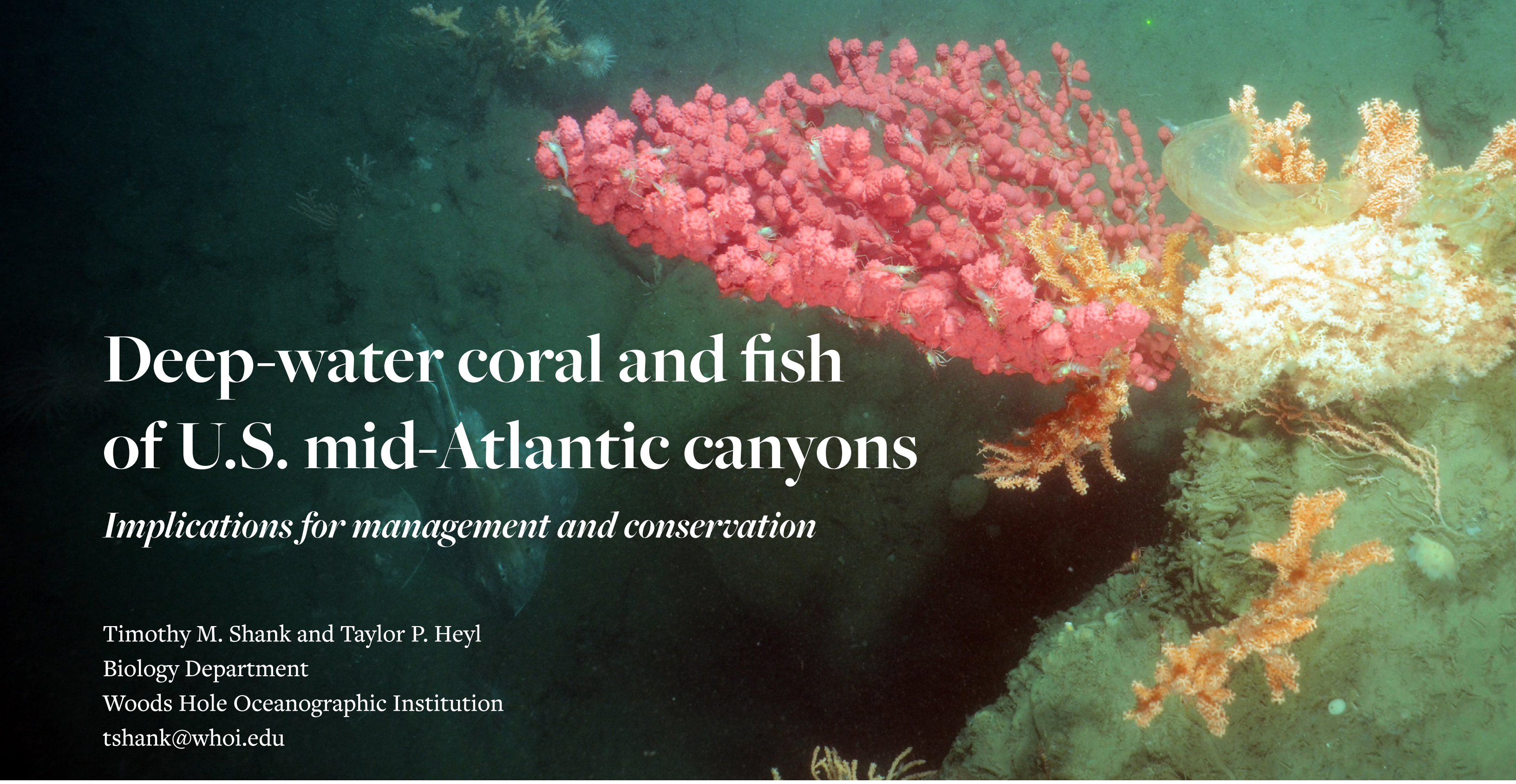

Deep-water coral and fish of U.S. mid-Atlantic canyons

Implications for management and conservation

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INTRODUCTION

Submarine canyons like those found off the Northeast and Mid-Atlantic U.S. coast are some of the most productive deep-sea habitats, hosting remarkably high biological abundance and diversity. Animals living in these hotspots are vulnerable to human disturbance and rapidly changing oceanic conditions. Despite their high potential for containing undiscovered new species and as-yet unknown natural resources, more than 90 canyons along the U.S. East Coast remain largely unexplored.

We investigated the Mid-Atlantic Canyons to explore patterns of animal life and to compare habitat types within and among the canyons. The goal of this study was to improve understanding of the location and diversity of deep-sea canyon ecosystems within U.S. territories. This knowledge will support informed decision-making about activities that could affect the life and resources found in these canyons, which include unique habitats worthy of protection, valuable commercial fisheries, and potential biomedical and pharmaceutical products.

This Executive Summary presents results of 28 surveys using a towed digital camera platform in July 2013 and August 2014 in the Mid-Atlantic region (see Appendix). This included seafloor mapping and visual analysis of more than 45,000 images from Ryan, Carteret, Lindenkohl, Spencer, Washington, Wilmington, Leonard, and Accomac Canyons. Results of this analysis found that 13 major types of deep-water corals dominate life in these eight canyons and also provided information on the broader composition and distribution of ecosystems in Mid-Atlantic canyons.

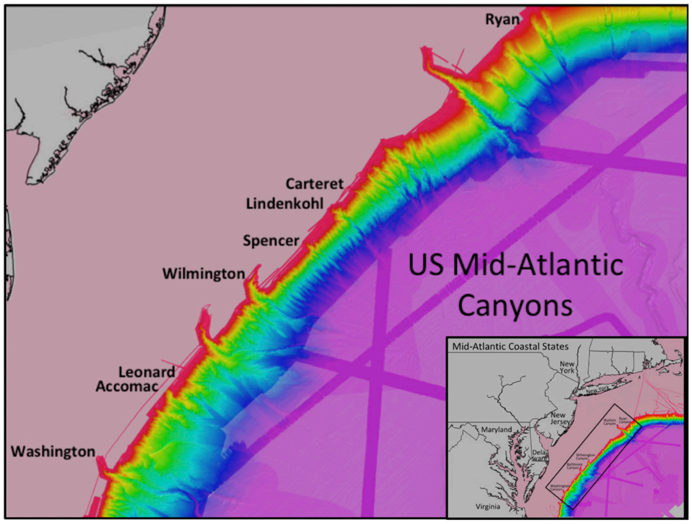


Figure 1: Canyons investigated in the U.S. Mid-Atlantic Region.
Top: Paragorgia bubblegum and Acanthogorgia corals on a rock wall in Wilmington Canyon (512 meters).

Acknowledgements: This report supported by the Mid-Atlantic Regional Ocean Council; project support from the NOAA Deep-Sea Coral Research and Technology Program; Martha Nizinski, Smithsonian Institution, project partner; technical support from the WHOI MISO Facility.

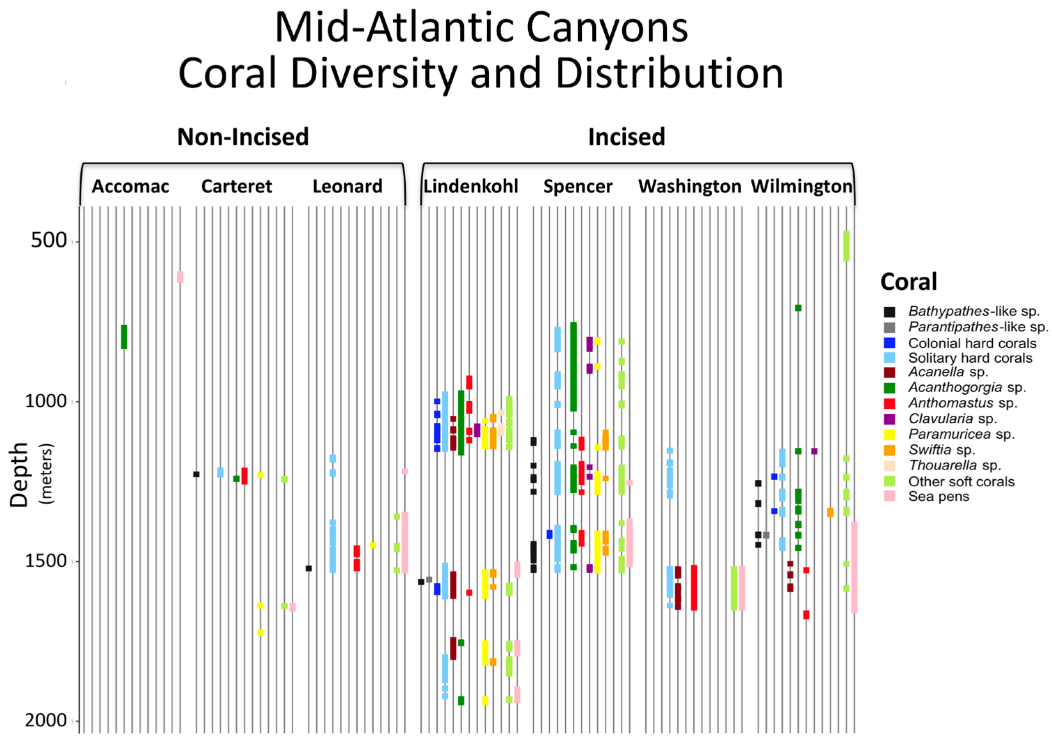


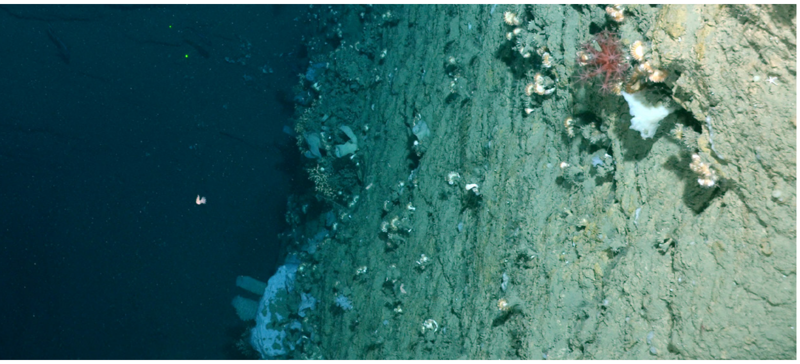
Figure 2: Distribution of coral by depth within Mid-Atlantic canyons.

1. CORAL ECOSYSTEMS

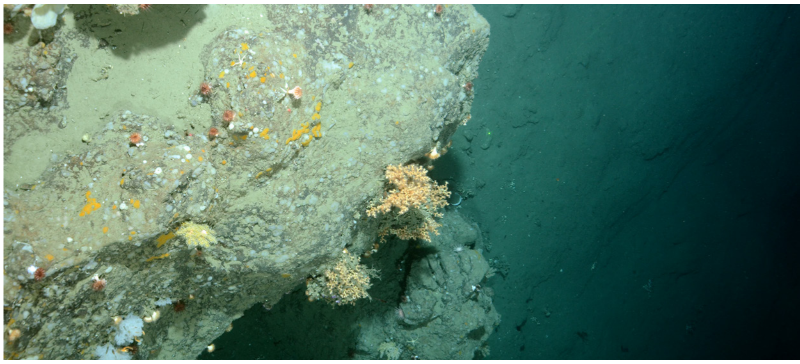
Our work found that deep-water corals are the most significant seafloor ecosystems in the canyons, often dominating the landscape, despite growing only microns a year (thousands of these corals are likely more than 500 years old, Roark et al., 2006). While corals occurred broadly between 700 and 1850 meters (2300 and 6050 feet), the greatest diversity and abundance occurred between 800 and 1600 meters (2624 and 5,250 feet). Scientists have known for over two decades that deep-water corals are critically important components of deep-sea ecosystems that provide substrate, refuge, and nurseries to support more than 3,500 invertebrate species worldwide, as well as commercially important fish species (Shank, 2010). Deep-water corals support diversity by building reef-like structures, or as single colonies that form large seafloor aggregations. These corals also provide biomedical resources that currently help treat more than 20 human diseases, including treatments for cardiovascular disease, leukemia, and osteoporosis.

However, corals and their associated biological communities are highly vulnerable to many of the changes occurring regionally and globally, including rising ocean temperatures, declining pH (acidification), and physical damage from bottom trawling and other destructive seafloor activity.

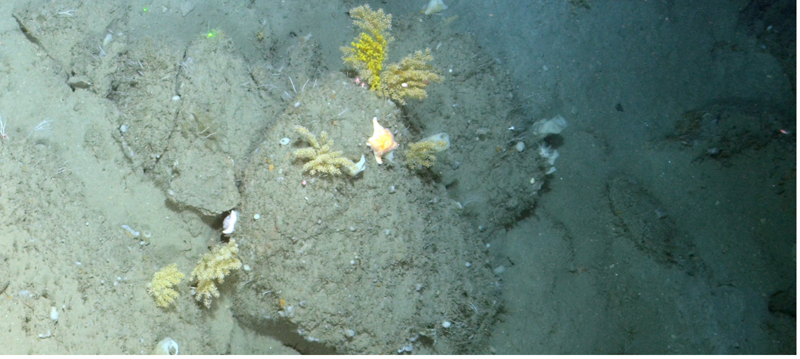
The diversity and abundance of corals varied among the canyons surveyed. The four largest canyons hosted a greater diversity of corals, fish, and rocky hard-bottom habitats than the smaller canyons. Hard-bottom seafloor has long been known to support a greater diversity of deep-water corals, as it provides a



Hard cup corals on a vertical wall in Wilmington Canyon (1157 meters).



Soft corals and glass sponges inhabiting the edge of a wall in Lindenkohl Canyon (1210 meters).



Soft corals living on rocky outcrops in Spencer Canyon (approx. 1300 meters).

Synaphobranchid eels in Spencer Canyon (850 meters).

secure anchor for corals on rock and is a sign of active currents that can bring nutrients up from deep water. Lindenkohl canyon hosted the greatest coral diversity of reef-building and habitat-forming colonial hard corals. In contrast, the three smallest canyons held the lowest diversity, with Accomac inhabited only by Acanthogorgia soft coral and sea pens over the observed depth, followed by Leonard and Carteret Canyons.

2. CANYON HABITATS

The patterns of coral diversity and distribution within and across seven Mid-Atlantic Canyons suggests that those that cut into the continental shelf ("incised") experience a greater transport of organic material through them, and thus are more productive and nutrient-rich to support corals and other organisms than canyons that are not incised. Thus, differences in productivity between incised and non-incised canyons may explain the remarkable observed differences in diversity. Sedimented habitats were found at the heads of all canyons and were largely unoccupied by deep-water corals (sea pens excepted), while vertical walls and their upper margins were the habitat of greatest coral abundance and diversity. Solitary cup corals and Anthomastus were richest along vertical walls, including slopes greater than 45°, in every canyon, with the exception of Accomac, which had no observed vertical wall structures. In all areas of steeply sloping rock, scleractinian cup corals and colonial corals were the most abundant. At least 10 other types of soft corals (Figure 2), including bamboo whip corals, Anthamastus soft corals, and associated sponge communities, were present in these areas. We suggest that steep canyon walls and rugged topography interact with fast-moving currents to bring nutrients to attached or fixed hard corals, making these locations of primary importance to support persistent coral habitats. In contrast, large areas of sediment, for example in Ryan Canyon, supported communities of ceriantharid tube anemones, sea cucumbers (holothurians), urchins (Phormosoma), bamboo corals, and the soft coral Acanella, which grow on small pebbles with the sediment. Regardless of the canyon, sea pen corals dominated almost all observed areas of extensive sediment, which was either at the shallower heads of the canyons (e.g., Accomac) or in deeper regions between about 1400 and 1600 meters in ponded sediments along the main floor of the canyons (e.g., Leonard, Lindenkohl, Spencer, Washington, and Wilmington). Thus, canyon seafloor morphology, specifically steep slopes, vertical rock faces and rugged topography, promote the establishment of extensive coral and fish communities. Such information can be used to create predictive models of where extensive coral communities are likely to exist in currently unexplored canyon regions.

3. NOTABLE DIFFERENCES AMONG CANYONS

There were many interesting differences in the location of similar coral species between canyons. For example, we observed black corals (e.g., Bathypathes) in greatest abundance and widest distribution in Spencer Canyon, but these were completely absent from Washington and Accomac Canyons, and only rarely observed in Lindenkohl, Leonard, and Carteret. There were single occurrences of the bottlebrush black coral Parantipathes in Lindenkohl and Wilmington Canyons but none in any of the other incised canyons. We did not observe the soft white coral Thourella in any of the Mid-Atlantic Canyons, but did observe it in the more northern Ryan canyon. The yellow fan coral Paramuricea and red plexaurid fan coral Swiftia had remarkably similar distributions in Lindenkohl, which held the greatest abundance of Paramuricea down to about 1900 meters, and Spencer (to about 1600 meters). Paramuricea hosting brittle stars were also present in Carteret and Leonard Canyons, but absent in Accomac, Washington, and Wilmington canyons. The red fan coral Swiftia was present only in Lindenkohl and Wilmington Canyons. These rare occurrences and marked absences are of particular importance in the consideration of any comprehensive management plan for the Mid-Atlantic and Northeast Canyon regions.

4. FISH

We identified least 45 fish species across the Mid-Atlantic canyons between about 400 and 2000 meters. Fish aggregations were most prevalent, including one image with more than 50 individuals, in soft sediments near canyon heads or locations adjacent to vertical walls populated by deep-water coral communities. Fish assemblages also appeared to be largely structured by depth (Figure 3), but some species such as synaphobranchid eels, the most abundant fish across all canyons, displayed broad

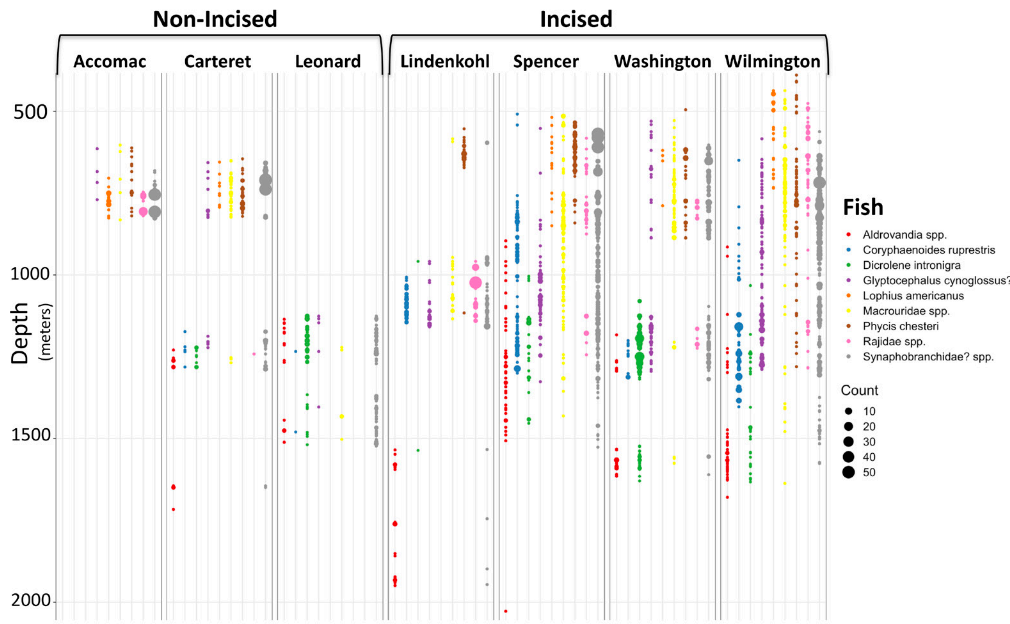


Figure 3: Distribution and abundance of fish with depth among canyons.

depth ranges. Several species, including synaphobranchid eels, the ray-finned fish Coryphaenoides rupestris, and skates, displayed high local abundance where steep features like outcrops and vertical walls dominated. While commercially important monkfish (Lophius americanus) occur at shallow to moderate depths (about 400 to 800 meters) throughout the canyons, we noted key differences between the canyons, including: 1) cusk eels (Dicrolene) were not observed in Lindenkohl despite being found in every other canyon between 1000 and 1500 meters; 2) the slender Halosaur Aldrovandia was abundant between 1000 and 1500 meters in all canyons except in Lindenkohl, where they were present only below 1500 meters; and 3) macrouids (rat tails), Phycis (hakes), and rajids (skates) were notably absent in Leonard while abundant in Lindenkohl. The regularity of fish aggregations near corals suggests that a variety of fish species are taking advantage of food and nursery habitat provided by canyon currents and coral ecosystems.

Our investigations reveal a dominance of coral and fish communities in the Mid-Atlantic Canyons, potentially governed by large-scale canyon shape, depth, habitat types, and habitat availability. High biological diversity and distribution of these fauna may be intimately linked to incised canyons. The resulting steep vertical rocky walls, buttresses, and rugged topography provide: 1) habitats preferred by different types of corals and fish; 2) oceanographic pathways of productivity that support robust coral ecosystems, and the mechanisms that control distribution and diversity of life in the Mid-Atlantic canyons.

5. MANAGEMENT IMPLICATIONS

Our results have strong implications for conservation and management of key U.S. marine resources. In particular, we find that deep-sea coral ecosystems are the foundation for biodiversity in submarine canyons, supporting many ecologically and commercially important species. More than 3,000 invertebrate species live on deep-water corals throughout the worlds' ocean, with new species being identified every year. Studies show that relationships between corals and animals living on them may be life-long (like brittle stars; Mosher and Watling, 2009). It is now critically important to identify coral distributions and these relationships in order to understand the diversity and maintenance of these natural resources in the deep ocean.

Corals are highly vulnerable to disturbance due to their often brittle structures and slow rates of growth. They are also not known to recolonize seafloor areas that have been disturbed. Our work has identified key habitat types that support coral-based ecosystems, from vertical walls to sediment ponds. Until additional canyons along the U.S. east coast can be systematically explored for biological diversity, habitat, and environmental conditions, these regions should be the focus of protection and sustainable management in the U.S. and worldwide.

References: 1. Mosher, C.V., & L. Watling (2009) Partners for life: A brittle star and its octocoral host. Marine Ecology Progress Series 397:81–88; 2. Roark EB, Guilderson TP, Dunbar RB, Ingram B (2006) Radiocarbon-based ages and growth rates of Hawaiian deep-sea corals. Mar. Ecol. Prog. Ser. 327: 1–14; 3. Shank TM. (2010) Seamounts: deep-ocean laboratories of faunal connectivity, evolution, and endemism. Oceanography; 23: 108–122.

APPENDIX

Deep-water coral and fish of U.S. mid-Atlantic canyons

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1.0 METHODS

1.1 FIELD PROGRAMS AND IMAGE ANALYSIS

In July 2013 and August 2014, we conducted TowCam towed camera surveys from the FSV Henry B. Bigelow to explore deep-water canyons of the Mid-Atlantic region of the U.S. and provide information on the composition and distribution of deep-water corals and fish. Operated by the Woods Hole Oceanographic Institution (WHOI), TowCam was supported by NOAA Fisheries Deep-Sea Coral Research and Technology Program and WHOI.

As a result, coral and fish fauna from seven mid-Atlantic canyons and one Northeast canyon have been identified utilizing high-quality, down-looking imagery from 30 TowCam surveys (Table 1). Towed at ~0.25 knots, TowCam recorded 16-megapixel images (f/5.6, 1/60 sec.) every 10 seconds at an altitude of between ~1 and 6 meters above the seafloor. TowCam was equipped with a co-registered Seabird CTD sensor (Seabird SBE25) and altimeter to provide accurate depth and altitude for each image. The images from the TowCam system were recorded internally and subsequently downloaded onto multiple hard drives, providing archived and working duplicates of the data. Each TowCam image of the seafloor was visually screened to generate presence/absence data using iView MediaPro 3.0, R package, and geo-referenced using excel software.

Table 1. A total of 30 TowCam imaging surveys were conducted at a variety of depths resulted in 46,211 seafloor images from which coral and fish fauna in Ryan Canyon and seven Mid-Atlantic Canyons were identified.

Canyon	TowCam Dive # (TCO)	Date	Latitude North	Longitude West	Depth range (meters)	No. of Images
Ryan	01	6/10/13	39 46.3115	71 41.9738	580-599	649
Ryan	02	6/11/13	39 43.9435	71 41.9149	610-771	420
Ryan	03	6/12/13	39 43.3885	71 41.3225	734-1007	2262
Ryan	04	6/12/13	39 41.5694	71 38.3807	916-1197	2079
Ryan	05	6/13/13	39 35.317	71 32.6441	1666-1964	1358
Washington	01	8/6/14	37 25.087	74 24.824	491-874	2946
Washington	04	8/7/14	37 22.5815	74 17.2256	1126-1294	2234
Washington	05	8/8/14	37 18.6327	74 13.0820	1515-1637	1531
Accomac	06	8/8/14	37 49.5832	74 03.0897	497-825	709
Leonard	07	8/8/14	37 49.5877	73 55.7825	1167-1235	1262
Leonard	08	8/9/14	37 47.5576	73 55.4035	1348-1522	1826
Wilmington	09	8/9/14	38 26.2101	73 32.5511	370-540	2484
Wilmington	10	8/10/14	38 19.9080	73 26.4575	1130-1492	2663
Wilmington	11	8/10/14	38 22.7823	73 30.3828	640-818	1266
Wilmington	12	8/10/14	38 21.2480	73 26.7960	574-1031	2023
Wilmington	13	8/11/14	38 17.1090	73 24.7006	1466-1610	2088
Wilmington	14	8/11/14	38 19.2628	73 30.9987	661-847	1518
Spencer	15	8/12/14	38 36.7995	73 07.9232	526-700	1452
Spencer	16	8/12/14	38 35.7369	73 08.8504	757-1020	1585
Spencer	17	8/12/14	38 34.4928	73 07.2639	1035-1313	2090
Spencer	19	8/13/14	38 33.6988	73 06.1232	1302-1522	1291
Spencer	20	8/13/14	38 29.5745	73 04.1680	2002-2121	1325
Lindenkohl	21	8/14/14	38 47.6467	73 01.2698	546-664	1011
Lindenkohl	22	8/14/14	38 46.1905	72 56.5147	945-1139	1184
Lindenkohl	23	8/14/14	38 44.0860	72 53.6111	1527-1607	1396
Lindenkohl	24	8/14/14	38 42.0646	72 50.8507	1762-1946	1292
Carteret	25	8/14/14	38 50.9024	72 45.6454	1373-1478	1003
Carteret	26	8/15/14	38 48.6365	72 43.8868	1651-1724	863
Carteret	27	8/15/14	38 51.2950	72 47.1788	1200-1286	1051
Carteret	28	8/15/14	38 53.7168	72 51.3923	627-823	1350

1.2 ASSIGNING TAXONOMIC IDENTIFICATION: CORALS

Cold-water or deep-sea corals of the mid-Atlantic are a diverse assortment of three Anthozoan subclasses. The subclass Hexacorallia includes the hard or stony corals (order Scleractinia), the subclass Antipatharia includes the black corals (order Antipatharia), and the subclass Octocorallia (Alcyonaria or octocorals) includes the true soft corals (order Alcyonacea) and sea pens (order Pennatulacea).

Assigning taxonomic identification to deep-water corals is difficult from seafloor images alone. Morphological and genetic analysis through DNA barcoding is typically required to resolve an identity of any given coral colony. Therefore, from these imaging surveys alone, a conservative approach was taken to designate or categorize the identify of corals and fish that were considered to have specific characteristics, i.e., coral branching pattern, polyp morphology, and pectoral and caudal fin arrangement in fish. Images containing corals were screened and observations placed into 12 categories (Table 2).

Table 2. Designations of soft and hard corals identified in this study.

Soft Coral Designations	**Order**	**Family**	**Common Name**
Bathypathes	Antipatharia	Schizopathidae	Black coral
Parantipathes	Antipatharia	Schizopathidae	Black coral
Acanella	Alconacea	Isididae	Bamboo coral
Anthamastus	Alconacea	Alcyoniidae	Mushroom coral
Acanthogorgia	Alconacea	Acanthogorgidae	Soft coral
Clavularia	Alconacea	Clavulariidae	Ribbon coral
Swiftia	Alconacea	Plexauridae	Soft coral
Paramuricea	Alconacea	Plexauridae	Soft coral
Thourella	Alconacea	Primnoidae	Soft coral
Sea pens	Pennatulacea	14 Families	Soft corals/sea pens
Other	Several		Largely primnoids
Hard Coral Designations			
Colonial hard corals	Scleractinia	Dendrophylliidae	Stony corals
Solitary hard corals	Scleractinia	Caryophiliidae	Cup corals

The major types of corals observed in US Mid-Atlantic Canyons were categorized by their closest taxonomic designation (Figure 1). Images were screened for 11 identifiable soft coral designations of (Table 2), while hard corals identified in each image were assigned one of two designations. The “Other” designation refers to the identification that a soft coral is present, and not clearly belonging to any of the other designations. In many cases, these corals could be inferred to be primnoids or bamboo corals. Conservatively, the category “Other” was created to capture these observations. With regard to sea pens, colonial soft corals, these could not be identified beyond belonging to the order Pennatulacea.

Figure 1. Major types of corals identified in this study (see Table 2 for full list).

Black Coral: Bathypathes

Black Coral: Parantipathes

Hard Coral: Colonial

Hard Coral: Solitary

Soft Coral: Sea Pen

Soft Coral: Anthomastus

Figure 1. continued

SoftCoral:Swiftia

Soft Coral: Acanthagorgia

SoftCoral:Other

Soft Coral: Swiftia

SoftCoral:Paramuricea

Soft Coral: Clavularia

1.3 ASSIGNING TAXONOMIC IDENTIFICATION: FISH

Fish and their relative abundance between 370 and 2121meters were documented and the occurrence of morphologically distinct putative fish species or higher-order taxonomic groups of related species (herein simply morphs) annotated. In order to ensure accurate and consistent identifications, and to expedite the annotation process, only fish that were well illuminated by the towed camera lighting and captured at a sufficient resolution for identification were annotated. Additionally, we did not typically record observations of small (less than approx. 10 centimeters) eels or eel-like morphs, which were difficult to distinguish to a distinct morph.

To obtain abundance estimates, fish were counted conservatively to avoid counting any individual twice and to be consistent among all taxonomic groups. Among subsequent images in which a fish morph was present, the maximum number of individuals in a single image was recorded. Individuals were not annotated if it was suspected for any other reason that they had been counted prior (for example due to a sudden loss of vehicle altitude or if an individ- ual clearly swam out of and back into the image swath). In cases where fish were abundant and difficult to count accurately the number of individuals, an estimate to the nearest 5 was recorded. In a few instances where the maximum number of fish estimated in a single image greatly exceeded 25, a maximum count of 50 was conservatively used.

Species-specific identifications were given to morphs that were morphologically distinguishable and likely represent a single species. If an individual fish could not be designated to a distinct morph (cryptic or due to poor resolution) it was designated as unidentified and filtered out from the data set. Any morph designated as spp. indicates that it is likely that such a morph contains multiple species. Similarly, question marks in the identifications of morphs indicate uncertainty given the limitations of the imagery, or that small numbers of other cryptic, but closely related species, may be included (e.g. Glyptocephalus cynoglossus?).

Identifications were made with reference to Ross & Quattrini (2015), a published species list from Baltimore and Norfolk Canyons; and FishBase (Froese & Pauly, 2019) for morphometric information, depth ranges, geographical ranges, and other information; to NOAAS Benthic Deepwater Animal ID Guide for examples of fish in each order/family/genus; and an unpublished guide to fish from seamounts in the Northwest Atlantic.

Each of the faunal and habitat catalogues were converted to text data files, exported and merged with ship navigation data using the time-date stamp from the image file names, resulting in excel spreadsheets containing all coral (and fish) presence/absence geo-referenced information. Quality assurance and control for each categorical designation was performed through comparisons of the independent scoring of the same TowCam images by expertly-trained research scientists experienced in identifying deep-water canyon fauna and who have participated with taxonomists in multiple coral identification expeditions.

2.0 DESCRIPTION OF MID-ATLANTIC CANYONS

2.1 RYAN CANYON

Five TowCam surveys in Ryan Canyon between 580 and 2000 meters revealed seafloor dominated by sedimented habitats notably absent of corals. Biological communities of witch flounder and Chaceon crabs (580-750 meters) were present. Between 750 and 1000 meters, supported hard bottom canyon margins, occupied by solitary cup hard corals and “Other” soft corals including bamboo whip corals. Hard bottom habitats continued between 900 and 1200 meters dominated by bamboo corals, Anthamastus soft corals, and scleractinians (cup corals and Solenosmilia) and their associated fauna. At the deepest depths in Ryan canyon, sedimented habitats supported communities of cerianthid anemones, holothurians, Phormosoma urchins, bamboo corals and the soft coral Acanella.

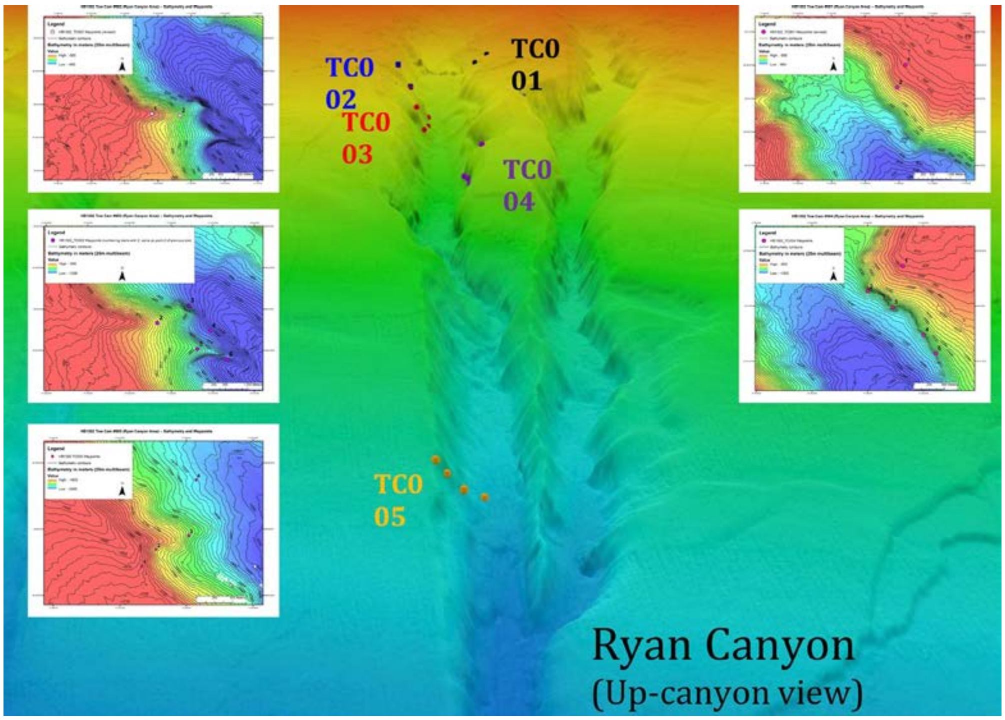


Figure 2: Bathymetric (topographic) map of Ryan Canyon (darker colors are deeper depths: red = ~500 meters, blue = ~2000 meters). Insets show each of the TowCam surveys, with survey #s and track line survey points for each of the 5 tows conducted in 2013.

2.2 CARTERET CANYON

Carteret Canyon is a roughly 24 kilometer long, narrow canyon that incises the shelf by more than 4 kilometers. Four TowCam surveys between 627 and 1724 meters encountered large areas of sediment with a notable absence of corals between 627 and 823 meters on the northeastern flank. Purple urchins, myctophid fish, and brittle stars dominated this highly sedimented seafloor. Deeper along the northeastern side of the canyon (1190 m to 1303 m) revealed the greatest coral diversity in the canyon. Acanthogorgia, Anthomastus, Bathypathes, Paramuricea, and solitary cup corals (as other soft corals) occupied cracks along vertical walls from roughly 1210 to 1230 meters).

Deeper on the northern side of the canyon (between 1370 and 1499 meters) revealed a variety of sedimented slopes and scarps with small rocky outcrops containing no corals. Investigation of the eastern and western rims of the canyon encountered vertical walls between 1646 and 1726 meters hosting Paramuricea, soft corals. Sea pens dominated the sedimented seafloor between the vertical walls joining western-facing steps, while large hexactinellid sponges dominated steep vertical walls, sediment draped areas were occupied by Chaceon crabs, galatheid crabs, brittle stars, purple urchins, white sponges, the large xenophyophore forams and a high abundance of cutthroat eels.

2.3 LINDENKOHL CANYON

The closest incised canyon north of Spencer is Lindenkohl, which incises the shelf by at least 6 kilometers, is more than 26 kilometers long, and has well-defined steeply diving walls, even at the head of the canyon. Surveys between 546 and 1946 meters revealed the notable absence of any corals shallower than approximately 1000 meters. Between approximately 1000 and 1200 meters, vertical walls gave host to a high diversity of coral communities, particularly Acanella, Acanthogorgia, Anthomastus, Clavularia, Paramuricea, Thouarella, and Swiftia (which were exclusively in this habitat). Interestingly, sea pens were not observed above approximately 1500 meters in Lindenkohl. Soft sediment habitats (hosting red crabs, galatheid crabs, white sponges, urchins and octopus) interspersed with frequent large boulders, which provided habitat for Acanthagorgia and bamboo (and other soft) corals. Hard corals, including scleractinian and solitary cup corals were observed on several smaller rocky outcrops, which also hosted several species of soft corals and white encrusting sponges. There were occasional rocky ledges on portions of the vertical walls, creating habitat for skates, solitary hard corals and soft corals, large white hexactinellid sponges, brittle stars and sea lilies in this area. Sponges and solitary cup and bamboo corals and brisingid sea stars dominated the edge of these vertical overhangs. Corals ranging across the greatest number of habitats were Acanella, Paramuricea, and solitary cup corals.

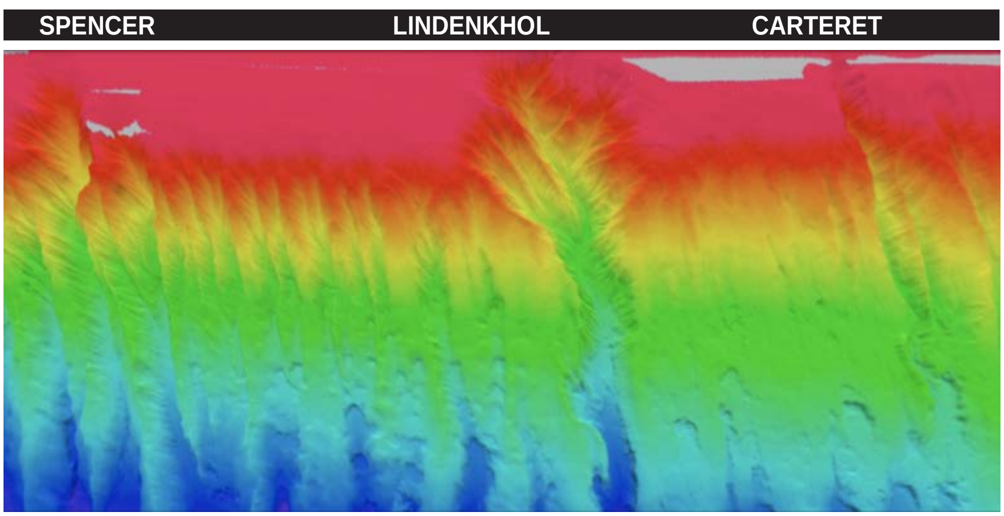


Figure 3: Bathymetric (topographic) map of Spencer, Lindenkohl, and Carteret Canyons (red = ~500meters, blue = ~2000 meters) showing the larger and more greatly incised Lindenkohl Canyon.

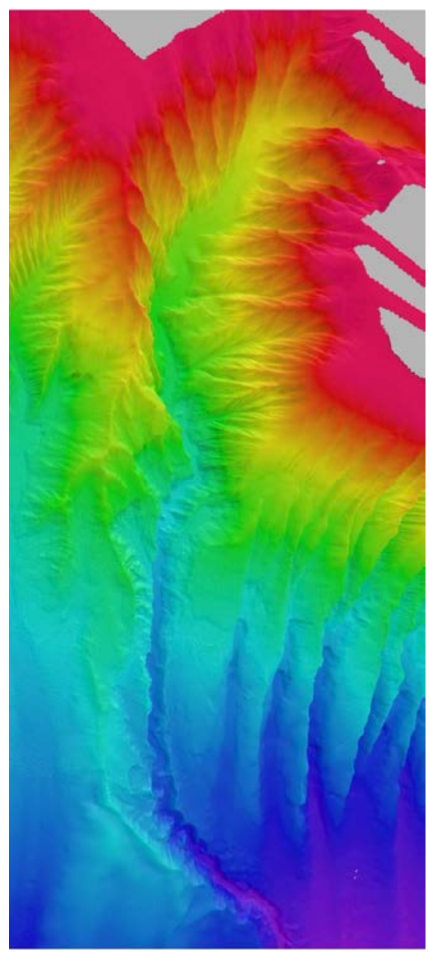
2.4 SPENCER CANYON

Spencer Canyon incises the continental slope by as much as 4 kilometers, extends to more than 2300 meters deep, and is more than 20 kilometers long. The five surveys conducted in Spencer Canyon provided an almost continuous record of observations from 526 to 2121 meters. While coral diversity and abundance was the highest observed in any of the mid-Atlantic (and Ryan) canyons, no corals were observed shallower than 700 meters. Between approximately 750 and 1000 meters, Acanthogorgia, solitary cup hard corals, and Clavularia dominated boulders, outcrops, the top margins of vertical walls, and vertical walls. While Acanthogorgia and cup corals dominated a variety of hard rock substrates from 750 to 1500 meters, the mushroom coral Anthomastus was only observed on or atop vertical walls.

Bathypathes had a shared distribution with Anthomastus on vertical walls, but was also found colonizing a sedimented area (to approx. 1520 meters) and a boulder (approx. 1515 meters). The greatest abundance of the purple soft coral Clavularia encountered in the mid-Atlantic canyons was in Spencer Canyon, clustering at 800 to 900 meters on diverse habitats of boulders, vertical walls and solitary rocks. Deeper, from 1200 to 1420 meters and again at approximately 1520 meters, Clavularia was solely observed on vertical walls. Paramuricea (each hosting large ophiuroid brittle stars) and Swiftia soft corals had a depth distribution that paralleled Anthomastus and “Other” soft corals, most abundant between approximately 1150 and 1520 meters on exposed vertical walls. The greatest concentration of Swiftia, observed here to be the greatest of all of the mid-Atlantic canyons, was at approximately 1110 meters and 1410 meters. Throughout Spencer Canyon, colonial hard corals were only observed at approximately 1400 meters on a vertical wall with sea pens only observed in sedimented habitats that were prevalent between approximately 1250 and 1520 meters, often on layered plateaus or steps between vertical walls. There were no corals observed in the deepest survey between 2002 and 2121 meters. A high diversity of canyon fauna, including white vase sponges, Venus fly trap anemones occurred on vertical and high-relief boulders, cerianthid anemones, red crabs, galatheid crabs, and ophiuroid brittle stars on soft sediment. Fish fauna, including eels and skates were concentrated around vertical walls while ophidiid and cutthroat eels were common over sedimented areas.

2.5 WILMINGTON CANYON

Wilmington Canyon is the largest, longest (more than 62 kilometers) and deepest (more than 2370 meters) of the mid-Atlantic canyons with an incision into the continental shelf of more than 25 kilometers. While other mid-Atlantic canyons (with the exception of Baltimore Canyon) expand their floor widely with ill-defined bounding walls into the abyssal depths, Wilmington maintains a narrow, well-defined canyon channel to its deepest depths. Six surveys between 370 and 1610 meters revealed low relief, sedimented habitats that transitioned to steep-sided cliffs along the western flank of the canyon head. Interestingly, the only corals observed were in the “Other” designation (likely primnoid and bamboo corals) on boulders and vertical cliff faces (370-540 meters). Jonah and red (Chaceon) crabs and anemones were observed on the sediment at approximately 630 and 450 meters, respectively. No black corals, hard corals, or sea pens were observed at these depths. While surveying several steep features, clusters of large of what may be Paragorgia and Primnoa coral colonies were observed on both sides of the canyon near 500 meters depth. Interestingly, there were no corals observed during the survey conducted between 640 and 818 meters. Burrows and red crabs were observed on flat sediment at a depth



Bathymetric map of Wilmington Canyon (red = ~500meters, deep blue = >2000 meters).

range of 580 to 680 meters. Actinaria-like and Actinoscyphia-like (Venus fly trap) anemones were observed on hard rock inhabited by sponges and a white plastic bag was visible. Red rockfish were observed along the hard bottom at about 400 meters. Fish were observed to be in greater abundance along more vertical slopes (approx. 730 meters).

Deeper surveys in Wilmington between 1000 and 1492 meters revealed highly abundant soft corals and solitary scleractinian corals attached to promontory margins (approx. 1250 meters) and laden on vertical walls (approx. 1350 meters). Acanthogorgia also dominated vertical wall faces, scattered boulders, and outcrops. The black corals Bathypathes and Parantipathes were present in small numbers on vertical rock and boulders between 1200 and 1400 meters. Fish were highly abundant on vertical structures (approx. 1150 meters). Other fauna included a benthic octopus on the seafloor (approx. 1400 meters).

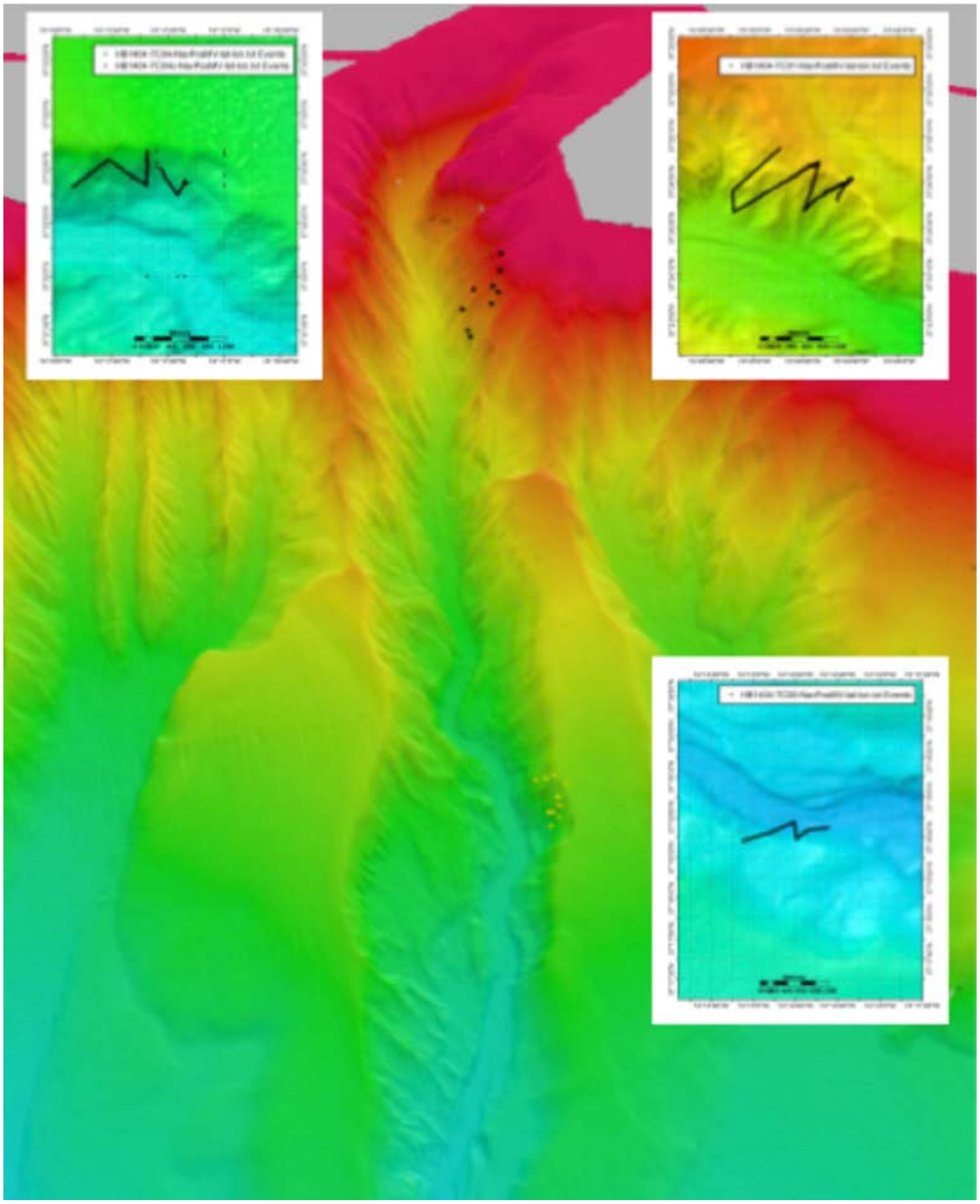
The deepest survey, between 1466 and 1610 meters, found extensive expanses of sediment hosting few non-coral fauna other than white urchins (Hygrosoma) with small burrows. Throughout these sedimented depths, sea pens (perhaps Pennatula sp.) were abundant. Clustering fields of Acanella (likely attached to small rocks in the sediment), scattered Anthomastus, and a few "Other" soft corals were prevalent below 1500 meters. Interestingly, no other corals were observed below this depth. Other fauna included sponges and brisingid sea stars on vertical faces near approximately 1600 meters.

2.6 LEONARD CANYON

A much smaller but wider (approx. 1880 meters) Leonard Canyon lies just north of Accomac Canyon and the two join together at approximately 1920 meters. Leonard does not incise the continental slope as much (approx. 6.3 kilometers) as Accomac, but it hosts two large, steep-walled semi-circular depressions (approx. 700 meters wide and 100 meters deep). Investigation of the northern-most depression between 1167 and 1235 meters revealed abrupt transitions between flat sedimented habitat (with rocks just below the surface) and steep vertical walls of the eastern and western sides of the depression. Sea pens and solitary cup corals dominated both in the sediment and the wall margins. No other corals were observed. Four thousand meters across the canyon and deeper on the southern flank between 1348 and 1522 meters revealed Anthomastus corals mostly atop and in cracks on vertical walls; a few black Bathypathes and soft Paramuricea corals were observed on a vertical wall and coral rubble, respectively. Both sea pens and solitary corals were present across the depths surveyed, but in much greater abundance than on the northern flank and also on vertical walls. Fish, predominantly synaphobranchid eels and pelagic polychaete worms were also associated with smooth sediment slopes. White echinus urchins were part of the low faunal diversity in Leonard. Grenadier fish and urchins dominate the Leonard landscape, but specific slope areas of Leonard appeared to have little to no fauna. Hygrosomid-like purple urchins were observed on soft sediment and Actinernus anemones and Venus flytrap anemones were visible on the canyon wall.

2.7 ACCOMAC CANYON

Accomac Canyon incises the continental shelf to approximately 420 meters and extends to approximately 1730 meters with a maximum width of ~1384m, before it joins a tributary with it's neighboring canyon to the south. A survey at the head of the canyon on the eastern flank of Accomac (approx. 500 meters) revealed heavily sedimented seafloor that changed from relatively flat topography to a steep slope with exposed rock piles and vertical rock walls. Coral communities in Accomac were dominated by Acanthogorgia on rock outcrops and vertical rock walls between 775 and approximately 825 meters. Sea pens, white hexactinellid sponges, galatheid crabs, white urchins and eels occupied soft sediments from 610 to 630 meters. Skates and many species of fish, white hexactinellid sponges, and red crabs (Chaceon quinquedens) were observed over cobble seafloor and sediment chutes. A high diversity of non-coral fauna, including fish, occurred along vertical relief areas.



Bathymetric (topographic) map of the incised Washington Canyon (red = ~500meters, green = ~2000 meters)nsets show each of the TowCam surveys, with track line showing the area covered in the three tows conducted in 2014.

2.8 WASHINGTON CANYON

Surveys in Washington Canyon between 491 and 874 meters revealed no corals and generally low faunal diversity. This was likely due to the lack of hard bottom substrate habitats; only monotonous sediment with no bare rock surfaces were observed. Exposed rock habitats were observed in the deeper areas, often draped in thick sediments. Fish were abundant (e.g., hake and cutthroat eels). Actinoscyphia Venus flytrap anemones were observed attached to hard substrate. Red crabs (likely Chaceon quinquedens) and galatheid crabs (Munidopsis sp.) utilized abundant seafloor micro-relief as habitat. White branched sponges were observed in the highly-sedimented areas of this canyon and abundant at depths near approximately 850 meters.

On the deeper sloping canyon walls (approx. 1500 to 1950 meters) were shards of fallen rock debris, providing habitat for aggregations of solitary cup corals utilizing vertical relief in overhangs. Sea pens, Acanella, and solitary cup corals were common in soft sediments at these deeper depths. However, coral diversity at these depths was the highest of all of the mid-Atlantic canyons, which included all of the corals types (except Thouarella) as well as a large variety of soft corals as in the shallower region, but with the addition of the black corals Parantipathes and Bathypathes (on vertical rock).

Between 1119 and 1338 meters on the northeastern flank of Washington Canyon displayed hard corals, specifically solitary cup corals (possibly Flabellum sp.). At depths of 1192 meters, several images (40) documented small, dead corals (~Acanella sp.) that appeared to have advanced hydroid growth on their skeletons. Fish, including flatfish (i.e., witch flounder) and skates, were abundant on soft sediment. Soft sediments with burrows dominated this depth range in the canyon with red nematocarcinid-like shrimp, cerianthid anemones and pycnogonid sea spiders.

The seafloor in Washington Canyon between 1552 and 1693 meters on the northeastern flank was heavily sedimented with little relief. These sedimented areas hosted stalked sponges, solitary cup corals small octocoral species, and larger whip octocorals with ophiuroid brittle star associates. Abundant Anthamastus soft corals and small red sea pens were observed. Other fauna documented were Acanella-like octocorals, hake fish, cutthroat eels, urchins, Venus flytrap anemones, red (nematocarcinid-like) shrimp, and Chimera fish.

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