Marine Sanctuaries Conservation Series ONMS-14-07

The Containerized Shipping Industry and the Phenomenon of Containers Lost at Sea

U.S. Department of Commerce
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About the 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 14 marine protected areas encompassing more than 170,000 square miles of ocean and Great Lakes waters. The 13 national marine sanctuaries and one marine national monument 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 maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migrations 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 one square mile to almost 140,000 square miles and serve as natural classrooms, cherished recreational spots, and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each 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 Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the 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 Web site (http://www.sanctuaries.noaa.gov).

The Containerized Shipping Industry and the Phenomenon of Containers Lost at Sea

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Cover

Container loss disaster on the M/V *Rena* on Astrolabe Reef off the coast of Tauranga in New Zealand, October 12, 2011. Container shipping accidents have resulted in thousands of containers lost at sea. Photo credit: Maritime New Zealand.

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Abstract

During a transit from San Francisco Bay to the Port of Los Angeles on February 26, 2004, the M/V *Med Taipei* encountered a storm and lost 15 forty-foot shipping containers in the Monterey Bay National Marine Sanctuary (MBNMS), and another nine south of the Sanctuary. One of these containers was discovered by the Monterey Bay Aquarium Research Institute (MBARI) on June 9, 2004 on Smooth Ridge at a depth of 1,281 meters, 17.5 nm NW of Point Pinos. This was not an isolated incident. Containerized maritime trade grew eight-fold from 1985 to 2007, and worldwide there are now approximately 5 to 6 million containers in transit at any given moment. Thousands of shipping containers are lost at sea every year, often due to the nexus of rough seas, inadequate or faulty securing mechanisms, and failure to weigh all containers at the time of loading. On March 8-10, 2011, we conducted a research expedition to the container on Smooth Ridge using MBARI's R/V *Western Flyer*. The cruise aimed to assess the container's current condition, describe habitat and ecosystem impacts, and to bring public attention to this deep-sea phenomenon that has been increasing with economic globalization. Given the potentially severe ecological, economic, and navigational safety consequences associated with container loss, the issue has led to a range of responses from industry and the consideration of additional preventative measures at the international level.

Key Words

Containerization, container loss, shipping, ecological impacts, deep-sea research, Monterey Bay National Marine Sanctuary, MBNMS, continental shelf, marine debris

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Introduction

On June 9, 2004, researchers at the Monterey Bay Aquarium Research Institute (MBARI) made a surprising discovery on Smooth Ridge in the depths of Monterey Bay. While searching for a disabled sediment trap in Monterey Canyon, they found an intermodal shipping container resting upside down on the bottom. The Monterey Bay National Marine Sanctuary (MBNMS) later learned that this container was one of fifteen lost during a single incident of loss from a container ship earlier that year. Seven years later, as MBNMS and MBARI staff prepared to revisit the sunken container to assess ecological impacts, we became aware of the magnitude of the phenomenon of container loss at a global scale. The International Maritime Organization, governments, and marine insurers have estimated that up to 10,000 shipping containers may fall from cargo ships annually (Podsada 2001; Standley 2003; Hohn 2011; IMO 2004; BBC 2010; ITTS 2011; Countryman and McDaniel 2011).

Considered cumulatively, such quantities of cargo loss obviously have substantial economic consequences for the shipping industry, in addition to presenting navigational hazards throughout the world's oceans. But what implications does this accidental dumping have for ecological communities and for the global problem of marine debris? From a marine debris perspective, 10,000 containers lost overboard annually amounts to approximately 41,500 tons of littered steel in container weight alone. Average maximum payload weights of 20' and 40' containers range from 26–29 tons (Musson International 2012). The average weight of the contents of the fifteen containers lost in the MBNMS (Appendix A) was approximately 10 tons. Using this conservative estimate of average container weight, it is conceivable that 100,000 tons of substances in packaged form – many of which may be harmful – are falling off ships in containers each year. This figure represents approximately 1.5% of the 6.4 million tons of litter believed to enter the world's oceans each year (UNEP 2005). Arranged end to end, this estimate of loss would amount to 75 miles of littered containers being added to the seafloor each year. The accumulation of these slow-to-decay structures year after year is a cause for concern.

The discovery of the lost shipping container brought to light many questions: Why do so many containers fall off of ships? What becomes of them after they are lost? What steps could reduce these losses and the damage they cause to marine habitats? We attempt to address these questions and first outline the rapid growth of the containership industry and then explore patterns of vessel traffic along the US West Coast. We describe the discovery of the container in the deepwater habitat of the MBNMS, and discuss the causes of container loss and the trend in recent years toward heightened loss rates. Because very few containers are ever found, the March 2011 MBARI/MBNMS research cruise to the container on Smooth Ridge represents the first effort we are aware of to investigate the ecological impacts of a lost container on the seafloor. We describe the results of this survey and conclude with an overview of the various preventative measures that have either already been implemented or are currently under consideration.

Industry History and Growth

Container shipping is a shipping method that uses large intermodal containers that can be transferred between rail or truck and ship and are never opened while in transit between shipper and consignee (Levinson 2006). Malcolm McLean, a leader in the American trucking industry, designed the first standardized container and created Sea-Land Shipping in 1956 (ISBU 2010). Initial designs called for entire truck trailers to be loaded onto ships. To save space and weight, the industry standard quickly evolved to load only the containers themselves, rather than containers attached to chassis (Levinson 2006). The U.S. container shipping industry began in 1956 when 58 containers were sailed from Newark to Houston aboard a retrofitted tanker ship (Cudahy 2006).

Shipping cargo in containers offers several key advantages to the industry. Studies have shown that at U.S. ports, container cargo can be moved nearly twenty times faster than break bulk cargo (goods that must be loaded individually; Herod 1998). Gains in efficiency have greatly reduced costs: loading loose cargo cost $5.86 per ton to load in 1956; when that same cargo was containerized, it cost $0.16 per ton (ISBU 2010). Containers that remain locked also create improved cargo security and reduce cargo breakage and contamination risks. Because of these increases in efficiency, the industry has experienced tremendous growth in recent decades.

Container capacity is often expressed in units of twenty-foot equivalent units (TEU). One TEU of containerized cargo capacity is equal to one standard 20 ft × 8 ft container (World Bank 2009).[1] Container transshipment traffic figures are generally a measure of container traffic moving from land to sea transport modes, and include both international and coastal journeys. Movement of empty containers is included, and figures are a total of all countries for which data is available. From 2000 to 2008, port container traffic worldwide increased dramatically from 214,274,536 TEU to 473,821,055 TEU (World Bank 2009). Growth in the container sector far surpasses overall growth in maritime trade: from 1985 to 2007, total maritime trade doubled, while total containerized trade grew eight-fold over the same period (OECD 2008). The trend is expected to continue: Drewry Shipping Consultants forecast a more than six-fold rise in container movements from 2000 to 2020 (OECD 2008). Container volume through the Port of Los Angeles is representative of the steep rise in container use, broken only by the economic crisis of 2008-2009 (Figure 1).

[1] Standard container width is 8 ft; standard height is 8.5 ft or 9.5 ft for "high cube" containers. There are five standard container lengths: 20-ft (6.1 m), 40-ft (12.2 m), 45-ft (13.7 m), 48-ft (14.6 m), and 53-ft (16.2 m).

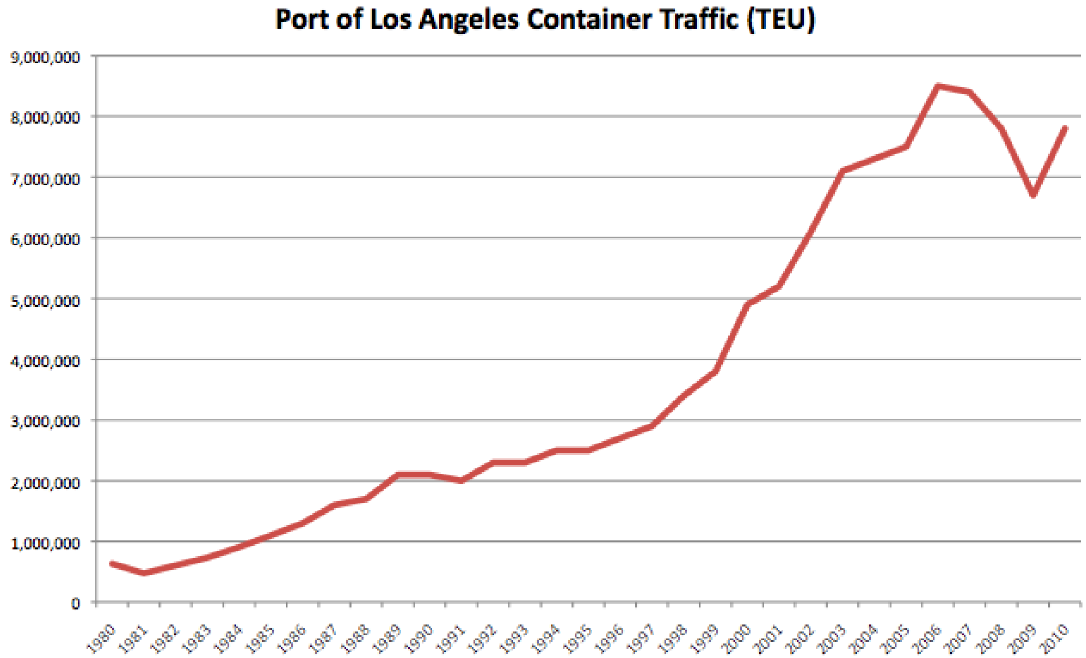

Figure 1. Port of Los Angeles container traffic in TEU (twenty-foot equivalent units), 1980-2010. Container shipping trends correlate with economic activity and the scale of international trade relations. Data from The Port of Los Angeles, http://www.portoflosangeles.org/maritime/stats.asp.

Of the 42,917 cargo ships in the world fleet as of 2010, 4,831 were dedicated container ships (Marisec 2010). The American Institute of Marine Underwriters (AIMU) estimates that the fleet has 8.1 million TEU of capacity at any given moment (AIMU 2008). Another estimate is that there are approximately 100 million containers shipped each year (WSC 2011).

In 2008 the average worldwide container ship load was 2,306 TEU (AIMU 2008). Currently, one of the main size constraints facing container ships is the size of the locks in the Panama Canal. Ships that are "Panamax" in size fit within the dimensions of the locks and have a capacity up to roughly 5,000 TEU (Payer 2005). After completion of expansion expected in 2014, the Panama Canal will be able to handle "Post-Panamax" container vessels up to capacities of 12,000 TEU (Payer 2005). Four 398-m Maersk ships were built in 2013 that each carry about 18,270 TEU. Ships with capacity greater than 10,000 TEU are known as Ultra Large Container ships (ULC). The next size limitation that will emerge is tied to the depth of the Straits of Malacca, which link the Indian and Pacific Oceans and are one of the busiest shipping lanes in the world. "Malaccamax" ship dimensions will be 470 m x 60 m (Levinson 2006). As each generation of ship becomes larger, the taller the stacks of containers become. The physics of taller stacks require new innovations to adequately secure them. While transport capacity per ship grew from 4,000 to 15,000 TEU over a period of only 15 years, design principles and securing methods remained largely unchanged (MARIN 2009).

NOAA's West Coast Sanctuaries and the Containership Industry

US National Marine Sanctuaries are areas of the ocean federally managed for special protection that can include regulations for ship transit, discharge of material, and disturbance of the seafloor, among other regulations. NOAA's West Coast Region Sanctuaries (Olympic Coast, Cordell Bank, Gulf of the Farallones, Monterey Bay, and Channel Islands National Marine Sanctuaries) are particularly exposed to the containership industry, as the world's busiest container trade routes lie between North America and East Asia. Of the thirteen countries that shipped more than 10 million TEU in 2008, 77.6% of those container equivalents originated in Pacific Rim countries (Figure 2; Containerisation International 2011).

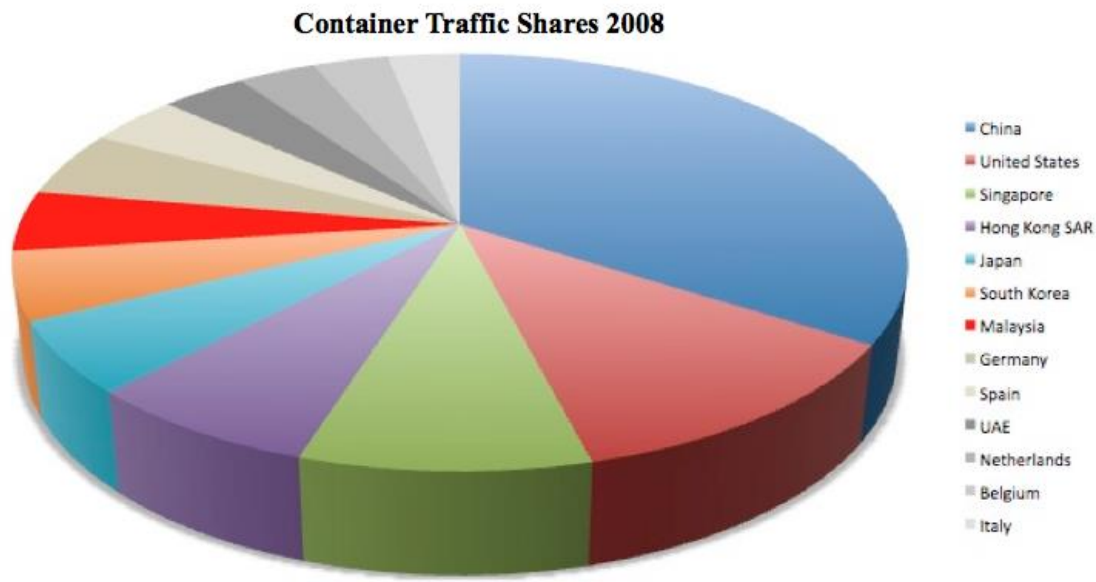

Figure 2. Percent of container traffic by volume of the 13 countries that shipped more than 10 million TEU in 2008. Almost three times as many containers are shipped from China as from the country with the next-busiest ports (U.S.). Data from Containerisation International. http://www.ci-online.co.uk

"Far East to North America West Coast" is the world's 2^{nd} busiest container shipping route by TEU, with 317 container vessels deployed on a typical day (February 1, 2011; Containerisation International 2011). Of the world's 20 busiest container ports, 13 are located around the Pacific Rim, and two are in California. Three of the four busiest container ports in the U.S. are in California (Los Angeles, Long Beach, and Oakland), together accounting for 50% of the nation's total container cargo volume (Port of Oakland 2011). As the 4^{th} busiest container port in the U.S., the Port of Oakland draws much of the container ship traffic that passes through the MBNMS.

Recommended tracks for large vessels transiting the MBNMS have been in place for over ten years. In the late 1990s, the MBNMS Vessel Traffic Workgroup met to work on development and implementation of strategies to move vessel traffic zones farther offshore. The working group recommended altering the Traffic Separation Scheme (TSS) off of San Francisco to move vessels away from the sensitive San Mateo shoreline. Container ships, in addition to bulk freighters and vessels carrying hazardous cargo, were moved about 10 km farther offshore to reduce the risk of groundings. Recommended shipping tracks were also organized into north/south lanes to reduce the risk of collisions (Figure 3). The working group's recommendations were approved by the International Maritime Organization and have been in effect since December 1, 2000. Vessel traffic zones are managed by the U.S. Coast Guard (USCG), the U.S. Department of Transportation, the U.S. Department of Commerce (NOAA), the IMO, and the United Nations (NOAA 2009). Container ships following these recommended tracks will travel 15 nm off Point Sur and 12.7 nm off Pigeon Point when heading north, and 20 nm off Point Sur and 16 nm off Pigeon Point when heading south.

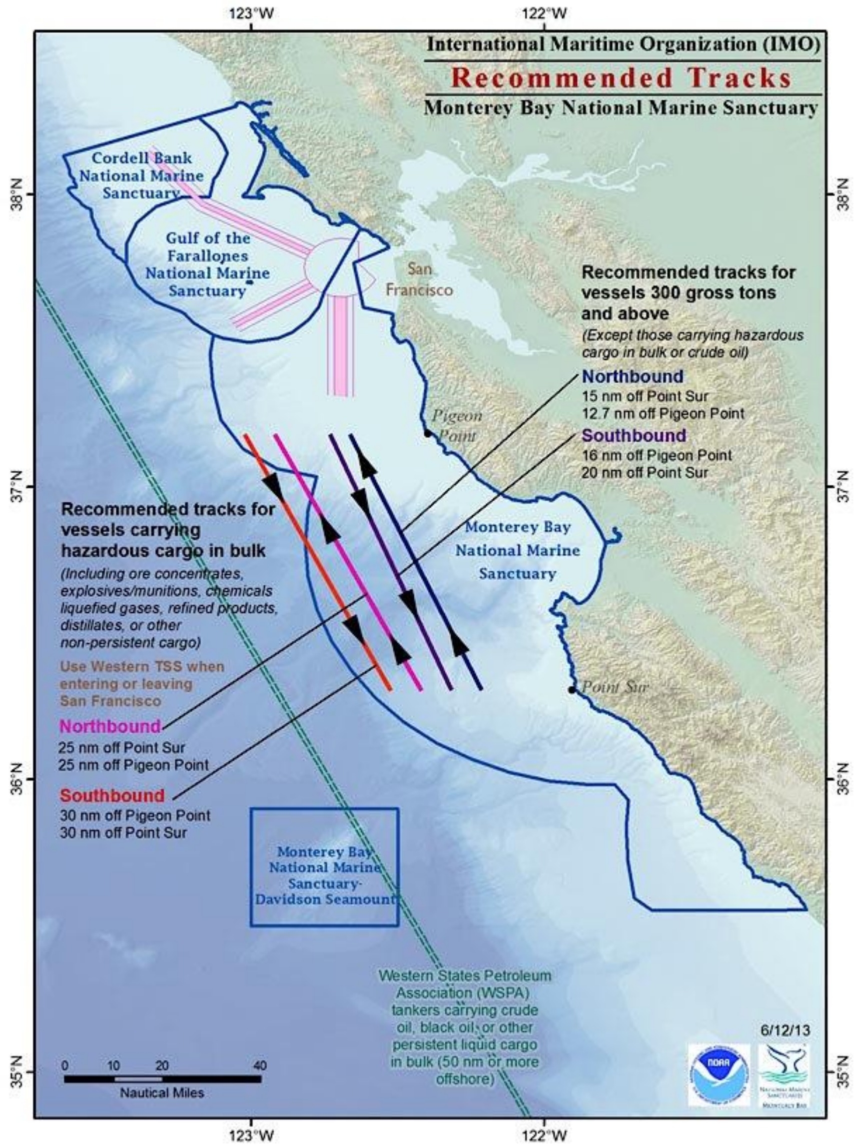

Figure 3. Shipping tracks through the MBNMS recommended by the IMO. Note that only the colored arrows represent the tracks, and there are not defined tracks extending beyond these. Source: http://montereybay.noaa.gov/intro/maps/vessel_lanes1_lg.jpg

It is not easy to approximate the number of containerships transiting the MBNMS and other West Coast Sanctuaries, but some estimates have been made using Vessel Traffic Service (VTS) Automated Identification System (AIS) data. Designed to increase the safety and navigation of vessels at sea, the AIS system automatically broadcasts vessel identification, call sign, destination, position, speed over ground, course over ground, ship type and dimensions to coastal receivers via Very High Frequency (VHF) radio waves (Miller 2011). There are up to 4,000 coastal transits of the MBNMS each year by large vessels (NOAA 2009). Crude oil tankers account for 20% of these transits; the remaining 80% are container ships and bulk product carriers (NOAA 2009).

Efforts to plot vessel traffic transiting the California coast allow for a visual representation of transits through the sanctuary and can show which areas have the highest vessel traffic. In September 2011, the Naval Postgraduate School (NPS) Oceanography Department analyzed archived 2010 AIS message data to calculate the total amount of all shipping traffic through the MBNMS and to create monthly vessel traffic density plots. Daily position reports of each vessel were interpolated to a 1 square arc-minute resolution, on a 1-minute time scale. Monthly ship densities along the California coast were then generated based on the total number of "ship-minutes" all vessels occupied in each 1 square arc-minute of space. The AIS messages were further categorized by reported ship type, with all cargo class vessels (AIS message types 70-79) isolated and monthly location totals calculated (Miller 2011). Cargo class vessels are not exclusively containerships, but containerized cargo is most common. The results for one month are shown as an example of overall patterns (Figure 4).

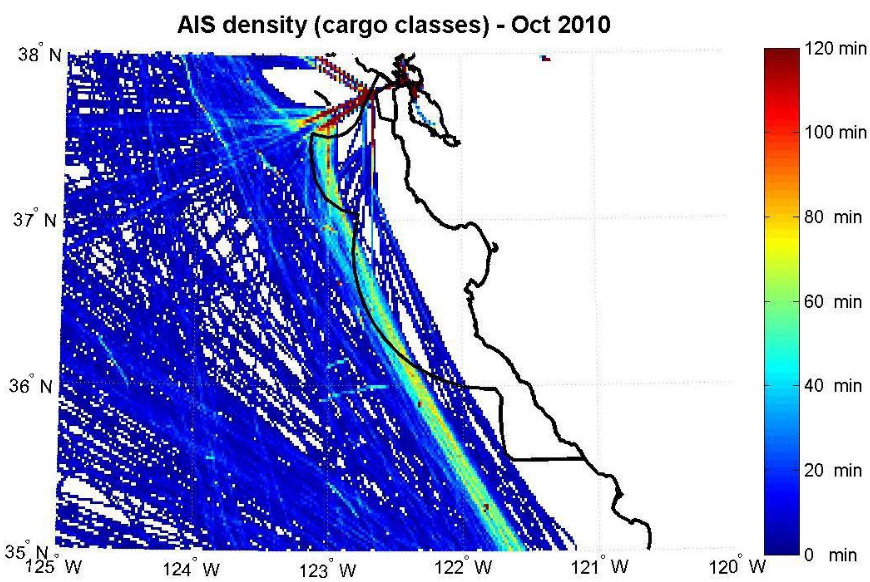

Figure 4. Automatic Identification System (AIS) cargo vessel density in the MBNMS for October 2010. The color axis represents the total number of minutes vessels spent in one square arc-minute of area over the course of October 2010.[2] Figure from Miller 2011.

[2] The color range of Figure 4 was truncated at 120 min. to preserve adequate contrast to distinguish the traffic patterns at sea, rather than having vessels at harbor dwarf the available resolution of the seagoing traffic (a ship sitting pier-side over the course of a month would total 43,200 minutes for the month).

Within the MBNMS, cargo vessels are generally contained within the prescribed shipping lanes (Figure 3). Traffic appears to primarily be a combination of coastal transits and Far East trade routes. An additional data product created by NPS was a comparison of monthly cargo class vessel traffic with total vessel traffic. Cargo class vessels comprise 40-50% of all vessel traffic within the MBNMS.

Table 1. 2010 cargo vessel daily totals, grouped monthly, which passed through the Monterey Bay National Marine Sanctuary (excluding the Davidson Seamount Management Zone). Due to the variability and gaps in the AIS data coverage, these figures are approximate.

Month	*# Cargo Class Vessels*	*Total # Vessels*	*% Cargo Vessels*
January	178	362	49
February	126	242	52
March	345	737	47
April	366	805	45
May	396	937	42
June	435	1000	44
July	439	1023	43
August	443	943	47
September	394	976	40
October	453	1053	43
November	426	858	50
December	471	877	54

Containers Lost in the MBNMS

In 2004, the M/V *Med Taipei* loaded its containerized cargo in China (port unknown). After exchange of containers in the San Francisco Bay Area, the ship was en route to the Port of Los Angeles on the night of February 25, 2004. While transiting the MBNMS, the *Med Taipei* began encountering seven- to nine-meter (23- to 30-foot) westerly swells and experiencing frequent rolls of approximately 25 degrees, with winds at or around 30 knots. At 0045 hours on February 26, 2004, 15 standard 40 ft ISO containers fell off the ship at coordinates 36°38.5'N, 122°28.7'W (70 nm south of the Golden Gate Bridge). Appendix A lists the contents of these containers. Later that same day, at 0908 hours, nine more containers fell overboard at 35°06.9'N, 121°54.0'W. By the end of the voyage, the *Med Taipei* had lost a total of 24 containers and had an additional 21 containers collapsed on the deck, according to a written report by the ship's Captain. The MBNMS was not notified of this incident of container loss.

On June 9, 2004, the Monterey Bay Aquarium Research Institute (MBARI) ROV *Ventana*, while searching for a disabled sediment trap, discovered an intermodal container resting on the seafloor at a depth of 1,281 meters on Smooth Ridge, 17.5 nm NW off Point Pinos outside Monterey Bay (coordinates 36°41.65' N, 122°17.94' W). MBARI collected video and still pictures of the container (Figure 5).

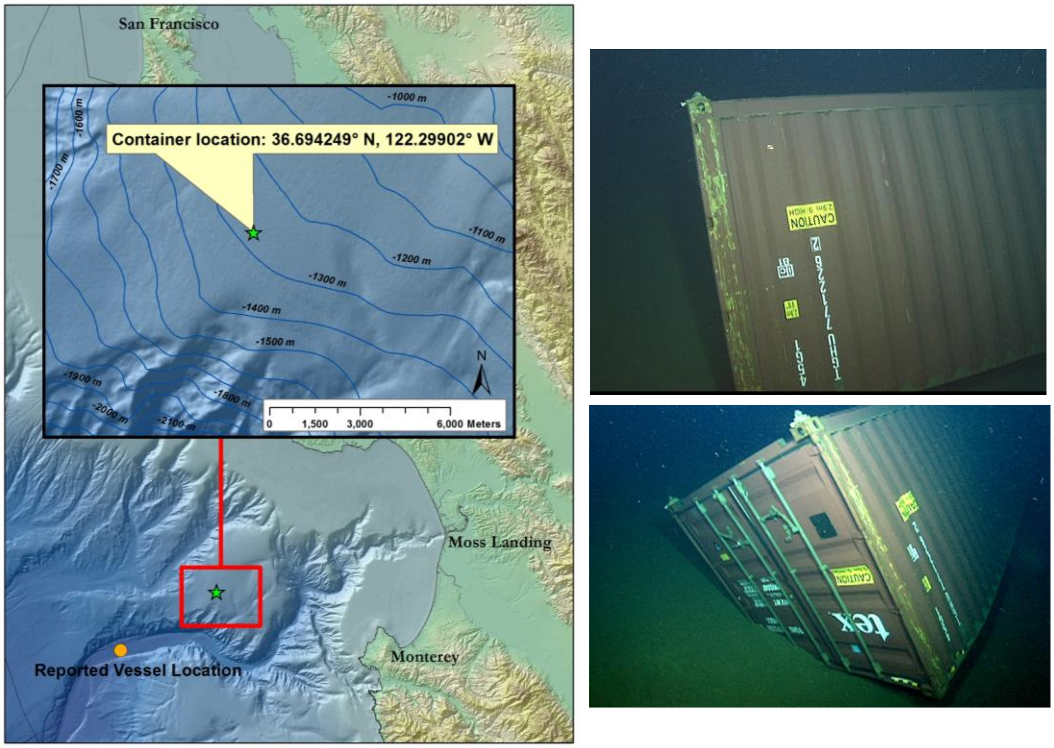

Figure 5. Location and photo of container TGHU7712262. Map shows the reported position of the container ship M/V *Med Taipei* when it lost 15 containers overboard on February 26, 2004 (orange circle). One of these containers landed on the seafloor, just outside of Monterey Bay (green star). This container (photos) was discovered by MBARI researchers on June 9, 2004 at a depth of 1,281 meters on Smooth Ridge 17.5 nm NW off Point Pinos (photo). Map credit: Chad King, MBNMS; photo credit: MBARI.

MBNMS regulations prohibit "discharging or depositing from beyond the boundary of the Sanctuary any material or other matter that subsequently enters the Sanctuary and injuries a Sanctuary resource or quality" (National Marine Sanctuary Program Regulations 2012). Shipping container loss is therefore considered a discharge that is subject to federal enforcement of Sanctuary regulations. NOAA enforcement staff used pictures of the container to track its ID number (TGHU7712262) through U.S. Customs. U.S. Customs confirmed that the container had been lost in transit from the M/V *Med Taipei* (now M/V *YM Prosperity*) just over three months prior. The Los Angeles/Long Beach USCG Marine Safety Office completed an investigation and full report of the incident, including weather and sea conditions at the time. It is unknown how long this container may have floated prior to sinking. Manifest information listed the container's contents as a shipment of 1,159 steel-belted Michelin passenger car tires. Other lost containers held cyclone fencing and poles, hospital beds, mattress pads, hair ribbons, hair turbans, cosmetic bags, leather furniture, and waste cardboard. It was believed that the containers were improperly stacked on the vessel, with some of the heaviest containers at the top of the stack. Additionally, the investigation documented D-rings missing from the deck of the ship and container locking joints with faulty welds.

A Seattle firm (Fugro, Inc.), ran a computer simulation model to estimate likely deposition areas for the 15 containers discharged in the MBNMS at 0045 hours, given container buoyancy characteristics and sea conditions recorded at a nearby NOAA data buoy. The model produced easterly drift patterns with potential deposition throughout a range of depths between 2743 and 914 meters in the outer Monterey Bay (4nm - 24nm offshore). Some of the containers may still be linked together in their original stack formations. Containers may have sunk onto relatively flat areas or onto submarine canyon slopes. This study cost approximately $12,000 (S. Kathey, pers. comm.). Attempted location and recovery of all 15 containers lost within the MBNMS was estimated at approximately $25 million, with a low expected rate of success. There is no record of a container having ever been successfully recovered from a depth of over 1,000 m. Therefore, this was not pursued.

A prolonged legal debate ensued between NOAA and the owners and operators of the vessel – All Oceans Transportation, Inc., Italia Marritema SpA and Yang Ming Transport Corporation – as there was some uncertainty regarding the extent of U.S. jurisdiction and the ability to prosecute for damages. On July 26, 2006, a $3.25 million settlement was announced for long-term damage to Sanctuary resources (NOAA 2006). The MBNMS agreed to use the settlement funds to undertake habitat restoration and characterization projects and to monitor the long-term impacts of container TGHU7712262.

Container Loss: A Widespread Phenomenon

Although containers lost overboard are rarely found on the seafloor, the loss from the *Med Taipei* was not an isolated incident. The nexus of rough seas, inadequate or faulty securing mechanisms, and improper container stacking procedures are responsible for making container loss a well-documented phenomenon in the shipping industry.

Scope of the Problem

The actual numbers of lost containers are difficult to confirm and estimates of the scope of this occurrence are wide-ranging. Many groups have cited a figure of 10,000 containers falling from ships each year (Podsada 2001; Standley 2003; Hohn 2011; IMO 2004; BBC 2010; ITTS 2011; Countryman and McDaniel 2011). The Chair of the European Parliament's Transport Committee, National Geographic News, BBC News, and Friends of the Earth International are among those citing this figure, which would amount to 83 million pounds (41,500 tons) of littered steel in container weight alone annually. The Through Transport Club, which insures 15 of the top 20 container lines for their losses, estimates that losses overboard are "probably less than 2,000 containers per year" (VMI 2011). Groups including the AIMU and a joint industry project of the Maritime Research Institute Netherlands (MARIN) have cited less specific numbers that are nonetheless in the 1000s (Lashing@Sea 2006; AIMU 2008). However, the origins of these estimates are not clear. Another estimate is that lost merchant freight at sea amounts to 1.3 million tons per year (Van den Hove and Moreau 2007). This figure includes bulk goods and break-bulk cargo in addition to containers.

No centralized database is maintained with comprehensive container loss statistics. Damage and loss reports are rarely shared beyond line operators, involved local maritime authorities and providers of protection and indemnity insurance (P&I clubs). Operators generally avoid exposing incident details for publicity reasons. Similarly, P&I clubs investigate loss incidents but do not share findings, making trends difficult to evaluate (Lashing@Sea 2009; AIMU 2008). Following the media's interest in the March 2011 MBNMS/MBARI lost shipping container cruise, the World Shipping Council (WSC) has countered these figures with its own. The WSC surveyed its members, who collectively account for 90% of global containership capacity. Although the WSC reports that the carriers that responded represent over 70% of global container ship capacity (WSC 2011), it is unclear what the survey's response rate was. Survey results were extrapolated to all container carriers to yield a much smaller estimate of 350 containers lost at sea each year, not counting catastrophic events (such as ship groundings). Including catastrophic losses, the WSC reports that average annual losses increase to approximately 675 containers (WSC 2011). The most recent highly publicized container loss incident was the grounding of the M/V *Rena* off New Zealand in October 2011. This single event resulted in the loss of an estimated 267 containers overboard prior to salvage operations (Maritime New Zealand 2012).

Causes

The time demands placed on the shipping industry mean that it can be difficult to balance safety and efficiency. The nature of the industry has been compared to a quote from car racer Mario Andretti: "If everything is under control you are going too slow" (Koning 2009). Following are some of the common problems that lead to container loss.

Misdeclared container weights: It is believed that shippers sometimes ignore the weight limitations of shipping containers. The U.K.'s Marine Accident Investigation Branch (MAIB) investigated the failure of the containership *MSC Napoli* in January, 2007 (Figure 6) and found that 137 (20%) of the 660 dry containers stored on deck had actual weights greater than their declared weights. Some containers were overweight by as much as 20 MT (AIMU 2008).

Figure 6. The *MSC Napoli*, which broke apart in January 2007 in the English Channel. MAIB investigation determined that 20% of the containers were overweight. Photo from AIMU 2008.

Containers passing through U.S. and many other ports are only weighed before loading if they arrive by truck. The declared weights of containers arriving by rail are generally not verified (AIMU 2008). The WSC and International Chamber of Shipping (ICS) acknowledge that misdeclared container weights have contributed to the loss of containers overboard, as well as to other safety and operational problems, and have encouraged the IMO to require container weight verification in all cases (WSC 2011).

Faulty connections between containers*:* Containers in a stack are connected to each other with the use of bottom twistlocks. These are used in combination with lashing rods (Figure 7). The replacement of semi-automatic twistlocks (required for ships calling on U.S. ports) with fully automatic twistlocks (FAT) in the past decade has been a cause for concern. FAT require less work by longshoremen on the dock but are smaller and their failure has been a common factor in several loss incidents (AIMU 2008).

Figure 7. Lashing rods tightened by turnbuckles are attached by hand by longshoremen to help secure loads. (This container was damaged by a bow-slamming wave). Figure from Koning 2009.

Heavier containers placed on top of lighter containers*:* Placing heavier containers in the higher tiers places increased forces on the securing gear and all containers underneath. Vessel planners, who use container weights and port of discharge to determine the optimal arrangement of containers on a vessel, aim to prevent this. Yet a common trend is for carriers to accept additional cargo while a ship is already being loaded, rendering the vessel planner's cargo plan obsolete. When late arriving heavy containers end up in the highest tiers, stability is compromised and excessive load pressures become likely (AIMU 2008).

Stacking height*:* With each new generation of container ship, the stacking height has increased. Stacks may now be up to nine containers high below deck and eight tiers high above deck (AIMU 2008). Current vessel designs have up to three-quarters of their containers on deck (VMI 2011). A publication of the Standard P&I Club and Lloyd's Register states "if one container in a stack fails, it is likely that the entire stack will collapse" (Murdoch and Tozer 2006). Commonly, a lashing or overloading problem with one container stack will lead to interactions with other container stacks and unexpected high loads in the securing system, rendering it less effective (MARIN 2009). Other problems associated with high deck loadings include reduced ship stability, interference with visibility from the bridge (which increases the likelihood of collisions), increased exposure of the cargo to storms and seas, and difficult maneuverability at slow speeds due to excessive wind impacts (AIMU 2008). These problems are compounded when containers are stacked high at the bow and stern of the ship, where accelerations and forces are at their greatest.

Container contents improperly loaded*:* Since the contents of containers are often loaded at remote inland locations (especially in emerging nations like China), the cargo inside containers is often haphazardly arranged and inadequately blocked and braced. Poorly loaded or overloaded containers can cause the contents to damage the container or break through its side. Such structural damage, especially when it occurs to a container in the lower tiers, can lead to collapse of the entire stack (AIMU 2008).

Containers in poor condition*:* During periods of high shipping demand, shortages of containers sometimes result in the use of containers in unsatisfactory structural condition. Container corner posts and structural fittings in a degraded condition or not built to ISO standards in the first place can jeopardize an entire stack of containers (Figure 8).

Figure 8. Container corner posts and fittings in unsatisfactory condition. Figures from AIMU 2008.

A study by the IMO from 1996-2002 found that of 19,704 containers inspected, 1,737, or about 9%, had Container Safety Convention (CSC) plate and structural deficiencies (AIMU 2008).

Failure to adapt course to weather conditions*:* Waves can cause ships to roll, sway, pitch, surge, yaw and heave, subjecting container stacks to strong accelerations and extreme motions, such as parametric rolling (MARIN 2009). When combined with the effects of strong winds, these movements can place the containers and securing gear under high stress (Figure 9a). Bow slamming can also occur when large waves break over the bow of the ship (Figure 9b). A study of container loss in the Bay of Biscay and its approaches found that of 1,251 containers lost in 158 incidents from 1992-2008, 83% were lost between the months of November and February when sea conditions are roughest (Interreg III B, undated). Crew failure to take precautionary measures (changing course early) can place the ship in a risky situation. Once heading and speed become difficult to control, heavy rolling is occurring, and green water is on deck, few alternatives remain and accidents are likely (AIMU 2008).

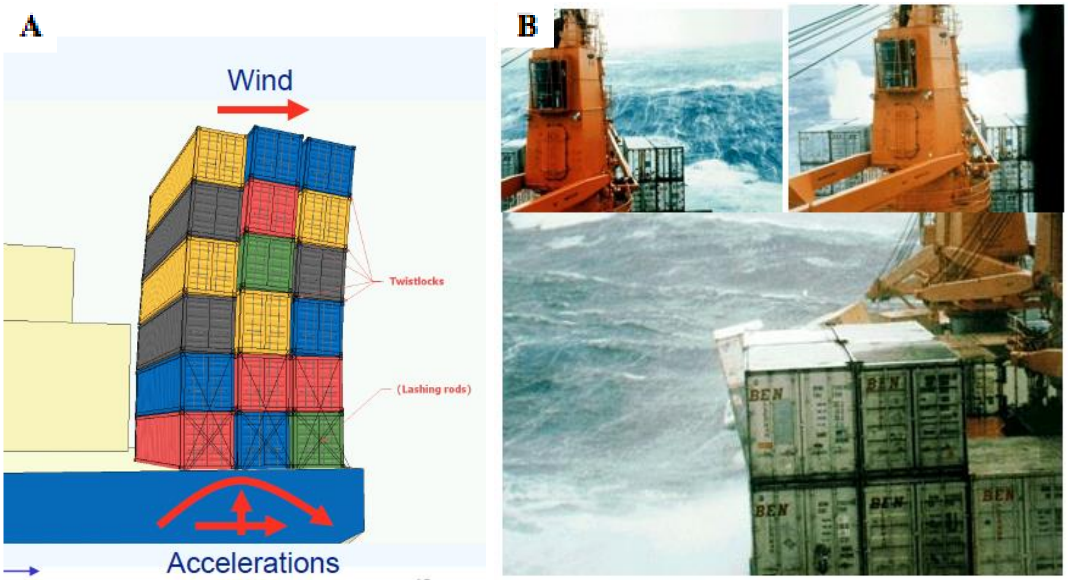

Figure 9. Impact of weather on container stacks. A) In rough seas, the effects of waves on a ship can create accelerations and forces that combine with wind to compromise the stability of container stacks. B) Wave impacts such as bow-slamming can cause containers to fall from a containership in a storm. Figures from Koning 2009 and VMI 2011.

***Ship crew in the bridge unaware of dangerous conditions**:* A questionnaire focused on the causes of cargo loss was distributed to operational experts on board container ships (MARIN 2009). Crew were asked about the feasibility to determine from the bridge when loads on securing gear become too high (Figure 10). Whether or not crew can detect rough conditions placing undue strain on securing gear is a major factor in determining whether remedial actions (such as speed and heading adjustments) are needed.

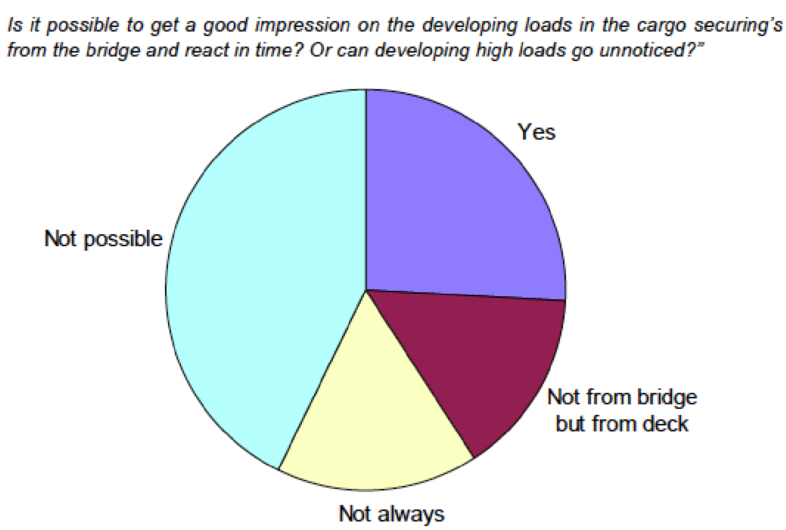

Figure 10. In rough seas, ship crews on the bridge are often not aware of the strains being placed on container stacks on deck. Figure from MARIN 2009.

Crew opinions*:* In the crew survey referenced above, 30% of crew respondents had experienced incidents involving lost or damaged containers. Crew had a variety of opinions about the causes of these incidents. The results of 158 responses are shown in Figure 11 (MARIN 2009).

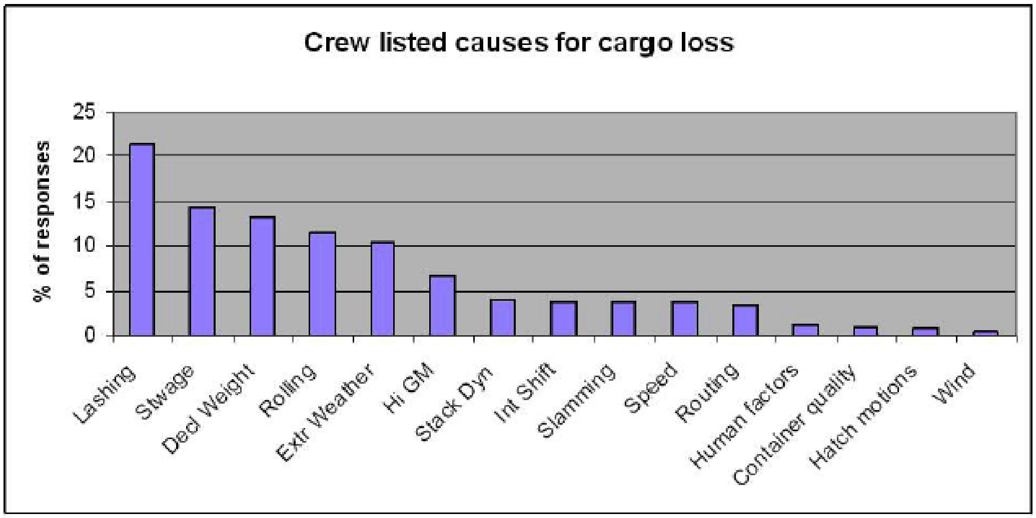

Figure 11. Crew listed causes for cargo loss. Factors named in order of frequency included lashing problems, poor weight distribution during stowage, inaccurate declared container weights, rolling, extreme weather, conditions leading to high metacentric height (GM), stack dynamics, internal cargo shifting, bow slamming, vessel speed, vessel routing, other human factors, poor container quality, hatch motions, and the effects of high winds. Figure from MARIN 2009.

Container Fate After Loss

Following loss incidents, containers rarely sink immediately. Depending on whether they are full or empty, and on the nature of the cargo inside, containers may float at the surface for several days or weeks prior to sinking. Containers are not generally entirely watertight; while an empty container is likely to sink due to water ingress, a full container will likely float until air trapped in the cargo has escaped. Using the deadweight principle that the forces required to sink an object must exceed the volume of water to be displaced, a New Zealand insurance company has calculated that a 20' container would have to exceed 16 tons before it sank, and a 40' container would have to exceed 32 tons (VMI 2011). Other factors affecting the time it takes for a container to sink include the condition of the container, damages to the container as it breaks free, the strength of impact with the ocean and the battering effect of loose cargo upon impact, and the size of waves, which can have a smashing effect.

When floating, most of the container lies below the surface of the water, like an iceberg, creating a serious navigational hazard for smaller vessels – particularly to fishing vessels and small craft, but also to other containerships and tankers (VMI 2011). One of the best-documented accidents occurred on January 11, 2000, when marine investigators believe the British scallop trawler, *Solway Harvester*, struck a fully loaded container in the Irish Sea. The trawler sank, all seven crewmembers were killed, and rescuers who arrived on the scene found plastic vats filled with mayonnaise floating on the surface

(Geoghegan 2013). A large container ship colliding with a floating container could lead to the release of up to one million gallons of bunker fuel oil (NOAA 2009). Floating containers thus pose a risk to navigation and to Sanctuary resources. Although we are not aware of any statistics or reports on the number of containers that may be floating at a given time, the phenomenon is believed to be widespread enough to have recently inspired an invention designed to sink lost containers (Container Sinka 2014). There are strong incentives for being able to predict, announce, and track the positions of lost containers. Calculation of container drift trajectories allows vessels to avoid areas potentially dangerous to navigation and can aid in any recovery efforts.

Numerical models have been developed to predict container drift by incorporating wind direction, currents and tides, container buoyancy, degree of immersion, and other hydrodynamic factors. The Ocean Surface CURrent Simulator (OSCURS) model for the North Pacific Ocean and Bering Sea has been used to predict with some accuracy where lost containers and their contents would travel. The Central and Northern California Ocean Observing System (CeNCOOS) has an online tool available to the public for predicting drift. The "Drop-a-Drifter" Surface Water Trajectories in Central California website uses the Regional Ocean Modeling System (ROMS) tool created by NASA's Jet Propulsion Lab.[3] This technology allows the prediction of where surface water and flotsam will travel during the past (since Oct. 4, 2010), present, and future (up to 48 hours ahead). For the *Med Taipei* incident in the MBNMS, the meteorological and oceanographic consulting firm Fugro, Inc. was contracted to run the CASP 2.0 program to forecast the likely locations of the remaining, undiscovered containers. The results of this modeling, which created an estimate based on 5,760 track replications, can be seen in a probability map (Figure 12).

[3] "Drop-a-Drifter" website http://www.cencoos.org/sections/products/drop_a_drifter.shtml

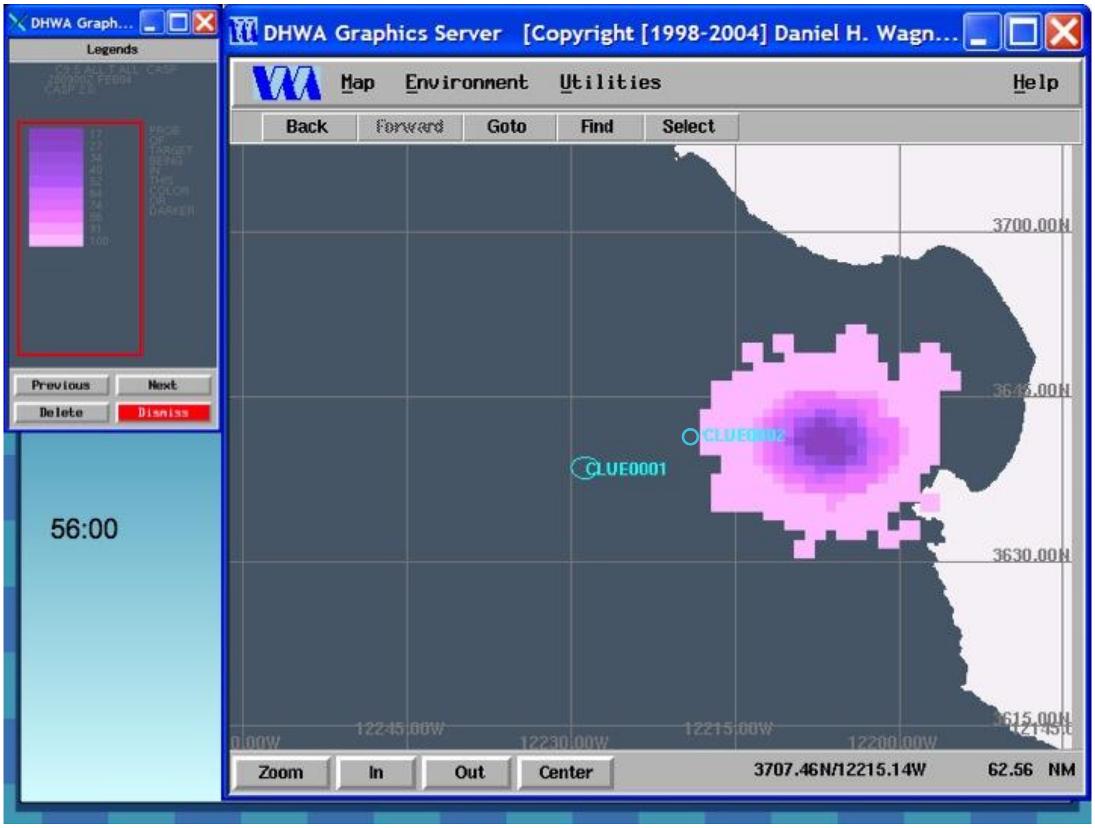

Figure 12. Modeling of likely drift of M/V *Med Taipei* containers after 56 hours. Clue0001 shows location of the container loss incident; Clue0002 shows the location of discovered container TGHU7712262. The darker the shade of purple, the greater the probability of containers being found within that area. Credit: Fugro Inc.

Containers can then either sink or drift onto shore. In either case, a container may remain intact or its contents may escape via collisions with other cargo, the vessel, rough seas, reefs, or the shore. A damaged container can thus serve as a point-source of marine debris. Potential impacts to marine natural resources include falling containers crushing and smothering of benthic organisms, introduction of foreign habitat structure, shifts in local ecology, an expanding benthic footprint over time as the containers degrade and collapse, marine species entrapment and ingestion risks from released container contents, and the deposition of plastics or other oil-based products, hazardous or radioactive materials, and subsequent bioaccumulation (NOAA 2006). The corrosion-resistant marine coatings used to paint the interiors and exteriors of containers are also a concern, as they have traditionally contained toxic substances such as zinc powder. Product safety data sheets for the marine coatings preferred by container manufacturers provide detailed information about the composition of these paints. The risks of some ingredients are described with phases such as “very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment” (Appendix D; Hempel Group 2012). Some of the leading container manufacturers have recently switched to using zinc-free, water-based coatings, which may represent an improvement (Valspar Corporation 2011).

In the section “MBNMS/MBARI Lost Shipping Container Cruise” we provide a preliminary description of the ecological impacts associated with the container found in the Monterey Bay National Marine Sanctuary. In addition to causing a host of potential ecological impacts, container losses represent a tremendous waste of manufacturing effort, energy, and money. The phenomenon is responsible for capital costs associated with search, recovery, investigation, and legal actions following container loss, and causes substantial losses to maritime insurers.

Are Losses Becoming More Frequent?

Whether or not container losses are becoming more frequent is a difficult question to answer, as the vast majority of losses are not reported beyond notification to "need-to-know" parties: the ship's owner, line operator, the exporter, the importer, and the insurer (VMI 2011). The Lashing@Sea government/industry investigation noted that about 50 lost container incidents were reported between the years 1989-2000 (MARIN 2009). Appendix 2 shows the AIMU's "casualty list" of lost containers during this period. Both the frequency and severity of reported losses began to increase sharply in 1997. While more than two-thirds of the losses reported over the 12-year period occurred in the last 5 years, several well-documented incidents such as the M/V *Sherbro* accident (1993) are not included in this list (AIMU 2008). Analysis of container loss incidents in the Bay of Biscay by the European Commission's Interreg III B Community Initiative found a 15-year trend toward increasing loss (Figure 13); these regional data can likely be extrapolated to the global level. We should note that these trends could also reflect an increase in reporting or an increase in the use of shipping containers.

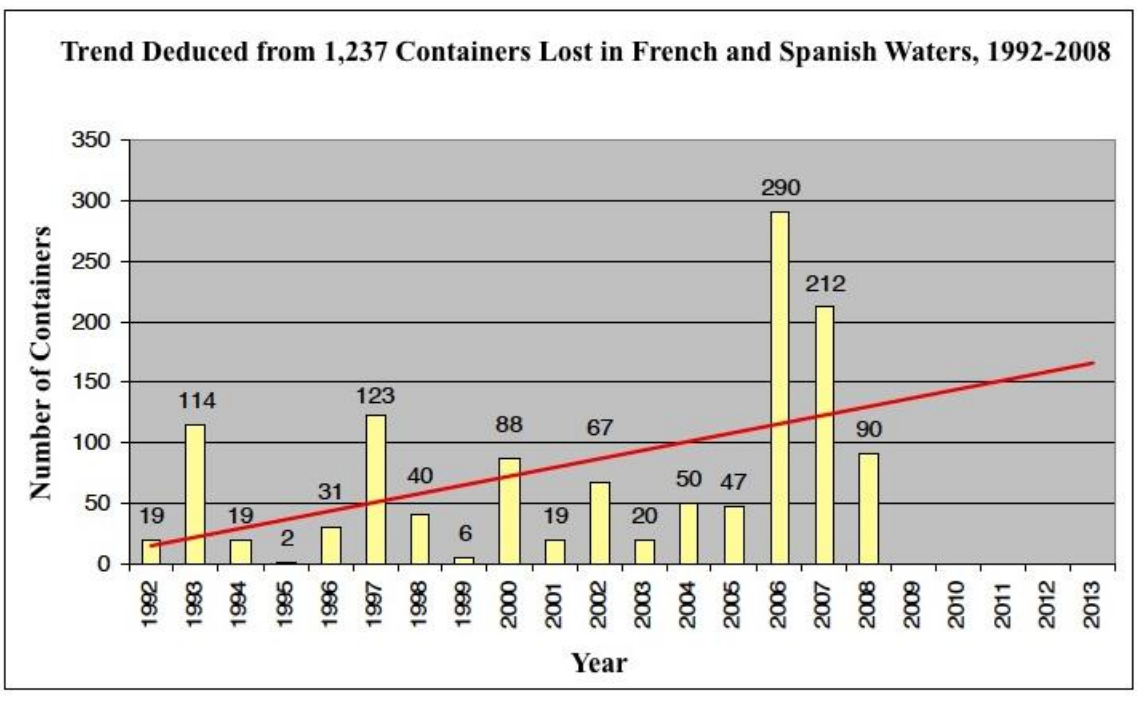

Figure 13. Container loss in the Bay of Biscay, 1992-2008. The red line illustrates the regional trend toward increased losses. Figure from Interreg III B, undated.

The Lashing@Sea Excecutive Summary summarizes: *"Over past years various signals have come forward from the industry with regards to safety. An increasing number of incidents in the container sector suggest that risks have increased. The question is raised* *whether increase of the transported volume, or reduced safety in general is the cause of this"* (MARIN 2009). The World Shipping Council has expressed that the industry's goal is to "reduce those losses to as close to zero as possible" (WSC 2011).

MBNMS/MBARI Lost Shipping Container Cruise

One of the diverse mitigation projects identified during the settlement negotiation process with the shipping companies involved in the M/V *Med Taipei* incident called for monitoring of the impacts, natural habitat recovery rate, and decomposition rate/characteristics of container TGHU7712262. On March 8-10, 2011, a science team conducted a research expedition aboard MBARI's R/V *Western Flyer*. The ROV *Doc Ricketts* was deployed to address the following goals:

- Assess the container's current condition by gathering high-resolution imagery.
- Describe sea life on the container and at different distances from it using 500 meter transects along two different axes.
- Assess the macrofaunal communities, chemistry, and grain size of sediments at different distances from the container using sediment core samples.
- Bring public attention to this deep-sea phenomenon that has been increasing with economic globalization.

Biological Observations

Video imagery collected by ROV *Doc Ricketts* showed that the muddy sand seafloor at 1,281 m was anything but a barren deep-sea desert. Rather, the container landed in a beautiful smooth seascape with a high diversity of fauna. In the areas surrounding the container there were delicate tube worms every few inches, abundant lacey-white sea cucumbers, red sea pens, and many other fragile deep sea taxa. A representation of the deep sea life found on Smooth Ridge near the container is presented in Figure 14. We discovered a previously undocumented association between sea pigs (*Scotoplanes globosa*; a deep sea holothurian) and juvenile lithodid crabs (Fig 14g). The lithodid crabs typically appeared to be taking shelter, perhaps from predators or from bottom currents, under *Scotoplanes globosa*. A majority of the sightings of *Scotoplanes* were observed with lithodid crabs inferior, and very few lithodid crabs were seen unaccompanied by *Scotoplanes.*

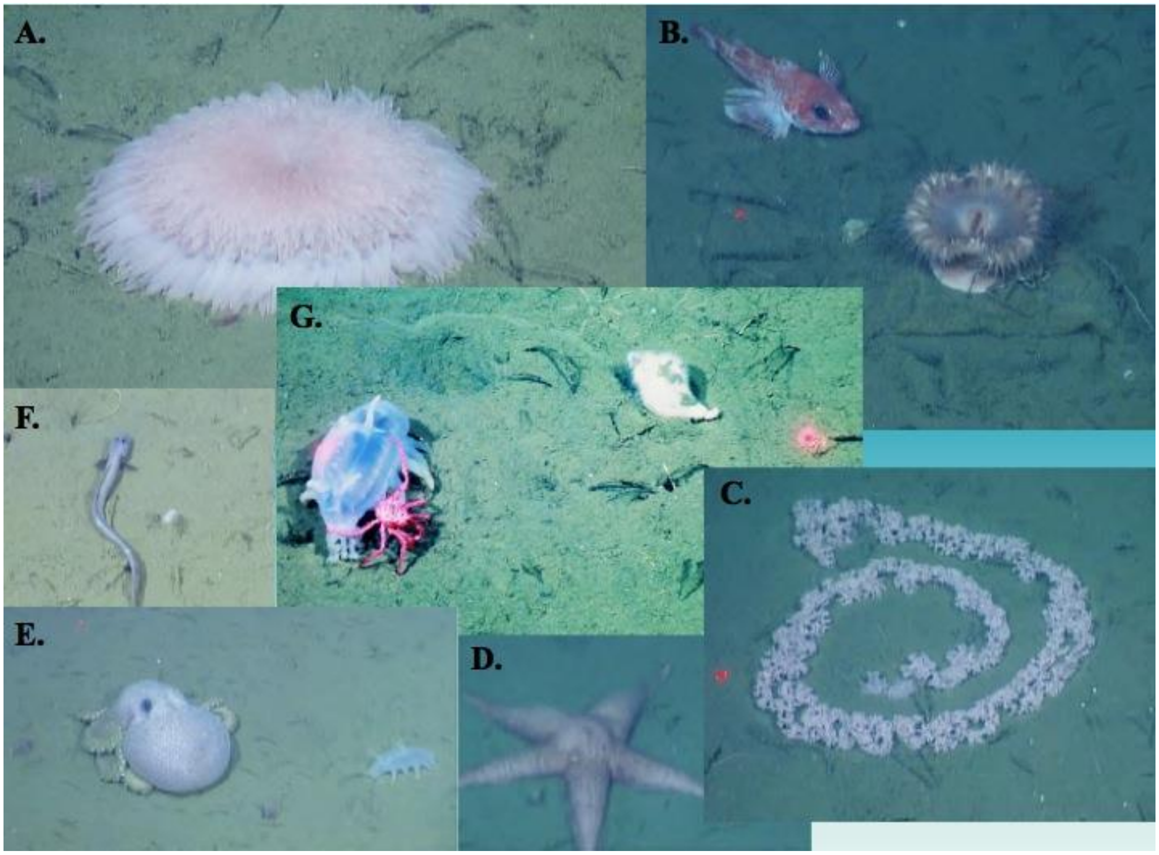

Figure 14. Taxa observed on the deep sea floor surrounding the lost container included a) *Liponema brevicornis* (pom-pom anemone), b) *Sebastolobus* sp. (thornyhead rockfish) and Actiniaria (anemone), c) *Chrysaora fuscescens* (sea nettle) tentacle d) *Lophaster* sp. (sea star), e) *Granelodeone* sp. (octopus), f) *Lycenchelys* sp. (snake head eelpout), and g) *Neptunea amianta* (snail) and *Scotoplanes globosa* (sea pig) with juvenile lithodid crab. Photo credits: MBARI/MBNMS.

Visual surveys and biological community assessments conducted by ROV *Doc Ricketts* preliminarily indicated that the fallen container has likely contributed to ecological impacts in the deep sea at three different scales:

First, upon impact with the seafloor, there was presumably displacement of habitat and an immediate crushing and smothering of any organisms beneath the container. Without a baseline survey of benthic taxa present at the site prior to the arrival of the container, it is difficult to quantify the extent of this impact. However, post-cruise analysis of the abundance and diversity of megafauna and macrofauna at transect sites near the container could be used to estimate the number of crushed organisms (Taylor et al., in review).

Second, taxa on and immediately adjacent to the container were different from those that were further away, suggesting that the introduction of hard substratum caused local changes in ecology (Figure 15; Table 2; Taylor et al. in review). There was also evidence of indirect effects such as predator-prey relationships that are unlikely to have otherwise occurred in this area. One example involved lithodid crabs at the base of the container preying on *Neptunea* snails that appeared to have fallen from the upper areas of the container.

Lastly, this container and the thousands of other lost containers comprise an expanding benthic footprint, which may be serving as hard substratum "stepping stones in the deep" in a seascape otherwise dominated by sand and mud. As cargo ships typically travel over the same routes when traveling between ports, lost containers are potentially forming underwater highways across previous biogeographic breaks, enabling the migration of invasive species between world ports. This effect may not be confined to invasive species, as containers may act like artificial reefs in promoting the movement of native species as well. As an example, this container appeared to be serving as a nursery for *Neptunea amianta* (Fig. 15a), which is naturally occurring but may otherwise lack suitable substrate to attach its eggcases to.

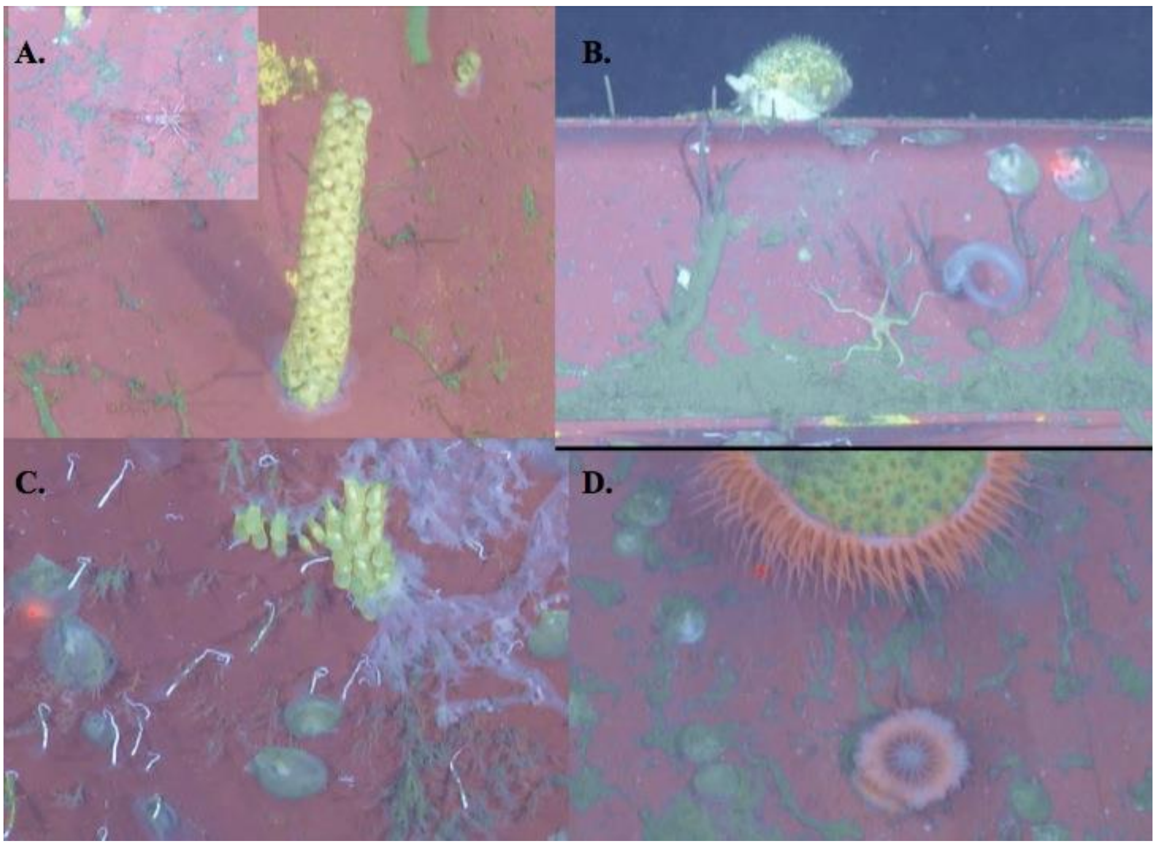

Figure 15. Taxa observed on the surface of the lost container included a) egg cases of *Neptunea amianta* (snail) and *Pandalopsis ampla* (shrimp) b) *Neptunea amianta* (snail), *Lycodapus* sp. (midwater eelpout), serpulid polychaetes, scallops, and brittle star, c) Tunicates and scallops, and d) Hormathiidae (fly trap anemone), scallops, and *Clavularia* sp. (octocoral). Photo credits: MBARI/MBNMS.

Table 2. Taxa observed on container differed substantially from species identified on surrounding seafloor, with a small number of shared species. This is most likely due to the container offering a hard substratum in a benthic environment otherwise dominated by sand and mud habitat. *Neptunea amianta* was one of the few species found on both the container and on the nearby seafloor, but this species had greater abundance on the container than elsewhere.

Taxa On Container	Taxa on Surrounding Seafloor
Aeolidiidae (nudibranch)	*Allocentrotus fragilis* (fragile urchin)
Brisingida (Asteroidea)	*Anthoptilum grandiflorum* (sea pen)
Calliostoma (white top snail)	*Asteronyx* sp. (brittle stars on whips)
Clavularia sp. (octocoral)	*Bathysiphon* (benthic foram)
Eggcases *(Neptunea amianta)*	Lithodidae (crabs)
Eggcases (unknown)	*Lycenchelys* sp. (snake head eelpout)
Hormathiidae (fly trap anemones)	*Neptunea amianta*
Neptunea amianta	Ophiuroidea
Rare deep sea scallop	*Pennatula phosphorea californica*
Sabellid polychaetes	*Scotoplanes globosa* (sea pigs)
Serpulid polychaetes	*Tritonia diomedea* (large nudibranch)

Seabed sediments were collected for faunal and sediment characteristics on 500 meter transects along two different axes. 30-cm diameter tube cores were used to penetrate the sediment to a depth of ~20 cm at distances of 0.1, 1, 5, 25, 50, 100, 250, and 500 meters from the container site (Figure 16). The top 0-5 cm of 21 samples were analyzed for macrofaunal community composition, while the top 0-1 cm of 11 samples were analyzed for grain size, percent carbon and nitrogen, and stable isotopic composition of carbon and nitrogen. Grain size and faunal distribution patterns indicated that the container is a mild disturbance to the seabed that (1) alters local flow patterns, likely leading to changes in grain size assortment very nearby, (2) increases habitat heterogeneity and adds structure, leading to megafauna aggregation, and (3) promotes a number of cascading indirect effects (e.g. changes in predation, competition, restructuring of sediment community due to change in grain size, and related biological effects). These effects are very local in scale, with a 10 m halo of significantly altered biological patterns. Combined with the container's approximate 30 m^2 footprint, a 10 m halo gives approximately 600 m^2 of disturbance – 20 times the size of the container itself (Taylor et al., in review.).

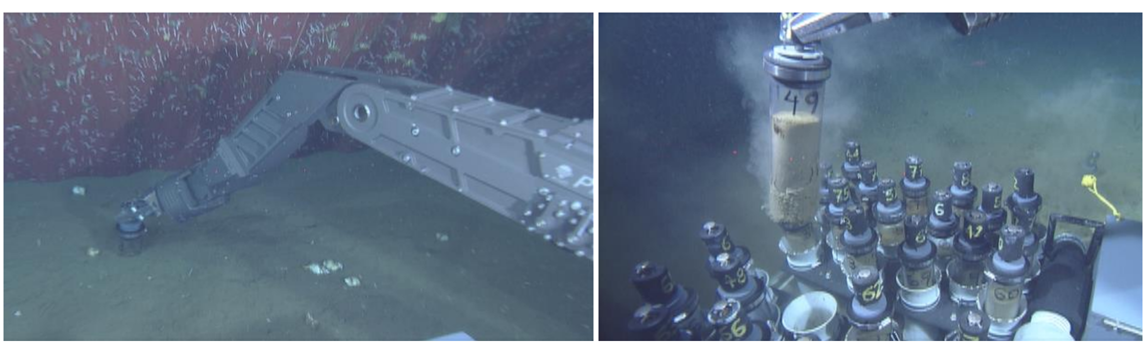

Figure 16. Sediment samples were taken from adjacent to the lost container and along 500 meter transects using the ROV's manipulator arm. Photo credits: MBARI/MBNMS.

Container Condition

The container showed little sign of wear or decay after seven years in 1,281 m of water (Figure 17). One concern is that released container contents – which can be toxic – can cause contamination, but in this case the cargo of 1,159 steel-belted tires had not escaped. The toxicity of the container's paint is also of concern, but the paint appeared to be in good condition and almost entirely intact, with few observations of paint chips on bottom sediment.

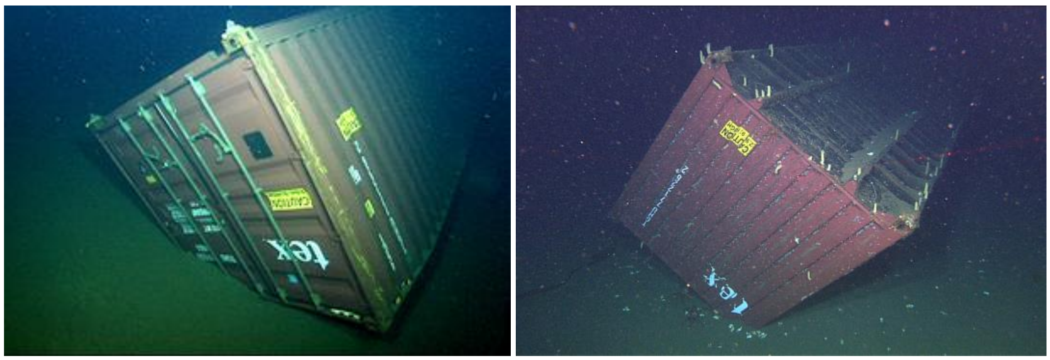

Figure 17. Container TGHU7712262 in 2004 (left) and 2011 (right). Although colonized by various deep-sea species such as *Neptunea* snails, the container appeared to be in near perfect structural condition. Photo credit: MBARI/MBNMS.

Twistlocks – used between containers in a stack – were still present on all four bottom corner castings of the container (Figure 18). These were identified as semi-automatic twistlocks. The locking cones are still in place and appear to be undamaged. The +/- 45 degree alignments of the triangular cones and the positions of the yellow knobs on the steel wires indicate that the twistlocks are still in the "locked" position. It is unknown whether the container originally beneath container TGHU7712262 was lost or remained onboard. If it could be found or if it was documented in an incident survey, its top corner castings would likely have experienced severe damage or tears. If this container were found without damaged top castings, one could conclude that the twistlocks between the containers were probably not securely locked in the first place, either due to improper container loading, misaligned castings, or blocking objects in the castings (J. Koning, pers. comm., April 26, 2011).

Figure 18. Intact and undamaged semi-automatic twistlocks on container TGHU7712262. Photo credits: MBARI/MBNMS.

Public Interest

An unexpected outcome of the cruise was the level of public interest it generated. Possibly due to the public's fascination with deep sea exploration and the container's connections to the global economy and our own consumption, the container study captured the interest of people around the country and around the world. MBNMS/MBARI staff responded to many inquiries from international, national, and local media. Stories on the 2011 MBNMS/MBARI lost container cruise were featured in the *San Francisco Chronicle* and the *San Diego Union Tribune,* and aired on BBC News, NPR, Radio New Zealand, Discovery Channel Canada, and numerous science blogs (SIMoN 2013; MBNMS 2011).

Moving Forward: Can Container Losses Be Reduced?

The thousands of containers already on the seafloor will likely be there for many hundreds of years and will be joined by thousands more each year, leading to high cumulative impacts. Eventually the container found in the MBNMS will rust and expose its water-logged and rotting contents, which could physically smother the bottom biota of an enlarged area. It is apparent that humans are impacting the deep-sea environment with containers and the marine debris they contain before we even understand what species live there and how the ecosystem functions.

In the past two decades container ships have grown tremendously in capacity, but it is unclear whether safety protocols and securing methods have been able to keep up. The AIMU concluded in 2008 that the industry "can expect even more frequent and severe losses, unless corrective action is taken." This issue has begun to receive international attention, and there are several encouraging signs of progress:

Industry Led Efforts

From 2006-2009, a consortium of 23 participants including ship owners, lashing gear manufacturers, governments and classification societies conducted "Lashing@Sea," a study organized by MARIN. Methods included a monitoring campaign of five ships in operation, model tests of secured cargo and an extensive crew survey (MARIN 2010). One of the vessels monitored was the *NYK Argus*, which was equipped with an instrumented container carried in the lowest tier to record forces imparted from the stack above and from lashing arrangements (Figure 19). The vessel was also fitted with a grid of 11 acceleration sensors, hull deformation and load sensors, and weather forecast and ship movement data links (MARIN 2009). Lashing@Sea provided the IMO and the International Association of Classification Societies (IACS) with recommendations to improve safety levels.

Figure 19. The *NYK Argus* leaving San Francisco Bay, with an instrumented MARIN container on the bottom tier to help monitor forces while underway. Photo credit: MARIN 2009.

Depending on the route traveled, carriers may also reduce the likelihood of loss by adjusting course when possible. Tracking of the *NYK Argus*, which completes a roundtrip crossing of the North Pacific every two months, showed that the ship varied its course from one crossing to the next (Figure 20b). The variation in the sailed tracks reveals the encouraging efforts taken by the crew to avoid severe wave fields and weather depressions (MARIN 2009).

A. B.

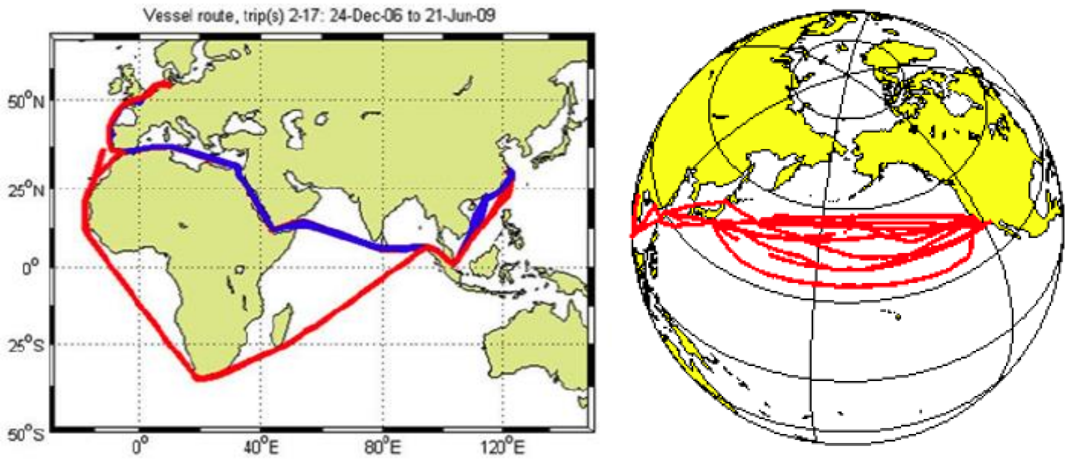

Figure 20. Compared to a Far East – Europe route (a), the Far East – North America West Coast route of a ship like the *NYK Argus* (b) allows for considerable course alteration and weather avoidance. Red lines in the figure at right show actual routes of the *NYK Argus* over several months. Figures from MARIN 2009.

New software also exists that alerts ship Masters when parametric rolling conditions exist, allowing them to make better judgments about the need to change their course or speed. Many new ships are also being engineered to resist parametric rolling (AIMU 2008). Some companies have constructed “bird cages,” buttresses, or other stabilizing structures on the stern, where forces are greatest, to aid in keeping containers in place. These have proved highly effective in reducing the severity and frequency of losses (AIMU 2008).

In December 2008, the ICS and WSC jointly published *Safe Transport of Containers by Sea: Industry Guidance for Shippers and Container Stuffers*. The document recommends best practices for ships, port facilities, and shippers in the loading and handling of cargo containers, including crew training on parametric rolling, safer stacking and security for above-deck cargo in heavy swell (Lloyd’s List 2008). The guidelines were developed by an expert industry working group that met in London and Washington D.C. during 2008. Marine insurers and P&I clubs also have strong incentives to reduce losses, and have produced various publications such *A Master's Guide to Container Securing* (Murdoch and Tozer 2006).

In 2011, five of the world’s largest container carriers – Maersk Line, Mediterranean Shipping Co, CMA CGM, Evergreen and Hapag-Lloyd – announced an effort to share safety-related information across the industry. The Cargo Incident Notification System (CINS) Network aims to create a comprehensive database of cargo-related incidents and mishaps. By making long-term trends easier to detect and industry responses more readily accessible, CINS is expected to increase transparency in the maritime shipping sector (Lloyd’s List 2011).

Regulatory Measures Enacted

In the late 1990s, the IMO amended the International Convention for Safety of Life at Sea (SOLAS) treaty to include regulations requiring vessels over 500 gross tons traveling in international waters to carry a "Cargo Securing Manual" on board that is custom-written to account for the particular forces expected on individual ships. This requirement was first implemented on January 1, 1998. Cargo Securing Manuals now include guidelines from a 2003 IMO book titled "Code of Safe Practice for Cargo Stowage and Securing" and are intended to guide loading, stowage and securing (AIMU 2008). The USCG enforces this rule for all vessels operating in U.S. waters, regardless of whether they are SOLAS signatories.

Proposed Regulatory Measures

In 2008, Egypt proposed to the Maritime Safety Committee (MSC) of the IMO that beacons capable of emitting pulses from 20,000 feet be installed on all containers carrying dangerous goods in order to facilitate search operations (IMO 2008). Tracking specialist Tri-Mex International has investigated the feasibility of container monitoring systems. While an effort to tag all the world's containers would greatly assist with recovery efforts and would reduce the risk of collisions while afloat, the economic costs could be high (VMI 2011). A less costly possibility could involve placing transponders on only the uppermost containers of ships, as they are the most likely to be lost.

In March 2011, the IMO Sub-Committee on Ship Design and Equipment (DE) considered a proposal by Friends of the Earth International (FOEI), the International Fund for Animal Welfare (IFAW), the World Wide Fund for Nature (WWF), and Pacific International focused on the increased threat to the Arctic marine environment from the loss of containers and harmful substances in packaged form (HSPF) by vessels. Proposed measures included more stringent lashing requirements, stricter standards for stack height and vertical weight distribution, increased use of weather and ice forecasts, prompt reporting of loss incidents to the proper authorities, use of tracking devices, and salvage of overboard containers to the maximum extent feasible. The DE delayed action on incorporating these concerns into the development of a new mandatory Polar Code, as it was foreseen that comprehensive measures to reduce container loss would soon emerge from another IMO body.

At its 89^{th} session in May 2011, the IMO MSC considered a proposal by Australia, Denmark, and the Netherlands titled 'Proposed measures to prevent loss of containers' (IMO 2011a). The proposal envisaged four outputs, including:

1. Mandating verification of the actual weights of all loaded containers by strengthening SOLAS regulations VI/2 and VI/5.5. This information would then be provided to vessel operators prior to stowage.
2. Creating guidelines on the appropriate stowage and vertical weight distribution in container stacks.

3. A unified interpretation[4] on cargo securing, which takes into account environmental conditions such as wind, sea state, and accelerations.
4. A feedback instrument and guidelines for ships' crew on dealing with extreme metracentric height (GM)[5] conditions.

The WSC and ICS, both of which are industry groups, submitted comments in support of the above proposal, admitting that "industry self-help efforts have not solved the problem" (IMO 2011b). As requiring comprehensive weight verification offers the greatest chance of reducing the likelihood of future losses, the WSC and ICS focused their support on that desired output. The MSC agreed to address the issue, with the Dangerous Goods, Solid Cargoes and Containers (DSC) Sub-Committee as the coordinating organ and 2013 as the target completion year for an output. (IMO 2011c). The DSC recognized the importance of these proposed reforms issues at its 16th session in September 2011. The Baltic and International Maritime Council (BIMCO) joined the WSC and ICS in their support of container weighing, and the DSC invited member governments and international organizations to submit comments and refined proposals to DSC 17, which took place from September 17–21, 2012. Both IMO members and non-members were also invited to submit comments related to strengthening the requirements for lashing gear and container stacking to both DSC 17 and the DE Sub-Committee (IMO 2011d).

At DSC 17, draft amendments to the International Convention for Safe Containers (1972) were agreed upon, and these were approved at MSC 91 in November 2012 (IMO 2013). Additionally, draft guidelines for the development of an approved continuous examination program for containers were agreed upon at DSC 17 (IMO 2013). A correspondence group was also established to further work on mandating verification of gross weight of containers for proposed draft amendments to SOLAS chapter VI (IMO 2013).

Opportunities for Collaboration with NOAA

MBNMS would like to encourage key shipping industry players to demonstrate leadership on addressing this issue. MBNMS/NOAA has undertaken efforts to work with Maersk Line Limited, its parent company A.P. Moller-Maersk A/S, and other shipping lines to explore partnering on additional research. Several opportunities have been

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[4] Unified interpretations are adopted resolutions on matters arising from implementing the requirements of IMO Conventions or Recommendations. Such adopted resolutions can involve uniform interpretations of Convention Regulations or IMO Resolutions on those matters which in the Convention are left to the satisfaction of the Administration or vaguely worded.
http://www.iacs.org.uk/publications/publications.aspx?pageid=4&sectionid=4

[5] Metacentric height (GM) is a measurement of the initial static stability of a floating body. It is calculated as the distance between the center of gravity of a ship and its metacenter. Although a larger metacentric height implies greater initial stability against overturning, metacentric height also has implications on the natural period of rolling of a hull, with very large metacentric heights being associated with shorter, more intense periods of roll.

discussed, including:

- Shipping lines could incorporate existing container loss minimization efforts into their portfolio of environmental initiatives and as a sustainability report metric. This would serve the purpose of entering container loss into the broader environmental discussion.

- MBNMS/NOAA is interested in locating additional lost containers, both from the 2004 *Med Taipei* accident and elsewhere in the Sanctuary. We would like to conduct a multi-beam or side-scan survey (from an AUV or from a ship such as the RV *Thompson*) over the known location of the container in the MBNMS. This will allow us to detect other missing containers in the Sanctuary and elsewhere. The industry could help to sponsor such a project as a form of outreach.

- Shipping lines could also financially support further ecological surveys and research by MBNMS/NOAA on the impacts of lost containers. These impacts include introduction of marine debris, local changes in community structure and relationships, and the possible creation of invasive species corridors along shipping routes. We would like to compare these impacts in different locations.

- Industry could work with NOAA to develop a database of previously lost containers and coordinate reporting protocols for new incidents to better understand the patterns of container loss.

- Industry and NOAA could investigate the feasibility of using inexpensive tracking devices to monitor the location of lost containers while they are still on the sea surface.

MBNMS is also engaged in dialogue with NGOs such as the Ocean Conservancy and business alliances such as the World Ocean Council that are addressing the issue of marine debris. Including container loss minimization as part of their efforts could help to further focus international attention on the ecological impacts of lost containers.

Conclusions

Given that container ships sometime fail to comply with industry safety protocols, in the absence of significant regulatory changes container losses seem likely to continue. Mandating the verification of container weights likely offers the best hope of abating the frequency of loss incidents, as overloading and improper stacking of containers on ships is often identified as a root cause of loss. To stop the additional accumulation of containers on the seafloor in NOAA’s National Marine Sanctuaries and elsewhere, international efforts to prevent these accidents from occurring should be supported.

A streamlined mandatory container loss reporting system implemented by the IMO would also provide resource managers with a powerful tool. Resource managers could better understand and respond to the phenomenon of container loss if they were informed of all accidents that occur. In the meantime, Sanctuaries could potentially review USCG shipping loss inspection records on a regular basis to identify cargos lost in Sanctuary waters and refer such cases to NOAA's Office of Law Enforcement (OLE) for investigation. Consistent enforcement through repeated assessment of fines and damage settlements might spur greater shipping industry attention to this problem – at least where shipping traffic passes through sanctuaries.

Rather than working antagonistically with industry to address this issue, however, numerous opportunities exist for collaboration. No company wants their name or image to be associated with being a primary contributor to marine debris and pollution, and creating underwater invasive species corridors. Though not previously viewed from an ecological perspective, container loss is inherently an environmental issue. Accidents will always occur in an industry subjected to the forces of the ocean and storms, but there is certainly room for improvement upon current loss levels. Shipping companies interested in promoting their progress toward sustainability can recognize this and shine the spotlight on their efforts to mitigate container loss.

While this report broadens awareness of the diverse and widespread impacts of container loss, the long-term ecological and toxicological impacts of shipping containers lost in deep sea habitats remains to be determined. Because almost none of the thousands of containers at the bottom of the world's oceans have been studied, the existence of a known container location in the MBNMS presents an excellent opportunity for further research. Monitoring local ecological and geological conditions at the container site and comparing future observations to the baseline data collected in 2011 will make it possible to better assess the impacts of a fallen container over the course of its lifespan. Moreover, the identification of additional containers would make it possible to assess the generality of patterns of change and would allow testing of the invasive species "stepping stone" hypothesis.

Acknowledgments

We thank Jos Koning for personal communication on technical aspects of container loss, Jim Barry for co-leading the science team, Lonny Lundsten, Erica Burton, and Josi Taylor for their contributions to fieldwork and species identification, the MBARI video lab, Huff McGonigal, Chad King, Patrick Whaling, and Kurt Buck for mapping and processing of sediment samples, Kim Fulton-Bennett and Sacha Lozano for education and outreach, the ROV *Doc Ricketts* pilots, and the crew of the R/V *Western Flyer*. Finally, we also thank the three anonymous peer reviewers who commented on this report.

Appendix A: M/V *Med Taipei* Container Contents Manifest

M/V MED TAIPEI ISO Container Contents
Discharged Into MBNMS
February 24, 2004

Container ID #	Container Manifest Description	Container Contents Description	Units (Cargo)	Packaging	Units (Packing)	Cargo Weight
EMCU9421142	Fencing Product	Kennel Kits, Galvanized Cyclone Fencing, Poles, & Hardware	198 Kits	Cardboard Ctns	18 Ea	18,504 kg/ 40,794 lbs
TGHU7309540	Fencing Product	Kennel Kits, Galvanized Cyclone Fencing, Poles, & Hardware	198 Kits	Cardboard Ctns	18 Ea	18,504 kg/ 40,794 lbs
TGHU8115889	Fencing Product	Kennel Kits, Galvanized Cyclone Fencing, Poles, & Hardware	198 Kits	Cardboard Ctns	18 Ea	18,504 kg/ 40,794 lbs
TOTALS			**594 Kits**		**54 Ea**	**55,512 kg/ 122,382 lbs**
NOTE: 594 kennel kits shipped in 54 cardboard boxes with internal packing materials. Each kit includes galvanized steel cyclone fencing, poles, gate, and hardware for a 10-ft(L) x 6-ft(W) x 6-ft(H) enclosure. Total area of cyclone fencing: 192 sq ft/kit X 594 kits =114,048 sq ft (or a **6ft tall fence that is 3.6 miles (19,008 ft) long**). Estimated number of galvanized steel poles: 9 poles/kit X 594 Kits = **5,346 poles**. Estimated number of total assembly hardware (e.g. brackets, bolts, nuts, latches, etc.) **exceeds 50,000 hardware pieces**.						
TGHU7712262	Passenger Car Tires	Steel-Belted Michelin Passenger Car Tires	1,159 Tires	N/A	N/A	11,724 kg/ 25,847 lbs
TGHU8123143	Passenger Car Tires	Steel-Belted Michelin Passenger Car Tires	1,101 Tires	N/A	N/A	11,138 kg/ 24,555 lbs
TOTALS			**2,260 Tires**			**22,862 kg/ 50,402 lbs**
NOTE: Steel-belted radial tires contain synthetic rubber (petroleum product) and internal steel support fibers						
TGHU7567098	Electric Bed & Wheelchair Accessory	Metal Hospital Beds, Dalton Model B-2000	132 Kits	Cardboard Ctns & Packing Material	264 Ea	10,420 kg/ 22,972 lbs
TOTALS			**132 Kits**		**264 Ea**	**10,420 kg/ 22,972 lbs**
NOTE: Components include metal frames, electric motors, wheels, spring mattress support system, handles, and electrical wiring						
TGHU7578153	Housewares (Cotton Mattress Pads)	100% Cotton Down Proof Fabric 200 TC Polyfilled 12" Diamond Box Mattress Pads	2,492 Pads	Paper-Cardboard Ctns	1,037 Ea	4,842.5 kg/ 10,676 lbs
TOTALS			**2,492 Pads**		**1,037 Ea**	**4,842.5 kg/ 10,676 lbs**
NOTE: Matress pads are made of polyester fiber fill and cotton fabric. Total area of fabric for all mattress pads equals **109,542 square feet**						

Container ID #	Container Manifest Description	Container Contents Description	Units (Cargo)	Packaging	Units (Packing)	Cargo Weight
GATU8496935	Hair Ornaments, Scarf, Hat	Hair Ribbons	61,200 Ea	Cardboard Ctns/ Plastic-Paper Pks	130 Ea/ 5,100 Ea	7,000 kg/ 15,432 lbs
		Hair Wraps	12,000 Ea	Cardboard Ctns/ Plastic-Paper Pks	100 Ea/ 1000 Ea	
		Hair Turbans	25,500 Ea	Cardboard Ctns/ Plastic-Paper Pks	85 Ea/ 2,125 Ea	
		Cosmetic Bags	3,360 Ea	Cardboard Ctns/ Plastic-Paper Pks	14 Ea/ 280 Ea	
		Hair Beads	2,880 Ea	Cardboard Ctns/ Plastic-Paper Pks	10 Ea/ 240 Ea	
		Hair Barrettes	25,920 Ea	Cardboard Ctns/ Plastic-Paper Pks	90 Ea/ 2,160 Ea	
TOTALS		**Hair Ornaments & Apparel Items**	**132,060 Items**	**Cardboard Ctn/ Plastic-Paper Pks**	**429 Ea/ 10,905 Ea**	**7,000 kg/ 15,432 lbs**
NOTE: Apparel items are made of plastic, other petrochemical derivitives (e.g. nylon, polyester, etc.), and possibly cotton						
EISU1377410	Wooden Frame Sofa	Benchcraft Leather Sofas	16 Ea	Cardboard Ctns/ Plastic Wrap	16 Ea/ 16 Ea	3000 kg/ 6,614 lbs
		Benchcraft Leather Love Seats	14 Ea	Cardboard Ctns/ Plastic Wrap	14 Ea/ 14 Ea	
		Benchcraft Leather Chairs	10 Ea	Cardboard Ctns/ Plastic Wrap	10 Ea/ 10 Ea	
		Benchcraft Leather Ottomans	10 Ea	Cardboard Ctns/ Plastic Wrap	10 Ea/ 10 Ea	
TGHU7747931	Wooden Frame Sofa	Thomasville Leather Sofas	31 Ea	Cardboard Ctns/ Plastic Wrap	31 Ea/ 31 Ea	3000 kg/ 6,614 lbs
TTNU9298065	Wooden Frame Sofa	Thomasville Leather Sofas	31 Ea	Cardboard Ctns/ Plastic Wrap	31 Ea/ 31 Ea	3000 kg/ 6,614 lbs
EMCU1179583	Wooden Frame Sofa	Thomasville Leather Love Seats	31 Ea	Cardboard Ctns/ Plastic Wrap	31 Ea/ 31 Ea	3000 kg/ 6,614 lbs
CAXU7120249	Wooden Frame Sofa	Thomasville Leather Love Seats	31 Ea	Cardboard Ctns/ Plastic Wrap	31 Ea/ 31 Ea	3000 kg/ 6,614 lbs
FSCU6976236	Wooden Frame Sofa	Thomasville Leather Sofas	31 Ea	Cardboard Ctns/ Plastic Wrap	31 Ea/ 31 Ea	3000 kg/ 6,614 lbs
* * *	* * *	Seat Cushions (see note below)	479 Seat Cushions	N/A	N/A	
TOTALS		**Leather Furniture Items**	**684 Items**	**Cardboard Ctn/ Plastic Wrap**	**205 Ea/ 205 Ea**	**18,000 kg/ 39,684 lbs**

Container ID #	Container Manifest Description	Container Contents Description	Units (Cargo)	Packaging	Units (Packing)	Cargo Weight
NOTE: Furniture was constructed of polyurethane foam, solid pine and plywood, leather, tempered metal coils, bleached textile fiber batting, felt padding, resin treated polyester fiber, polyester fiber, brass nails, steel staples. Each sofa had 3 leather upholstered loose seat cushions. Each love seat had 2 leather upholstered loose seat cushions.						
EMCU9110541	Bales	Waste Cardboard	66 Bales	Steel Wire	66 Sets	17,237 kg/ 38,000 lbs
TOTALS			**66 Bales**		**66 Sets**	**17,237 kg/ 38,000 lbs**
NOTE: Kraft corrugated cardboard trimmings from box manufacturing process (bales bound by steel wire)						
* * *	* * *	ISO Shipping Containers	15 Ea	N/A	N/A	57,154 kg/ 126,000 lbs~
TOTALS			**15 Ea**			**57,154 kg/ 126,000 lbs~**
NOTE: Standard 40ft dry shipping containers have dimensions of 40ft(L) X 8ft(W) X 8.5ft(H) and weigh approximately 8,300 lbs each. High Cube 40ft dry shipping containers have dimensions of 40ft(L) X 8ft(W) X 9.5ft(H) and weigh approximately 8,500 lbs each. At least eight of the containers lost by the MED TAIPEI were high cube containers. ~ Aggregate container weight calculations were based on an average weight of 8,400 lbs per container						
TOTAL CARGO WEIGHT (DRY)						**135,874 kg/ 299,548 lbs/ 150 tons**
TOTAL ISO CONTAINER TARE WEIGHT (DRY)						**57,154 kg/ 126,000 lbs/ 63 tons**
TOTAL COMBINED WEIGHT (DRY)						**193,028 kg/ 425,548 lbs/ 213 tons**

Appendix B: AIMU Casualty List of Containers Lost Overboard, 1989-2000

1989		
December 12	*MERCEDES DEL MAR*	5 containers Bay of Biscay
1992		
January 3	*SANTA CLARA I*	21 containers off New Jersey
January 24	*HYDERABAD*	2 containers off U.S. East Coast
February 11	*AZILAL*	15 containers off French coast
September	23 JANS	22 containers at LaGuardia
October 23	*UNI-HUMANITY*	13 containers off Hong Kong
October 27	*STELLA I*	9 containers off Hong Kong
December 14	*CLYDEBANK*	4 containers North Atlantic
1994		
February 14	*MARINE TRADER*	21 containers off Dutch coast
April	*KAMINA*	3 containers
April 14	*MING FORTUNE*	8 containers English Channel
December	*HYUNDAI SEATTLE*	30+ Hyundai Seattle
1995		
June 30	*ALEXANDRIA III*	111 containers off South Korea
1996		
January	*MSC CLAUDIA*	21 containers off Boston
February 27	*MARITIME LEE*	3 containers in North Sea
September 11	*PONCE TRADER*	27 containers off New Orleans
December 20	*IBN SINA*	A number of containers off N.Y.
1997		
February 13	*TOKYO EXPRESS*	62 containers off U.K.
February 17	*RENNE*	28 containers North Sea
March 8	*DISARFELL*	A number of containers
March 26	*CITA*	100 containers off U.K.
March 31	*POL AMERICA*	23 containers off Nantucket
April 14	*JANG YUNG LOTUS*	30 containers off Korea
August 7	*VISHA NANDINI*	14 containers off India
November 24	*MSC CARLA*	Hundreds lost as ship split
November	*KATE MAERSK*	26 containers off Coruna, Spain
December 17	*MSC RITA*	15 containers off Nantucket

1998		
January 20	*SEALAND PACIFIC*	26 containers in Pacific
February	*ARCTIC OCEAN*	An unknown number of containers
April 21	*KOON HONG 211*	17 off Hong Kong
September 19	*LEERORT*	94 containers Indian Ocean
October	*APL CHINA*	233 containers in mid-Pacific + 450 damaged
October	*PRESIDENT ADAMS*	22 containers in mid-Pacific + 54 shifted
October	*EVER UNION*	23 containers in mid-Pacific + 54 shifted
November 11	*SEABARGE TRADER*	200 containers
December 20	*EVER GIVEN*	19 containers in mid-Pacific
1999		
Unknown	*MSC BOSTON*	A number of containers in mid-Pacific
April 26	*UNION ROTOITI*	12 containers off New Zealand
October 22	*EVER DIVINE*	80 containers at Pusan
December	*GUAYAMA*	9 containers off Puerto Rico
December	*HUMACAO*	51 containers off Puerto Rico
2000		
January 26	*OOCL AMERICA*	300 containers in mid-Pacific
Unknown	*ASTORIA BRIDGE*	17 containers in mid-Pacific
Unknown	*SEA LAND HAWAII*	21 containers in mid-Pacific
Unknown	*SEA LAND PACIFIC*	26 containers in mid-Pacific
February 4	*CHOYANG HONOUR*	A number of containers in mid-Pacific
April	*MING OCEAN*	A number of containers in North Atlantic

Appendix C: Container Loss Incidents That Have Received Broad Media Attention

This list is a small sampling of other container loss incidents of that have brought media attention to this issue. These examples demonstrate that in addition to deep-sea impacts, marine debris and coastal pollution are important dimensions of the phenomenon of container loss.

May 27, 1990
The *Hansa Carrier* lost 21 containers while en route from South Korea to Los Angeles. Five of the containers contained a total of 80,000 pair of Nike sneakers, hiking boots, and children's shoes. The pairs were unlaced, creating twice as many individual pieces of flotsam. The shipper did not disclose the loss to the public until some of the shoes were found eight months later on Vancouver Island. Shoes have been identified that were carried in four of the containers, but there has been no sign of shoes from the fifth (Ebbesmeyer and Scigliano 2009). A pair of athletic shoes can float as surface marine debris for as long as ten years (Podsada 2001). Jim Ingraham of NMFS' Alaska Fisheries Science Center used the OSCURS (Ocean Surface CURrent Simulator) model for the North Pacific Ocean and Bering Sea to predict where the shoes would drift (Figure C-1).

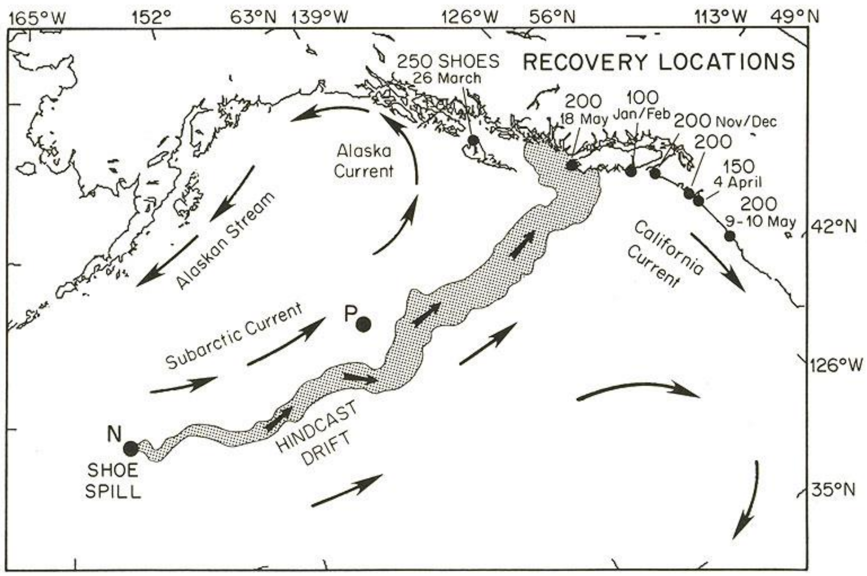

Figure C-1. Drift of the Nike shoe spill of May 27, 1990 as simulated by OSCURS. From the spill site N, the lost cargo followed the shaded drift path. The dots at upper right show dates and locations where shoes were discovered. Map credit: Ebbesmeyer and Scigliano 2009.

January 4, 1992
The M/V *Santa Clara 1* lost 21 containers during a severe storm off the coast of New Jersey while en route from New York to Baltimore. Seas were estimated at 25-40 ft, with winds up to 50 knots. Four containers contained a total of 432 25-gallon drums of highly toxic arsenic trioxide. A U.S. Navy minesweeping helicopter, ROVs and vessels equipped with side scan sonar were used to try to locate the containers. Many of the drums were found in 120-130 ft of water and recovered weeks later. A National Marine

Fisheries Service fishing ban went into effect in the area for 90 days. Upon the ship's subsequent arrival in Charleston, SC, the USCG found that 10 drums of magnesium phosphide had been damaged and spilled into the vessels' hold during the earlier incident (Gilreath 1995). The incident was investigated by the USCG and the National Transportation Safety Board (NTSB), and a long list of operational problems was discovered. The probable causes identified encompass many of the root problems associated with other loss incidents (see "Causes" section of "Container Loss: A Widespread Phenomenon" section of this report).

January 10, 1992
A container of 29,000 floating plastic bathtub toys – in the shapes of turtles, ducks, frogs, and beavers – fell overboard in the central Pacific. The toys, which have become known as the "Friendly Floatees," escaped from the container, and traveled through the Bering Strait and into the Arctic. In 2003, a duck was found on a Massachusetts beach (Johnston 2003). Such incidents have provided opportunities for oceanographers to study ocean currents.

December 8, 1993
The French container ship *Sherbro* was caught in a heavy storm while en route from Cherbourg to Montoir, France. Of the 88 containers that fell overboard, 10 contained dangerous substances. The total accidental discharge amounted to 12.2 tons of two types of pesticides, 21.6 tons of nitrocellulose, 1 ton of sulfur, 200 kg of phenolm 3.5 kg of methyl-ketone and 3.6 tons of a 'flammable product.' Although one container of pesticides was recovered at sea, four others released plastic sacks of their contents, which washed up on French, Dutch and German coasts. An additional 80 containers – containing chemicals including chlorine, hydrochloric acid, diisocyanate, toluene, hydrogen peroxide and cresol – had broken loose, been damaged, and were unpacked in port. Fourteen years later, on October 11, 2007, the Versailles Court of Appeals sentenced the ship's owner to reimburse the cost of container recovery operations (476,000 €), with interest. The French Supreme Court confirmed this judgment on December 16, 2008 (Cedre 2010).

November 30, 2006
A container washed up on the shore of Frisco, NC, just south of the Cape Hatteras Fishing Pier in the Outer Banks. The container had drifted for several days after falling overboard with three others from the M/V *Courtney L*, underway from Wilmington, Delaware to Costa Rica. Its cargo of Doritos snacks had escaped the container, and thousands of bags of chips also washed up on the beach (Figure C-2; www.cargolaw .com/2000nightmare_singleonly10.html, 2011).

Figure C-2. Shipping container and cargo of snacks deposited on the Outer Banks, NC. Photo credit: *The Virginian-Pilot.*

January 20, 2007

Following abandonment on January 18, 2007 and subsequent towing, the *MSC Napoli* was beached on the soft seabed less than one nautical mile off Branscombe Beach, Devon (U.K.) on January 20, 2007 (Mercer 2008). The beaching of a loaded containership this close to shore was unprecedented. Salvors managed to remove 2,300 containers from the ship, but at least 50 containers were lost overnight as the ship lay listing. Some sank, while others were deposited on Branscombe Beach (Mercer 2008). Some of the beached containers contained hazardous materials including nitric acid and airbag inflators. "Looting mayhem" ensued on Branscombe Beach over the course of the following days. Although some containers may have opened due to impacts, others are believed to have been forcibly opened by looters (Figure C-3; Mercer 2008).

Figure C-3. Container loss associated with the February 2007 grounding of the *MSC Napoli*. Many lost containers washed up on Branscombe Beach, allowing "beachcombers" the opportunity for extensive illegal looting, especially after initial reports of "whisky galore." Photo credits: Mercer 2008.

October 5, 2011

Just before completing a coastal transit from Napier to Tauranga, the MV *Rena* and its cargo of 1,368 containers ran aground on Astrolabe Reef, off the north coast of New Zealand (Figure C-4). With the front of the ship stuck on the reef, the vessel started to leak oil. Although about 350 tons of oil were released from the *Rena*'s fuel tanks between October 5-11, over 1,300 tons of the 1,712 tons of oil on board at the time of grounding had been recovered (Maritime New Zealand 2012). Still, New Zealand declared the oil spill its "worst ever environmental disaster." Container loss began to occur as rough seas and winds arrived on the night of October 11. The ship had completely cracked in half by October 14, but remained in place on the reef until the weekend of January 7-8, 2012 when sinking of the stern commenced. Container loss and recovery is summarized in Table C-1. To aid salvage operations, 219 transponders were fitted to containers. Following recovery, transponders have been relocated to other containers as their locations are identified. A gallery of stunning photos of this incident is available at http://www.maritimenz.govt.nz/Rena/gallery.asp.

Figure C-4. MV *Rena* and the location of its stranding near Tauranga, New Zealand. Photo credit: BBC News.

Table C-1. MV *Rena* container loss and salvage by the numbers. Data are as of 1 February, 2012. Source: Maritime New Zealand 2012.

Number of Containers	Status
1,368	on board ***Rena*** at time of grounding
547	stored above deck at the time of grounding
821	stored below deck at time of grounding
121	holding perishable foodstuffs
32	holding with dangerous goods
871	remain on board the severed bulk-head (bow section)
Unknown	remain on board sunken ***Rena*** stern section
98 (estimated)	lost overboard before 8 January 2012
150 (estimated)	lost overboard on 8 January 2012

463	removed from ***Rena*** by salvors since container recovery began on November 16
65	recovered from the water and beaches

Appendix D: Safety Data Sheet for a Common Container Coating

Hempel is one of the primary producers of the traditional zinc-based coatings used on the interior and exterior of containers. HEMPADUR ZINC 17369 is a base layer used in conjunction with other products. It is available in two shades and is recommended to be applied at 40 micron / 1.6 mils. Below are excerpts from Hempel's Safety Data Sheet for one of the two shades of this product, which is likely somewhat representative of the composition of similar products from other manufacturers. Sections 3 and 12 describe composition/ingredients and ecological information, respectively.

Safety Data Sheet

HEMPADUR ZINC 17369

Conforms to Regulation (EC) No. 1907/2006 (REACH), Annex II. - Europe

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifier

Product name :	HEMPADUR ZINC 17369
Product identity :	1736919830
Product type :	epoxy zinc primer (base for multi-component product)

1.2 Relevant identified uses of the substance or mixture and uses advised against

Field of application :	metal industry, ships and shipyards.
Ready-for-use mixture :	17360 = 17369 4 vol. / 97040 1 vol.
Identified uses :	Industrial applications, Used by spraying.

1.3 Details of the supplier of the safety data sheet

Company details :

HEMPEL A/S
Lundtoftevej 150
DK-2800 Kgs. Lyngby
Denmark
Tel.: + 45 45 93 38 00
hempel@hempel.com

Emergency telephone number (with hours of operation)

+45 45 93 38 00 (08.00 - 17.00)
See section 4 First aid measures.

Date of issue :	24 January 2011
Date of previous issue :	21 January 2011.

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Product definition : Mixture

Classification according to Directive 1999/45/EC [DPD]

The product is classified as dangerous according to Directive 1999/45/EC and its amendments.

Classification :	R10 Xi; R36/38 R43 N; R50/53
Physical/chemical hazards :	Flammable.
Human health hazards :	Irritating to eyes and skin. May cause sensitization by skin contact.
Environmental hazards :	Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

2.2 Label elements

Hazard symbol or symbols :

Indication of danger :	Irritant, Dangerous for the environment
Risk phrases :	R10- Flammable. R36/38- Irritating to eyes and skin. R43- May cause sensitization by skin contact. R50/53- Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
Safety phrases :	S23- Do not breathe vapor or spray. S24- Avoid contact with skin. S37- Wear suitable gloves. S51- Use only in well-ventilated areas.
Supplemental label elements :	Contains epoxy constituents. See information supplied by the manufacturer.
Hazardous ingredients :	bisphenol A-(epichlorhydrin) epoxy resin MW =< 700 bisphenol F-(epichlorhydrin) epoxy resin MW =< 700

Special packaging requirements

SECTION 2: Hazards identification

Containers to be fitted with child-resistant fastenings : Not applicable.

Tactile warning of danger : Not applicable.

SECTION 3: Composition/information on ingredients

Substances presenting a health or environmental hazard within the meaning of the Dangerous Substances Directive 67/548/EEC or assigned an occupational exposure limit or PBT or vPvB.

Product/ingredient name	Identifiers	%	Classification		Type
			67/548/EEC	Regulation (EC) No. 1272/2008 [CLP]	
zinc powder - zinc dust (stabilized)	EC: 231-175-3 CAS: 7440-66-6 Index: 231-175-3231-175-3	50-75	N; R50/53	AQUATIC TOXICITY (ACUTE) - Category 1 AQUATIC TOXICITY (CHRONIC) - Category 1	[1]
xylene	EC: 215-535-7 CAS: 1330-20-7 Index: 601-022-00-9	1-5	R10 Xn; R20/21 Xi; R38	FLAMMABLE LIQUIDS - Category 3 ACUTE TOXICITY: SKIN - Category 4 ACUTE TOXICITY: INHALATION - Category 4 SKIN CORROSION/IRRITATION - Category 2	[1] [2]
bisphenol A-(epichlorhydrin) epoxy resin MW =< 700	EC: 500-033-5 CAS: 25068-38-6 Index: 603-074-00-8	2.5-5	Xi; R36/38 R43 N; R51/53	SKIN CORROSION/IRRITATION - Category 2 SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 2 SKIN SENSITIZATION - Category 1 AQUATIC TOXICITY (CHRONIC) - Category 2	[1]
zinc oxide	EC: 215-222-5 CAS: 1314-13-2 Index: 030-013-00-7	2.5-25	N; R50/53	AQUATIC TOXICITY (ACUTE) - Category 1 AQUATIC TOXICITY (CHRONIC) - Category 1	[1]
n-butanol	EC: 200-751-6 CAS: 71-36-3 Index: 603-004-00-6	1-3	R10 Xn; R22 Xi; R41, R37/38 R67	FLAMMABLE LIQUIDS - Category 3 ACUTE TOXICITY: ORAL - Category 4 SKIN CORROSION/IRRITATION - Category 2 SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 1 SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE) [Respiratory tract irritation and Narcotic effects] - Category 3	[1] [2]
bisphenol F-(epichlorhydrin) epoxy resin MW =< 700	CAS: 28064-14-4	1-2.5	Xi; R36/38 R43 N; R51/53	SKIN CORROSION/IRRITATION - Category 2 SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 2 SKIN SENSITIZATION - Category 1 AQUATIC TOXICITY (CHRONIC) - Category 2	[1]
solvent naphtha (petroleum), light arom.	EC: 265-199-0 CAS: 64742-95-6 Index: 649-356-00-4	1-2.5	Xn; R20, R65 Xi; R36/37/38 N; R51/53	ACUTE TOXICITY: INHALATION - Category 4 SKIN CORROSION/IRRITATION - Category 2 SERIOUS EYE DAMAGE/ EYE IRRITATION - Category 2 SPECIFIC TARGET ORGAN TOXICITY (SINGLE EXPOSURE): INHALATION [Respiratory tract irritation] - Category 3 ASPIRATION HAZARD - Category 1 AQUATIC TOXICITY (CHRONIC) - Category 2	[1] [2]
ethylbenzene	EC: 202-849-4 CAS: 100-41-4 Index: 601-023-00-4	1-3	F; R11 Xn; R20	FLAMMABLE LIQUIDS - Category 2 ACUTE TOXICITY: INHALATION - Category 4	[1] [2]
(C12-C14) Alkylglycidylether	EC: 271-846-8 CAS: 68609-97-2 Index: 603-103-00-4	0.1-1	Xi; R38 R43	SKIN CORROSION/IRRITATION - Category 2 SKIN SENSITIZATION - Category 1	[1]
			See Section 16 for the full text of the R-phrases declared above.		

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Type

[1] Substance classified with a health or environmental hazard
[2] Substance with a workplace exposure limit, see section 8.
[3] Substance meets the criteria for PBT according to Regulation (EC) No. 1907/2006, Annex XIII
[4] Substance meets the criteria for vPvB according to Regulation (EC) No. 1907/2006, Annex XIII

SECTION 4: First aid measures

4.1 Description of first aid measures

General : In all cases of doubt, or when symptoms persist, seek medical attention. Never give anything by mouth to an unconscious person.

Eye contact : Check for and remove any contact lenses. Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Seek immediate medical attention.

Inhalation : Remove to fresh air. Keep person warm and at rest. If unconscious, place in recovery position and seek medical advice.

Skin contact : Remove contaminated clothing and shoes. Wash skin thoroughly with soap and water or use recognized skin cleanser. Do NOT use solvents or thinners.

SECTION 11: Toxicological information

xylene	LC50 Inhalation Gas.	Rat	5000 ppm	4 hours
	LD50 Dermal	Rabbit	>1700 mg/kg	-
	LD50 Oral	Rat	4300 mg/kg	-
n-butanol	LC50 Inhalation Gas.	Rat	>8000 ppm	4 hours
	LC50 Inhalation Vapor	Rat	24000 mg/m3	4 hours
	LD50 Dermal	Rabbit	3400 mg/kg	-
	LD50 Oral	Rat	790 mg/kg	-
solvent naphtha (petroleum), light arom.	LD50 Oral	Rat	8400 mg/kg	-
ethylbenzene	LD50 Dermal	Rabbit	>5000 mg/kg	-
	LD50 Oral	Rat	3500 mg/kg	-
(C12-C14) Alkylglycidylether	LD50 Oral	Rat	17100 mg/kg	-

Acute toxicity estimates

Route	ATE value
Oral	29335.6 mg/kg
Dermal	38084.7 mg/kg
Inhalation (gases)	91647.6 ppm
Inhalation (vapors)	375.8 mg/l

Irritation/Corrosion

Product/ingredient name	Result	Species	Score	Exposure	Observation
xylene	Eyes - Severe irritant	Rabbit	-	-	-
	Skin - Mild irritant	Rat	-	-	-
	Skin - Moderate irritant	Rabbit	-	-	-
bisphenol A-(epichlorhydrin) epoxy resin MW =< 700	Eyes - Moderate irritant	Rabbit	-	-	-
	Skin - Moderate irritant	Rabbit	-	-	-
zinc oxide	Eyes - Mild irritant	Rabbit	-	-	-
	Skin - Mild irritant	Rabbit	-	-	-
n-butanol	Eyes - Severe irritant	Rabbit	-	-	-
	Skin - Moderate irritant	Rabbit	-	-	-
solvent naphtha (petroleum), light arom.	Eyes - Mild irritant	Rabbit	-	-	-
ethylbenzene	Eyes - Severe irritant	Rabbit	-	-	-
	Skin - Mild irritant	Rabbit	-	-	-
(C12-C14) Alkylglycidylether	Skin - Moderate irritant	Rabbit	-	-	-

Potential chronic health effects

Sensitization : Contains bisphenol A-(epichlorhydrin) epoxy resin MW =< 700, bisphenol F-(epichlorhydrin) epoxy resin MW =< 700, (C12-C14) Alkylglycidylether. May produce an allergic reaction.

Other information : No additional known significant effects or critical hazards.

SECTION 12: Ecological information

12.1 Toxicity

Do not allow to enter drains or watercourses. Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

Product/ingredient name	Result	Species	Exposure
zinc powder - zinc dust (stabilized)	Acute EC50 2.8 mg/L	Daphnia	48 hours
	Acute LC50 0.41 mg/L	Fish	96 hours
xylene	Acute LC50 8500 ug/L Marine water	Crustaceans - Palaemonetes pugio	48 hours
	Acute LC50 8200 - 10032 ug/L Fresh water	Fish - Oncorhynchus mykiss - 0.6 g	96 hours
zinc oxide	Acute LC50 98 ug/L Fresh water	Daphnia - Daphnia magna - Neonate - <24 hours	48 hours
	Acute LC50 1.1 - 2.5 ppm Fresh water	Fish - Oncorhynchus mykiss	96 hours
	Chronic NOEC 0.4 mg/L Fresh water	Daphnia - Daphnia magna - Neonate	48 hours
n-butanol	Acute EC50 1983000 - 2072000 ug/L Fresh water	Daphnia - Daphnia magna - 6 - 24 hours	48 hours
	Acute LC50 1730000 - 1840000 ug/L Fresh water	Fish - Pimephales promelas - 33 days - 20.6 mm - 0.119 g	96 hours
ethylbenzene	Acute EC50 2930 - 4400 ug/L Fresh water	Daphnia - Daphnia magna - Neonate - <=24 hours	48 hours
	Acute LC50 >5200 ug/L Marine water	Crustaceans - Americamysis bahia - <24 hours	48 hours
	Acute LC50 11900 ug/L Fresh water	Fish - Pimephales promelas - 30 days - 0.079 g	96 hours
	Chronic NOEC 6800 ug/L Fresh water	Daphnia - Daphnia magna - <=24 hours	48 hours
	Chronic NOEC 3300 ug/L Marine water	Fish - Menidia menidia	96 hours

SECTION 12: Ecological information

12.2 Persistence and degradability

No known data avaliable in our database.

12.3 Bioaccumulative potential

Product/ingredient name	$LogP_{ow}$	BCF	Potential
xylene ethylbenzene	- 3.15	6 - 23.4 -	low high

12.4 Mobility in soil

Soil/water partition coefficient (K_{OC}) : No known data avaliable in our database.

Mobility : No known data avaliable in our database.

12.5 Results of PBT and vPvB assessment

PBT : Not applicable.

vPvB : Not applicable.

12.6 Other adverse effects

No known significant effects or critical hazards.

SECTION 13: Disposal considerations

13.1 Waste treatment methods

The generation of waste should be avoided or minimized wherever possible.
Residues of the product is listed as hazardous waste. Dispose of according to all state and local applicable regulations.
Spillage, remains, discarded clothes and similar should be discarded in a fireproof container.

European waste catalogue no. (EWC) is given below.

European waste catalogue (EWC) : 08 01 11*

Packaging

The generation of waste should be avoided or minimized wherever possible. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible.

SECTION 14: Transport information

Transport may take place according to national regulation or ADR for transport by road, RID for transport by train, IMDG for transport by sea, IATA for transport by air.
Transport within user's premises: always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

	14.1 UN no.	14.2 Proper shipping name	14.3 Transport hazard class(es)	14.4 PG*	14.5 Env*	Additional information
ADR/RID Class	UN1263	PAINT	3	III	Yes.	**Special provisions** 640 (E) **Tunnel code** (D/E)
IMDG Class	UN1263	PAINT. (Zinc)	3	III	Yes.	**Emergency schedules (EmS)** F-E, S-E
IATA Class	UN1263	PAINT	3	III	Yes.	-

PG* : Packing group
Env.* : Environmental hazards

14.6 Special precautions for user

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