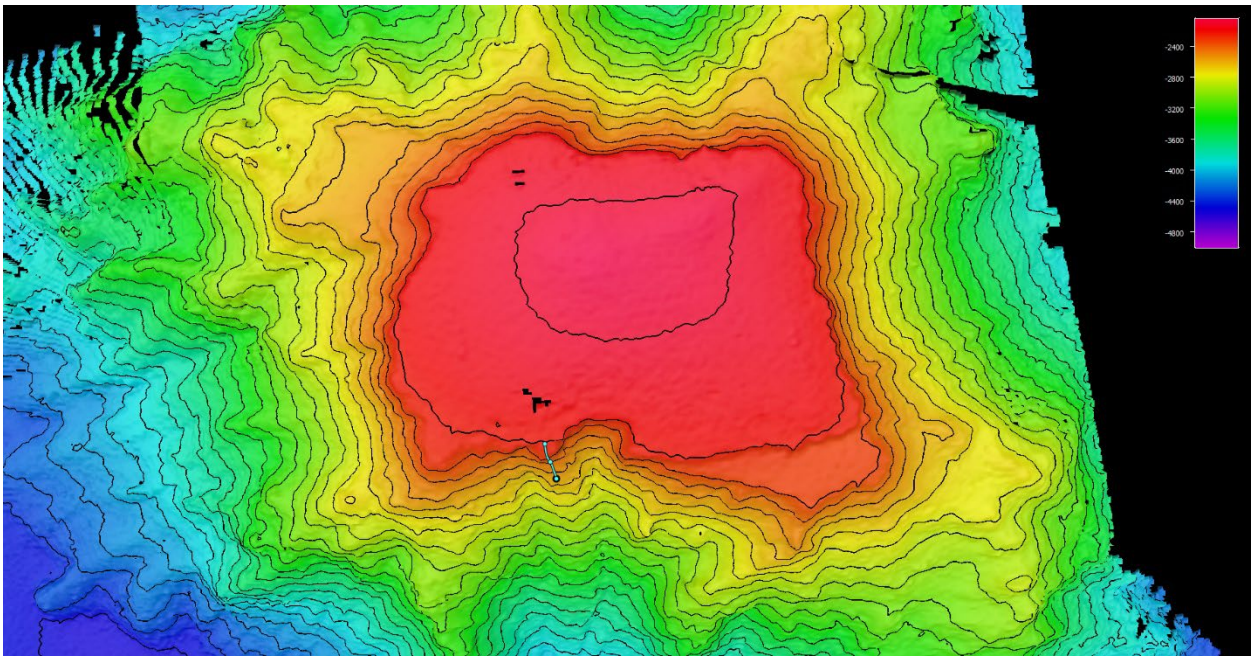

Figure 20. Image showing the dive track of Dive 13 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

The dive started at approximately 2,550 meters depth on a sedimented slope (Figure 20) that appeared to be a chute of debris from above. During the dive, several of these sediment chutes as well as large igneous boulders, lobate lava flow formations, and thick ferromanganese crust coating the rock surfaces were observed. Biological observations were sparse throughout the dive, though the ROV did observe several species of corals and various sponges as well as single-celled xenophyophores, sea stars, sea cucumbers, several fish, and other organisms (Figure 21). A mature coral (*Metallagorgia melanotrichos*) was seen once on the dive, along with several primnoid octocorals, *Bathypathes* black corals, and *Chrysogorgia* soft corals.

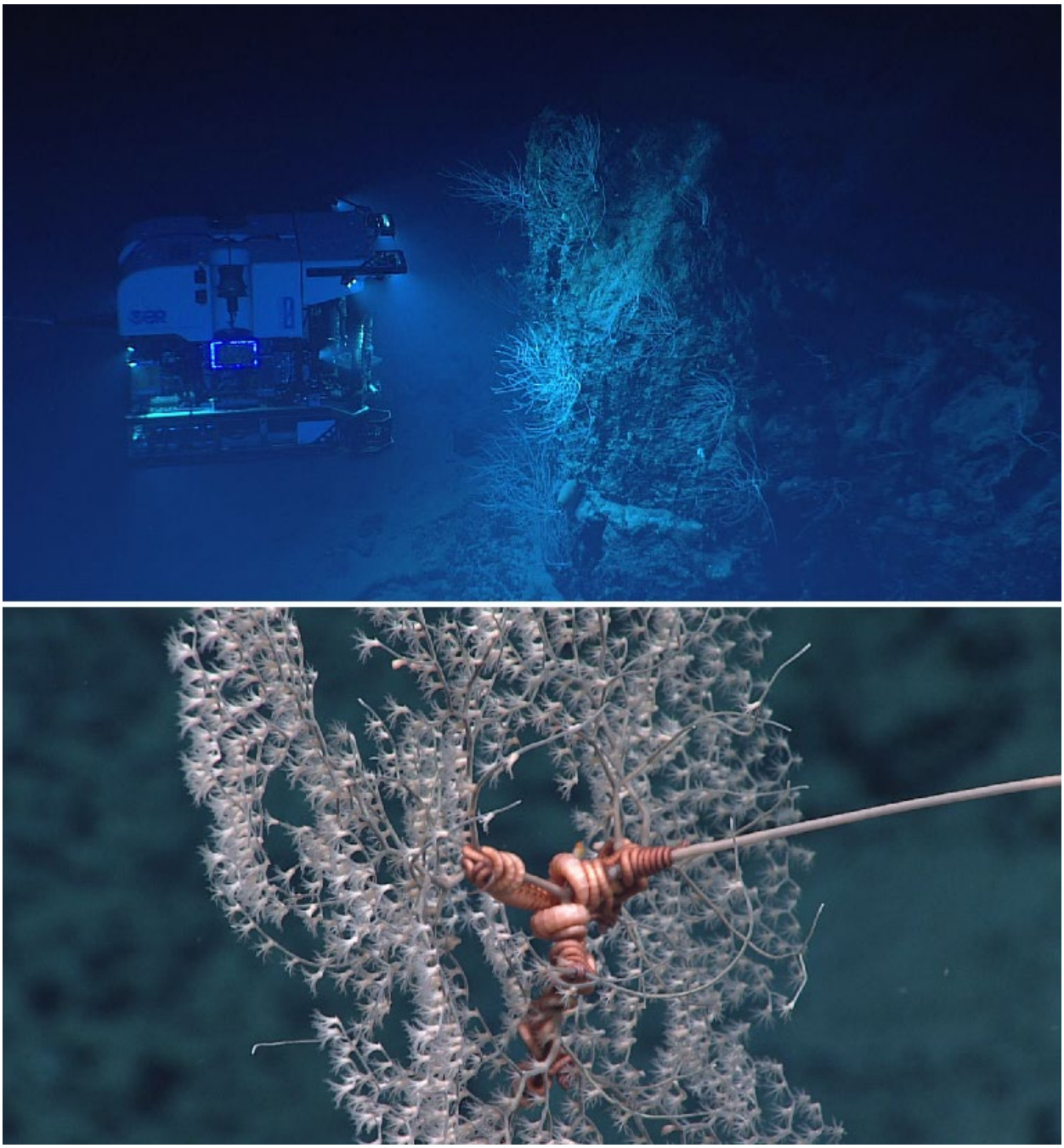

Figure 21. Examples of coral vulnerable marine ecosystem indicators observed on Dive 13 during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration. A mature coral (*Metallagorgia melanotrichos*) with its obligately-associated brittle star (*Ophiocreas oedipus*) was seen once on the dive (lower).

New England Seamount Chain

Dive 14: "Seven" Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive14/welcome.html

https://www.youtube.com/watch?v=VYI_O-WYFag

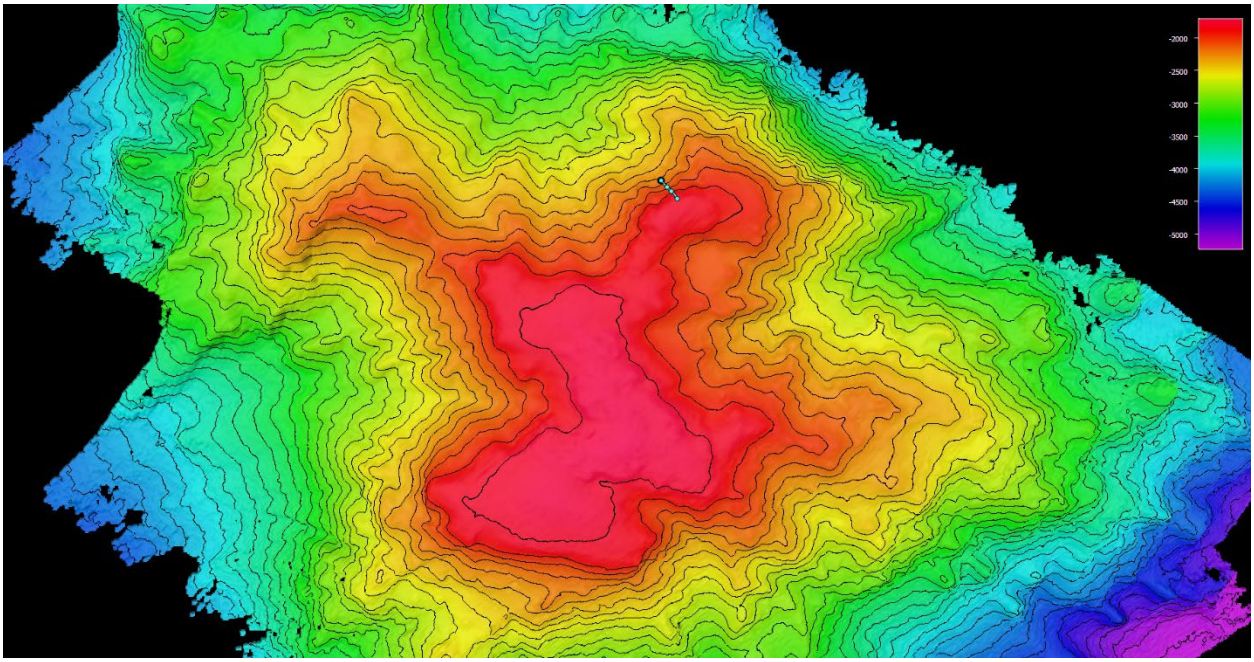

Figure 22. Image showing the dive track of Dive 14 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

Dive 14 of the 2021 North Atlantic Stepping Stones expedition, explored "Seven" Seamount, so (unofficially) named because it was the seventh seamount of this expedition that, prior to this expedition, had never been mapped or visually surveyed (Figure 22).

The dive began on ferromanganese-encrusted pavements with botryoidal textures (grape-like). As the dive progressed, the pavement showed a number of lava-flow ridges (pillow lava morphology) and debris aprons/chutes. As the slope gradient increased, the seafloor morphology shifted to a series of steep, near-vertical walls and benches dominated by ferromanganese-encrusted pillow lava. Towards the end of the dive, the ferromanganese crust became smooth, suggestive of varying current velocities.

This area had a highly biodiverse community dominated by a wide variety of fish, sea stars, sponges, and corals (Figure 23) - including a potentially new bamboo coral morphotype. Throughout the dive transect, the ROV observed thick coral and sponge debris layers covering every crack and crevice of the variable volcanic substrates. This coral debris also showed numerous fossil coral skeletons with dark ferromanganese coatings and structures suggestive of some level of cementation.

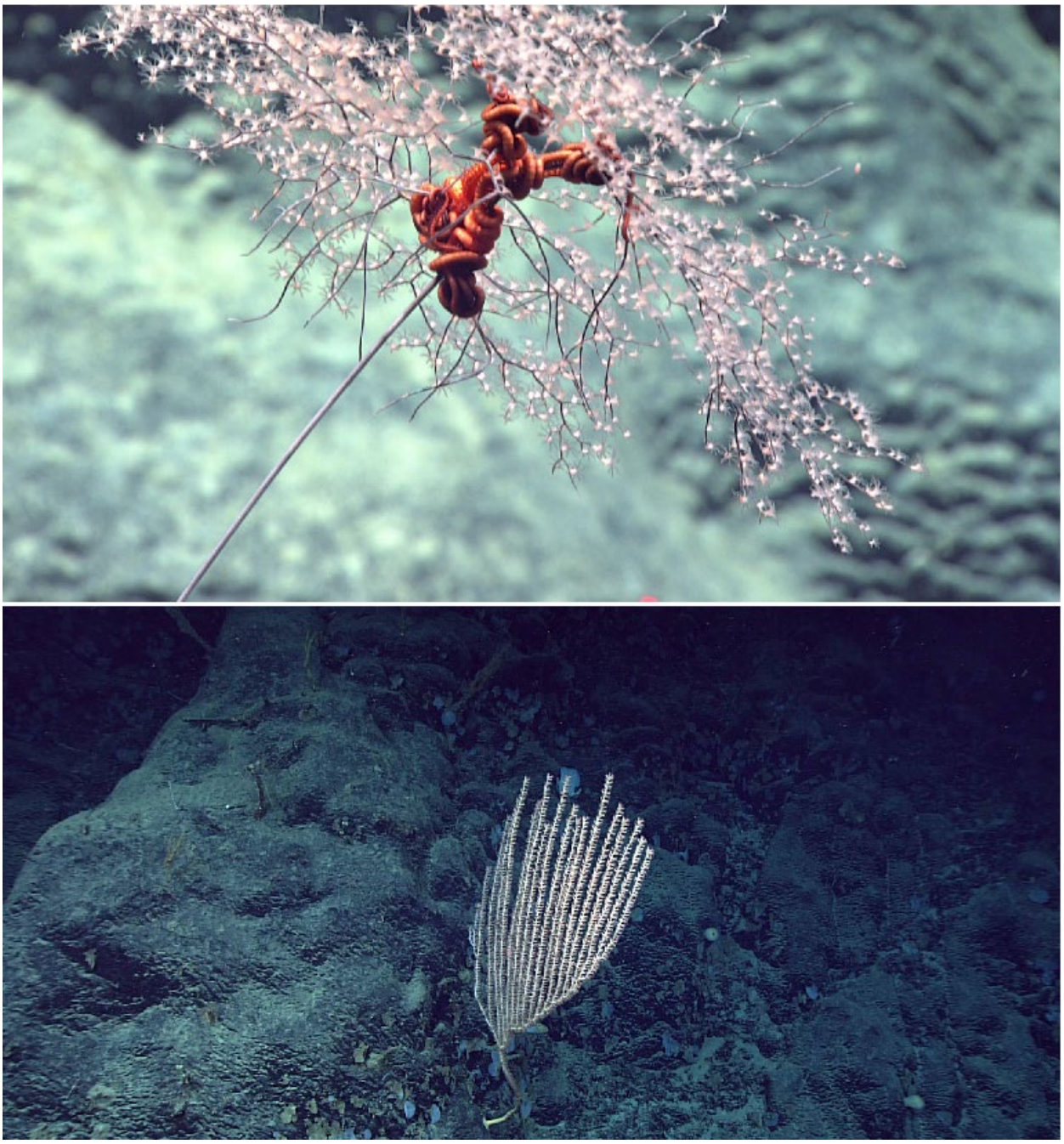

Figure 23. Examples of coral vulnerable marine ecosystem indicators observed on Dive 14 during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration. A mature coral (*Metallagorgia melanotrichos*) with its obligately-associated brittle star (*Ophiocreas oedipus*) (upper) and candelabra bamboo coral (lower) were common.

New England Seamount Chain

Dive 15: Allegheny Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive15/welcome.html

https://www.youtube.com/watch?v=MmHpviK4Kqk

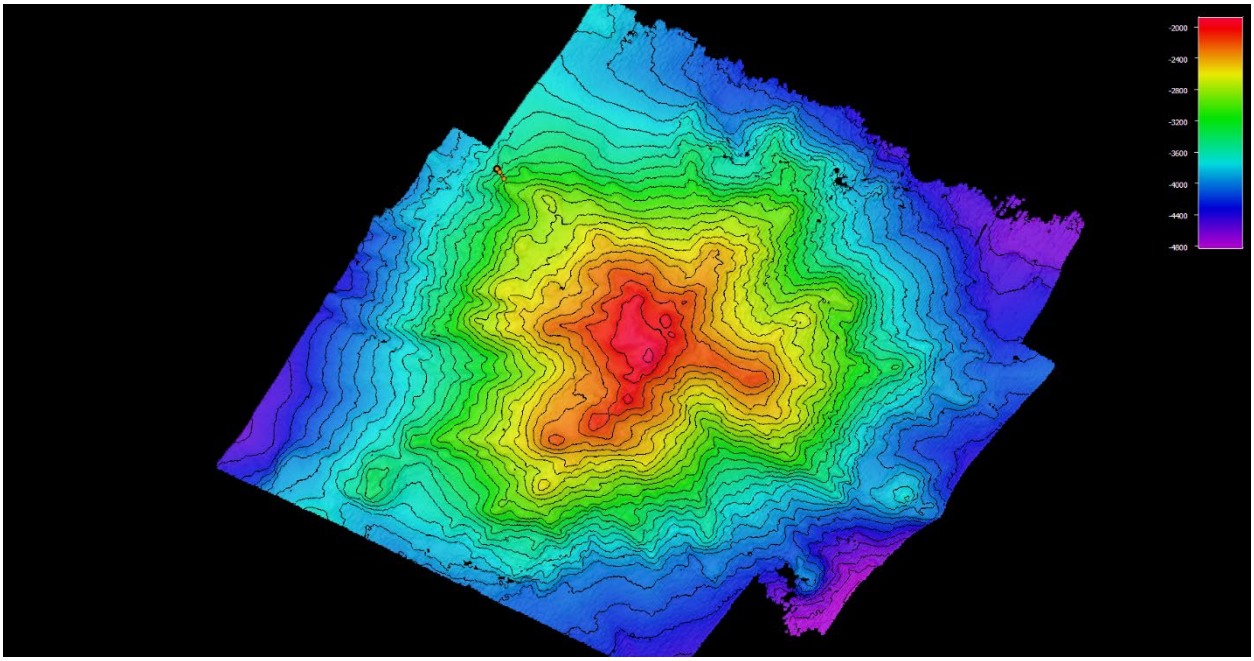

Figure 24. Image showing the dive track of Dive 15 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

During Dive 15 of the 2021 North Atlantic Stepping Stones expedition, the ROV dove to around 3,400 meters (Figure 24) to explore Allegheny Seamount. The geology and substrate morphology encountered on this dive was some of the most varied seen during the expedition. The geology was diagnostic of the construction and destruction processes that have acted on the seamount. Biological observations were much more diverse than expected, given the depth of the dive.

The dive began on a rock debris apron with a mix of sediment and blocks of volcanic material. The ROV then crossed over mixed pavement, rock debris, sediment, and tabular failure substrate on an overall moderate-gradient sloped bottom. The ROV recorded impressive stacked sheet lava flow layers and abundant evidence of downslope transport of large rocks and tabular blocks, which provided the background for the dive.

The sponges were particularly diverse during this dive. *Stelodoryx* sp., *Hylanomema* spp., encrusting and barrel sponges (Figure 25), as well as an unusual, cream-colored sponge thought to be a glass sponge were observed. Corals were also very well represented, particularly by *Anthomastus* sp. and bamboo corals, as well as *Bathygorgia* whip corals, *Stauropathes* black corals, small primnoids, and octocorals. Within the deep cracks of the final sloped overhang area a potentially new and unusual morphotype of a *Chrysogorgia* coral was observed. Cerianthid anenomes were also observed (Figure 25).

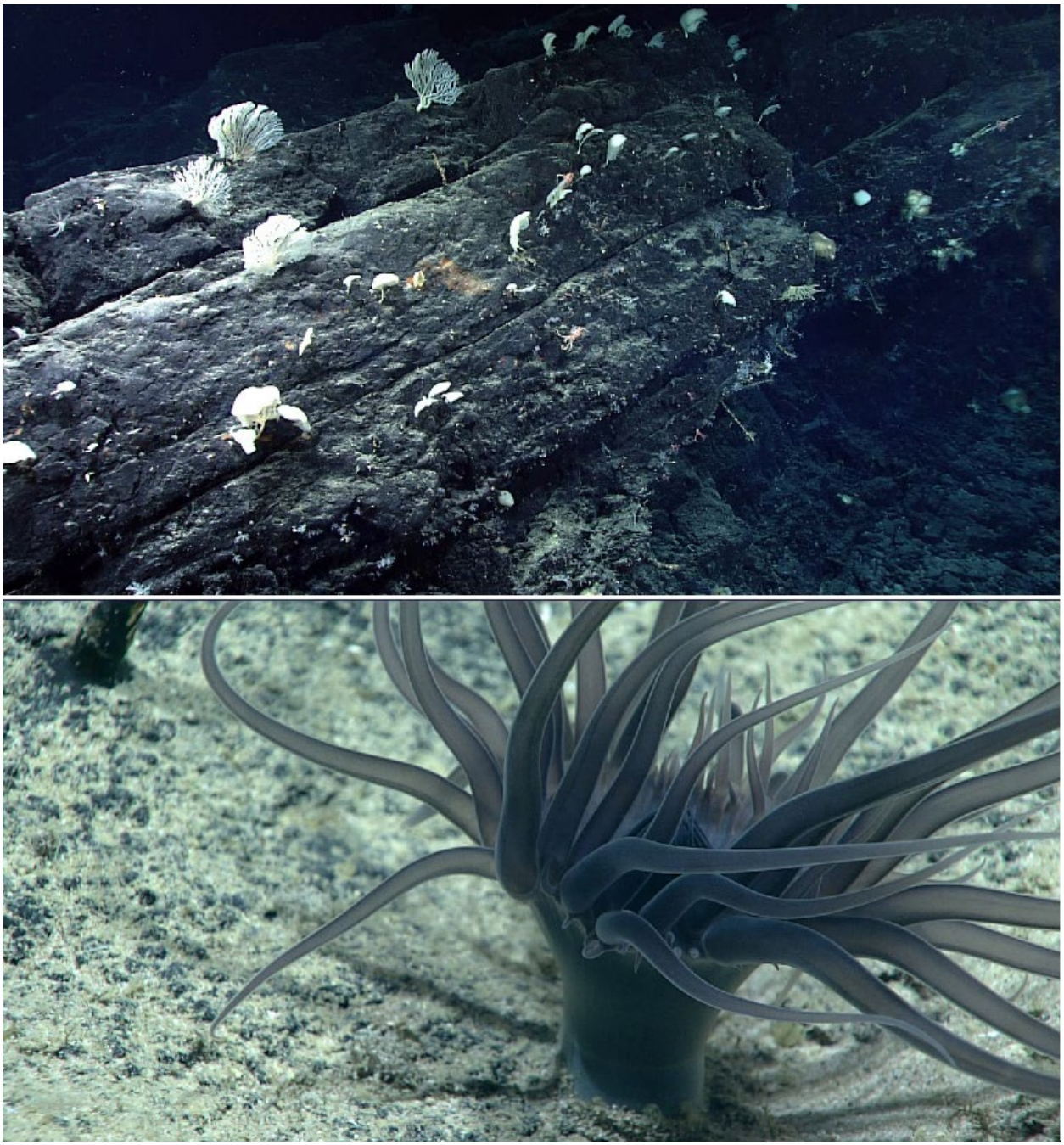

Figure 25. Coral and Sponge vulnerable marine ecosystem indicators observed on Dive 15 during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration. Dipping sheet flow layers rich with biodiversity including multiple *Stelodoryx* sp. and other sponges. (upper) and cerianthid anenomes (lower) were observed.

New England Seamount Chain

Dive 16: Gosnold Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive16/welcome.html

https://www.youtube.com/watch?v=3q37W-96nwg

Dive 16 of the 2021 North Atlantic Stepping Stones expedition took place on Gosnold Seamount, within the New England Seamount Chain, starting at a depth of approximately 3,200 meters (Figure 26). The ROV arrival on the bottom was met with a spectacular and unexpected field of ferromanganese nodules blanketing the seafloor. This nodule field continued for the entire length of the bottom transect, until the slope gradient began to increase and larger ferromanganese nodules and ferromanganese-encrusted cobbles and boulders entered into the mix. High densities of some species, including small primnoid octocorals, sponges (Figure 27), and *Parapagurus* sp. hermit crabs, seen throughout.

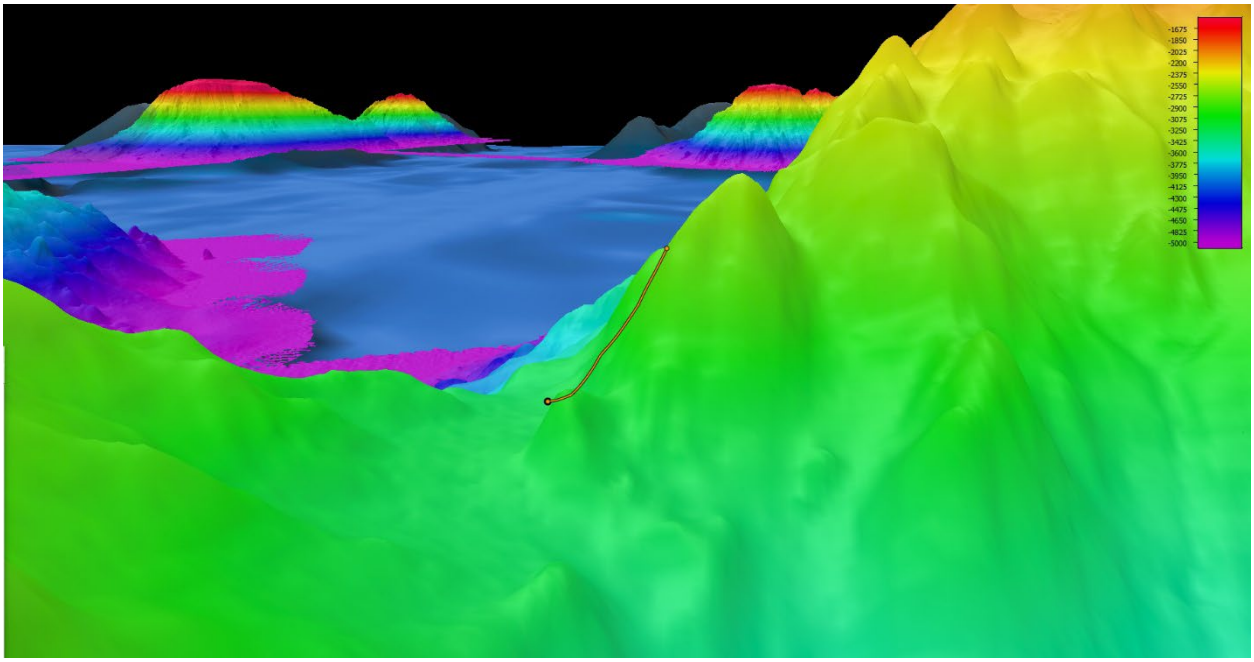

Figure 26. Image showing the dive track of Dive 16 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

Figure 27. Mushroom sponge vulnerable marine ecosystem indicator observed on Dive 16 during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition led by the NOAA Office of Ocean Exploration.

New England Seamount Chain

Dive 17: Gosnold Seamount (Shallow)

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive17/welcome.html

https://www.youtube.com/watch?v=Ty1ReHymQDE

Dive 17 of the 2021 North Atlantic Stepping Stones expedition took place on Gosnold Seamount. This was the second dive of the expedition on Gosnold, this one taking place at a much shallower depth, on the summit plateau at the northwest end of the seamount (Figure 28).

Much like Dive 16 on Gosnold Seamount, upon arrival to the seafloor, the ROV found abundant ferromanganese nodules as well as seafloor extensively modified by high currents that seem to have been persistent in the region for some time. Diversity and density of biological communities were high throughout most of the dive, with many species of large corals (Figure 29) growing on larger ferromanganese nodules and a wide range of sponges, brittle stars, stalked crinoids, and large sea stars were observed as well. Coral diversity was high throughout the dive, and the ROV encountered black corals (*Bathypathes*, *Stauropathes*, *Leiopathes*, *Telopathes*, and *Parantipathes*); bamboo corals (several species of Keratoisidae and *Acanella*); octocorals (*Paragorgia*, *Metallogorgia*, *Iridigorgia*, *Clavularia rudis*, *Anthomastus*, *Hemicorallium*, and *Chrysogorgia*); and the scleractinian, *Enallopsammia rostrata*. Pelagic gelatinous animals were present throughout the dive, which, combined with the high benthic biodiversity, suggests this is potentially a highly productive area.

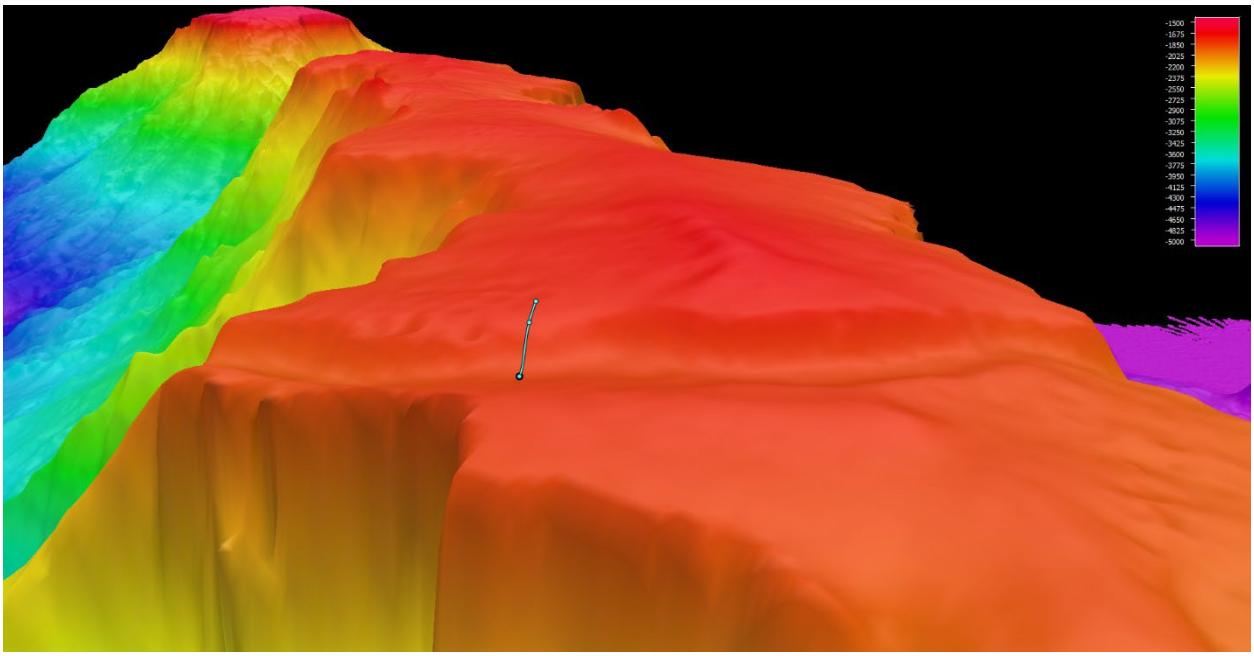

Figure 28. Image showing the dive track of Dive 17 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

Figure 29. Image of a bublegum coral *Paragorgia* sp. colonized by a zoonthid anemone (yellow). Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

New England Seamount Chain

Dive 18: Asterina Seamount

https://oceanexplorer.noaa.gov/okeanos/explorations/ex2104/dives/dive18/welcome.html

https://www.youtube.com/watch?v=sVW0EFMP0PA&list=PLvuqYlgyQQ6bJsbLjX3ePZAujxJkkm3md&index=20&t=2s

"Asterina" Seamount is the easternmost of three small star-shaped seamounts west of Kelvin Seamount, within the New England Seamount Chain (Figure 30).

Seafloor geology primarily consisted of large, sediment-free, ferromanganese-encrusted lobate and pillow lava outcrops and pockets of sediment and gravel cover. Biological observations included multiple types of glass sponges, anemones, bamboo and black corals, sea pens, and several individuals of rare rock pens (Figure 31) of an unknown species that also set a new depth record for rock pens in the Atlantic.

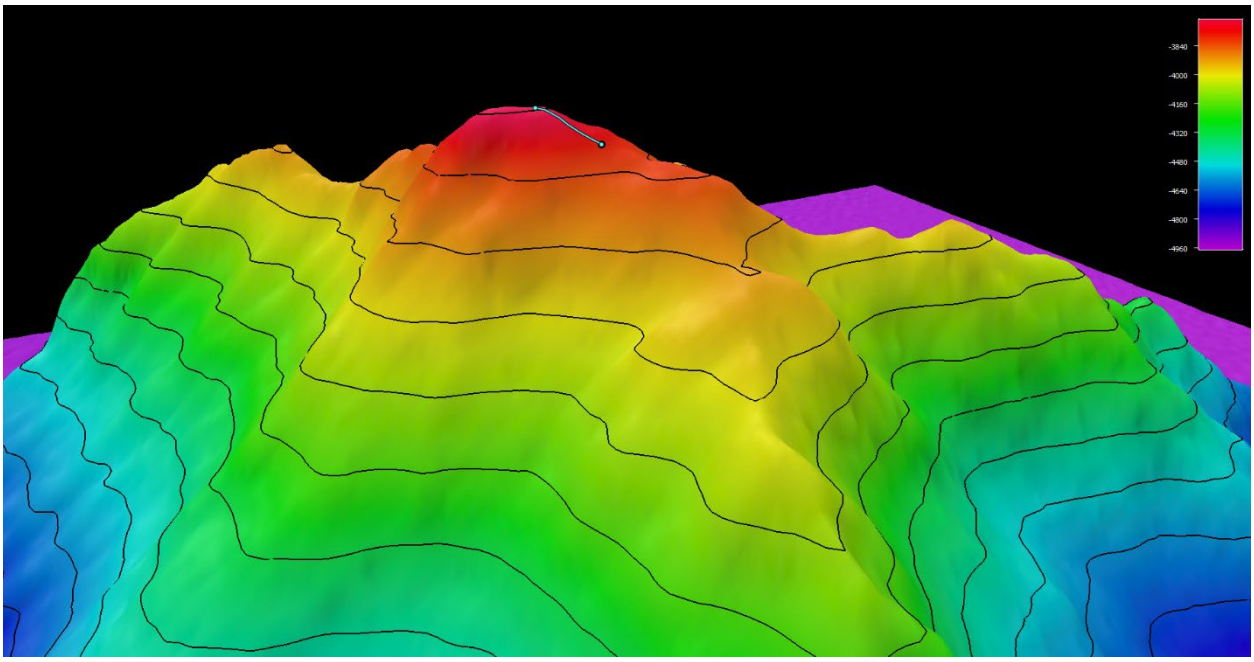

Figure 30. Image showing the dive track of Dive 18 of the 2021 North Atlantic Stepping Stones expedition. Scale is water depth in meters. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

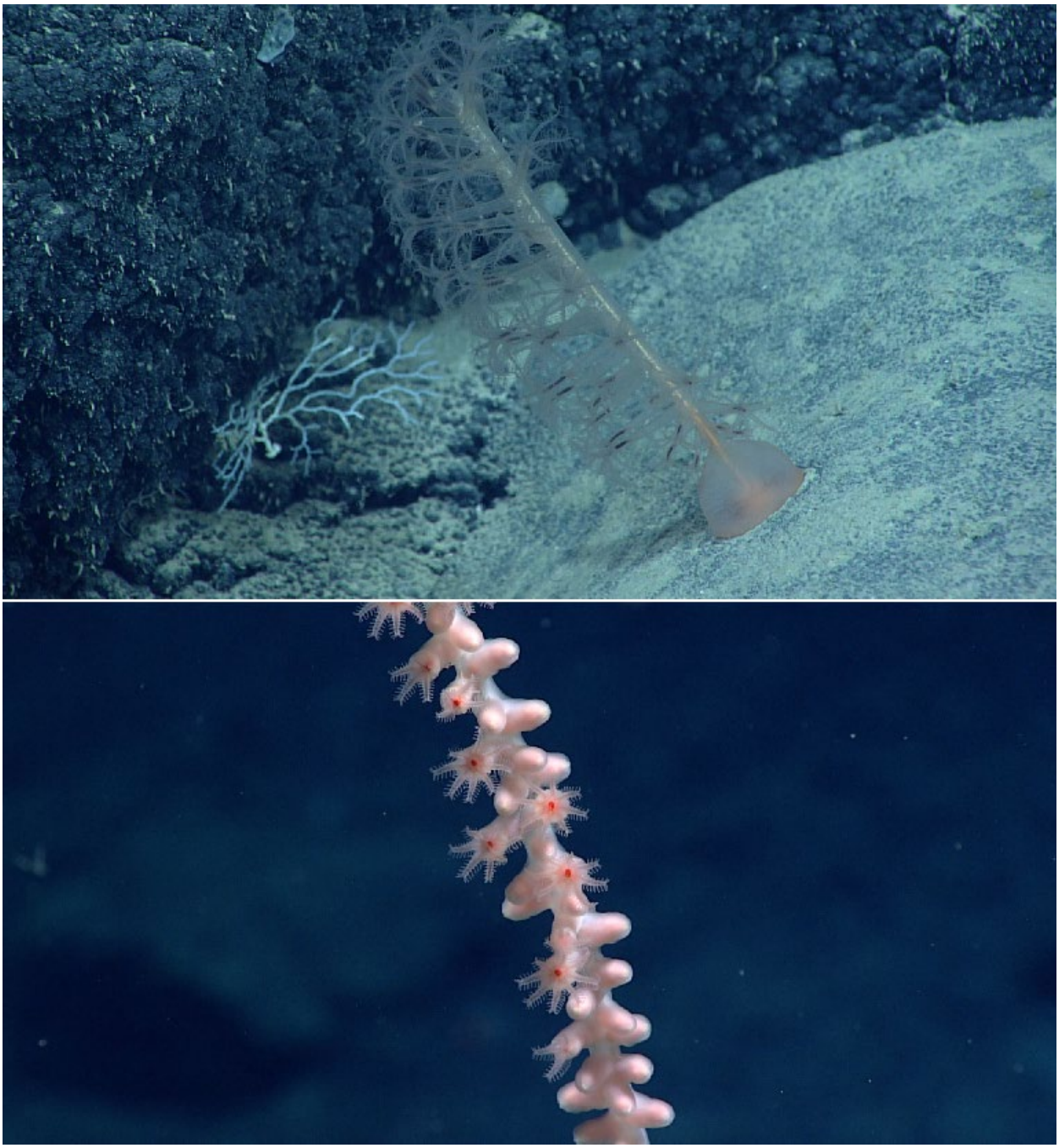

Figure 31. Image of a rock pen (upper) and a bamboo coral (lower) observed on Asterina Seamount. Image courtesy of NOAA Ocean Exploration, 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts.

Discussion

The thirteen ROV dives conducted by the *Okeanos Explorer* in 2021 in the NAFO area surveyed 6 seamounts in the Corner Rise (Figure 32) and 7 seamounts in the New England (Figure 33) Seamount Chains. These areas are also considered Ecologically or Biologically Significant Areas (EBSAs) by the Convention on Biological Diversity (CBD) (https://chm.cbd.int/database/record?documentID=204106). NAFO VME Indicator taxa identified on the dives were Deep-sea Sponges, Stalked Crinoids, Small and Large Gorgonian Corals, Black Coral,

Stony Coral, Sea Pens, Xenophyophores, Stalked Crinoids and Cerianthid Anemones, with only the Stalked Tunicates and Bryozoans not being specifically identified to date (note that they are likely present but just not confirmed). In particular, the rock pen, a rare type of sea pen that is able to attach to rock, was observed and it is likely that several species of sponge and coral are new to science (samples have been taken of some for future determination). At two of the seamounts the VME Indicators formed extensive habitats representing VMEs. In the Corner Rise Seamount Chain VMEs were observed on MacGregor Seamount (Dive 08) where deep sea sponge grounds were identified while coral gardens composed of large and small gorgonian corals and sponges were seen on Caloosahatchee Seamount (Dive 11) outside of the NAFO Convention Area (Figure 32). Even the deepest dives at ~4,000 m observed VME indicator taxa. Collectively these ROV dives support the presence of VME Indicators on the seamounts to depths of 4,000 m and more.

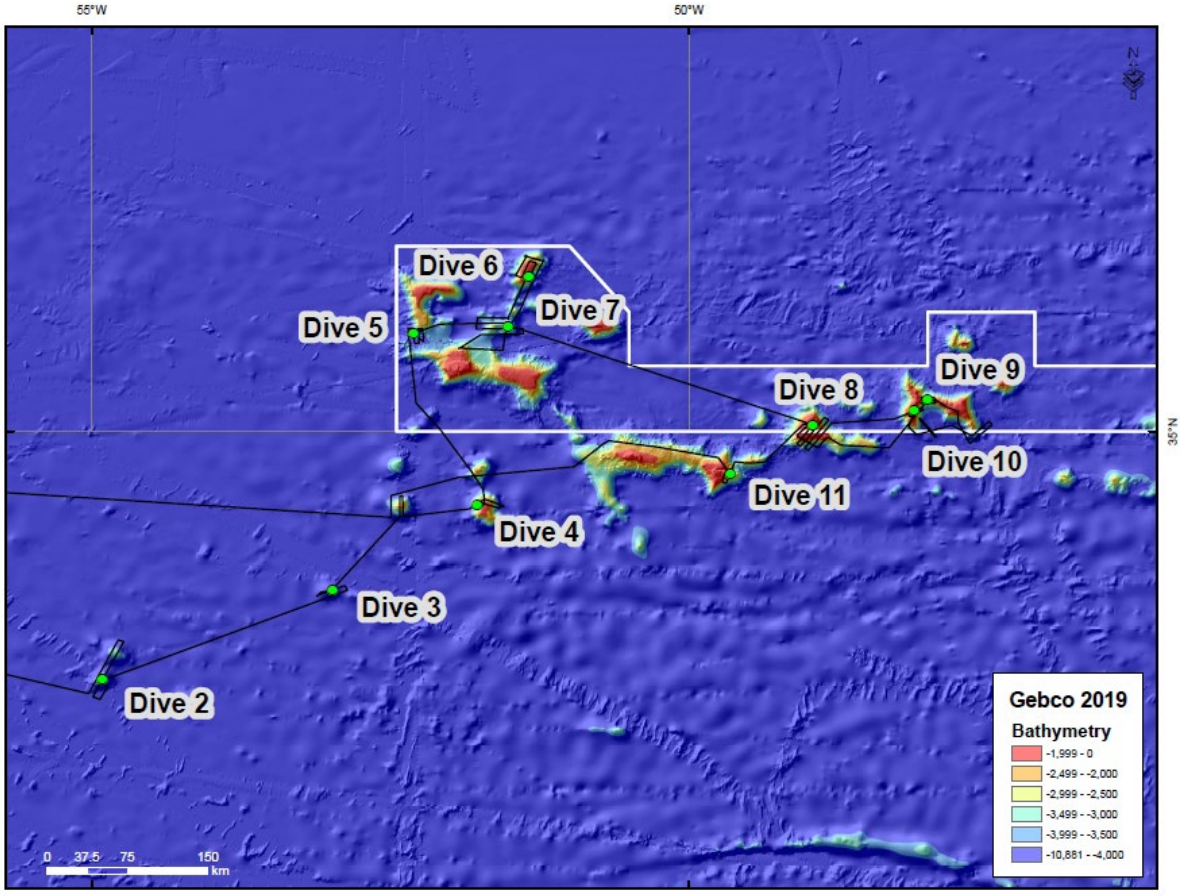

Figure 32. Location of the six seamounts surveyed during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition. Dives 5, 6, 7, 8, 9 and 10 are inside the NAFO Corner Rise Seamount Closure (white line) which comes into effect January 1, 2022.

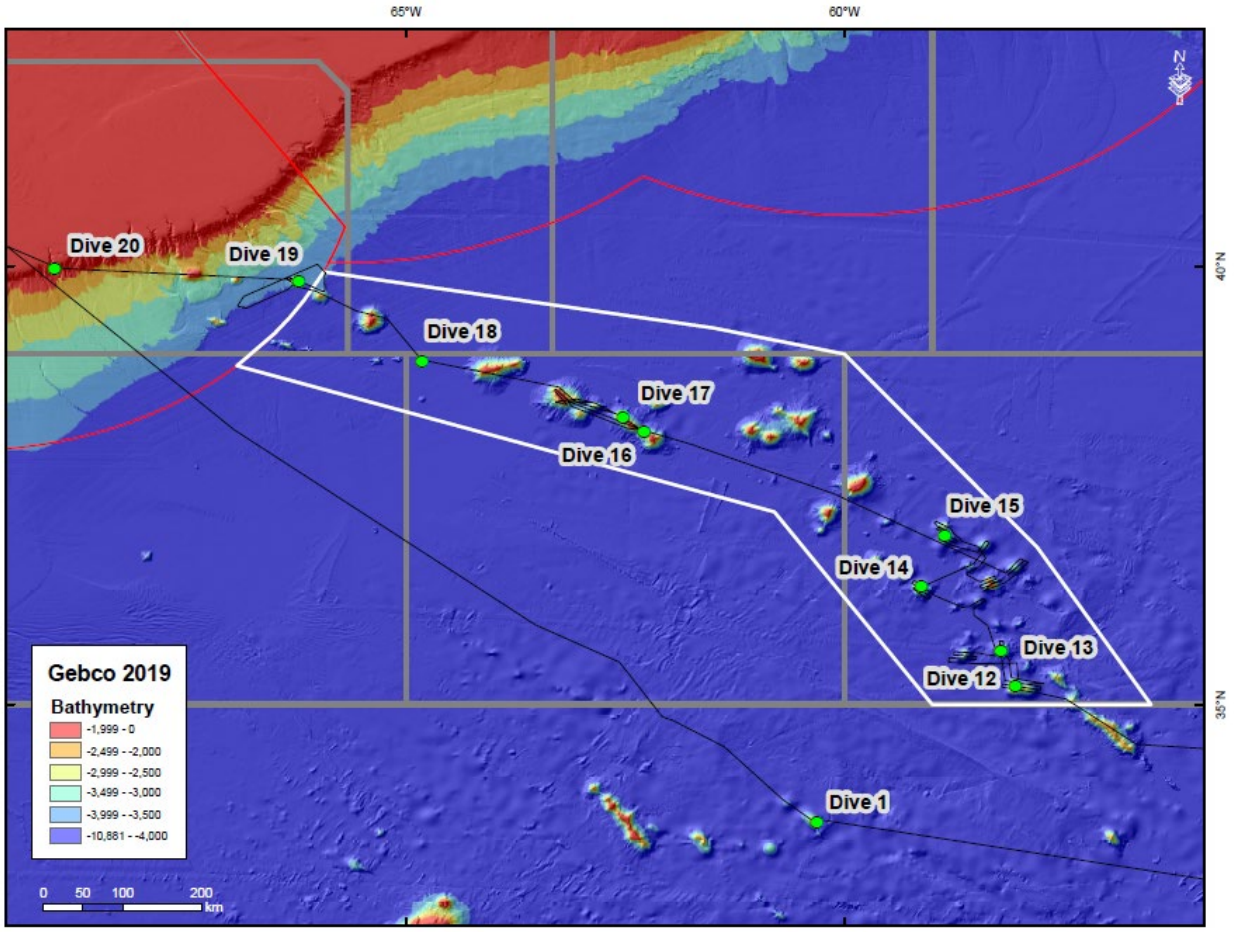

Figure 33. Location of the seven seamounts surveyed during the 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts (EX-21-04) expedition. Dives 12, 13, 14, 15, 16, 17 and 18 are inside the NAFO New England Seamount Closure (white line) which comes into effect January 1, 2022.

Acknowledgements

The 2021 North Atlantic Stepping Stones: New England and Corner Rise Seamounts contributes to NOAA's Atlantic Seafloor Partnership for Integrated Research and Exploration (ASPIRE), a major multiyear, multinational (USA, Canada, EU) collaborative field program focused on raising collective knowledge and understanding of the North Atlantic.