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Trends and Issues in Marine Transportation and the Environment

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Trends and Issues in Marine Transportation and the Environment

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Introduction

The Standing Committee on Marine Environment encompasses a broad range of expertise and research topics. Since the committee cannot address all potential research topics that might fit under its umbrella, committee members identified the subject areas that seem to have the most urgency or far-reaching impacts. This e-circular provides a sense of the major research areas and why they are important.

Marine Emissions and Air Quality Impacts

Marine vessels are a significant source of air pollutants that are associated with environmental, health, and climate change impacts (see section on Marine Transportation, Air Quality, and Human Health). There are ongoing improvements to methodologies used to quantify emissions, which will lead to a better understanding of the impact shipping has (see section on Improving Marine Vessel Emission Inventory Methods). Studies and regulations continue to try to reduce emissions and mitigate impacts; typically these activities focus on improving engine fuel efficiency (see section on Marine Vessel Fuel Conservation and Emission Reduction Options); transitioning away from highly polluting residual fuels to commercially available distillate or alternative fuels (see section on Alternative Fuels); and the promulgation of fuel and exhaust standards (see section on Fuel Exhaust Regulations Related to Marine Vessel and Port Emission Sources).

ALTERNATIVE FUELS

Alternative technologies for marine fuels and energy sources have great potential for improving the environmental footprint of waterborne commerce. Innovations are providing new policies, products, and methods to reduce emissions. These innovations include the following:

- New international and national standards for conventional marine fuels,
- New innovative fuel concepts,
- New exhaust remediation technology,
- Shore-to-ship alternative powering techniques, and
- Ocean-based renewable energy.

Large, slow-speed diesel engines currently predominate in the powering of cargo ships, principally burning heavy fuel oil (HFO). Of all the fuel types used by cargo ships, HFO results in the highest level of pollutants due to its relatively high sulfur content. Typical ship exhaust contains the following pollutants, leading to adverse effects on human health and climate change (*1*):

- Nitrogen oxide (NO_x),
- Sulfur oxide (SO_x),
- Carbon monoxide,
- Carbon dioxide (CO_2),
- Particulate matter (PM), and
- Other greenhouse gases (GHGs).

Ship emissions are being reduced through testing and using less-polluting fuel to meet new International Maritime Organization (IMO) and U.S. Environmental Protection Agency (EPA) fuel standards. Other new tools and methods that are or are becoming available are liquefied natural gas (LNG) as a marine fuel, biofuels, exhaust gas scrubbers, and cold ironing (providing electrical power in port).

Biofuels are an interesting option although fuel availability and uncertainty about long term engine maintenance may affect its application. Exhaust scrubbers, particularly those using salt water, may allow for continued use of high-sulfur fuels but could shift an air pollution problem to a water pollution problem and would not help with pending NO_x control requirements. Cold ironing is being considered at a number of ports where infrastructure costs are balanced with benefits. Cold ironing has been implemented at military bases and several California ports; these systems mitigate dockside port emissions but do not address emissions while the vessel is underway. Recently there has been a lot of attention on LNG due to current pricing of natural gas and low emissions associated with this fuel. Lloyd's Register estimates that LNG could reach 11% share of marine fuel usage by 2030 (*2*).

The use of natural gas as a transport fuel has been growing steadily over the past decade. This increased activity is evident in many different spheres, including industrial initiatives, public investment in new infrastructure, statements by technology providers, new government policies and incentives, and emerging research projects. Developments in the deployment of LNG-powered vessels and in the construction of new LNG refueling and import infrastructure have been steady since 2006.

Three manufacturers—Rolls Royce, Wärtsilä, and MAN—have developed different LNG engine technologies for marine applications. Spark-ignited, lean-burn engines allow the gas to be mixed with an excess of air before passing through the intake valves, more completely combusting the fuel and reducing efficiency losses. Dual-fuel diesel engines, which can run on LNG or distillates, are gaining traction.

The infrastructure for LNG is being ramped up to meet the demand for these ships. Norway has already developed a system of small-scale LNG production and storage facilities that supply ferries and other working ships. New LNG shipbuilding contracts around the world are now aligned with some installation of bunkering facilities to provide the fuel. Over the longer term, several governments have bigger plans for LNG in the maritime sector. For example, the European Commission launched an ambitious plan to have 139 LNG refueling facilities for seagoing and inland vessels in the 2020 to 2025 timeframe.

Yet LNG as a marine fuel is still in the fledgling stages. The following LNG ships are in operation or are planned:

- About 30 operating LNG-powered cargo ships (ferries, platform supply vessels, merchant ships, coast patrol—mostly in Norway), with about 25 on order (including in Canada, Finland, Norway, Sweden, and the United States);
- About 400 operating LNG oceangoing vessels, with an additional 50 to 100 planned for 2015 through 2018; and
- A few large oceangoing vessels in Europe and a handful of container ships in the United States to be delivered between 2015 and 2016.

As a result of these numbers, forecasts are that the growth of LNG-powered ships is unlikely to play a major role in the shipping market in the next decade. Invariably, many barriers to the development of LNG as a shipping fuel will have to be addressed sooner rather than later.

Implications for the Marine Environment

Use of LNG as fuel reduces air emissions, in particular NO_x, SO_x, and PM.

Potential Areas for Research

Organizations such as the U.S. Maritime Administration may partly fund needed research in this area to demonstrate and improve marine technologies and practices. The goal is to achieve environmental improvements by reducing air emissions, increasing fuel economy, and using alternative fuels and shore power.

Potential research topics include the following:

- How to ensure a safe switch between residual fuel (in open seas) and low-sulfur fuel prior to entering an emissions control area (ECA).[1] There is also concern about how to ensure enforcement when ships are in transit through ECAs.
- How to improve the fuel efficiency of cargo ships and the best policies to stimulate more efficient technology, thereby reducing emissions.
- Barriers to the use of scrubbers as a technology to enable ships to continue to use cheaper HFOs.
- Low-sulfur bunker fuel availability and strategies to deal with regulatory uncertainty. The default IMO deadline is 2020 for all shipping to switch to 0.5% sulfur fuel.
- Guidelines for switching from HFO to marine diesel oil and marine gas oil.
- How to stimulate the use of LNG as a marine fuel by addressing:
  - The lack of LNG refueling infrastructure;
  - The high capital cost of new LNG ships (ships that can use LNG as a propulsion fuel, not LNG tankers) or new engines and associated equipment;
  - Range limitations; and
  - Loss of cargo or passenger space due to the need for large LNG storage tanks and safety zones.
- The potential for using LNG in inland shipping.
- The impact of IMO's low-sulfur fuel standards, first in the ECAs and then globally, on the rate of development of LNG use in the shipping industry.
- The major technology barriers to LNG engines in shipping.
- The environmental impacts of LNG used as a marine fuel.
- How to assess the near-term and long-term environmental risks that expansion of LNG production and movement pose (risks are associated with LNG use as a shipping fuel, physical transport of LNG, and LNG terminal construction).

MARINE TRANSPORTATION, AIR QUALITY, AND HUMAN HEALTH

Most air pollution from port activities is associated with the operation of diesel engines used to power ships, cargo-handling equipment, drayage trucks, and locomotives. Large diesel engines operate using petroleum-based fuels ranging from high-sulfur residual fuels to lighter distillate fuels.

Collectively, port diesel engines emit significant amounts of SO_x, NO_x, diesel PM, and regulated hazardous air pollutants. Figure 1 compares the NO_x and PM_{10} (PM with a mean aerodynamic diameter of 10 micrometers) emissions of ports to those of other sources.

The combination of fine particulates and hazardous air pollutants can have significant impacts on human health, ranging from respiratory ailments such as asthma, bronchitis, and lung

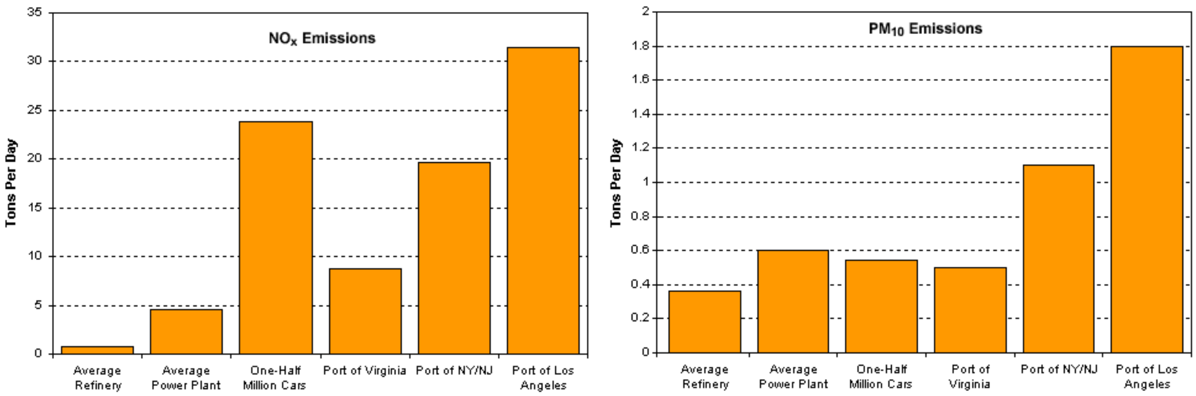

FIGURE 1 Pollution from ports compared with that from refineries, power plants, and cars (*4*).

cancer to cardiovascular disease and premature death. Emissions of SO_x and NO_x also have deleterious effects on air quality and the environment.

The health effects associated with diesel combustion can also be prevalent within low-income environmental justice communities located adjacent to ports and railyards. For example, asthma rates for children living in communities adjacent to the Port of Long Beach are almost twice that of the rest of the country (*3*). Many of these communities have nongovernmental groups that monitor local health impacts, advocate for programs to reduce risk associated with port-related emissions, and pursue legal actions on behalf of the community.

Programs to reduce emissions and protect human health are often important elements of ports' environmental programs and demonstrate a port's commitment to the surrounding communities. These initiatives can include the following:

- Use of shore power to reduce hoteling emissions;[2]
- Enforcement of reduced speed zones to reduce vessel emissions while approaching and leaving the port; and
- Conversion of drayage trucks, yard locomotives, and cargo-handling equipment to alternative fuels or electrification.

Implications for the Marine Environment

Better understanding of port-related emissions, their sources, and potential health effects can provide port authorities, policy makers, and regulatory agencies with tools for making informed policies that effectively reduce risk to exposed communities.

Potential Areas for Research

Potential research topics include the following:

- Assessment of emissions and potential impacts to human health;
- A summary of available policy instruments and market incentives; and
- A searchable database that allows users to match their ports to appropriate policy options.

IMPROVING MARINE VESSEL EMISSION INVENTORY METHODS

Methods to estimate ship emissions continue to evolve, driven by growing concern about hazardous air pollutants and the need to quantify GHG contributions associated with port and marine vessel activities.

Over the last 20 years, computing power and the availability of detailed vessel data have increased significantly, allowing for improvements to marine vessel emission inventories. These improvements include linking of automatic identification system (AIS)[3] vessel traffic data to individual vessel characteristics that classification societies compile. This approach allows emissions to be estimated for individual vessel movements, which can be spatially allocated using geographic information systems. This approach also provides for better quantification of engine load by comparing the vessel's actual speed to its maximum speed. AIS data are reported every few seconds, so temporal elements can also be better quantified. Figure 2 shows the geographical coverage of the first (2007) and last (2012) years' AIS datasets.

Ports have a growing interest in developing emission inventories that include all emission sources—not just marine vessels but also drayage trucks, cargo-handling equipment, locomotives, and stationary point sources such as electric generation units, incinerators, boilers, and vessel maintenance facilities.

Implications for the Marine Environment

Emission inventories are critical for policy makers, regulatory agencies, nongovernmental organizations, and port authorities in quantifying and prioritizing emission reduction strategies.

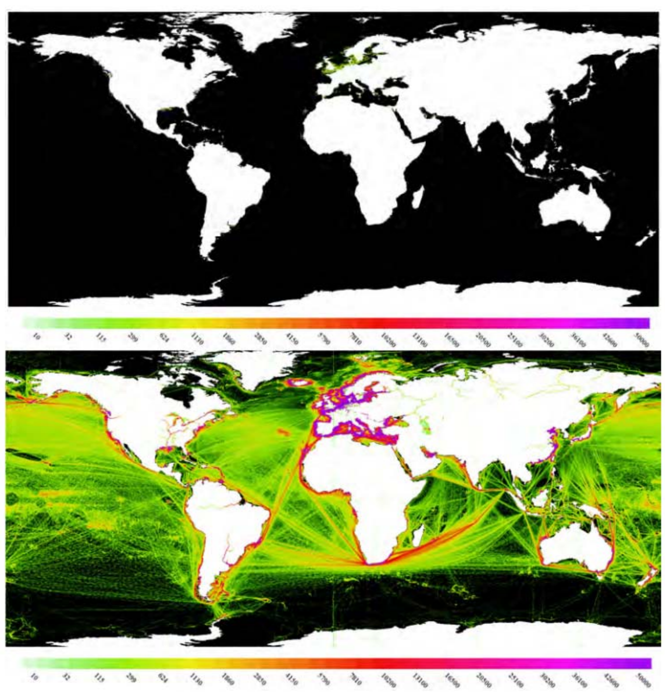

FIGURE 2 AIS geographical coverage in 2007 (*top*) and 2012 (*bottom*), colored according to the intensity of messages received per unit area (*5*).

Coupling improved emission inventory data with air quality modeling can help identify pollution hot spots associated with port and marine vessel activities.

Potential Areas for Research

Potential research topics include the following:

- Software tools for estimating emissions for ports, regulatory agencies, and ship operators. Several mobile source categories have software tools for estimating emissions (e.g., the EPA MOVES model for highway vehicles and the FAA's Emission and Dispersion Modeling System, which is soon to be replaced by the Aviation Environmental Design Tool). These software tools allow for standardization in data collection, easy updating of fuel and emission factors, and development of emission estimates of similar quality to those from other agencies using the same tool. A useful assessment could evaluate the need for a similar electronic tool to help ports, regulatory agencies, and ship operators assess their emissions, evaluate compliance with state implementation plan targets, and meet regulatory requirements.
- A database of internationally peer-reviewed emission factor and hazardous air pollution speciation profiles to ensure that the latest and most representative factors are used.
- Further development of vessel traffic and engine data, which will allow the development of techniques to better quantify emissions of smaller vessels, such as tugs and towboats, that travel throughout the United States.
- Better emission factors and hazardous air pollutant speciation profiles to ensure that vessel engines are matched to the most appropriate factors.

MARINE VESSEL FUEL CONSERVATION AND EMISSION REDUCTION OPTIONS

A reduction in the amount of fuel used by marine vessels leads to a reduction of the volume of pollutants emitted. This relationship is particularly strong for the emission of GHGs. It is the cornerstone of IMO's 2013 mandatory measures to reduce GHG emissions, which require vessel manufacturers to use the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all vessels. EEDI estimates ship CO_2 emissions per ton-mile of goods transported relative to a reference average of similar ships. The SEEMP is a 'live' document, containing energy improvement measures identified by the ship owner that will be kept onboard each ship. The document will be reviewed regularly to establish the relevance and impact of each measure on ship and fleet operations.

IMO has found that improved vessel fuel efficiency is possible through a variety of approaches including the following:

- Changes in ship design;
- Use of high-performance propellers;
- Application of wind and solar power to supplement ship energy supply (thereby reducing required energy from propulsion or auxiliary engines);
- Hull friction reduction options;
- Hybrid low-carbon alternative fuels; and

- Operational changes such as slow steaming,[4] shore power, and engine controls that better match engine output to a ship's energy demand.

These fuel conservation initiatives are particularly attractive to vessel operators, given that fuel costs account for between 40% and 70% of a vessel's operating expenses, and that the demand for low-sulfur ECA-compliant fuel will be increasing, along with the price of these fuels.

Fuel conservation options are not appropriate in all situations. For instance, certain biodiesel applications may cause elevated NO_x emissions, and the use of biodiesel and slow steaming may cause engine maintenance concerns.

Implications for the Marine Environment

To ensure the sustainability of marine cargo shipments, port authorities, ship operators, and policy makers must have up-to-date information about options to enhance vessel fuel efficiency in a cost-effective manner. Such information will facilitate a reduction in emissions and possibly lower shipping costs as well.

Potential Areas for Research

Potential research topics include the following:

- A compendium of fuel conservation options for port authorities, ship operators, and policy makers to encourage cost-effective changes to the industry. The compendium should include a ranking system for options that have the greatest impact on air quality, infrastructure requirements, and cost.
- Identification of future technological initiatives. Vessels tend to have a long useful life, so identification of future technological initiatives that could significantly improve fuel usage and air quality is critical to ensuring that changes can be anticipated and applied at an early stage of a vessel's life cycle.

FUEL AND EXHAUST REGULATIONS RELATED TO MARINE VESSEL AND PORT EMISSION SOURCES

EPA has been tightening marine vessel emission standards since 1999 for all marine engine categories. Early regulations focused on standards that are implemented at the time the vessel is constructed and only affect U.S.-flagged ships. Recently, ECA rules have been developed that require that all vessels traveling through the ECA comply with the same schedule of emission and fuel standards.

The North American ECA (NA-ECA) includes the waters within 200 nm of the coast for most of the United States, Canada, and the Caribbean. EPA implemented a regulatory program in the NA-ECA under Annex VI of the International Convention for the Prevention of Pollution from Ships. The program has taken the following actions:

- In 2010, EPA's program began regulating vessel fuel and engine standards for any vessel traveling in the NA-ECA.

- In 2012, the NA-ECA imposed a limit on fuel sulfur at 10,000 ppm.
- In 2015, the NA-ECA further reduced the limit on fuel sulfur to 1,000 ppm.
- In 2016, NO_x standards go into effect and require application of control devices that that will reduce NO_x emission by 85%. The reduction in the fuel sulfur content will also reduce SO_x and PM emissions by 85%.

Mexico is currently developing a similar program for vessels that transit a proposed Mexican ECA. Additional ECAs are being considered for waters near Japan, off the coast of Norway, and in the Mediterranean Sea.

The ECA sulfur rule allows ship owners to either use fuels that are compliant with the sulfur concentration requirement or continue to use high-sulfur fuels in conjunction with scrubbers that provide an equivalent reduction in sulfur emissions (see Figure 3). The extent to which vessels will switch to lower-sulfur fuels or use scrubbers is uncertain.

Vessels built in the United States and equipped with smaller Category 1 and Category 2 engines[5] are required to comply with nonroad standards that apply to engines that were manufactured from 1996 to 2010 (see Table 1).

Knowledge of current and pending international, regional, or national regulatory instruments is necessary to accurately quantify anticipated emission levels within a port or region, or to estimate benefits associated with implementation of more-stringent local standards or voluntary programs.

Implications for the Marine Environment

Careful understanding of new marine fuels and exhaust regulations at local, state, regional, national, and global levels is important to ensure alignment of international standards and practices.

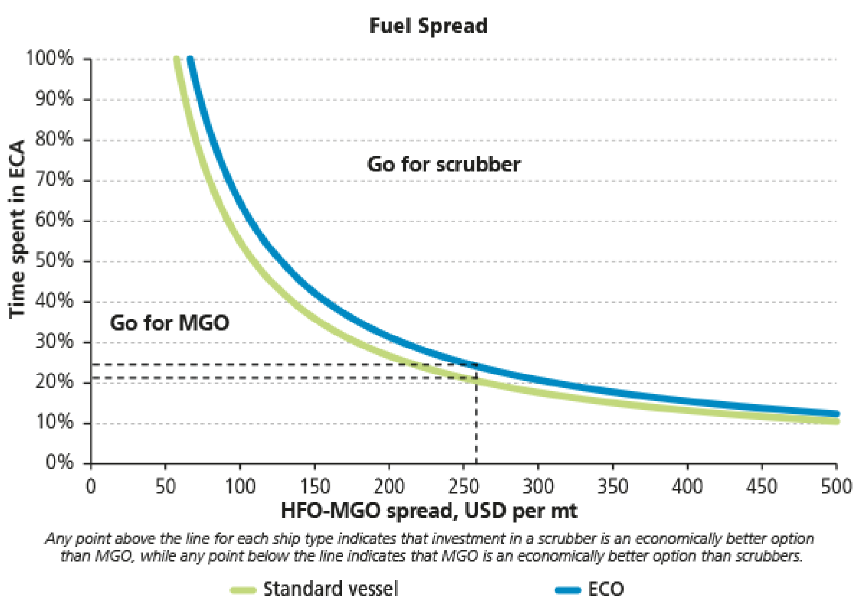

FIGURE 3 Investment function for scrubbers (*6*).

TABLE 1 Schedule for Application of New Emission Standards for Certifying Engines and Vehicles (*7*)

Engine category	Engine subcategory	Manufacturing date after which emission standards start to apply
A. Heavy-duty highway engines	—	Model year 1970
B. Locomotives or locomotive engines	—	January 1, 1973
C. Marine compression-ignition engines at or above 37 kW	**Commercial**: displacement < 0.9 L/cyl	Model year 2005
	Commercial: 0.9 ≤ displacement < 2.5 L/cyl	Model year 2004
	Commercial: displacement ≥ 2.5 L/cyl	Model year 2007
	Recreational: displacement < 0.9 L/cyl	Model year 2007
	Recreational: 0.9 ≤ displacement < 2.5 L/cyl	Model year 2006
	Recreational: 2.5 ≤ displacement < 5.0 L/cyl	Model year 2009
D. Other nonroad compression-ignition engines.	**Marine compression-ignition engines**: Power < 19 kW	January 1, 2000
	Marine compression-ignition engines: 19 kW ≤ Power < 37	January 1, 1999
	Nonroad engines: Power < 19 kW	January 1, 2000
	Nonroad engines: 19 kW ≤ Power < 37	January 1, 1999
	Nonroad engines: 37 kW ≤ Power < 75	January 1, 1998
	Nonroad engines: 75 kW ≤ Power < 130	January 1, 1997
	Nonroad engines: 130 kW ≤ Power ≤ 560	January 1, 1996
	Nonroad engines: Power > 560 kW	January 1, 2000
E. Marine spark-ignition engines.	Outboard	Model year 1998
	Personal watercraft	Model year 1999
	Sterndrive/Inboard	Model Year 2010
F. Recreational spark-ignition engines and vehicles	—	Model year 2006
G. Other nonroad spark-ignition engines at or below 19 kW	—	Model year 1997
H. Other nonroad spark-ignition engines above 19 kW	—	Model year 2004

Knowledge of lessons learned and best practices from voluntary programs can be particularly useful to appreciate the full range of control strategies available to port authorities as well as state and federal regulatory agencies.

Potential Areas for Research

A listing of current and pending regulations and voluntary programs by region could be a useful tool to help stakeholders maintain awareness of important regulations and better understand the availability and utility of nonregulatory tools.

NOTES

1. ECAs are sea areas in which stricter controls are established to minimize airborne emissions (SO_x, NO_x, ozone-depleting substances, and volatile organic compounds) from ships as defined by Annex VI of the 1997 MARPOL Protocol, which took effect May 2005.

2. Hoteling refers to the time when a ship is berthed and is using auxiliary engines to provide a ship's electrical needs.
3. The AIS is an automatic tracking system used on ships and by vessel traffic services to identify and locate vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites.
4. Slow steaming is operating ship engines at less than their maximum speed to save fuel consumption at the expense of travel time.
5. Category 1 and Category 2 marine diesel engines typically range in size from about 700 to 11,000 hp. These engines are used to provide propulsion power on many kinds of vessels including tugboats, pushboats, supply vessels, fishing vessels, and other commercial vessels in and around ports.

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Supply Chains, Ecological Systems, and Climatic System Impacts

Marine vessel movements are associated with a broad range of environmental impacts; variations in vessel traffic patterns can change the extent and location of the impacts. These impacts can affect air quality, water quality, release of invasive species into vulnerable ecosystems, and noise pollution. Examples of new areas affected by changes in traffic patterns include the Arctic passages and Central American canals along with dredging activities associated with the movement of larger vessels through these new areas. Similarly, development of offshore energy sources such oil and gas production and wind farms often generate new vessel traffic patterns. It is also important to understand the relationship between changes in climate patterns and vessel routings. The following subsections break these issues down into discrete research objectives.

MARINE TRANSPORTATION AND THE ARCTIC

Marine transportation takes several forms in the Arctic. The Arctic has what could be termed local traffic—tugs and barges delivering essential supplies to communities. Waterborne transport is often the only way to deliver these goods.

Resource extraction, such as undersea oil, gas, and minerals, has become increasingly important. The U.S. Geological Survey estimates that 22% of the undiscovered oil and gas resources are in the Arctic. Exploration and recovery require a variety of marine vessels at the sites and then traveling to markets.

Fishing is an important industry and provides subsistence to indigenous communities. Tourism in the form of cruise ships is also rising.

The current extent of the Arctic ice cap is approximately 40% smaller than it was in 1979 (see Figure 1). Continued shrinkage in the ice cap, projected to disappear in the next 15 to 25 years, would allow for development of Arctic shipping lanes between Asia and Europe that avoid

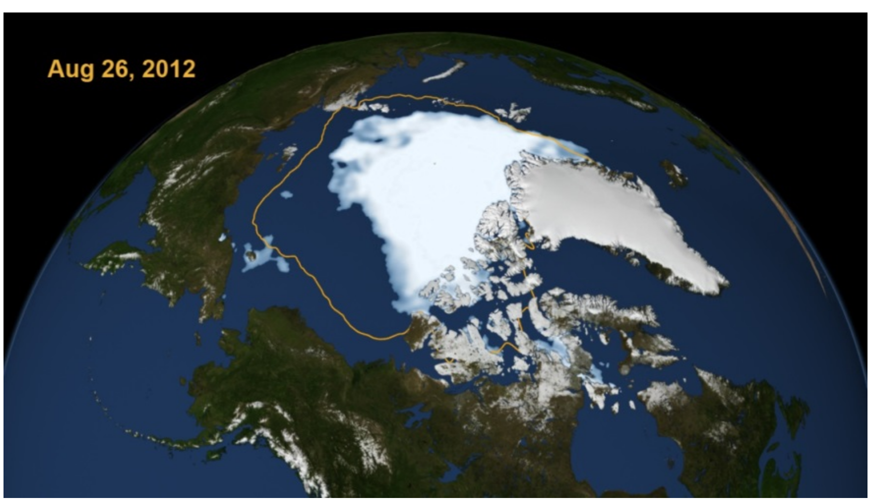

FIGURE 1 Shrinkage of the Arctic ice cap (*1*).

both the Panama and Suez Canals. These Arctic routes would reduce ship travel distance between these two markets by 5,200 mi, cutting transit time by an estimated 30%. Two possible routes include:

- The Northern Sea Route (NSR), which transits Russian Arctic waters, and
- The Northwest Passage (NWP), which transits territorial waters of the United States and Canada.

Both routes are only open during summer for a period of weeks but potentially offer a commercially viable alternative to the Panama and Suez canals.

The number of vessels passing through the Bering Strait, the entry or exit point for both passages, increased from 220 vessels in 2008 to 480 vessels in 2012, a more than 100% increase. The growth rate was highest for tank vessels; tugs and other cargo vessels were the second and third largest categories of movements, respectively.

While passage through the NSR is fairly limited, it is increasing. Only four ships passed in 2010, but 34 ships passed in 2012 and 71 in 2013. However, the NSR is challenging because vessels need to navigate through ice fields and shallow straits.

Even more challenging is the NWP (see Figure 2). In 2013, the first large commercial vessel, *MS Nordic Orion*, transited the NWP, and it is anticipated that by 2050, vessels will be able to move through this area without aid of an ice breaker.

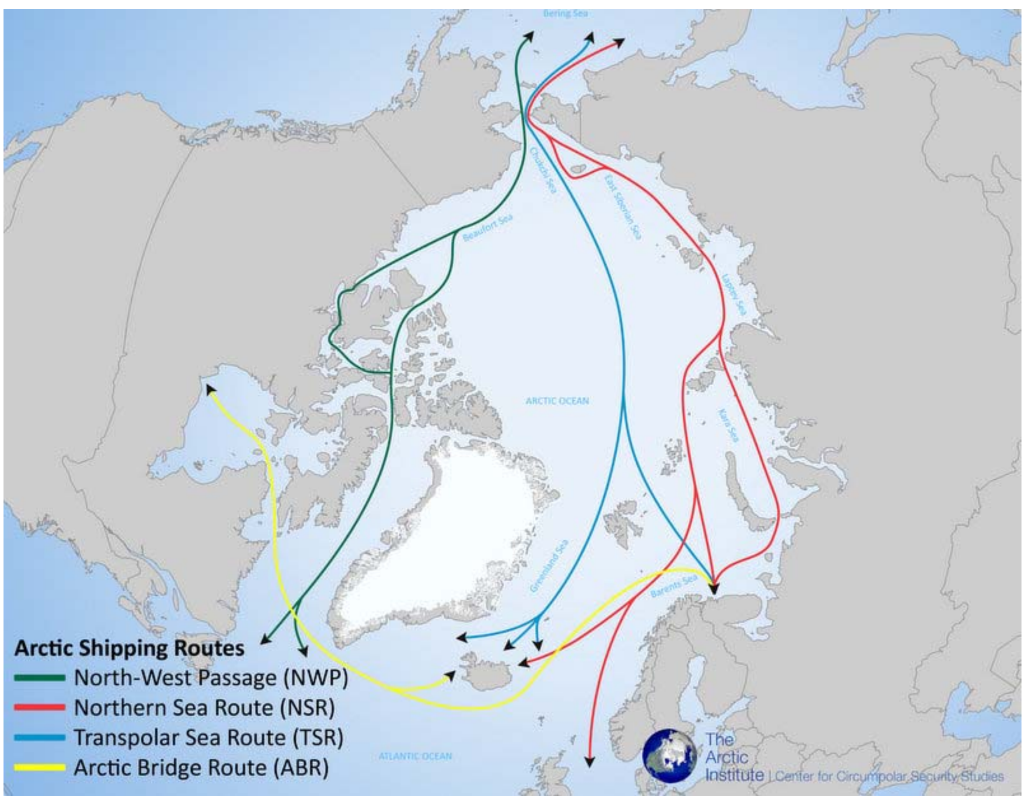

FIGURE 2 Northwest Passage (*2*).

The NWP could also facilitate the movement of crude from the Alaskan North Slope to U.S. East Coast refineries. A limited amount of exploratory drilling offshore of the Alaskan North Slope has been permitted, with plans to increase these activities along with the eventual development and operation of offshore oil and gas production platforms. This industry will be serviced by a wide range of vessels including survey ships, drilling rigs, support vessels, crew boats, spill response vessels, offshore tugs involved in the construction of gravity base offshore platforms or artificial gravel islands, and pipe-laying vessels.

Additionally, the opening of Arctic waters could increase cruise ship traffic in the area. Crystal Cruises is currently taking bookings for a 2016 cruise though the NWP.

The shorter Arctic routes will substantially reduce vessel fuel consumption and emissions by reducing shipping distances. However, the increased marine transport in the area could also have negative local air quality impacts. One of the issues concerns persistent organic pollutants (POPs). Due to their physical–chemical properties, POPs are readily transferred to the Arctic by air and water currents, where they bioaccumulate in the fatty tissues of local wildlife. Increased vessel traffic patterns in the Arctic will also facilitate concentration of select hazardous air pollutants in northern latitudes. Aerial deposition of stack emissions also poses a unique threat to the Arctic; researchers are finding that the black soot from ship smokestacks settles on polar ice sheets and helps cause melting (*1*).

There is considerable debate about whether an Arctic sea route offers the safety and reliability necessary for commercial shipping. Even with the diminishing sea ice, the Arctic is still a challenging environment:

- Weather and sea ice conditions are highly unpredictable.
- Accurate charts and navigational support are needed.
- No harbors of refuge exist and emergency response capabilities are limited.
- Communications infrastructure is inadequate for many of the remote areas.
- Multiple governing bodies are in the region.

All of these contribute to the environmental risks of Arctic marine transportation.

At present, all of these activities are in their infancy. Careful monitoring and planning can help mitigate air quality impacts associated with the development of these shipping lanes.

Implications for the Marine Environment

Arctic sea routes may play an important role in reducing fuel usage and emissions for select routes between Asia and Europe, as well as Alaska and the U.S. East Coast ports.

Policy makers and regulatory agencies will need to work with academic research groups to monitor the effects of shipping on local air quality, and develop plans that mitigate the impacts that hazardous air pollutants may have on local wildlife.

Increased vessel traffic combined with communication, navigation, and meteorological challenges may increase the risk of an oil spill in a fragile ecosystem. This threat is exacerbated by the lack of safety infrastructure to contain an oil release.

Increases in shipping traffic may increase the risk of ship collision with large marine mammals such as bowhead whales. Some have migratory paths that intersect with navigation routes.

Increased shipping traffic will increase the level of underwater noise.

Potential Areas for Research

Potential research topics include the following:

- Monitoring of traffic along Arctic shipping lanes by using AIS data that track individual vessel movements. These vessels include transit vessels that carry freight between Asia and Europe and resident vessels that provide support for offshore oil and gas platforms.
- Better POP emission factors for marine vessels, including careful assessment of how these pollutants behave in Arctic environments.
- The effect on aerial deposition of stack emissions on sea ice.
- Transport vulnerabilities and environmental risks from increased shipping, along with mitigation opportunities.
- The effects of increased shipping on Arctic water quality and habitats, in particular increased potential for spills in the Arctic.

PANAMA CANAL EXPANSION AND NICARAGUA CANAL CONSTRUCTION

The Panama Canal Authority is investing nearly $6 billion to make infrastructure improvements to the Panama Canal. These improvements, which are scheduled for completion in 2016, include deepening and widening critical segments of the canal and making improvements to three of the major lock chambers (see Figure 3).

Plans call for a Nicaragua canal between Punta Gorda and Brito transiting Lake Nicaragua. Nicaraguan authorities estimate that the canal will take 5 years to construct and cost $50 billion. However, the status and viability of that project are uncertain.

Enhancements to the Panama Canal or the development of a second canal in Nicaragua will allow significantly larger ships (more than twice the size of current Panamax vessels[1]) to

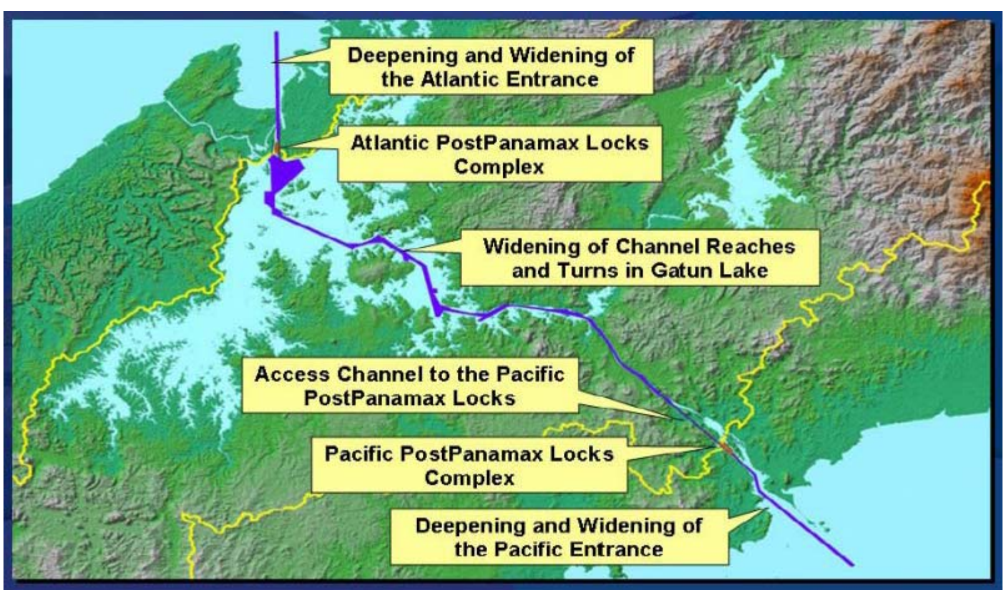

FIGURE 3 Planned enhancements to the Panama Canal (*3*).

transit the isthmus and are expected to result in significant changes to global shipping patterns. Use of these larger vessels will increase emissions in the Canal Zone, corresponding shipping lanes, and the ports that these larger vessels visit. Many of these ports are also investing billions to deepen entrance channel and raise bridges to allow port calls for these larger vessels.

On the other hand, larger, more-efficient vessels will have lower CO_2 emissions per cargo ton-mile. And, because they will be able to travel through the canal, they will no longer have to travel around Cape Horn or use the Suez Canal, reducing their trip length, fuel usage, and overall emissions.

The proposed Nicaragua Canal would pass through a number of undisturbed areas including several biosphere reserves, coastal wetlands, and migratory pathways. In addition, the canal route would run through Lake Nicaragua, an important source of drinking water and habitat for a number of rare species.

Implications for the Marine Environment

Changes in vessel traffic patterns will provide air quality benefits through lower emissions in some areas and increases in others, depending on the new routes that carriers select. Policy makers should monitor actual changes in traffic to target initiatives for controlling emissions.

Construction of a new canal route in Nicaragua and the resultant increased vessel traffic could harm several fragile ecosystems. The route could change the salinity regime and hydrodynamics, and increase underwater noise, spill potential, and air emissions.

Considerable research has been conducted on the impacts that the Panama Canal expansion will have on global trade, but less research has been conducted for the Nicaragua Canal.

Potential Areas for Research

Potential research topics include the following:

- Environmental impacts and benefits of the Panama Canal expansion and the Nicaragua Canal.
- Anticipated changes in vessel traffic, how the changes will affect downstream infrastructure at the affected ports, and how the changes will impact air quality.

INVASIVE, NONNATIVE SPECIES

Vessels act directly as a vector for introduction of invasive, nonnative species to new areas. Invasive, nonnative species often out-compete native species and can dramatically reduce biodiversity. This can significantly impair the resilience of coastal and marine ecosystems, resulting in both short-term and long-term economic and environmental impacts. These impacts include but are not limited to the following:

- Species extinction (e.g., some marine life has pharmaceutical applications and loss of these species would be detrimental);
- Damage to infrastructure (e.g., zebra mussels); and
- Loss of recreational and commercial fisheries opportunities.

Implications for the Marine Environment

Diminished water quality has adverse effects on ecosystem health and on recreational use of coastal waters.

Invasive species can disrupt the natural community of plants and animals, resulting in changes to ecosystem health and resiliency, as well as populations of commercially and recreationally important fish and shellfish.

Potential Areas for Research

Potential research topics include the following:

- New technologies and practices to manage ballast water and invasive species and
- The role of IMO, EPA, and the U.S. Coast Guard in controlling threats.

POINT AND NONPOINT WATER POLLUTION SOURCES

Oil and chemical spills remain a dominant issue related to maritime transportation. While only accounting for about 10% of the total contribution to ocean oil levels, spills tend to be very visible to the public. A better understanding of oil spill prevention programs and clean-up options can facilitate better linkage between governance, policy, and current science knowledge.

Direct pollution from vessel discharges and upland maritime support operations introduce toxins, nutrients, bacteria, pathogens, pharmaceuticals, and plastics into waterways. For example, EPA estimates that a single 3,000-person cruise ship discharges 150,000 gal of sewage a week. Vessels, vessel support operations, and port operations also directly and indirectly pollute waterways through a variety of sources including:

- Gray water, bilge water, black water (sewage), and ballast water;
- Antifouling paints (and their leachates);
- Hazardous materials;
- Garbage and other wastes; and
- Aerial deposition to aquatic habitats of stack emissions.

Vessel emissions increase atmospheric CO_2, which reduces the ocean's pH, a phenomenon known as ocean acidification. Vessel discharges contribute to increased nitrogen, which further contributes to ocean acidification. Ocean acidification harms marine organisms that have calcareous exoskeletons, such as corals, mollusks, and crustaceans. Many of these species are important habitat formers (corals) or are recreationally or commercially important.

Implications for the Marine Environment

Increased point and nonpoint sources of pollution adversely affect ecosystem health and recreational use of marine waters. Ocean acidification reduces survival of important marine organisms, which further disrupts ecosystem balance and threatens to affect stocks of commercially and recreationally important species.

Potential Areas for Research

Potential research topics include the following:

- Current threats to water quality from marine transportation, including vessel discharges, spills, wastes, and more;
- New controls and practices that the cruise industry employs to reduce discharges;
- The role of regulations in controlling shipping discharges;
- Shipping's contribution to ocean acidification and global warming; and
- The effect of air quality controls on the shipping industry's contribution to ocean acidification.

DREDGING AND NAVIGATION

Billions of cubic yards of material are dredged each year from waterways around the world to facilitate safe and reliable navigation. In the United States alone, the U.S. Army Corps of Engineers dredges over 400 ports and 25,000 mi of channels to ensure the efficient flow of goods to and from more than 200 deepwater harbors (*4*). Maintenance dredging of the nation's navigation channels is crucial for commerce because more than 95% of U.S. international trade comes through U.S. ports, and more than 90% of all global trade travels by water (*5*).

However, many of the nation's deepwater ports are ill-equipped to accommodate the majority of international trade that will be shipped on post-Panamax vessels because of the depth and width limitations of the ship channels and berthing areas (Figure 4). By the year 2030, it is expected that post-Panamax vessels will account for 27% of the world's container fleet and carry more than 62% of all cargo. Many of the deepwater ports in the Gulf of Mexico and the southeast United States do not currently have the capacity to support the draft requirements or dockside requirements of post-Panamax vessels or the larger new Panamax [12,000 2-ft equivalent unit (TEU) vessels[2] (*6*, *7*)]. Channel deepening and widening projects are being considered in the Gulf of Mexico and along the East Coast that could cost tens of billions of dollars in total. The demand to service larger ships will increase coastal and harbor dredging.

When managed properly, the increased dredging required to deepen U.S. navigation channels can have positive environmental benefits. For example, over the past 20 years, the U.S. Army Corps of Engineers has been using 20% to 30% of port and waterway-dredged sediments for habitat creation and other beneficial uses (*5*).

However, dredging and development activities to support maritime uses can also

- Result in suspended sediment;
- Re-expose buried toxic contaminants;
- Create sediment plumes;
- Impair natural habitats, such as wetlands, that help filter nutrients and protect shorelines;
- Increase saltwater intrusion into freshwater ecosystems;
- Disrupt benthic communities; and
- Alter tidal circulation and transport (*5*).

Port	Post-Panamax Status/Impediment	2012 TEUs (Est. 000s)	2011 TEUs	Global Rank
LA/Long Beach	Currently Ready	14,000	14,000	6th
New York/NJ	2015 – Bayonne Bridge	5,600	5,500	20th
Oakland	Currently Ready	2,400	2,350	< top 50
Seattle	Currently Ready	2,100	2,000	< top 50
Houston	2013 – Dredging	2,100	1,900	< top 50
Norfolk	Currently Ready	1,900	1,900	< top 50
Miami	2015 – Dredging/ Cranes	950	900	< top 100
Baltimore	2013 – Cranes	650	630	< top 100

FIGURE 4 North American post-Panamax-ready ports (*8*).

Mega-dredging projects, like the planned Nicaragua Canal (Panama Canal expansion and Nicaragua Canal construction), can connect separated waterbodies, expose long-buried contaminants, and introduce new pathways for invasive species. It is therefore expected that such projects could have both expected and unforeseen environmental damages that must be managed and mitigated.

Implications for the Marine Environment

Channel deepening, widening, and increased dredging have environmental impacts that include the following:

- Water quality is diminished by increased suspended sediments and associated contaminants, habitat disruption, increased underwater noise, and vessel collisions with federally listed species;
- Channel-deepening affects water quality in deepened channels (hypoxia) and surrounding bottoms;
- Saltwater can intrude into freshwater ecosystems;
- Exotic species can be transported through ballast water; and
- Changes in ship wake characteristics may have shoreline impacts.

Potential Areas for Research

Potential research topics include the following:

- Alternative dredge disposal options for beneficial reuse (in bay, thin layer, etc.);
- Impacts of channel deepening or widening on hydrodynamics and ecosystems;
- Application of systems engineering concepts to analyze interdependencies and risk;
- Effects of increased suspended sediments on marine habitat and the ability of marine life to move from, into, or through affected areas;

- Methods for fine tuning or eliminating dredge windows for certain species and geographic locations;
- Habitat degradation related to infrastructure development;
- Indirect impacts of destroying or impairing coastal habitat that helps filter nutrients;
- Sediment suspension on coastal habitat; and
- New techniques or practices for sediment management (dredging and prop wash).

OFFSHORE ENERGY

Activities related to the production and distribution of offshore energy (conventional and renewable sources) occur within a natural environment of valued biological and cultural resources. This resource base is comprised of the following:

- Freshwater and saltwater;
- Air, marsh, and mudflat habitat for wildlife, birds, and plants;
- Recreational parks and refuges; and
- Historically valued structures and view sheds.

The production and transport of LNG and use of offshore renewable power pose varying degrees of risk to the environment at offshore production sites and along the associated supply chains. Similarly, shipping is a vital means of transporting goods but can also cause cumulative environmental risk.

The interplay of economic and environmental imperatives related to these areas is an emerging issue that provides opportunities for collaborative efforts among TRB committees and other stakeholders. In addition, environmental research to build the national knowledge base would benefit the ability to take science-based action in policy, permitting, and practical application.

Implications for the Marine Environment

Production and transport of both renewable energy sources (offshore wind, tide, and current) and conventional energy (LNG, oil, and gas) have the following implications:

- Increased vessel traffic, with the associated potential for vessel collisions with marine mammals;
- Increased underwater noise;
- Habitat disruption (e.g., from underwater cabling) and conversion (ocean bottom to energy extraction structures); and
- Increased potential for spills and contaminant release.

Potential Areas for Research

A better understanding of the following emerging issues will help create a landscape in which regulations, policies, and science work toward avoiding conflicts, rather than managing conflicts that have already arisen, including the following:

- Appropriate metrics for assessing ecosystem services as part of marine spatial planning;
- Risks and benefits of offshore renewable energy generation that can be generalized across geography or projects; and
- Proper methodologies for comprehensive assessments of cumulative environmental risk posed by offshore energy installations.

UNDERWATER SOUND

Human-generated sound in the marine environment has been increasing. Marine shipping is one of the major sources of underwater sound. According to Hildebrand (*9*), commercial shipping is the major contributor to low frequency (5–500 Hz) noise in the world's oceans. Ship noise carries over large geographic areas, especially at higher latitudes such as the Arctic.

The following activities also contribute to increases in underwater sound:

- Energy exploration and production (including offshore renewable sources).
- Port infrastructure improvements (e.g., dredging).
- Structure demolition and replacement.

The effects of sound vary depending on its intensity, frequency, and duration (Figure 5). Effects are species specific and range from behavioral responses such as avoidance to injury and death. Effects are most severe for species that are susceptible to barotrauma effects (e.g., certain fish) and species that rely on sound to communicate and find prey and mates (e.g., marine mammals). Many of these species are also protected under federal regulations (e.g., Endangered Species Act and Marine Mammal Protection Act), at least in U.S. waters.

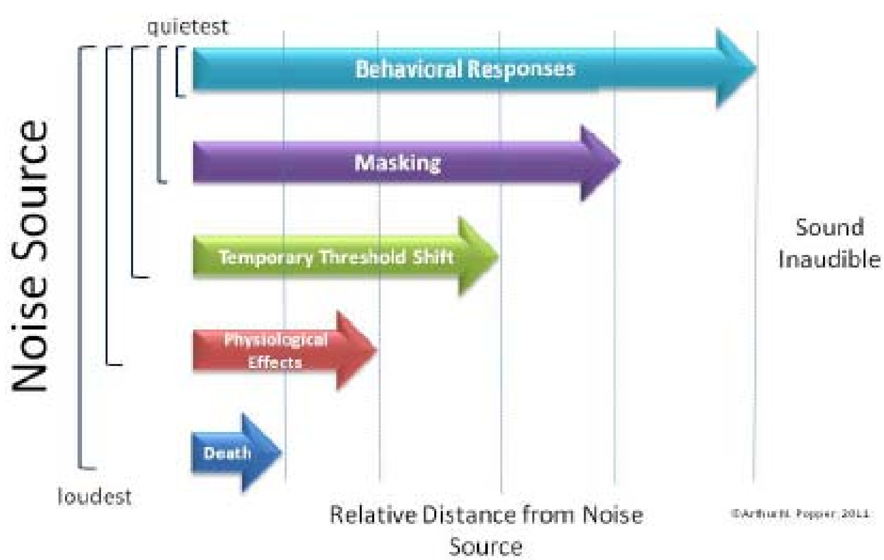

FIGURE 5 Relationship between noise level, distance, and potential effects (*10*).

Implications for the Marine Environment

Increases in shipping will add to ambient underwater noise. Marine mammals are particularly susceptible to the low frequencies generated by shipping. It is not known what the critical thresholds are for these species, and whether ambient noise is approaching those levels.

Infrastructure improvements (e.g., bridge demolition, pile driving, and blasting) generate different sound frequencies and intensities. Regulatory agencies have established thresholds for underwater sound generated by pile driving and for marine mammals in general.

Potential Areas for Research

Research is ongoing concerning the species and habitats most at risk to anthropogenic underwater sound and what frequencies, intensities, and duration of sounds pose an unacceptable level of impact.

Potential research topics include the following:

- Sounds related to marine transportation;
- Marine shipping's contribution to underwater sound;
- Global models to predict ocean noise and its source;
- Areas such as ports and shipping lanes where shipping could be adding an unacceptable level of sound;
- Ways to mitigate shipping noise, including propeller cavitation, without compromising safety and efficiency;
- Long-term, large-scale noise monitoring in the ocean;
- Characterization of noise features based on location and environment type;
- Collection and integration of existing datasets through a national network to share data on marine sound, using social media and innovative, modern means for expanding the size of and access to data;
- Cost-effective target-of-opportunity measurements of individual ships using existing and planned networks of underwater sensors in conjunction with AIS and other ancillary data sources; and
- Response of certain species to vessel traffic using telemetry and other remote sensing methods.

CLIMATE VARIABILITY

Critical U.S. intermodal transportation systems are currently vulnerable to coastal flooding, storm surge, and damaging waves, and their exposure is expected to increase due to climate change and extreme events. Over 60,000 roadway miles are within the Federal Emergency Management Agency's 100-year floodplains delineated in U.S. coastal counties (Figure 6) (*11*). More than 36,000 bridges are located within 15 mi of the coast, and over 1,000 of these bridges have simply supported spans that are vulnerable to damage by storm surge and waves (*12*). As sea levels rise, the risk of flooding or damage to this infrastructure is expected to increase, and it is likely that the number of at-risk roadway miles will increase as well.

Climate change and climate variability are expected to impact transportation infrastructure in many ways. Outcomes of climate change that can impact all transportation modes include the following:

- Sea level rise;
- Changes in storm frequency and storm intensity;
- Changes in precipitation patterns and amounts;
- Changes in temperature; and
- An increase in the frequency of extreme events (*13*).

Any of these expected changes can cause transportation disruptions, failure of transportation infrastructure, and increased long-term maintenance or replacement costs (Figure 7).

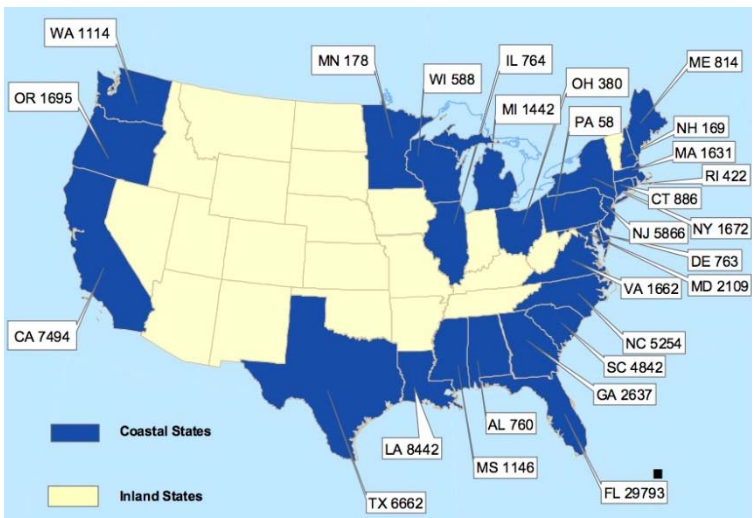

FIGURE 6 Estimate of roadway miles in 100-year coastal floodplains (*11*).

FIGURE 7 Pavement damage from surge and waves (*13*).

While thousands of U.S. roadway miles and bridges are currently exposed to coastal and riverine flooding, their vulnerability (i.e., risk, sensitivity, and adaptive capacity) is expected to increase in light of climate variability and associated extreme events (Figure 8) (*13*). The U.S. DOT's Gulf Coast Study Phase 2 (*14*) describes changes in exposure and sensitivity of intermodal transportation systems and critical infrastructure in Mobile, Alabama, to storm surge, waves, and flooding under the expected impacts of climate change. This study is also developing transferable tools that will allow other metropolitan planning organizations to assess their vulnerability to climate change impacts. Some of the methodologies already developed in the Gulf Coast Study Phase 2 served as the genesis of new FHWA (*13*) regional guidance for assessing exposure of transportation infrastructure to extreme events. Unfortunately, there are few other studies or methodologies to demonstrate potential changes in transportation infrastructure vulnerability, but FHWA expects to release the results of ongoing vulnerability assessment pilot projects in the near future.

Implications for the Marine Environment

- Ports and intermodal systems may be more vulnerable to flooding and waves.
- Nuisance flooding and transportation system disruptions may increase.
- Extreme events may disrupt vessel operations.
- Water quality and water quantity may change.
- The hydrodynamic regime and sediment transport may change.
- Climate variability may have impacts on inland navigation systems.

Potential Areas for Research

Potential research topics include the following:

- Vulnerability assessments for intermodal transportation systems and infrastructure.

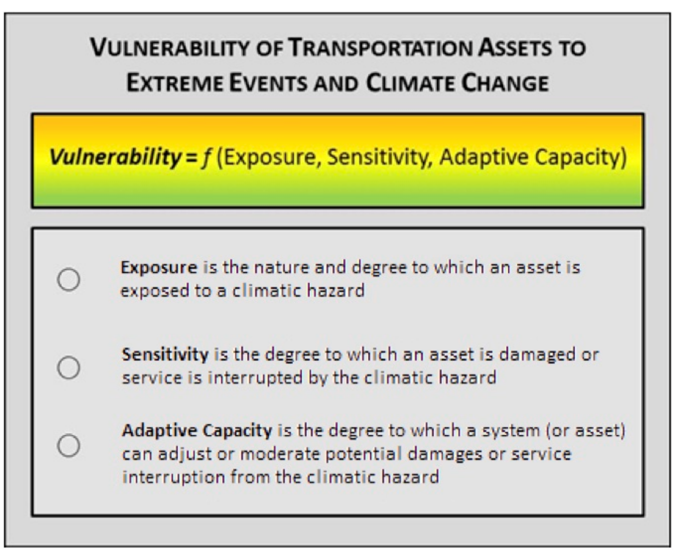

FIGURE 8 Vulnerability of transportation assets to extreme events and climate change (*13*).

- Life-cycle approaches for describing risk and vulnerability to extreme events.
- Use of nature-based methods, or green infrastructure, to increase resilience of transportation systems and infrastructure.
- Design and implementation of retrofits and countermeasures to increase resilience of transportation systems.
- Models describing the fragility of transportation infrastructure to known hazards.

NOTES

1. Panamax is the maximum vessel size that can currently transit the Panama Canal. The allowable dimensions are 950 ft long, 106 ft wide, and 39.5 ft draft. Panamax vessels can carry 10,000 20-ft equivalent units.
2. Vessels rated at 8,000 TEU or above require channel depths of at least 45 to 48 ft, whereas most of the large new Panamax vessels require channel depths of at least 52 ft.

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