Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

NATIONAL MARINE SANCTUARIES CONSERVATION SERIES

Effects of a Lost Shipping Container in the Deep Sea

June 2023 | sanctuaries.noaa.gov
National Marine Sanctuaries Conservation Science Series ONMS-23-05

U.S. Department of Commerce
Gina Raimondo, Secretary

National Oceanic and Atmospheric Administration
Richard W. Spinrad, Ph.D., Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator

National Ocean Service
Nicole LeBoeuf, Assistant Administrator

Office of National Marine Sanctuaries
John Armor, Director

Report Authors:
Sydney McDermott[1,2], Andrew DeVogelaere[3], Jim Barry[4], Amanda S. Kahn[1,2]

1. Moss Landing Marine Laboratories, 8272 Moss Landing Road, Moss Landing, CA 95039
2. San Jose State University, 1 Washington Sq, San Jose, CA 95192
3. Monterey Bay National Marine Sanctuary, 99 Pacific Street, Bldg. 455A, Monterey, CA 93940
4. Monterey Bay Aquarium Research Institute, 7700 Sandholdt Road, Moss Landing, CA 95039

Suggested citation: McDermott, S., DeVogelaere, A., Barry, J., & Kahn, A. S. (2023). *Effects of a lost shipping container in the deep sea*. National Marine Sanctuary Conservation Series ONMS-23-05. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries.

Cover photo: The lost shipping container in 2021. Photo: J. Barry/MBARI

About the National Marine Sanctuaries Conservation Series

The Office of National Marine Sanctuaries, part of the National Oceanic and Atmospheric Administration, serves as the trustee for a system of underwater parks encompassing more than 620,000 square miles of ocean and Great Lakes waters. The 15 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our nation's maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique or endangered species and are important to America's cultural heritage. Sites range in size from less than one square mile to almost 583,000 square miles. They serve as natural classrooms and cherished recreational spots, and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each national marine sanctuary has a tailored management plan. Conservation, education, research, monitoring, and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The National Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the National Marine Sanctuary System. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and cultural sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate. All publications are available on the Office of National Marine Sanctuaries website.

Disclaimer

Report Availability

Electronic copies of this report may be downloaded from the Office of National Marine Sanctuaries website.

Contact

Sydney McDermott
Moss Landing Marine Laboratories
8272 Moss Landing Road
Moss Landing, CA 95039
sydney.mcdermott@sjsu.edu

and

Andrew DeVogelaere, Ph.D.
Monterey Bay National Marine Sanctuary
99 Pacific Street, Bldg. 455A
Monterey, CA 93940
andrew.devogelaere@noaa.gov

Table of Contents

Abstract

Shipping containers are the most common method for transporting goods both domestically and internationally. Maritime shipping poses a threat to benthic communities when containers lost overboard disturb marine habitats and later become colonized as novel hard substrate. One such lost container was discovered in 2004 in Monterey Bay National Marine Sanctuary. The container was visited by remotely operated vehicle in 2011, 2013, 2014, and 2021. High-definition video collected during these visits was used to identify the species present to determine how the community that formed on the container changed over time. A previous study found that the container had ecological effects limited to the surrounding 10 m area, but that, with the exception of a few key taxa such as corals, the faunal community on the container was similar to that occurring on hard substrata naturally present in the deep sea. While we observed significant changes in the presence and dominance of certain species through the study period, the assemblage hosted on the container remained typical of hard substrate communities within Monterey Bay National Marine Sanctuary.

Key Words

deep sea ecology, community ecology, pollution, marine debris, national marine sanctuary

Introduction

Every year, more than 11 million shipping containers arrive at U.S. ports, carried by some of the roughly 6,000 container ships found around the world. Shipping containers as we know them trace back to the early 1950s, when a former box truck driver sought to revolutionize and streamline the process of transporting goods. Malcom McLean recognized the inefficiency of loading loose cargo onto ships and initially proposed driving a box truck onto a ship, detaching the trailer onboard, and reattaching the trailer to a different truck at the destination (Levinson, 2008). This idea was insufficient for McLean, as the chassis and wheels took up space that could otherwise be used for cargo. With the help of engineer Keith Tantlinger, a standardized 33 foot (10.06 m) long aluminum container was designed. These containers could be loaded onto a ship by a crane and stacked, maximizing the cargo that could be carried. Thus, on April 26, 1956, the former World War II T-2 oil tanker SS *Ideal-X* was loaded with 58 containers for its maiden voyage as a container ship (Figure 1). *Ideal-X* departed from Newark, NJ to Houston, TX, where it arrived with all cargo intact, successfully marking the first container-specific shipping journey. The economy of shipment by containers was clear; the cost of shipping loose cargo was $5.83 per ton compared to $0.158 per ton for containers, cementing large-scale container shipping as a profitable and efficient strategy to move goods.

Figure 1. A size comparison of (A) the original container ship *Ideal-X* in 1956 and (B) the modern container ship *COSCO Shipping Leo* in 2020. *Ideal-X* was photographed during its inaugural voyage as a container ship with a maximum capacity of 58 containers on board. In photo B, *COSCO Shipping Leo* was loaded with a fraction of its 15,200 twenty-foot equivalent unit capacity (7,600 full size containers). Photos: (A) United States Merchant Maritime Academy; (B) Jacob Meissner/Unsplash

Since the popularization of transoceanic container shipping in the 1950s, containers of varying sizes and compositions, bearing an unknowable diversity of cargo, have been lost from ships. While reporting lost containers is generally not mandated, in 2021 alone, media and industry newsletters publicly reported that nearly 3,000 shipping containers were lost overboard. These containers pose a unique challenge to track, and are navigational hazards to other vessels, floating for days to months depending on their condition and the nature of the cargo (Breivik et al., 2012; Daniel et al., 2002; Monroy-Velázquez et al., 2020). These stray containers may sit low in the water, making them difficult to spot or track as they float away from their ship of origin

(Daniel et al., 2002) and eventually sink or are beached. Once on the seafloor, containers, which are designed to withstand inclement weather and global transport for upwards of 25 years, may take centuries to degrade, potentially releasing any number of toxins from their internal contents and external coatings (Herr, 2014; Monroy-Velázquez et al., 2020).

The number of shipping containers that have sunk to the bottom of the ocean is unknown, though up to 10,000 containers may be lost overboard each year (BBC News, 2010; Frey & DeVogelaere, 2014; Voytenko, 2019). The World Shipping Council estimates a loss of fewer containers per year; the council reports that an average of 1,382 containers were lost annually in the 12-year period between 2008 and 2019, a total of 16,584 containers within that time span (World Shipping Council, 2020). Only rough estimates are available for the number of containers lost before 2008 (World Shipping Council, 2020).

One lost shipping container found on the deep sea floor has served as the focus of the only long-term study of the impact of shipping containers on deep-sea communities. This report describes 17 years of observation of this container, located in the Monterey Submarine Canyon within Monterey Bay National Marine Sanctuary (MBNMS).

On February 26, 2004, a winter storm caused the loss of 24 standard sized (12.2 x 2.4 x 2.6 m, 4-ton empty weight, 2 twenty-foot equivalent unit) metal shipping containers from the container ship M/V *Med Taipei*. Fifteen of those containers were lost within MBNMS (36° 38.5' N, 122° 28.7' W) at 12:45 AM (Frey and DeVogelaere, 2014). Nine additional containers were lost outside of the sanctuary boundaries (35° 06.9' N, 121° 54.0' W) at 9:08 AM that same morning (Frey & DeVogelaere, 2014). Only one of these containers has been found. It was inadvertently discovered on June 9, 2004 by scientists at the Monterey Bay Aquarium Research Institute (MBARI) during a research dive by remotely operated vehicle (ROV) *Ventana* (dive V2522). The container (serial number TGHU7712262), reported to contain 1,159 steel-belted automobile tires, was found on soft sediment at a depth of 1,281 m. Following its discovery, the National Oceanic and Atmospheric Administration (NOAA) Damage Assessment, Remediation, and Restoration Program provided an evaluation of the potential financial impacts caused by the loss of the 15 containers within the sanctuary. This assessment resulted in $3.25 million paid to NOAA by the owners and operators of M/V *Med Taipei*: All Oceans Transportation, Inc.; Italia Marritema SpA; and Yang Ming Transport Corporation. Along with a series of mitigation projects, these funds supported periodic research cruises to revisit the container and assess its potential impacts on the diversity, abundance, and assemblages of nearby benthic organisms.

Study of the potential impacts of the container began on March 9, 2011, seven years after its initial loss and sinking. The video observations and cores collected during the study were used to assess faunal patterns and sediment characteristics in one of the first efforts to describe the ecological processes sparked by the introduction of a lost shipping container in the deep sea (Taylor et al., 2014). The study found that ecological effects were restricted to within 10 m of the container, and colonizing faunal communities differed from the surrounding sediment-dwelling community. However, with the exception of a few key taxa, fauna on the container were generally similar to those found in rocky habitats at comparable depths. Further visits in 2013, 2014, and 2021 extended this observational case study to span 17 years (Figure 2). Here we describe the observations made during these visits and assess the overall abundance, diversity, and assemblages of species, as well as changes in community composition over time.

The container is located at a depth of 1,281 m on soft sediment in a region called Smooth Ridge, on the upper continental slope in MBNMS (Figure 3). Temperature, salinity, and dissolved oxygen concentrations during ROV visits were typical for central California waters at the depth of the container (Table 1).

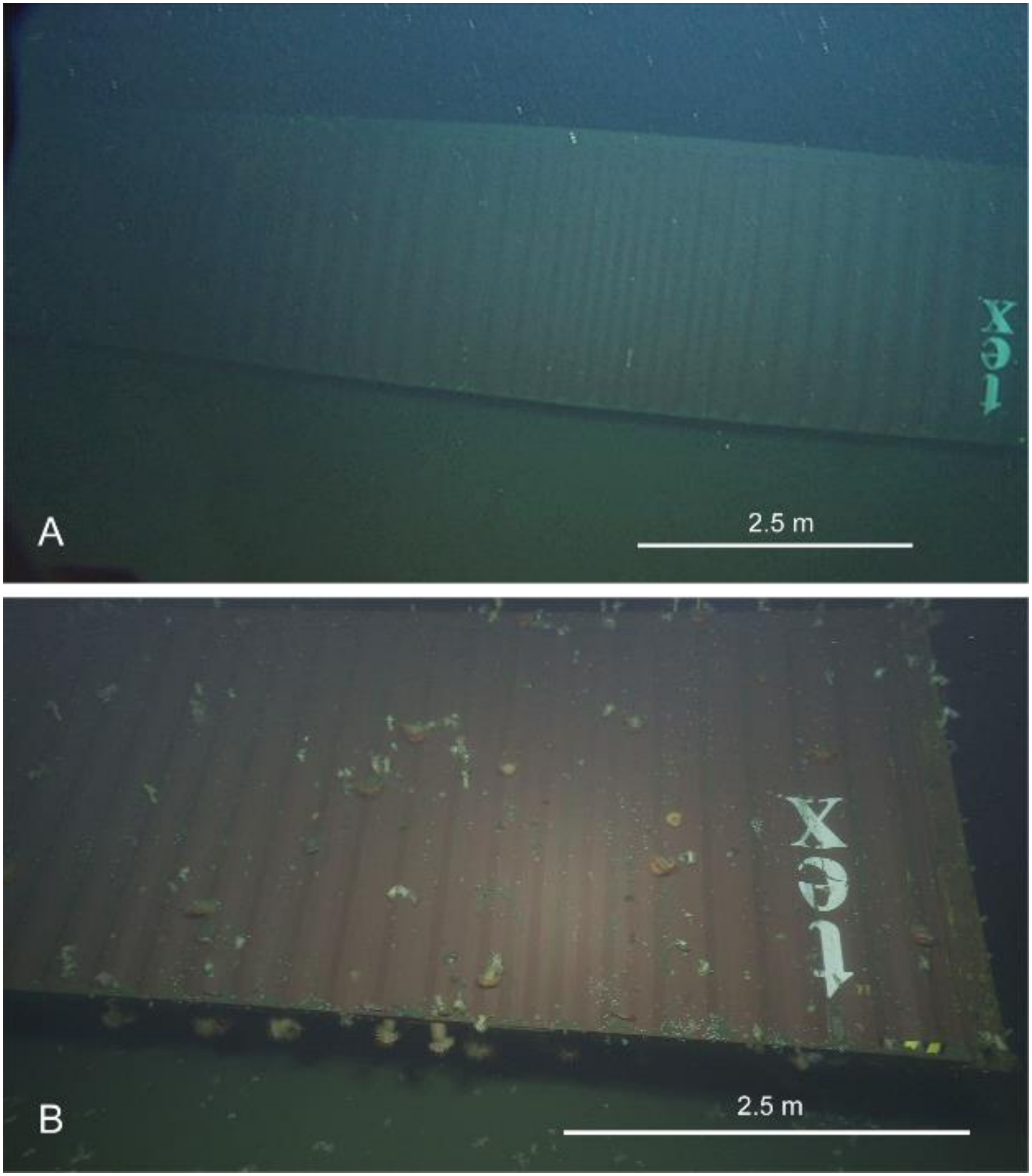

Figure 2. The same side of the container photographed (A) upon discovery in 2004 and (B) in 2021. Photos: J. Barry/MBARI

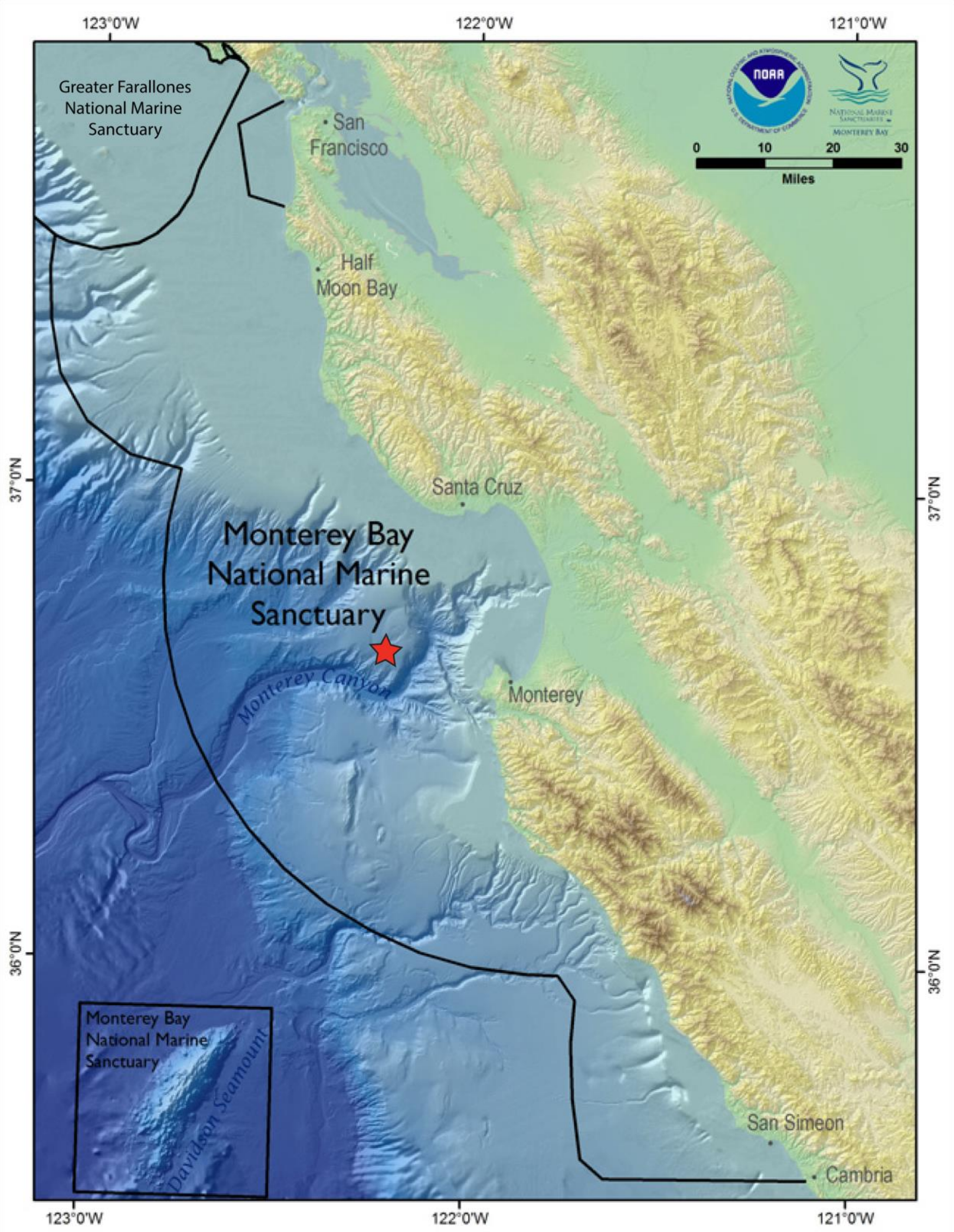

Figure 3. Map of MBNMS, with the location of the shipping container marked with a red star. Image: NOAA

Table 1. Average temperature, salinity, and dissolved oxygen concentration during each ROV survey.

Survey Date	Temperature (°C)	Salinity (ppt)	Oxygen (mg/L)
June 9, 2004	3.10	34.56	0.75
March 9, 2011	3.23	34.51	0.69
December 12, 2013	3.14	34.51	0.74
June 5, 2014	3.25	34.51	0.66
October 14, 2021	3.21	34.51	0.70
Mean ± standard deviation	3.19 ± 0.06	34.52 ± 0.02	0.71 ± 0.03

Methods

The container was visited to conduct ROV-based observations and sampling four times since its discovery in 2004 (Figure 4). In March 2011, scientists from MBNMS and MBARI observed the container and its surroundings using the ROV *Doc Ricketts* (dive D219), operated by MBARI from the R/V *Western Flyer*. ROV pilots recorded high-definition video up to a 500-m radius from the container along 12 transects that were each up to 480 m long (the total video survey area exceeded 3000 m^2). Similar techniques were used in December 2013 and June 2014 (dives D565 and D617 respectively). On October 14, 2021, the container was observed using the ROV *Ventana* (dive V4364) operated by MBARI from the R/V *Rachel Carson*. *Ventana* was equipped with a 4K camera. Two video transects to and from the container (approximately 60 m and 95 m) were performed along with multiple orbits of the container, documenting all visible surfaces. More than 9 hours of video were collected across the four visits (3 hours in 2011 [with an additional 7 hours of video surveys of the surrounding sediment], 3 hours in 2013, 1 hour in 2014, and 2 hours in 2021). The video was annotated as outlined in Taylor et al. (2014) using MBARI's Video Annotation and Reference System (Schlining & Jacobsen Stout, 2006). All observed benthic and demersal organisms were counted, identified, and annotated to the lowest possible taxonomic unit using current databases, such as MBARI's Deep Sea Guide (Jacobsen Stout et al., n.d.). Undescribed organisms were assigned a unique name as morphotypes (e.g., Actiniaria sp. 1). Organisms that were unidentifiable at the available resolution were excluded.

For each year surveyed, taxonomic richness was determined as the number of species present on the container. Taxonomic diversity was calculated using the Shannon Diversity Index ($H = -\Sigma p_i * \ln(p_i)$, where p_i is the proportion of the community made up of taxon i). Taxonomic evenness was calculated using Pielou's evenness index ($J' = H'/H'_{max}$), where $H'_{max}=\ln(S)$, where S is the total number of taxa, and H'_{max} is the maximum possible value of H' if every taxon was equally likely).

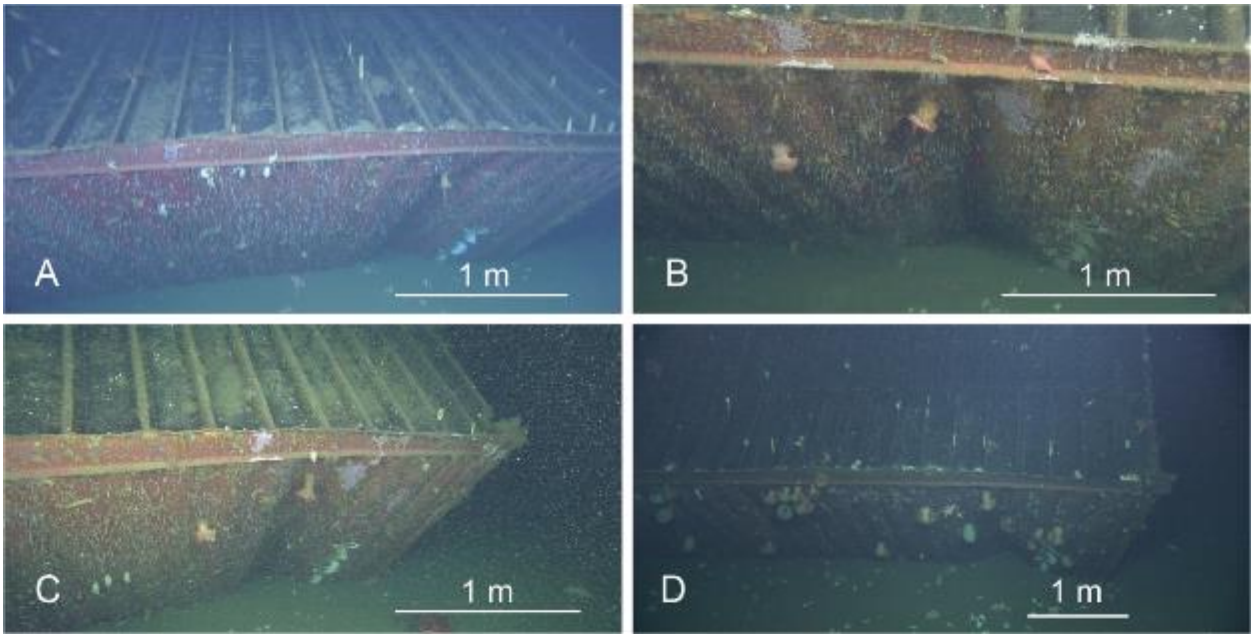

Figure 4. The same section of the container, photographed in (A) 2011, (B) 2013, (C) 2014, and (D) 2021. Photos: J. Barry/MBARI

Results

The container has remained relatively undamaged for the past 17 years, with little structural change visible. The walls of the container remained intact, with no severe degradation or loss of integrity. Uncoated components of the container (door assembly, top and bottom side rails, front and rear end frames, and ventilator) and the areas immediately surrounding them were slightly degraded; however, the majority of the external container remained intact, likely as a consequence of the low dissolved oxygen at this depth (Figure 5). Some blistering of the paint on the container was evident in 2021, potentially as a result of decay beneath the marine-grade coating (Figure 6). White microbial mats were first observed on the door assembly in 2013 and were smaller 2021 (Figure 7). Additionally, the level of sediment surrounding the container did not appear to change over time.

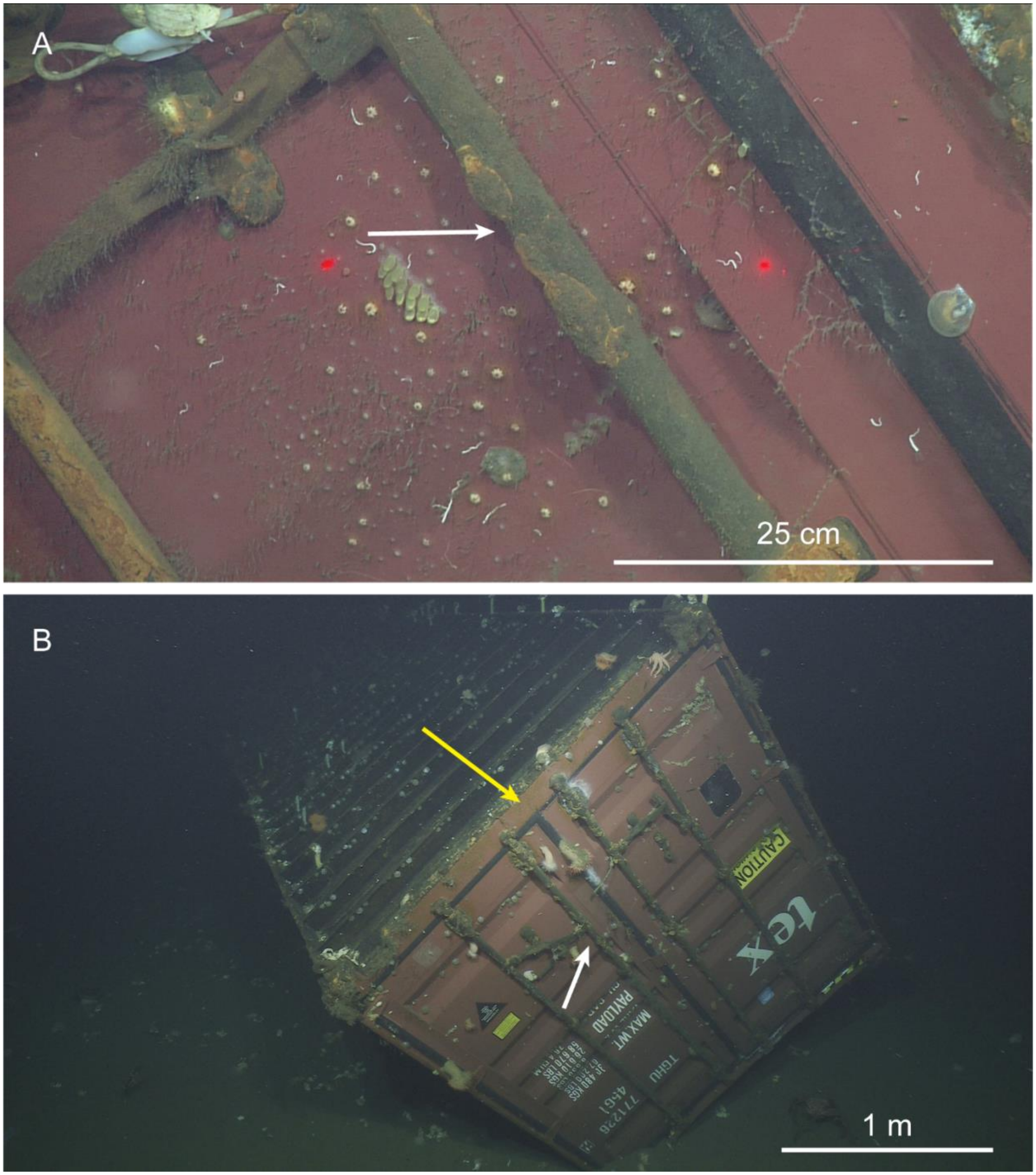

Figure 5. Visible rust on the same section of the container's door assembly (indicated by the white arrow) in (A) 2013 and (B) 2021. Additional rust, indicated by the yellow arrow, was visible on the exterior wall of the container in 2021. Photos: J. Barry/MBARI

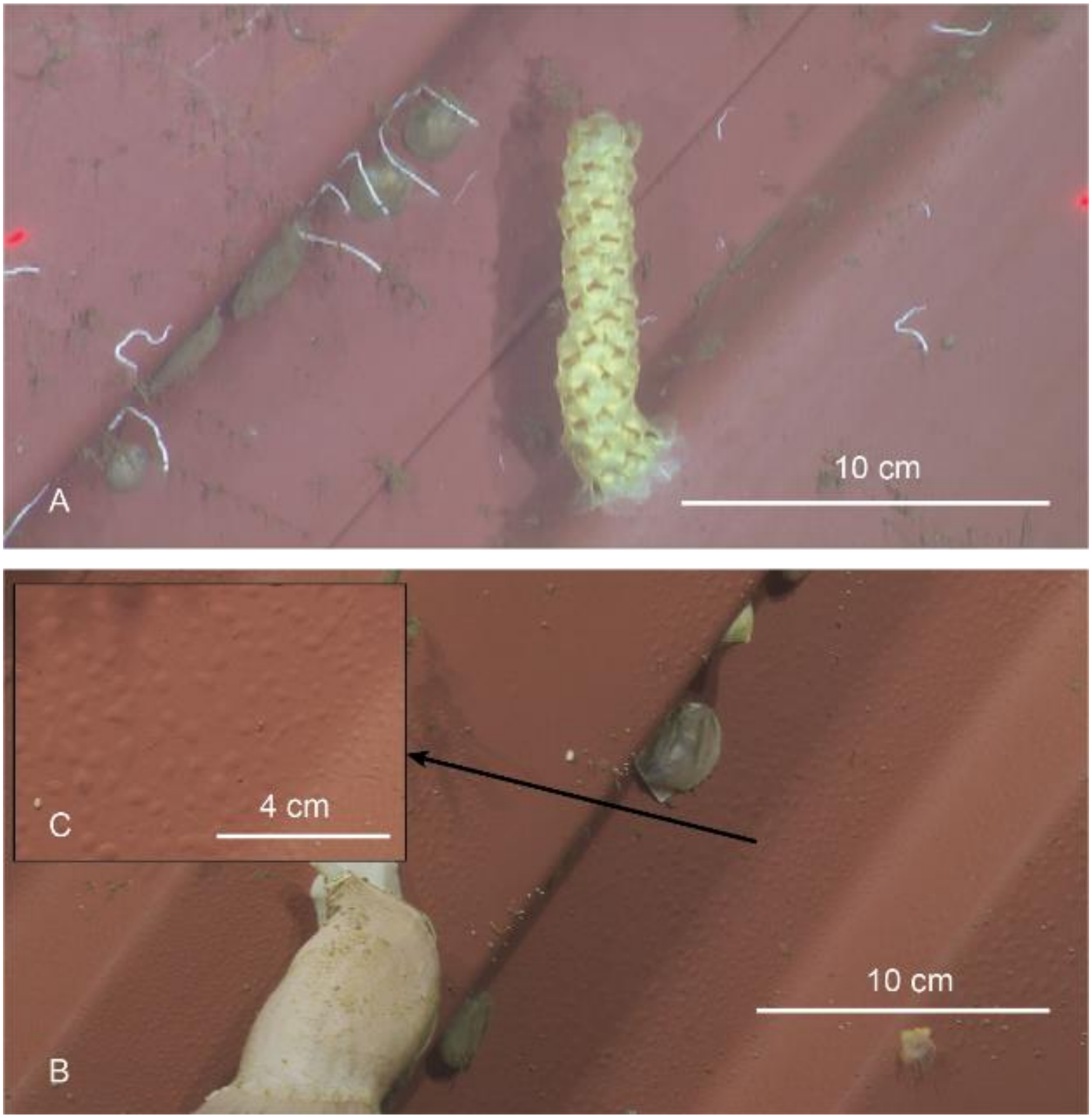

Figure 6. The paint on the container was smooth in (A) 2011, while blistering was observed in (B, C) 2021. A *Neptunea* sp. snail egg case, serpulid worm tubes, and scallops (*Delectopecten* sp.) are visible in the 2011 photo. In the 2021 photo, more scallops are visible, along with a *Neptunea* sp. snail carrying an anemone (*Isosicyonis* sp.), a juvenile anemone, and a limpet. Photos: J. Barry/MBARI

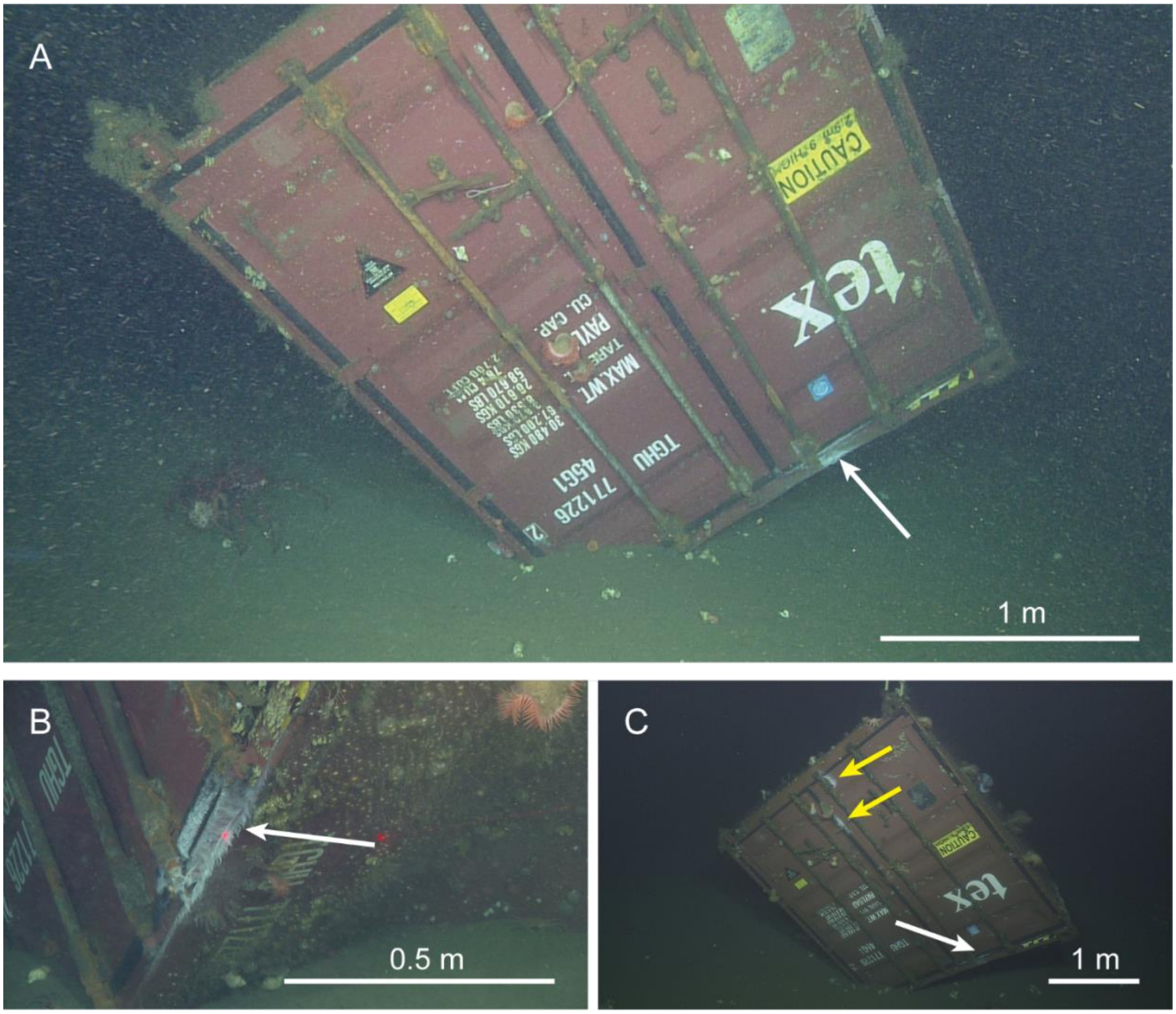

Figure 7. The growth of a white microbial mat, indicated by a white arrow, in (A) 2013, (B) 2014, and (C) 2021. There was a significant change in the area of the microbial mat along the bottom edge of the door over time; however, additional mats appeared toward the upper edge of the door assembly in 2021 (indicated by yellow arrows). Photos: J. Barry/MBARI

Taylor et al. (2014) reported that the most abundant taxa in the faunal community on the container in 2011 were serpulid worms, sabellid worms, scallops, top snails, and tunicates, in that order. Annelids were the most abundant phylum in 2011, accounting for 83% of the observed individuals. In 2013, the faunal community was dominated by the benthic jellyfish *Ptychogastria polaris*, followed in abundance by sabellid worms, serpulid worms, scallops, and top snails. Cnidarians were the most abundant phylum in 2013, accounting for 53% of the total faunal abundance. Trends in 2014 were similar to 2013; *Ptychogastria polaris* was the most abundant species, followed again by sabellid worms, serpulid worms, scallops, and top snails. It should be noted that despite the prevalence of *Ptychogastria polaris* in 2014, annelids were once again the most abundant phylum, accounting for 46% of the total faunal abundance. The community in 2021 was largely different than previous years, with scallops as the most abundant species, followed in order of abundance by top snails, serpulid worms, sabellid worms, and *Neptunea* snails. Mollusks were the most abundant phylum in 2021, accounting for 81% of observed individuals. This shift in prevalence from annelid worms, to cnidarians, back to annelid worms, and then to mollusks may reflect normal successional patterns for such habitats or simply stochastic, episodic pulses of larval recruits (Figure 8).

Table 2. Counts of epifauna observed on the lost shipping container in MBNMS over time, 2011 to 2021. Taxa were identified to the lowest taxonomic group that could be identified with confidence.

Phylum	Lowest Taxonomic Group	Common Name	2011 Count	2013 Count	2014 Count	2021 Count
Annelida	Sabellidae	Fan (tube) worm	1314	1152	1244	155
Annelida	Serpulidae	Tube worm	1416	1073	983	179
Arthropoda	Amphipoda	Amphipod	32	30	31	28
Arthropoda	*Chionoecetes* sp.	Tanner crab	0	9	3	3
Arthropoda	*Pandalopsis ampla*	Bigeye shrimp	2	20	3	4
Cnidaria	Actiniaria sp 1	Anemone	12	1	1	4
Cnidaria	*Actinoscyphia aurelia*	Fly trap anemone	7	32	49	95
Cnidaria	*Clavularia* sp.	Soft coral	17	20	13	1
Cnidaria	Gorgonacea	Sea fan	1	0	0	0
Cnidaria	*Isosicyonis* sp.	Anemone	0	0	1	109
Cnidaria	*Ptychogastria polaris*	Benthic jelly	11	3000	1870	1
Cnidaria	*Stomphia* sp.	Anemone	0	2	3	3
Echinodermata	Antedonoidea	Feather star	2	11	9	24
Echinodermata	Brisingida	Sea Star	0	0	1	0
Echinodermata	*Crossaster* sp.	Sun star	0	1	2	10
Echinodermata	Ophiuroidea	Brittle star	7	11	15	36
Echinodermata	*Peribolaster* sp.	Sea star	5	2	1	0
Mollusca	*Benthoctopus* sp.	Octopus	0	1	0	1
Mollusca	*Calliostoma* spp.	Top snail	108	135	161	1057
Mollusca	*Delectopecten* sp.	Scallop	285	180	306	1473
Mollusca	Fissurelloidea	Keyhole limpet	0	0	0	4
Mollusca	*Neptunea* sp.	Neptune snail	12	35	65	152
Mollusca	*Neptunea* eggcase	Neptune snail eggcase	2	33	25	73
Mollusca	Patellogastropoda	True limpet	2	24	19	80
Mollusca	*Tritonia* sp.	Giant nudibranch	0	3	0	1
Porifera	Hexactinellida	Glass sponge	0	0	0	11
Urochordata	Chordata	Tunicate	100	98	113	18
Total	N/A	N/A	3335	5873	4918	3521

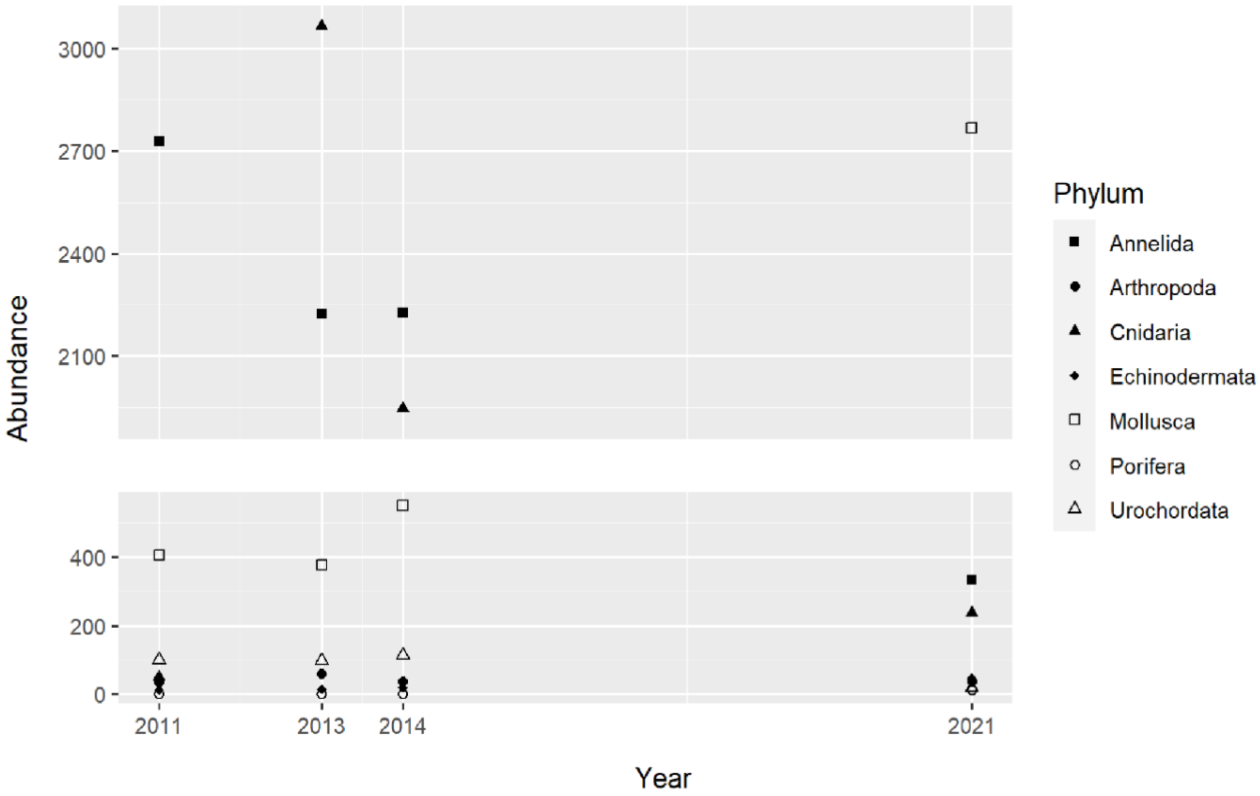

Figure 8. Scatter plot of the number of individuals counted from multiple phyla each year of study. There is a break in the y axis between 560 and 1900, as there were no data points in that range.

The total abundance of different taxa on the container has fluctuated, with the greatest number of individuals observed in 2013, followed by 2014, 2021, then 2011 (Table 2). Taxonomic richness, diversity, and evenness, however, all increased over time (Table 3).

Table 3. Taxonomic richness, diversity, and evenness for epifaunal communities on the shipping container during each year surveyed.

Year	2011	2013	2014	2021
Taxonomic richness (n species)	18	22	22	24
Shannon’s diversity index (H)	1.34	1.46	1.66	1.75
Pielou’s evenness (J’)	0.46	0.47	0.54	0.55

Sponges (phylum Porifera) were first observed in 2021. Absent in 2014 and prior, 11 individual sponges (class Hexactinellida, glass sponges) were found on two adjacent faces of the container (Figure 9). Their similar sizes (width = 13.5 ± 2.5 cm [mean ± standard deviation]; n = 11) and appearance support the possibility that they originated from the same spawning event.

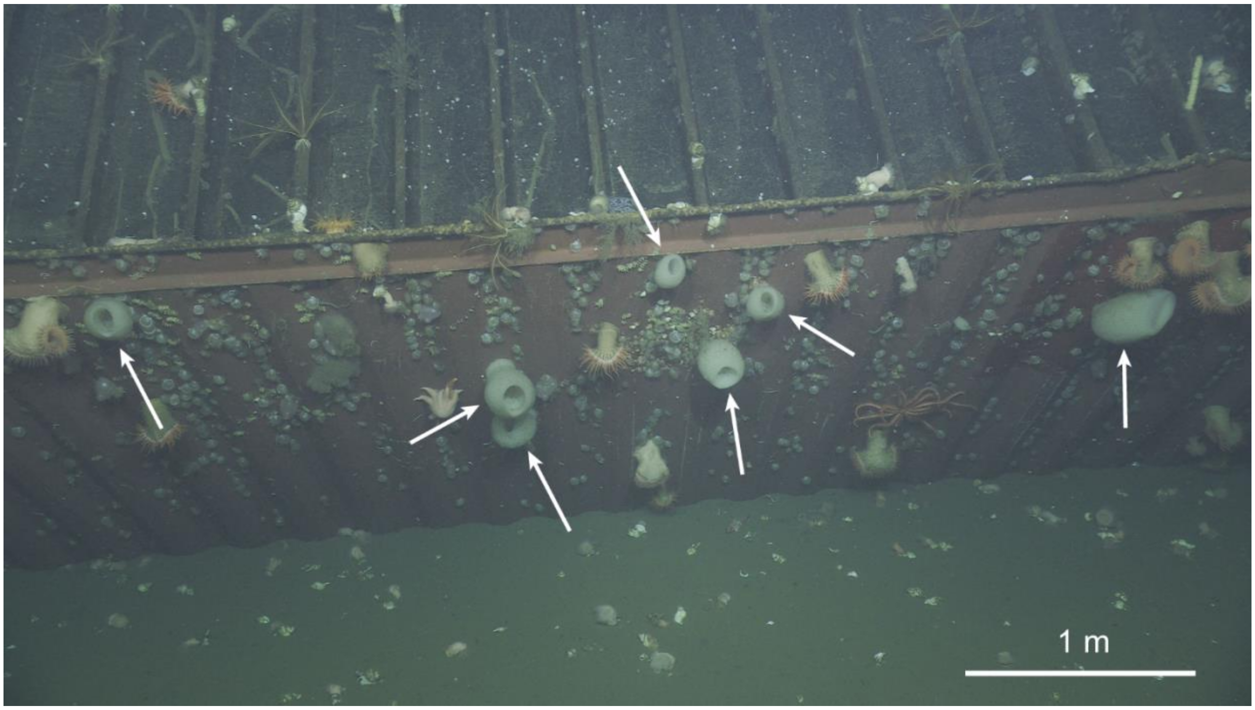

Figure 9. Seven of the 11 hexactinellid sponges observed on the container in 2021 (indicated by white arrows). Photo: J. Barry/MBARI

As previously mentioned, the iridescent shelled scallop *Delectopecten* sp. (Figure 10) increased in abundance from 2011 to 2021 (Table 2). Abundance during 2011, 2013, and 2014 was similar, with only 126 (70%) more individuals in 2014 than 2013, the year with the fewest scallops observed. In comparison, 1,473 scallops were counted in 2021, an increase of more than 1,100 individuals (5.7 times higher than the average of previous counts).

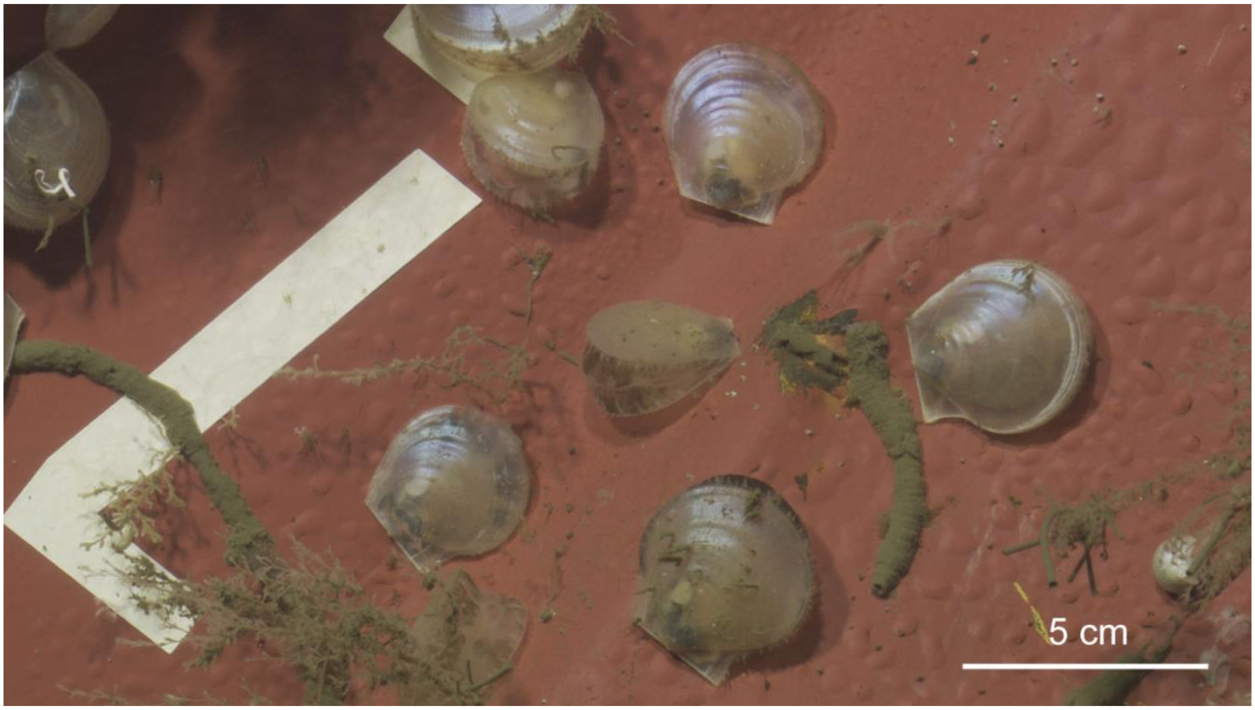

Figure 10. Close up image of pectinid scallops (*Delectopecten* sp.) in 2021. Photo: J. Barry/MBARI

A dramatic rise and unexplained fall in abundance of the benthic jelly *Ptychogastria polaris* was also observed. In 2011, 11 individuals of this species were observed. Two years later, in 2013, this species became the dominant taxon by a wide margin, totaling more than 3,000 individuals colonizing every face of the container (Figure 8; Figure 11). In 2014, *P. polaris* remained numerically dominant, with nearly 2,000 individuals present. Then, in 2021, only a single individual was observed on the container. This species is not very mobile, swimming in short bursts of up to 15 seconds, and is known to forage on soft sediment (Stübing & Piepenburg, 1998); however, no individuals were observed on the sediment surrounding the container in any of the visits.

Similarly, tunicates and both major classes of tube worms significantly decreased in abundance between the first three surveys and the 2021 survey (Figure 8; Figure 11; Figure 12).

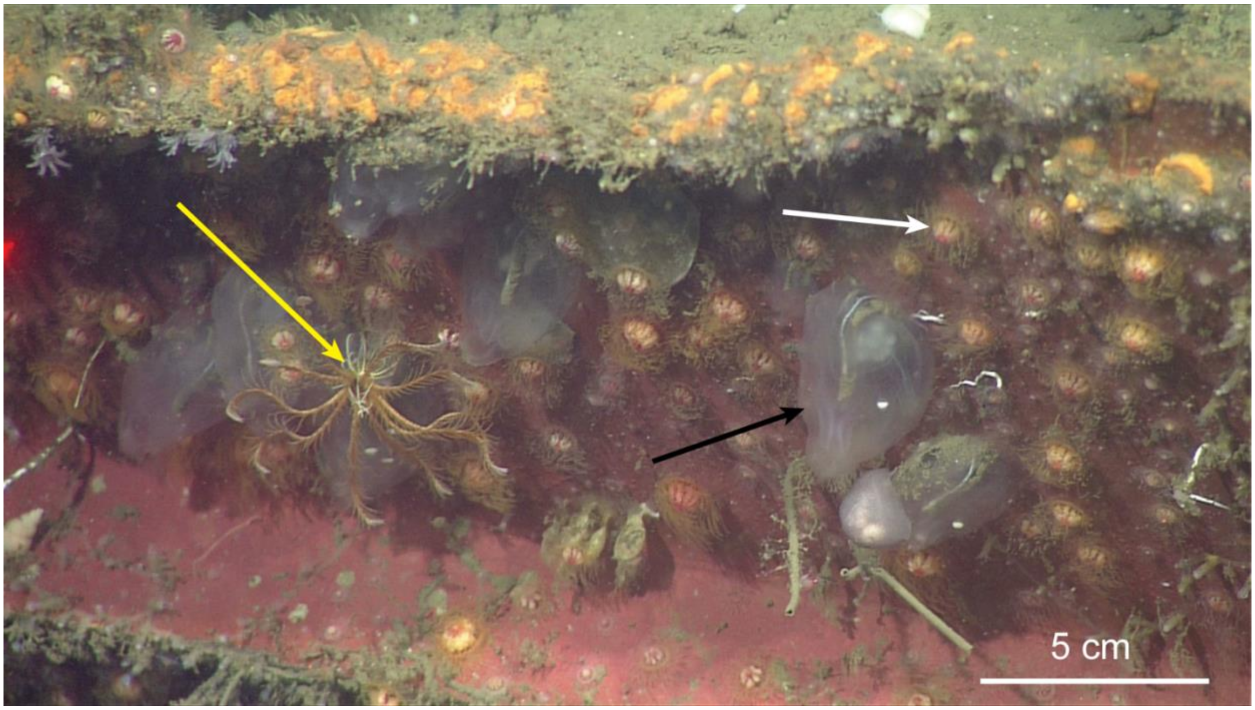

Figure 11. Close up image of the container in 2013 showing many *Ptychogastria polaris* (white arrow) along with several tunicates (Urochordata, black arrow), and a feather star (Antedonoidea, yellow arrow). Photo: J. Barry/MBARI

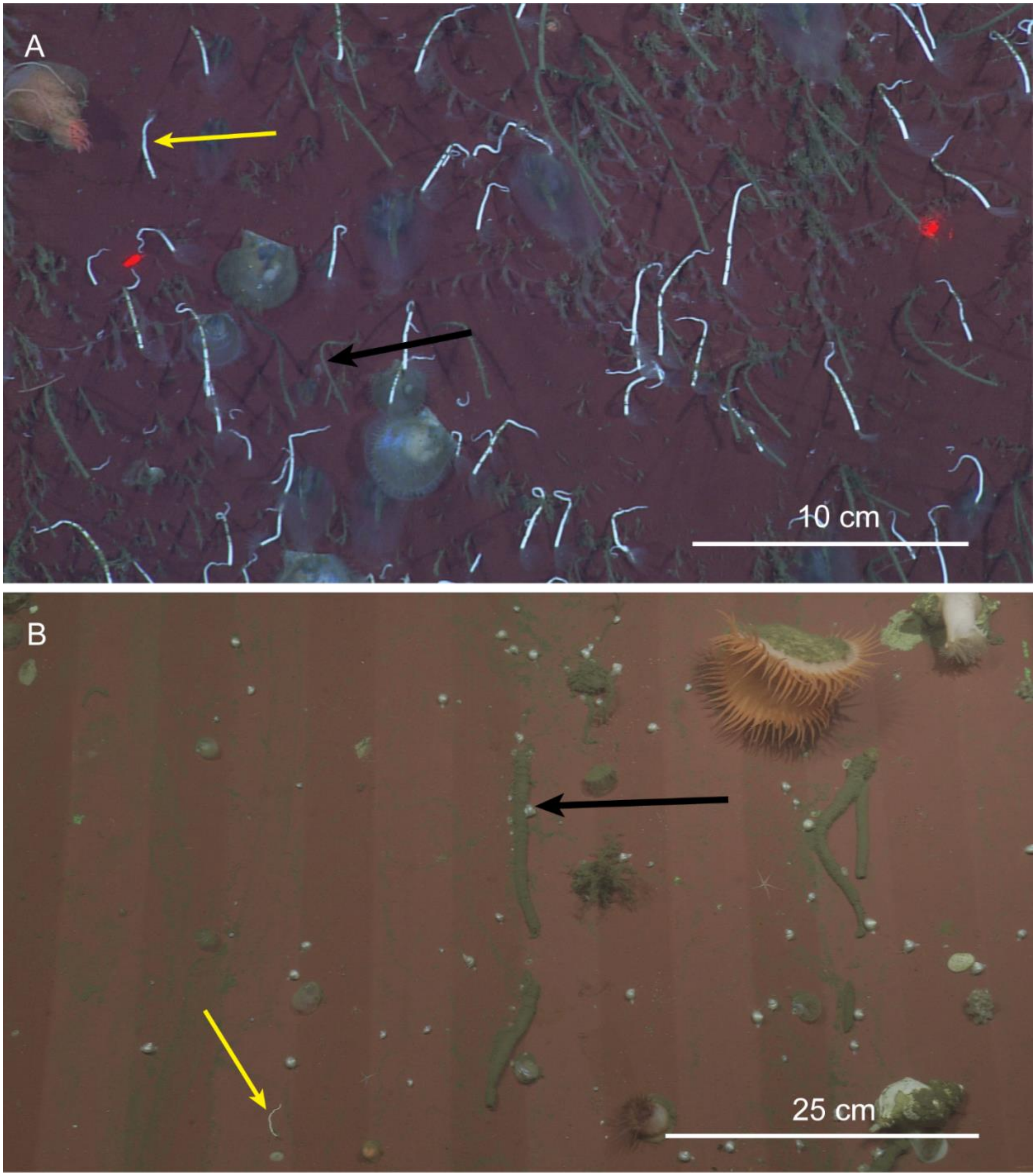

Figure 12. There were visible differences in the sabellid (black arrows) and serpulid (yellow arrows) tube worm populations over 10 years from (A) 2011 to (B) 2021. Photos: J. Barry/MBARI

Discussion

Lost shipping containers are an ongoing and growing conservation issue for the deep sea. We compiled publicly available reports of container loss incidents and found that in 2021, out of 2,776 containers reported lost, only seven were retrieved or reported as having washed ashore, indicating that 99.7% may still be on the seafloor. This is more than double the yearly estimate published by the World Shipping Council. And because containers are not required to be reported lost unless they pose a hazard to navigation, this is a conservative estimate of total containers lost in 2021. If we assume every container lost was a standard twenty-foot equivalent unit container that landed flat on a single face, a total of 41,263 m^2 (4.13 ha) of seafloor was directly impacted during 2021 alone. Taylor et al. (2014) showed that the seafloor community within 10 m of the container was significantly different than the community outside of that range, likely due to the effects of the container on bottom currents, faunal assemblages, or both. If so, the lost 40-foot container in our study affected an area of ~600 m^2. For the 2,776 containers lost in 2021, we estimate that as much as 815,293 m^2 of seafloor (81.53 ha) was affected. The area influenced by containers in their role as unnatural hardbottom features and "stepping stones" for the dispersal of associated assemblages (De Mesel et al., 2015) is not known, but could be quite large, and is likely to be density dependent. Moreover, these impacts are long term. A container experiencing average wear and use may last 15 years on ships and in ports (Hoffmann et al., 2020; Poo & Yip, 2019). A well-maintained container may be in use for up to 30 years (Hoffmann et al., 2020; Poo & Yip, 2019). The container in MBNMS has already been on the seafloor for more than 17 years, well over the natural lifespan of an unmaintained container, and as of 2021 showed only minor signs of decay. Other lost containers may be similarly long-lived in the deep sea, though factors like dissolved oxygen concentration may play a role in deterioration.

The present study documented repeated visits to a single lost shipping container, and the lack of replication precludes evaluation of the broader effects of lost shipping containers on deep-sea habitats and communities. Nevertheless, variations in benthic communities over time, as documented in this study, suggest the potential for lasting effects of the container on benthic infaunal and epifaunal communities. Changes to infauna could be mediated by either chemical alteration caused by the container and/or its contents, or localized changes in current flow around the container (Davis et al., 1982; Mendoza & Henkel, 2017). In addition, the container acts as an "island" of hard substrate occupied by species typically absent from or more dispersed in soft sediment areas. The faunal assemblage on the container is characterized by species found on hard substrata in the region, such as rock and the walls of Monterey Submarine Canyon (Lundsten et al., 2009; McClain et al., 2009; McClain & Barry, 2010). Hard substrata are rare in this region, and containers may provide avenues for species migration across expansive soft sediment habitats. Human-made structures (e.g., oil and gas installations and offshore wind farms) have been shown to act as stepping stones in shallow waters and can facilitate the migration of species into new environments (De Mesel et al., 2015; ter Hofstede et al., 2022). Thus, the impacts of the growing density of lost containers in the sea could be much greater than previously believed.

Our observations provide evidence of the potential for organisms to migrate using the container as a stepping stone. We found egg cases from various species of snails on the container but not on the surrounding sediment. On the other hand, apart from a single sea fan found in 2011, deep-sea corals, regionally present and of particular interest to resource managers, have not settled on the container to date. It is unclear if this is because the container is unsuitable for recruitment or survival, or simply due to a lack of larval supply in the 17 years since the container was lost.

Changes in the structure and abundance of species on the container could be driven by a variety of processes, ranging from the pool of available larvae to substratum effects, resource availability, and species interactions (Mullineaux et al., 2003, 2018; Ruhl, 2008). It remains unknown whether community structure is controlled by stochastic or deterministic processes (Måren et al., 2018), or will eventually lead to a climax community or dynamic equilibrium (Vance, 1988). Studies of other known sunken containers or comparable anthropogenic debris would broaden our understanding of their impacts in the deep sea. The impacts of this container will last well beyond the 17 years of study, and, if sunken ships are any indication, could extend to hundreds of years. This extensive period of impact should be considered in future mitigation and monitoring cost negotiations.

Acknowledgements

We would like to thank Josi Taylor, Erica J. Burton, and Oren Frey for their early and extensive work on this project. We would also like to thank the R/V *Western Flyer* captain and crew, ROV *Doc Ricketts* pilots, R/V *Rachel Carson* captain and crew, ROV *Ventana* pilots, and MBARI Video Lab. Finally, we also thank the anonymous peer reviewers of this report. We are grateful for funding from NOAA, MBARI, the *Med Taipei* Mitigation Fund, and Save the Earth.

Glossary of Acronyms

MBARI	Monterey Bay Aquarium Research Institute
MBNMS	Monterey Bay National Marine Sanctuary
NOAA	National Oceanic and Atmospheric Administration
ROV	Remotely Operated Vehicle

Literature Cited

BBC News. (2010). *Lost shipping containers question*. http://news.bbc.co.uk/democracylive/hi/europe/newsid_9112000/9112791.stm

Breivik, Ø., Allen, A. A., Maisondieu, C., Roth, J.-C., & Forest, B. (2012). The leeway of shipping containers at different immersion levels. *Ocean Dynamics*, *62*(5), 741–752. https://doi.org/10.1007/s10236-012-0522-z

Daniel, P., Jan, G., Cabioc'h, F., Landau, Y., & Loiseau, E. (2002). Drift modeling of cargo containers. *Spill Science & Technology Bulletin*, *7*, 279–288. https://doi.org/10.1016/S1353-2561(02)00075-0

Davis, N., VanBlaricom, G. R., & Dayton, P. K. (1982). Man-made structures on marine sediments: Effects on adjacent benthic communities. *Marine Biology*, *70*(3), 295–303. https://doi.org/10.1007/BF00396848

De Mesel, I., Kerckhof, F., Norro, A., Rumes, B., & Degraer, S. (2015). Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. *Hydrobiologia*, *756*, 37–50. https://doi.org/10.1007/s10750-014-2157-1

Frey, O., & DeVogelaere, P. A. (2014). *The containerized shipping industry and the phenomenon of containers lost at sea*. Marine Sanctuaries Conservation Series ONMS-14-07. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of National Marine Sanctuaries. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/science/conservation/pdfs/lostcontainers.pdf

Herr, R. (2014). *What is Corten steel and why are shipping containers made from it?* ContainerAuction.com. https://containerauction.com/read-news/what-is-corten-steel-and-why-are-shipping-containers-made-from-it

Hoffmann, N., Stahlbock, R., & Voß, S. (2020). A decision model on the repair and maintenance of shipping containers. *Journal of Shipping and Trade*, *5*(1), 22. https://doi.org/10.1186/s41072-020-00070-2

Jacobsen Stout, N., Kuhnz, L., Lundsten, L., Schlining, B., Schlining, K., & von Thun, S. (Eds.). (n.d.). *The deep-sea guide*. Monterey Bay Aquarium Research Institute. Consulted 2022-01-05 through 2023-03-20. https://www.mbari.org/data/deep-sea-guide/

Levinson, M. (2008). *The box: How the shipping container made the world smaller and the world economy bigger*. Princeton, NJ: Princeton University Press.

Lundsten, L., Barry, J., Cailliet, G., Clague, D., DeVogelaere, A., & Geller, J. (2009). Benthic invertebrate communities on three seamounts off southern and central California, USA. *Marine Ecology Progress Series*, *374*, 23–32. https://doi.org/10.3354/meps07745

Måren, I. E., Kapfer, J., Aarrestad, P. A., Grytnes, J.-A., & Vandvik, V. (2018). Changing contributions of stochastic and deterministic processes in community assembly over a successional gradient. *Ecology*, *99*(1), 148–157. https://doi.org/10.1002/ecy.2052

McClain, C. R., & Barry, J. P. (2010). Habitat heterogeneity, disturbance, and productivity work in concert to regulate biodiversity in deep submarine canyons. *Ecology*, *91*(4), 964–976. https://doi.org/10.1890/09-0087.1

McClain, C. R., Lundsten, L., Ream, M., Barry, J., & DeVogelaere, A. (2009). Endemicity, biogeography, composition, and community structure on a Northeast Pacific seamount. *PLoS ONE*, *4*(1), e4141. https://doi.org/10.1371/journal.pone.0004141

Mendoza, M., & Henkel, S. (2017). Benthic effects of artificial structures deployed in a tidal estuary. *Plankton and Benthos Research*, *12*, 179–189. https://doi.org/10.3800/pbr.12.179

Monroy-Velázquez, L. V., Rodríguez-Martínez, R. E., Blanchon, P., & Alvarez, F. (2020). The use of artificial substrate units to improve inventories of cryptic crustacean species on Caribbean coral reefs. *PeerJ*, *8*, e10389. https://doi.org/10.7717/peerj.10389

Mullineaux, L. S., Metaxas, A., Beaulieu, S. E., Bright, M., Gollner, S., Grupe, B. M., Herrera, S., Kellner, J. B., Levin, L. A., Mitarai, S., Neubert, M. G., Thurnherr, A. M., Tunnicliffe, V., Watanabe, H. K., & Won, Y.-J. (2018). Exploring the ecology of deep-sea hydrothermal vents in a metacommunity framework. *Frontiers in Marine Science*, *5*, 49. https://www.frontiersin.org/articles/10.3389/fmars.2018.00049

Mullineaux, L. S., Peterson, C. H., Micheli, F., & Mills, S. W. (2003). Successional mechanism varies along a gradient in hydrothermal fluid flux at deep-sea vents. *Ecological Monographs*, *73*(4), 523–542. https://www.jstor.org/stable/4134785

Poo, M. C.-P., & Yip, T. L. (2019). An optimization model for container inventory management. *Annals of Operations Research*, *273*, 433–453. https://doi.org/10.1007/s10479-017-2708-8

Ruhl, H. A. (2008). Community change in the variable resource habitat of the abyssal Northeast Pacific. *Ecology*, *89*(4), 991–1000. https://doi.org/10.1890/06-2025.1

Schlining, B. M., & Jacobsen Stout, N. (2006). MBARI's video annotation and reference system. *Proceedings of the Marine Technology Society/Institute of Electrical and Electronics Engineers Oceans Conference*, Boston, MA.

Stübing, D., & Piepenburg, D. (1998). Occurrence of the benthic trachymedusa *Ptychogastria polaris* Allman, 1878 (Cnidaria: Hydrozoa) off northeast Greenland and in the northern Barents Sea. *Polar Biology*, *19*, 193–197. https://doi.org/10.1007/s003000050234

Taylor, J. R., DeVogelaere, A. P., Burton, E. J., Frey, O., Lundsten, L., Kuhnz, L. A., Whaling, P. J., Lovera, C., Buck, K. R., & Barry, J. P. (2014). Deep-sea faunal communities associated with a lost intermodal shipping container in the Monterey Bay National Marine Sanctuary, CA. *Marine Pollution Bulletin*, *83*(1), 92–106. https://doi.org/10.1016/j.marpolbul.2014.04.014

ter Hofstede, R., Driessen, F. M. F., Elzinga, P. J., Van Koningsveld, M., & Schutter, M. (2022). Offshore wind farms contribute to epibenthic biodiversity in the North Sea. *Journal of Sea Research*, *185*, 102229. https://doi.org/10.1016/j.seares.2022.102229

Vance, R. R. (1988). Ecological succession and the climax community on a marine subtidal rock wall. *Marine Ecology Progress Series*, *48*(2), 125–136.

Voytenko, M. (2019). *Ships losses in 2018, how many ships were lost?* Fleetmon. https://www.fleetmon.com/maritime-news/2019/26281/ships-losses-2018-how-many-ships-were-lost/

World Shipping Council. (2020). *Containers lost at sea—2020 update*. https://www.iims.org.uk/wp-content/uploads/2020/11/World-Shipping-Council-containers-lost-at-sea-2020.pdf

NATIONAL MARINE
SANCTUARIES

AMERICA'S UNDERWATER TREASURES