Consequences of global shipping traffic for marine giants

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Shipping routes in the ocean are analogous to terrestrial roads, in that they are regularly used thoroughfares that concentrate the movement of vessels between multiple locations. We applied a terrestrial road ecology framework to examine the ecological impacts of increased global shipping on "marine giants" (ie great whales, basking sharks [*Cetorhinus maximus*], and whale sharks [*Rhincodon typus*]). This framework aided in identifying where such "marine roads" and marine giants are likely to interact and the consequences of those interactions. We also reviewed known impacts of shipping routes on these species, and then applied the road ecology framework to detect unknown and potentially threatening processes. In the marine environment, such a framework can be used to incorporate knowledge of existing shipping impacts into management practices, thereby reducing the detrimental effects of future expansion of shipping routes on marine giants.

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The expansion of trade routes and transport infrastructure in response to globalization is threatening the world's biodiversity (Halpern *et al*. 2015; Yang *et al*. 2018), yet research on the effects of this expansion on global biodiversity has primarily focused on the terrestrial realm (Laurance *et al*. 2009). This is because the emergence of "road ecology" as a discipline originated from attempts to understand the unintended effects of roads on terrestrial ecosystems (Forman *et al*. 2003). Road ecology focuses on both the direct and indirect impacts of roads by investigating the relationships between road systems and adjacent environments (Coffin 2007), and has been used to identify a number of road-related consequences for terrestrial wildlife (Alamgir *et al*. 2017; Laurance and Burgues 2017). For example, roads may directly impact terrestrial wildlife via physical contact (roadkill) or by creating barriers to animal movement, and indirectly by causing wildlife to modify their behavior to avoid roads (Alamgir *et al*. 2017). Roads also facilitate the expansion of human activity into formerly remote areas, hastening the introduction of anthropogenic impacts (eg pollution, hunting) into previously unaffected environments (Laurance *et al*. 2009).

In a nutshell:

- "Marine roads" (ie shipping routes) concentrate the movement of vessels between two locations
- "Marine giants" like the great whales, basking sharks (*Cetorhinus maximus*), and whale sharks (*Rhincodon typus*) are vulnerable to shipping impacts due to their need to spend time at the surface breathing or basking, their large body size, and long-range ocean movements
- We used a road ecology framework to assess the ecological consequences of marine roads on marine giants
- Transition zones may act as buffers, mitigating impacts that extend beyond the marine road (eg noise)
- Road ecology indicates that the expansion of marine roads has potential risks that may be unforeseen through existing approaches, thus improving potential monitoring and mitigation

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Like their terrestrial counterparts, marine habitats and species are also threatened by new and existing trade routes (Yang *et al*. 2018). Shipping routes are essentially "marine roads", analogous to terrestrial road systems because they provide pathways that facilitate transportation, connect locations, and concentrate vessel movements (Coffin 2007; Laurance *et al*. 2009). Here, we define a marine road as any marine thoroughfare in regular use that concentrates the movement of vessels between two locations. Marine roads are in effect extensions of terrestrial roads, and form national and international networks that facilitate the trade of goods through maritime services (McKenna *et al*. 2012). Although marine roads are well defined and structured on marine charts, their boundaries are typically featureless on the open ocean; moreover, by their very nature these routes are identifiable only to those with navigational expertise (Tournadre 2014).

The global demand for seaborne trade is driving an increase in the number of marine roads and the intensity of shipping (Tournadre 2014). In some open ocean regions, vessel intensity is so high that shipping traffic is permanently visible when plotted as a marine traffic map (Figure 1; Halpern *et al*. 2015). Shipping is one of the world's largest industries, accounting for 80% of the total world merchandise trade (UNCTAD 2016). In 2015, world seaborne trade volumes were estimated to have

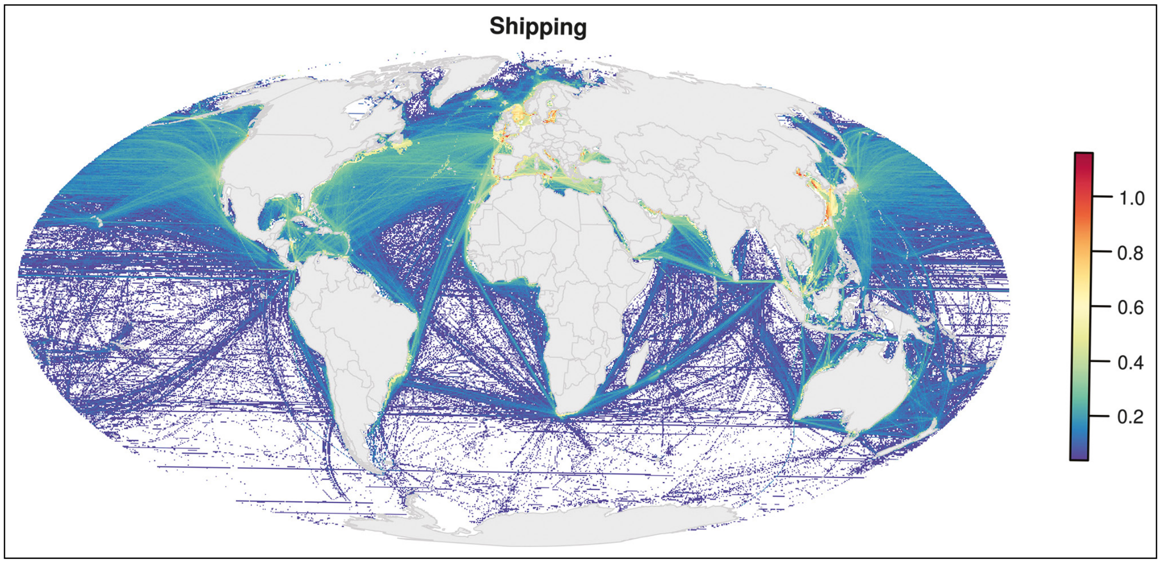


Figure 1. Visualizing marine roads. Global shipping activity showing cumulative human impacts on the ocean from shipping. The color scale and numbers indicate changes in cumulative human impact from 2008 to 2013 (Halpern *et al.* 2015). Major shipping routes are visible, with the greatest degree of shipping activity and changes in cumulative impacts from shipping occurring predominately in the Northern Hemisphere. Reproduced with permission from B Halpern.

exceeded 10 billion metric tons, and an estimated 53.6 billion ton–miles (UNCTAD 2016). To meet the growing demand in commerce, ships are now larger (eg new classes of ships known as Ultra Large Container Vessels) and more abundant, and may therefore pose a greater risk to marine megafauna than in the past (Su *et al.* 2016). The huge number of shipping routes provides a logistically efficient and cost-effective passage for the transportation of bulk goods by sea, but while marine roads are essential for the movement of commodities and global trade, shipping is negatively affecting the marine environment (Halpern *et al.* 2015). Ships produce oil pollution (Liubartseva *et al.* 2015), air pollutants, and greenhouse-gas (GHG) emissions (Hassellöv *et al.* 2013), the latter of which contribute to changes in ocean chemistry that result in ocean acidification (Hassellöv *et al.* 2013). The movement of ships from port to port also increases the risk of bioinvasions through ballast water discharges (Seebens *et al.* 2013), ship strikes with marine megafauna (Van Waerebeek *et al.* 2007), and acoustic pollution (Wilcock *et al.* 2014). Given that shipping impacts are predicted to increase as demand for international seaborne trade continues to grow, there is an urgent need for the development of effective mitigation strategies.

Marine roads and marine giants

Marine roads and shipping have consequences for large, highly mobile, surface-active marine megafauna, particularly the "great whales" (large baleen whales and the sperm whale [*Physeter macrocephalus*]), basking sharks (*Cetorhinus maximus*), and whale sharks (*Rhincodon typus*). We focus on these marine giants because they share traits that make them more vulnerable to shipping hazards relative to other species, specifically surface-active behaviors such as breathing or basking, large body sizes, and long-range ocean movements (Doughty *et al.* 2016). Marine giants play important ecological roles in a variety of marine ecosystems through the transference of nutrients and biomass to deep-sea environments (eg whale falls) and across entire ocean basins via their feces (Roman *et al.* 2014; Doughty *et al.* 2016), as well as through the suspension of sediments from feeding (eg gray whales [*Eschrichtius robustus*]). They traverse large areas of the world's oceans, and their migratory routes intersect numerous marine roads (Roman *et al.* 2014). Understanding the consequences of shipping is important for the management and conservation of marine giants, especially for endangered, recovering, or overexploited populations (Meyer-Gutbrod and Greene 2017). Although shipping interactions have been documented for some species, there is limited understanding of the overall impacts of shipping on marine giants (Van Waerebeek *et al.* 2007). Here, we borrow concepts from terrestrial road ecology to assess shipping impacts on marine giants in an effort to address this knowledge gap.

Applying road ecology theory to marine roads

In this review, we focus on four road impacts – (1) physical disturbances, (2) modification of animal behavior, (3) chemical pollution, and (4) roads as fragmenting features (Table 1; Forman *et al.* 2003; Alamgir *et al.* 2017) – to highlight how current understanding of road ecology in terrestrial environments may be applied to improve the understanding of marine environments, and in particular impacts upon marine giants. These terrestrial road impacts were chosen as most analogous to the potential impacts of marine roads on the marine environment. We use these impacts to provide a framework for reviewing the known

Table 1. Comparison between terrestrial and marine road consequences

Road consequence	Description of consequence: from road ecology	Description of consequence: from marine road context	Example of marine road pressure	Reference(s)
Physical disturbances	Interactions between road vehicles and fauna, which can result in injury or mortality (roadkill)	Ship strike/collision can result in injury, displacement, disturbance, behavioral modification	Ship strike or loss of individuals in small, vulnerable populations (eg North Atlantic right whales)	van der Hoop *et al.* (2015)
Modification of animal behavior	Disruption of animal movement, connectivity, avoidance, habitat fragmentation	Modification of behavior, reduced foraging	Altered communication among low-frequency communicators (eg changes in vocalization)	Parks *et al.* (2011); Castellote *et al.* (2012); Blair *et al.* (2016)
Chemical pollution	Habitat degradation, environmental contamination, introduction of chemicals into the terrestrial environment	Introduction of chemicals into the marine environment, production of greenhouse gases, sea surface temperature rise	Changes in ocean chemistry (eg rising sea surface temperatures may place pressure on whales to alter seasonal movements to coincide with a shift in productivity on feeding grounds)	Wiley *et al.* (2013)
Roads as fragmenting features	Habitat fragmentation and degradation, introduction of invasive species	Habitat fragmentation and degradation, introduction of invasive species	Polar species exposed to shipping impacts (eg chemical pollution, acoustic pollution, habitat degradation)	MacLeod (2009); Reeves *et al.* (2014)

consequences of shipping, as well as for investigating and identifying the potential impacts of shipping on marine giants. Road ecology provides a systematic, structured approach to enhance our current understanding of shipping impacts in the marine environment, enabling a more targeted approach for mitigation. Each consequence is discussed separately below.

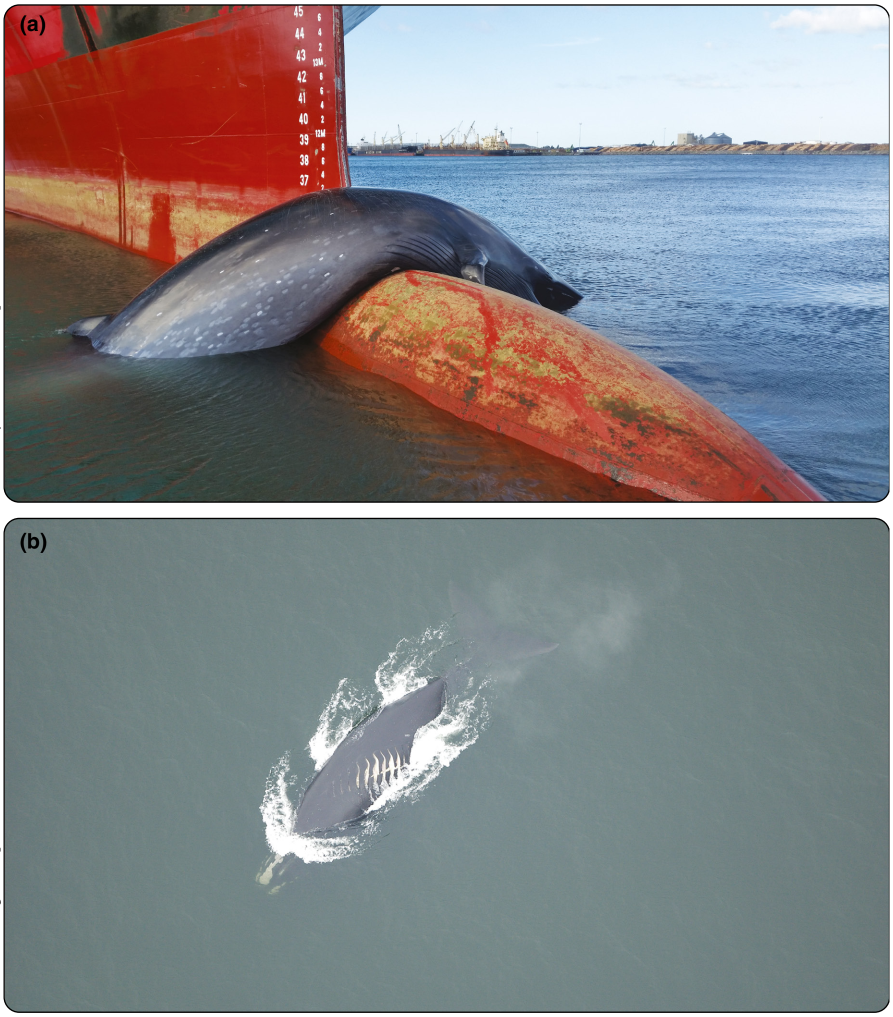
Physical disturbances

Physical disturbances are direct interactions between vehicles and animals along roadways. Unlike the two-dimensional terrestrial environment, which forces many ground-dwelling animals to directly cross the road, thereby increasing the risk of collision, the marine road is a three-dimensional environment that allows individuals to also dive to avoid being struck. Despite this, ship strikes are the most well documented marine road interaction with marine giants. Ship strike is a result of unintentional interactions and can be fatal or result in serious trauma or injury (Figure 2; Van Waerebeek *et al*. 2007). For some populations, such as the North Atlantic right whale (*Eubalaena glacialis*), ship strikes have been responsible for over half of all mortalities in recent decades and as such are a major limiting factor to the survival of this species (Meyer-Gutbrod and Greene 2017). For many populations of marine giants, the consequences of interactions with shipping vessels remain largely unknown. This knowledge gap exists for several reasons: difficulties in studying species because of their behavior, rarity, or remoteness; changes in species movement over time, affecting the ability to predict interactions; or underreporting or lack of reporting of interaction events.

Modification of animal behavior

Modification of behavior refers to an animal's response to road presence or vehicle activity. In the ocean, many species respond to nearby vessels with surface-active (ie present at the surface for breathing or basking) or avoidance behaviors (New *et al*. 2015). Unlike terrestrial roads, marine roads are not permanent structures, but underwater shipping noise and the presence of ships in the marine environment may act as a persistent reminder of marine road presence. Shipping produces low-frequency sounds that can travel many kilometers underwater, and is now the largest contributor of anthropogenic noise in the ocean (Wilcock *et al*. 2014). These low-frequency sounds range from 5 to 500 hertz (Hz), and global shipping networks have added an estimated 12 decibels (dB) to ocean ambient noise levels over the past several decades (Hildebrand 2009). Low-frequency shipping noise is most apparent close to the source (ie the ship) but is often detectable well beyond the marine road (McKenna *et al*. 2012), a propagation level similar to the low-frequency communication used by large baleen whales to stay in contact over entire ocean basins (ie thousands of kilometers) (Tyack 2008). Exposure of marine giants to shipping noise may induce a number of behavioral modifications, including avoidance, altered foraging and movement patterns, habituation, and disrupted communication (Blair *et al*. 2016; Tennessen and Parks 2016).

Shipping noise may also disrupt or interfere with vocal communication (Tennessen and Parks 2016), and in response to such changes in the acoustic environment, some whales modify the way they communicate. For example, when band-limited background noise occurs, right whales (*Eubalaena* spp) often shift their call frequencies, becoming louder in the presence of shipping (Parks *et al*. 2011), while male fin whales (*Balaenoptera physalus*) modify song characteristics (Castellote *et al*. 2012). Such variability in response behaviors complicates understanding the consequences of marine road presence and shipping noise across species. In addition, exposure to shipping noise is not uniform across the marine environment but varies according to ship movement, ship type (size, engine type, gross tonnage), ship operating conditions, weather conditions, and unevenness of shipping sound propagation throughout the ocean (McKenna *et al*. 2013). Moreover, exposure is highest



K McCarthy, New Zealand Dept of Conservation

B Kraus, New England Aquarium

Figure 2. Marine giants such as whales are vulnerable to shipping impacts due to biological traits like the need to frequent the surface often to breathe. (a) A sei whale (*Balaenoptera borealis*) that was struck by a ship, shown at port in New Zealand. (b) A North Atlantic right whale (*Eubalaena glacialis*) with extensive scarring from an interaction with a ship.

where shipping density coincides with hotspots of marine giants (Redfern *et al.* 2017). Clark *et al.* (2009) outlined ways to use simple physical acoustic models to convert chronic ocean noise into "lost" communication space; such masking metrics could allow us to translate the conceptual framework described here into quantitative metrics of habitat effectively lost to whales due to chronic ocean noise.

Predictive models like the Population Consequences of Disturbance (PCoD) model described by New *et al.* (2015) (Figure 3) are potential tools that can lead to a better understanding of the impacts of shipping and that enable researchers to move beyond the limited knowledge about behavioral responses (New *et al.* 2015). PCoD models can be used to predict the demographic and population outcomes of repeated exposure to shipping-related disturbances (eg ship noise) on marine giants (New *et al.* 2015). For example, off the coast of California, whales feeding within so-called Biologically Important Areas are repeatedly exposed to shipping noise (Redfern *et al.* 2017); understanding the consequences of disrupting this feeding activity may therefore help to prioritize disturbances and assist in species management. Moreover, models such as the PCoD may help scientists and managers learn more about the impacts of other shipping-related disturbances as well, such as pollution and the expansion of human activities into new areas.

Chemical pollution

Pollution derived from marine roads refers to the direct and indirect contribution of waste produced by shipping into the oceans. Some forms of shipping pollution may be concentrated within marine roads, whereas others will have a larger footprint; furthermore, vessel pollution can enter the marine environment either directly (eg oil spills, chemical discharge) or indirectly (eg ship emissions/exhaust) (Hassellöv *et al.* 2013). The dispersion of chemicals resulting from the spillage of oil into the ocean is similar to runoff from terrestrial roads (ie the spread of chemicals into previously unaffected environments), in that it can extend beyond the marine road and be transported into adjacent areas (Laurance *et al.* 2009). Severe oil spills in the marine environment can cause serious harm; for example, a large proportion of killer whales (*Orcinus orca*) exposed to the 1989 *Exxon Valdez* oil spill died, presumably from inhalation of vapors or oil, oil contact with the skin, and/or ingestion of contaminated prey. Subsequent recovery of these populations has been poor (Matkin *et al.* 2008).

As compared with terrestrial road vehicles, ships contribute much less to air pollution (Sims *et al.* 2014); although overall GHG emissions from the transport sector have doubled since 1970, nearly 80% of this increase derives from terrestrial road vehicles (Sims *et al.* 2014). Nevertheless, shipping now produces close to 1 billion metric tons of CO_2 annually (comprising 2.5% of global GHG emissions), with emissions projected to increase by 50–250% by 2050 (IMO 2015). Shipping emissions contribute to already occurring changes in marine conditions, such as increasing sea surface temperatures (SSTs) and ocean acidification (Hassellöv *et al.* 2013; Hazen *et al.* 2013). Changes in SST may alter the distribution and abundance of prey species, which in turn influence the foraging behaviors and diets of marine giants (Hazen *et al.* 2013; Ramp *et al.* 2015); such shifts may be especially detrimental to specialized feeders, including the Southern Ocean great whales, North Atlantic right whales, basking sharks, and whale sharks (Hazen *et al.* 2013). One recent study concluded that fin whales and humpback whales (*Megaptera novaeangliae*) in Canada's Gulf of St Lawrence modified their seasonal movements to coincide with a shift in productivity in their feeding grounds due to rising SSTs (Ramp *et al.* 2015).

Pollution or by-products of shipping, such as noise, may extend well beyond the marine road. Areas surrounding the artificial edges of these routes function as transition zones (similar to "ecotones", which refer to ecological transitions between two communities). The physical extent of transition zones depends on the spatial reach of shipping by-products, as some shipping by-products travel farther in the marine environment than others. With regard to ship noise, for example, the intensity of sound is greatest at the source (the ship, along the road) and attenuates beyond marine road edges (transition zones; McKenna *et al.* 2012) but may be detected many kilometers away depending on shipping intensity and sound propagation through the water (Wilcock *et al.* 2014). In contrast, the spatial distribution of shipping-related oil dispersed at the sea surface may be more localized and dependent on ocean circulation patterns (Liubartseva *et al.* 2015). Transition zones may serve as an important management approach to mitigate shipping impacts in areas surrounding marine roads because they buffer impacts arising directly from the source (the ship) out to their full extent, thereby reducing risks to marine giants (Figure 4). Management of transition zones requires an adaptive approach to account for spatial variation in impacts within the marine environment.

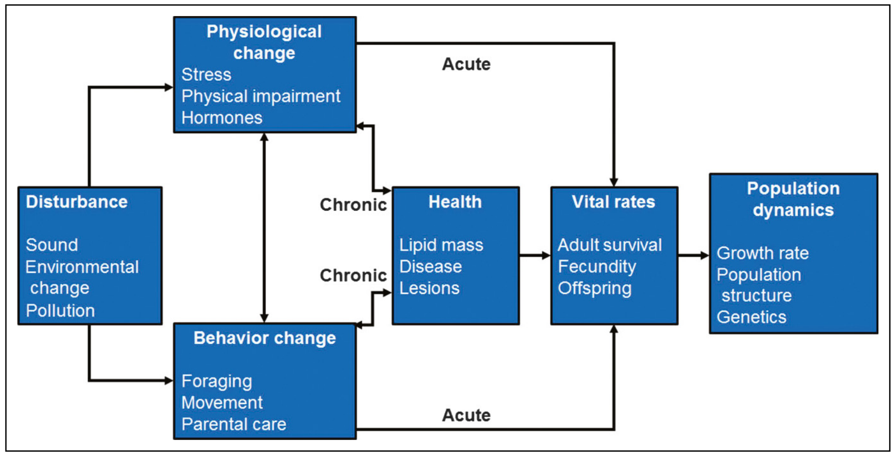


Figure 3. The Population Consequences of Disturbance (PCoD) model described by New *et al.* (2015) is a tool for estimating demographic and population-level consequences of repeated disturbances, such as shipping noise on marine giant behavior. PCoD models can be used to help identify areas where information is lacking and highlight potential long-term population-level consequences arising from the disturbance. Reproduced with permission from L New.

Roads as fragmenting features

New marine roads are being developed as a direct result of climate change opening up previously non-navigable waters, such as the recent emergence of ice-free lanes across the Arctic (Smith and Stephenson 2013; Yang *et al.* 2018). Anthropogenic activities, including shipping, are expanding into formerly inaccessible parts of the marine environment (Yang *et al.* 2018); for instance, declines in Arctic sea ice have created potential new marine roads like the Northwest Passage and the Northeast Passage (Figure 5; Buixadé Farré *et al.* 2014), which have shortened shipping routes between Europe and Asia by 35–60%, an economically preferable alternative to routes via the Suez and Panama canals (Arctic Council 2009). Potential environmental benefits would include fewer emissions, reduced fuel requirements, and less time spent travelling between locations. Although these new shipping routes provide immense economic benefits to the shipping industry, there are numerous potentially adverse environmental consequences to their use (Lindstad *et al.* 2016). Atmospheric and marine pollution are likely to increase in Arctic regions, as will the risk of bioinvasions due to the spread of invasive species released via ballast water (Seebens *et al.* 2013).

As marine roads in the Arctic become used more and more frequently for resource extraction, tourism, and cargo transport, concomitant shipping-related impacts on marine giants are also likely to intensify (Yang *et al.* 2018). New marine roads threaten a number of endemic, ice-associated whale species, including narwhals (*Monodon monoceros*), beluga whales (*Delphinapterus leucas*), and bowhead whales (*Balaena mysticetus*) (Reeves *et al.* 2014). Such roads may even connect populations that were formerly separated by permanent ice, possibly diluting local adaptations and simultaneously exposing those populations to shipping impacts (Reeves *et al.* 2014). The road ecology framework could play a role in systematic conservation planning processes aimed at safeguarding biodiversity (here, marine giants) from anthropogenic threats in the Arctic. At a global scale, it could also be used to identify sites of high potential for interactions between marine giants and shipping, and thus inform planning for newly emerging marine roads to minimize adverse interactions.

Mitigation of marine road consequences for whales

In this section, we identify current mitigation efforts and offer recommendations for mitigating both known (eg ship strike, pollution, noise) and potential consequences of marine road (eg beyond marine roads, within transition zones) in the marine environment. We suggest that shipping routes as a whole – not just individual impacts (eg noise) – contribute to the fragmentation of cetacean populations.

Mitigation within the marine road

Data on whale migrations and habitat use are important tools in marine spatial planning, and help to inform strategies for reducing direct physical disturbances from shipping (Silber *et al.* 2012). For example, the International Maritime Organization (IMO) has used whale migration, habitat use,

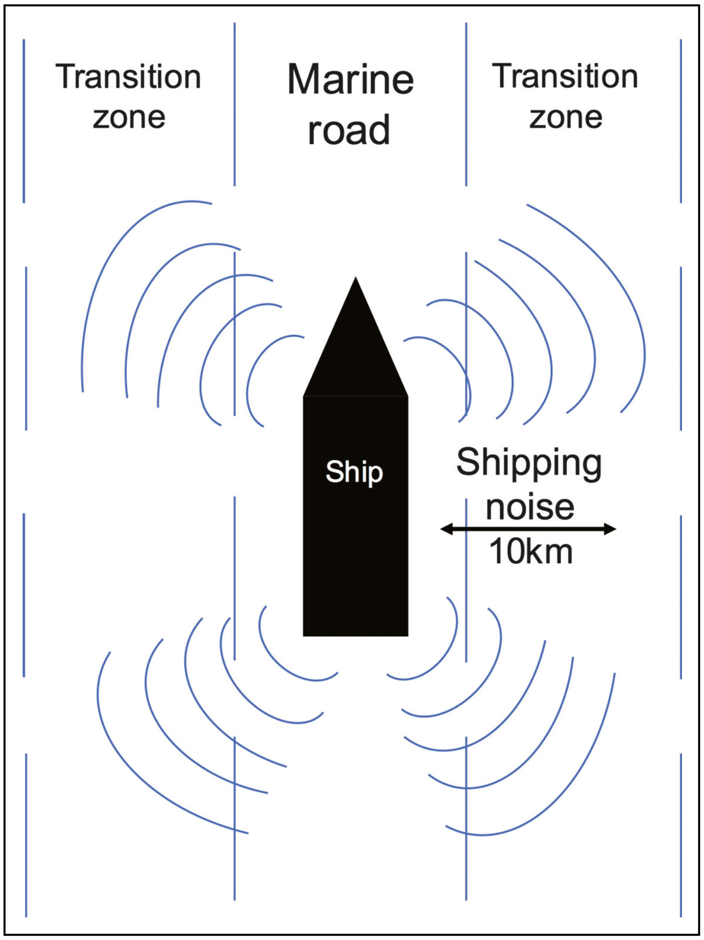


Figure 4. Conceptual illustration of transition zones. By-products of shipping produced (such as shipping-related noise) can extend beyond the marine road. Transition zones adjacent to these routes may help buffer the spread of shipping by-products.

and ecology data to enforce special mitigation measures at certain times of the year in areas where whale numbers are likely to be highest (Silber *et al*. 2012). As part of the IMO mitigation measures, shipping lanes have been relocated and Traffic Separation Schemes implemented to avoid passage through areas of high whale densities, as well as decreasing vessel speed limits in some areas – actions that have proven to be successful in reducing ship-related whale deaths (Silber *et al*. 2012; van der Hoop *et al*. 2015). In addition, specifically for North Atlantic right whales, a US regulation known as the "Ship Strike Rule" defined Seasonal Management Areas, which are intended as a means to reduce vessel collisions, as well as Dynamic Management Areas, which help to minimize whale mortality by accounting for the species' interannual distribution (van der Hoop *et al*. 2015). Similarly, research on whale populations in the waters off Sri Lanka suggests that shifting current shipping lanes 15 nautical miles south of their existing location would reduce blue whale (*Balaenoptera musculus*) ship strike interactions by 95% (Priyadarshana *et al*. 2015). In areas undergoing rapid environmental change, such as polar regions, the IMO is working with the International Whaling Commission and the Arctic Council, an intergovernmental forum, to implement mitigation strategies aimed at reducing the risk of ship strikes and shipping noise disturbances (Arctic Council 2015). Mitigation of shipping impacts along marine roads is contingent on widespread compliance (van der Hoop *et al*. 2015) with both shipping lane boundaries and speed limits (Silber *et al*. 2012).

Mitigation beyond the marine road

The impacts of noise (eg behavioral modifications) and chemical pollution from shipping have important consequences for marine giants that extend beyond the marine road. The road ecology framework brings a new perspective to our understanding of these consequences by highlighting how marine roads facilitate shipping impacts over time and space, including in areas beyond defined routes. Accordingly, mitigation efforts are also important along the boundaries of marine roads. Identifying transition zones should be a primary focus in mitigating shipping impacts, and may prove useful for understanding how long-range impacts spread throughout the marine environment. Transition zones are a critical buffer for protecting marine giants from impacts such as noise and pollution, particularly where responses to shipping impacts are unknown. When designating new shipping lanes, sound propagation models should be used to help establish appropriate boundaries for protecting marine giants, as was done along the coast of Southern California (Redfern *et al*. 2017). Modeling of shipping noise levels in Southern California revealed that noise from shipping propagates far beyond marine roads, and penetrated into whale habitat designated as shipping mitigation areas (eg Traffic Separation Scheme, an Area to be Avoided, and a National Marine Sanctuary; Redfern *et al*. 2017). Broadening shipping exclusion zones to incorporate acoustic buffer areas could enhance protection wherever ship impacts impede endangered species recovery.

For all marine giant taxa, information about noise propagation, habitat distribution, and movement patterns is critical for informing and implementing shipping mitigation strategies in transition zones, as well as within the marine road itself. For example, efforts to reduce shipping noise led to the development of spatial management areas by rerouting marine roads around areas where whales may be located and vulnerable to noise (Petruny *et al*. 2016). Recognition of the potential effects of noise on marine life has also resulted in the recent adoption of IMO guidelines to reduce underwater noise generated by commercial ships (IMO 2014), including recommendations for designing quieter ships and best practices for minimizing noise output (IMO 2014). Ship designs have been modified to reduce the risk of oil spills/chemical pollution and emissions under the International Convention for the Prevention of Pollution from Ships (known as MARPOL; IMO 2018). Inclusion of anthropogenic ocean noise in a revision of the existing MARPOL agreement was proposed by Nowacek *et al*.

(2015). In addition, efforts to reduce chemical pollution along new marine roads resulted in the implementation of a new international code of safety – known as the Polar Code – for ships transiting polar waters (1 January 2017; IMO 2018). Yet not all international efforts have been proactive in mitigating shipping pollution; the 2016 Paris Climate Agreement, for instance, failed to include maritime transport as part of the framework to slow climate change.

Avoid new marine road construction

Mitigating the ecological consequences of marine roads could be as simple as avoiding the establishment or limiting the use of new marine roads, an approach that may be essential to the conservation of many species of marine giants. However, this is unrealistic in practice, as global demand continues to drive shipping activity; attention should therefore be focused on critical areas where limiting the development of new marine roads (roughly the equivalent of establishing no-fishing marine reserves) would have the greatest benefit to marine giants. This is especially important in formerly remote parts of the ocean, such as the Arctic, where climate change is exposing marine species to new shipping impacts arising from rapidly increasing traffic (Figure 5; Smith and Stephenson 2013; Reeves *et al.* 2014). Along with this growth and development, responsibility for monitoring and managing new marine road consequences should be a high priority for the IMO, the global shipping industry, and Arctic management authorities, although this may be challenging, as debate over sovereignty issues pertaining to new marine roads continues (eg between Canada and the UN regarding the Northwest Passage; Gerhardt *et al.* 2010). International leadership from agencies such as the IMO is required to limit the expansion of marine roads into new regions, and to mandate no-go areas in important marine reserves and key migratory areas. Management of marine roads in international waters is also needed, to ensure migratory marine giants are protected throughout their range. Effective management of existing marine roads in international waters will therefore likely be an important focus of marine conservationists and the global shipping industry well into the future.

Using novel technologies to mitigate marine road impacts

Recent technological advances have improved the monitoring and management of interactions between marine giants and marine roads (Wiley *et al.* 2013); for example, improvements in animal tracking technologies provide scientists with valuable tools for monitoring (and thus better understanding) marine animal movements (Hazen *et al.* 2017). Data on the movement of marine giants combined with ship Automatic Identification System data facilitate the spatial overlay and comparison of habitat use and shipping intensity (Hazen *et al.* 2017). In a dynamic environment subject to climate-change

Figure 5. Climate change has led to the formation of new shipping routes into formerly remote areas, which will have implications for Arctic ice-associated cetaceans like the narwhal (*Monodon monoceros*), beluga whale (*Delphinapterus leucas*), and bowhead whale (*Balaena mysticetus*). Projection: azimuthal equidistant. Adapted from Arctic Council (2009).

impacts, where species may respond by altering foraging patterns, migration paths, and habitat use, such information is particularly important; this scenario is already occurring for certain species, such as those that rely on sea-ice habitats or those with specialized diets (MacLeod 2009). An adaptive management approach may prove essential in areas where existing static mitigation measures are currently in place (eg Seasonal Management Areas to protect whales).

Conclusions

Although marine roads are ubiquitous in the world's oceans, our understanding of their impacts on marine giants is limited. The application of a terrestrial road ecology framework to the marine environment represents an opportunity for improving current awareness of the ecological consequences of shipping. Furthermore, interpreting shipping routes as marine roads provides a systematic framework that enhances mitigation of shipping consequences for marine giants by identifying and prioritizing impacts. Mitigation of shipping impacts is not uniform across all species and can be challenging, but technological advances can improve our knowledge of species and shipping movements, and therefore their potential interactions. This applied framework provides a link with terrestrial road ecology, and invites discussion and potential collaboration with scientists experienced in terrestrial and marine wildlife conservation.

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Enigmatic display

The anole lizards from the Caribbean and Central America are known to perform dewlap displays for species recognition and, in some cases, for predatory defense. *Norops townsendii* is an endemic anole from Isla del Coco in the Pacific Ocean halfway between Costa Rica and the Galápagos Islands. On a small island with only one lizard species, how does a characteristic for species recognition get retained over time? Perhaps it is just a vestigial character. Perhaps it has a role in predator avoidance. Perhaps it thought that I was a predator – or perhaps, a potential mate…

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